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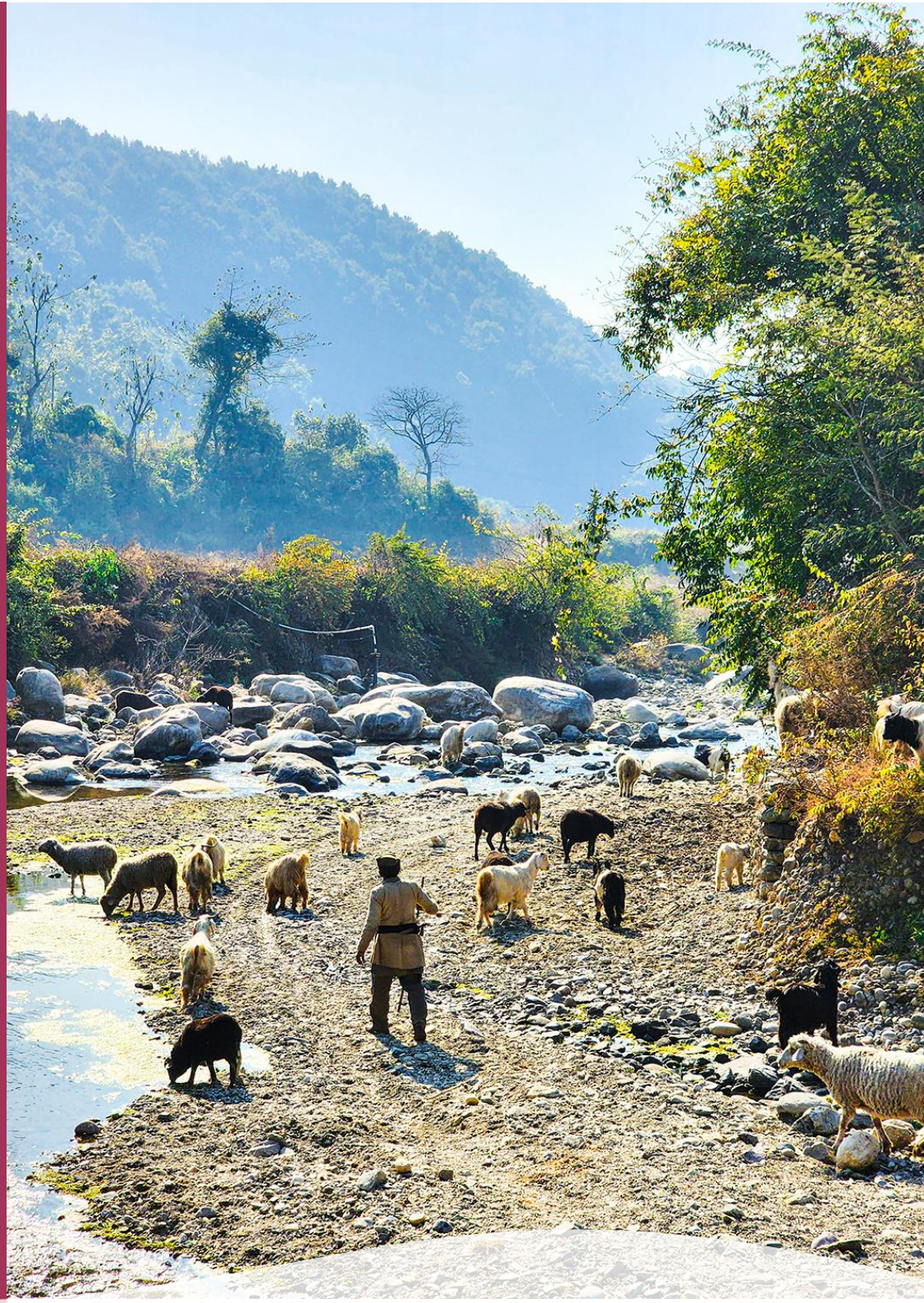

03/2024

COASTAL AND TERRESTRIAL WATER SECTOR INTERVENTIONS IN DEVELOPING COUNTRIES

A systematic review

John Ategeka, Genta Konci, Laurenz Langer, Mike Muller, Promise Nduku, Jennifer Pampolina, Martin Prowse, Andreas Reumann

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About this IEU Learning Paper

This paper presents a systematic review of water sector interventions in achieving desired outcomes at various scales in developing countries. The synthesis is based on 40 studies assessing the impact of the six interventions included in the review. These cover four domains: built infrastructure, nature-based options, institutional interventions and financial/market mechanisms. The outcome area is adaptive capacity. Our meta-analysis suggests water-efficient irrigation systems and ecosystem-based management interventions stand out as particularly valuable tools for enhancing adaptive capacity, warranting specific attention. The scarcity of studies, particularly on coastal interventions, along with the fragmented nature of intervention types, highlights the extreme importance of combining evidence gap maps with meta-analyses of saturated intervention/outcome combinations. This combination highlights knowledge gaps which needs to be filled for effective climate programming (such as on coastal interventions) as well as the calculation of effect sizes of studies with identical interventions and outcomes.

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ABBREVIATIONS

CA	Conservation agriculture
CI	Confidence interval
CPR	Common pool resource
EGM	Evidence gap map
EPPI	Evidence for Policy and Practice Information and Co-ordinating Centre
EPWS	Equitable payments for watershed services
GCF	Green Climate Fund
GHG	Greenhouse gas
GRADE	Grading of Recommendations, Assessment, Development and Evaluations
IEU	Independent Evaluation Unit of the Green Climate Fund
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
PICOS	Population, Intervention, Comparison, Outcomes and Study
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomized controlled trials
REML	Restricted Maximum Likelihood
SMD	Standardized mean difference
SR	Systematic review
ToC	Theory of change
WASH	Water, sanitation and hygiene

EXECUTIVE SUMMARY

Background

Climate change is severely affecting global water resources and threatening water security goals. However, our understanding of the impact of key interventions, particularly in coastal zones and certain terrestrial water projects, is limited. Interventions—projects, programmes or policies—that aim to enhance adaptive capacity and mitigation co-benefits in the coastal and terrestrial water sectors are critical to achieving water security. Analysing their impacts will help developing countries achieve their climate targets. To the best of the authors' knowledge, no systematic review (SR) currently assesses the effectiveness of coastal and terrestrial water sector interventions on adaptive capacity in developing countries. This SR addresses this gap and considers the implications for climate programming.

Objectives

The primary objective of this SR is to identify, assess, and synthesize evidence on the effectiveness of coastal and terrestrial water sector interventions in achieving desired outcomes at various scales in developing countries. The evidence review achieves this objective through two products. First, the completion of an evidence gap map to show the landscape of causal evidence on the effectiveness of water sector intervention. Second, the completion of meta-analyses of saturated intervention/outcome cells within the EGM. These products have been sequenced and completed according to best practice as described in global benchmarks for completing systematic reviews. The goal is to facilitate the use of evidence in informing policy and practice decisions within the water sector, particularly for climate adaptation and mitigation co-benefits, and feed this evidence into the future programming of the Green Climate Fund and wider entities involved in financing climate projects in developing countries.

Search methods

The protocol for this systematic review presents the overall approach with a particular focus on data collection and analysis. To identify relevant studies, we conducted an exhaustive search of 56 academic and grey literature sources, as well as backward and forward searches. The search strategy returned a total of 19,435 papers. The screening included 172 impact evaluations of interventions across eight intervention categories: (i) nature-based options; (ii) built infrastructure; (iii) technological options; (iv) informational/educational schemes; (v) institutional interventions; (vi) financial/market mechanisms; (vii) social/behavioural; and (viii) coastal interventions. The 172 included studies were subject to a detailed data extraction process. An evidence mapping tool was utilized to visualize the evidence base in an evidence gap map. In consultation with the engagement committee, the SR focused on four saturated terrestrial water sector intervention categories: (i) built infrastructure; (ii) nature-based options; (iii) institutional interventions; and (iv) financial/market mechanisms. These intervention categories included 103 studies. Following international best practice, the SR followed an aggregative review approach, including only rigorous quantitative impact evaluations for these intervention categories. We used statistical meta-analysis to establish the overall effects of six specific intervention types within the four categories. We completed a narrative synthesis where the identified evidence base did not allow us to statistically pool studies' impacts.

Selection criteria

To be included in this SR, studies must have been published in or after 2000, evaluated a coastal and terrestrial water sector intervention, and focused on at least one of the review's outcomes of interest. Additionally, studies had to be conducted in developing countries to be included across all the eight intervention categories. However, one exception to this rule was that institutional interventions were included for both developing countries and developed countries. The review included only English-language evidence. We included randomized controlled trials and quasi-experimental studies that used quantitative methods. Studies could be either published peer-reviewed articles or grey literature.

Risk bias

Two reviewers worked independently of each other to produce an independent assessment of studies for inclusion. Using critical appraisal checklists, they extracted data and assessed confidence in the findings of included studies.

Results

We conducted 17 meta-analyses in our SR to examine the overall effects of:

- Ecosystem-based watershed management (three meta-analyses)
- Water-efficient irrigation systems (six meta-analyses)
- Development of formal regulatory framework (three meta-analyses)
- Insurance for losses due to flood and drought (three meta-analyses)
- Establishment of user-based organizations (one meta-analysis)
- Payments for ecosystem services (one meta-analysis)

These meta-analyses focused on the impact of these interventions on adaptive (buffer) capacity and the adoption of interventions, involving 40 studies. Appendix 1 and Appendix 2 offer full definitions of interventions and outcomes, respectively. The indicators for adaptive capacity in the meta-analyses include:

- Income (five meta-analyses)
- Crop yield (four meta-analyses)
- Consumption and expenditure (two meta-analyses)
- Income growth (one meta-analysis)
- Water consumption (one meta-analysis)
- Dietary diversity (one meta-analysis)
- Food security (one meta-analysis)
- Poverty levels (one meta-analysis)
- Adoption of interventions (one meta-analysis)

The largest meta-analysis consisted of 12 studies assessing the effects of water-efficient irrigation systems on income. The smallest included two studies for nine meta-analyses across all the intervention types. We conducted 17 meta-analyses and reported the significant results from 12 by intervention type, starting with water-efficient irrigation systems – which falls under the built infrastructure intervention category. The main text covers the quality of evidence assessments using the grading of recommendation, assessment, development and evaluation framework.

The meta-analysis of water-efficient irrigation on income (12 studies) showed a pooled effect estimate of 0.23 (CI: 0.04 to 0.42), which is statistically significant at the 95 per cent level. The effects are largest in Latin America and the Caribbean compared to other regions and for programmes implemented by international aid agencies or firms. The pooled effect estimate for water-efficient irrigation systems on yield (9 studies) was 0.20 (CI: 0.10 to 0.30), statistically significant at the 99 per cent level. The largest effect sizes were found in Sub-Saharan Africa. The results from water-efficient irrigation systems on poverty (3 studies) show a significant effect estimate of -0.21 (CI: -0.32 to -0.09) at the 99 per cent level. Moreover, the results from water-efficient irrigation systems on food security status (3 studies) show a large significant pooled effect size of 0.55 (CI: -0.06 to 1.15) but only at the 90 per cent level. Here, a study with a moderate risk of bias has the largest effects. The impact of water-efficient irrigation systems on consumption or expenditure is statistically insignificant with a pooled effect estimate of 0.79 (CI: -0.18 to 1.76). Overall, water-efficient irrigation systems increase intermediate outcomes (yields, income), and there is some evidence that this translates into final outcomes (reduced poverty, better dietary diversity and possibly improved food security).

Next, we report results for ecosystem-based watershed management (a nature-based option), firstly on yield (8 studies). The pooled effect estimate was 0.21 (CI: 0.03 to 0.38), statistically significant at the 95 per cent level. The largest effects were noted from programmes implemented by a government agency alongside an international financial institution. The impact of ecosystem-based watershed management on income (7 studies) showed a small impact (pooled effect estimate 0.11, CI: -0.01 to 0.23), only significant at the 90 per cent level. We found, once again, that effects were greatest when a government agency implements programmes alongside an international financial institution. Ecosystem-based watershed management on dietary diversity (2 studies) did not show a significant effect (pooled effect estimate -0.04, CI: -0.25 to 0.16). Overall, ecosystem-based watershed management enhances intermediate outcomes (yields, income). However, this does not translate into final outcomes (dietary diversity), possibly due to the thin causal evidence base.

Turning to wider intervention types, the four further interventions all showed positive significant effects on income. The development of formal regulatory frameworks led to improved income growth rates (pooled effect estimate 0.84, CI: 0.38 to 1.30) at the 99 per cent level across two studies. The establishment of user-based organizations also showed a significant pooled effect estimate of 0.4 (CI: 0.12 to 0.68) at the 99 per cent level but only across two studies. In addition, payment for ecosystem services significantly improved income (pooled effect estimate 0.23, CI: 0.11 to 1.34) at the 99 per cent level but again only across two studies. Insurance for losses due to flood and drought (2 studies) showed a large significant effect (pooled effect estimate 0.68, CI: -0.10 to 1.46) but only at the 90 per cent level. Finally, a meta-analysis of the impact of insurance for losses due to flood and drought on consumption and expenditure (2 studies) showed an overall pooled effect estimate of 1.26 (CI: 1.23 to 1.29) at the 99 per cent level.

Conclusions

As evaluators, it is important to be open and frank about limitations and shortcomings. In common with many systematic reviews in the social sciences, we identified a causal evidence base that is thin and heterogeneous in terms of the applied interventions and limited in terms of the methodological trustworthiness of studies and consistency of effects. Due to these limitations, our review focused on only four out of the eight intervention categories: built infrastructure, nature-based solutions, institutional interventions, and financial/market mechanisms. Our meta-analysis suggests that these interventions can effectively lead to desired outcomes at various scales in developing countries. Water-efficient irrigation systems and ecosystem-based management stand out as valuable tools for enhancing income and crop yield, warranting specific attention. The scarcity of studies, particularly

in the coastal intervention domain, along with the fragmented nature of intervention types, highlights the extreme importance of mapping the evidence base in a rigorous and careful manner. Further SRs would benefit from the generation and utilization of more rigorous evidence and the utilization of standardized metrics across outcome areas to support more comprehensive estimations of what works in the water sector in developing countries.

I. INTRODUCTION

A. THE PROBLEM, CONDITION, OR ISSUE

Water is crucial for attaining internationally agreed goals and targets, including the 2030 Agenda for Sustainable Development[1] (United Nations, 2023). The Secretary-General's Plan: Water Action Decade 2018-2028 recognizes water as the heart of these agreements (United Nations, 2018). It connects and supports terrestrial, freshwater, coastal and marine ecosystems through the hydrological cycle, making it valuable from an environmental, economic, cultural, and political standpoint (United Nations, 2023). Water is also recognised in the recently adopted 2022 Kunming-Montreal Global Biodiversity Framework at the Conference of the Parties to the UN Convention on Biological Diversity, which replaced the Aichi Biodiversity Targets. Climate change affects – and is affected by – global water resources. Climate change has modified all components of the global water cycle in recent decades, and hundreds of millions of people are now regularly experiencing hydrological conditions that were previously unfamiliar. It is reported that in 2018, 2.3 billion people (close to 30 per cent of the world's population) lived in regions under water stress, with 3.6 billion people not having access to adequate water for at least one month per year (Food and Agriculture Organization of the United Nations and UN-Water, 2021). About half of the world's 8 billion people are estimated to experience severe water scarcity for at least some part of the year due to climatic and non-climatic factors (Caretta and others, 2022). At the same time, greenhouse gas (GHG) emissions also emanate from water-based processes (Ye, Porro and Nopens, 2022). For example, conventional treatment processes rely on a constant energy supply derived partly from burning fossil fuels. Sludge disposal methods and sewage treatment plants tend to generate methane, a highly potent GHG. Climate-smart water management has the potential to avoid and reduce emissions of carbon, methane and nitrous oxide released from water and wastewater management, as well as mismanaged or drained freshwater systems such as wetlands (United Nations, 2023).

Climate change, unsustainable human activities and poor environmental management affect water availability, quality and quantity. These hinder the human right to water, sanitation and a clean and healthy environment, among other related human rights (United Nations Educational, Scientific and Cultural Organization and UN-Water, 2020). In its Sixth Assessment report published in 2023, the Intergovernmental Panel on Climate Change (IPCC) states that in the past decade, "human-induced climate change is already affecting many weather and climate extremes in every region across the globe". The evidence of observed shifts in extreme weather events (heatwaves, heavy precipitation, droughts, and tropical cyclones) has strengthened, as has the evidence of their link to human influence. The report warns that "continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation, and the severity of wet and dry events". Climate change impacts due to changes in water availability are projected to increase with every degree of global warming (Caretta and others, 2022). The Intergovernmental Panel on Climate Change (IPPC) projects more frequent water-related hazards and threats to water availability and quality, exacerbated by increased global warming. In the absence of adaptation, an increase in global warming by 2^0C or 3^0C may result in direct flood damages that are 1.4 to 3.9 times higher than would occur with a 1.5^0C increase. River basins dependent on snowmelt, glaciers, groundwater availability, and surface water storage will be affected (Intergovernmental Panel on Climate Change, 2022). The IPCC projections confirm previous predictions that global warming

[1]SDG Goal 6: Ensure access to water and sanitation for all.

will cause substantial changes in the water cycle at both global and regional scales unless a large reduction in GHG emissions is attained (Douville and others, 2021).

Unless urgent action is taken, this will alter temporal and spatial rainfall patterns with implications for run-off, surface and groundwater storage, and river flow regimes (United Nations Framework Convention on Climate Change, 2014). These impacts will occur in different parts of the world and be most severely felt in developing countries (Japan International Cooperation Agency, 2010). As a result, all major human livelihood systems, particularly those dependent on direct access to natural resources, will be negatively affected. In Africa, for instance, most countries depend heavily on agriculture and natural resources that are inextricably linked to water availability and are highly sensitive to climate change's impacts (United Nations, 2023). Rain-fed agriculture, human settlement patterns and movement, water supplies, sanitation and irrigation will all be affected, leading to changes in human health, wealth, and security (Nicol and Kaur, 2009). Susceptibility to water-related impacts of climate change and extreme weather is already being felt in all major sectors, including agriculture; energy and industry; water for health and sanitation; water for urban, peri-urban, and municipal sectors; and freshwater ecosystems (Caretta and others, 2022).

These changes will aggravate demand-side water challenges. In addition to the estimated 4 billion people who currently experience severe water scarcity for at least some part of the year due to climatic and non-climatic factors (Caretta and others, 2022), economic development – together with population growth and movement – will lead to spatial and temporal changes in demand for water resources. Some estimates (Greve and others, 2018) suggest that global water demand for domestic, industrial and agricultural uses may increase by 20–30 per cent by 2050. The rudimentary infrastructure and increasing water demand in developing countries emanating from population growth and rapid urbanization exacerbate the threat posed by climate change.

Addressing these challenges requires robust strategies at all levels – global, regional, national and local. These strategies should support communities in adapting to emerging changes in their water resources and manage the many risks these changes pose. As such, adaptation strategies must address the different dimensions of change, including uncertainty, variability and increasingly extreme weather events. Furthermore, as identified by the Global Commission on Adaptation, mitigation strategies will have to mobilize a range of responses to enhance the resilience of societies and communities and support their adaptation efforts. It is equally important to ensure that such innovation is relevant to different social and political contexts and works effectively with natural systems to strengthen societal resilience to climate change. Responses will include new approaches to using and managing natural water resources and the development of cost-effective institutional and risk management innovations. Effective responses will also include designing, implementing, and financing built infrastructure for water resource management (Global Commission on Adaptation, 2019).

Without sufficient knowledge of the scales required, there is a risk that policymakers and practitioners will make mistakes and generate "maladaptation" responses. There is also a danger that inappropriate adaptation interventions may miss the opportunity to deliver significant co-benefits for mitigation (increased carbon sinks or reduced carbon emissions) while delivering sustainable development, including strengthened livelihoods, reduced poverty, and improved gender equity (Boyd and others, 2022). It is thus imperative to identify which adaptation interventions can work in different contexts to promote sustainable development and to consider how they may be designed to generate significant co-benefits. In the process, it is recognized that human communities have developed approaches to water resource management for thousands of years that have enabled their societies to grow and thrive (Muller, 2021). The knowledge and insights derived from this history of practice and more recent formal research offer a potentially invaluable resource to guide today's

communities in addressing the new challenges climate change poses. The present review represents an attempt to begin to unlock this knowledge resource.

B. THE RATIONALE OF THIS SYSTEMATIC REVIEW

The authors conducting this review aim to examine which interventions effectively promote desired outcomes at various scales. While we primarily focus on nature-based interventions, the systematic review (SR) recognizes that most hydrological systems consist of complex relationships. These relationships exist between the built water use infrastructure that supports water extraction, storage, and other uses (such as recreation, navigation, and power generation) and the original pristine water infrastructure and its accompanying ecosystems.

Water is a complex sector due to the intrinsic linkage between using freshwater resources and its impact on other sectors and ecosystems. For example, dams and water diversions in one location will impact users and ecosystems in another part of the same water resource system. In addition, adaptive interventions may have significant consequences for mitigation with potential co-benefits and synergies but also negative trade-offs. Trade-offs are especially significant in the water sector, where conflicts may exist between water security and clean energy generation provided by largescale projects and their environmental impacts (United Nations Framework Convention on Climate Change, 2014). Conflicts may also exist between adaptation interventions to recuperate wetlands and the additional GHG emissions they generate. Responding to climate change thus poses considerable challenges to water managers, users and policymakers at different levels. In developing their planning and implementation processes, they must consider a range of potential interventions and impact scenarios within and between sectors and hydrological geographies.

C. WHY THIS REVIEW IS IMPORTANT

Through this review, we identified and synthesized the current causal evidence base regarding selected coastal[2] and terrestrial water sector interventions in developing countries[3]. At the time of writing, no SRs had been identified that assessed the effectiveness of coastal and terrestrial water sector interventions on adaptive capacity in developing countries. Current reviews not only vary in geographical scope but also tend to focus on terrestrial interventions in fields such as infrastructure (Zheng and others, 2021), agriculture (Zheng and others, 2019; Jiang and others, 2019), and institutions (Bisaro, Roggero and Villamayor-Tomas, 2018). No SRs have been identified that assess the impact of coastal water sector interventions. In terms of the outcomes assessed, existing SRs do not evaluate adaptive capacity but address areas such as water use, poverty and soil fertility. This suggests a gap in the analysis necessary to understand the full effects of climate change on human and natural systems and how policymakers can improve adaptative capacity and mitigation co-benefits at all levels.

[2] The review originally considered marine interventions but based on advisory group feedback, the scope was refined to focus on coastal interventions.

[3] We define developing countries as those included as non-Annex I countries within the Kyoto Protocol. We sub divide this category into low-income countries, lower-middle-income countries and upper-middle-income-countries when describing the geographical distribution of included studies and within the meta-analyses. This is to offer greater detail to the reader to supplement the main UNFCCC categorisation as determined in the Kyoto Protocol.

D. OBJECTIVES

The primary objective of this SR is to identify, assess, and synthesize evidence about the effectiveness of coastal and terrestrial water sector interventions in achieving desired outcomes at various scales in developing countries. The goal is to facilitate the use of evidence in informing policy and practice decisions within the water sector, particularly climate adaptation and mitigation co-benefits, and to feed support programming, strategies and sectoral guides of the Green Climate Fund (GCF) and wider entities financing climate projects in developing countries. In doing so, we address the following review questions:

What is the effectiveness of selected coastal and terrestrial water sector interventions in achieving desired outcomes (including mitigation co-benefits) at various scales in developing countries?

What factors influence the effectiveness of coastal and terrestrial water sector interventions in developing countries?

E. THE INTERVENTION AND HOW THE INTERVENTION MIGHT WORK

The theory of change (ToC) helped to inform the PICOS[4] design framework we used to develop inclusion and exclusion criteria (see Figure 1 and Appendix 1). The focus of the review is deliberately kept broad ("coastal and terrestrial water sector"), as are the extensive outcomes considered ("adaptive capacity" and "mitigation co-benefits"). This focus is made more challenging because the "water sector" is extremely diverse and involves most areas of human activity – it both determines the human impact on the natural environment and is impacted directly by the natural environment through climate variability and change. This complexity is clearly captured when we consider how water security is defined as "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies" (Grey and Sadoff, 2007). In the context of this review, the goal is expanded to include the assurance that the water security goal can be achieved even when considering the likely impacts of climate change on existing climate variability and extremes.

A particular challenge is that, unlike other sectors such as energy and transport, activities involving the use and management of water as a "common pool resource" are governed by a proliferation of formal and informal institutions at various scales that are often guided by non-commensurate values. Different groups of users may take individual action to meet their water needs, often using built infrastructure that may negatively impact other groups. Integrated water resource management and development approaches are promoted to address such potential conflicts. These approaches encourage identifying and adopting systemic interventions that will optimize the use of natural systems in ways that complement or replace built infrastructure.

Unlike many other sectors, water use and water management are already undertaken in a manner that explicitly tries to support societies in becoming resilient against climate variability and climate extremes. This is why many significant adaptation and mitigation interventions involve identifying, intensifying and expanding existing practices rather than adopting new approaches. This expansion of existing approaches poses challenges for attempts to attribute effects to specific interventions. It also suggests that interventions to strengthen existing water management institutions that enable them to perform their functions more effectively may contribute significantly to adaptation. However, such broad interventions are beyond this review's scope.

[4] PICOS stands for Population, Intervention, Comparison, Outcomes and Study.

Interventions

This SR uses the above definition of "water security" to identify interventions. These interventions will include measures that may enhance resilience and adaptive capacity and, in turn, directly impact the achievement of a range of the United Nations Sustainable Development Goals.[5] The review will also consider water sector interventions that may affect GHG emissions, recognizing that some interventions may generate additional emissions while others will produce mitigation co-benefits through emissions reduction.

As outlined above, a broad set of eight water sector interventions[6] has been identified that could have effects on climate change mitigation and adaptation. The eight intervention types are described in detail in the protocol for this systematic. Appendix 1 provides precise definitions of the coastal and terrestrial water sector interventions.

Considering its limited financial and time resources, this SR does not address interventions involving the development of new infrastructure for water resource management as a primary intervention for achieving water security goals. Similarly, the review does not address interventions that use existing water storage and hydropower infrastructure to support and optimize the use of other intermittent, renewable energies to aid the regulation of electricity generation and transmission systems. However, these interventions may offer substantial adaptation and mitigation co-benefits and may complement or expand the contribution of nature-based interventions. Subsequent reviews may usefully consider these issues.

Outcomes

As with the range of interventions, the range of outcomes is equally broad. The outcomes considered in this review are not necessarily mutually exclusive: one intervention could target more than a single outcome. The outcome areas are described in detail in the protocol for this systematic review and are summarised in Appendix 2. They are divided into three distinct groups: (i) process and implementation outcomes, (ii) secondary outcomes, and (iii) final outcomes.

There has been a growing focus among policymakers and researchers on investigating the unintentional effects of initiatives attributed to the recognized connection between the consequences of climate change and issues concerning sustainable development (Serra and others, 2022). As such, we also capture unintended consequences of coastal and terrestrial water sector interventions, including positive or negative consequences, spill-overs to non-programme participants and reduced resilience to climate change.

Due to time and resource constraints, the review does not consider the potential impact of adjustments to the operational management of existing water resource infrastructure on GHG emissions from water resource systems. Similarly, the review will not consider the mitigation impact of energy storage from existing hydropower infrastructure and its contribution to integrating intermittent renewable generators into electricity systems and reducing the use of fossil fuel-generated electricity. It may be appropriate to propose a separate review to assess the significance of their potential contribution to mitigation.

The health impact of water interventions is outside this review's scope[7]. Although the effective provision of water supply and sanitation services – which underpin public health – derives from and

[5] By their nature, interventions in water will impact on a range of SDGs. Our limited set of intervention areas for this evidence review are related to outcomes connected with SDGs 1, 2, 3, 7, 9, 10, 11, 13, 14, and 15.
[6] Nature-based solutions and coastal interventions are cross-sectoral/cross-cutting such that at the data extraction stage, a study will be coded in two or more intervention categories where relevant. The theory of change will be refined at the intervention specific level of the synthesis stage.
[7] For example, the health impacts of improving drinking water supply, sanitation and hygiene provision are clearly outside the scope of this review. The review team recognizes that there are potential health benefits from wider water resource management (such as maintaining nutritional benefits from inland fisheries, reducing vector-borne disease transmission, addressing the risks of anti-microbial resistance by reducing sewage pollution loads in waterways, minimising risks to life

impacts water resources, it is generally considered separately from the management of those resources. Water services have been the subject of many systematic evaluations and reviews that have also included climate change impacts. Their inclusion in this review would generate extensive evidence, distracting the review from its primary focus on the challenges of managing the water resource itself and the nature-based interventions that can contribute to greater resilience.

and limb from floods and other water-related hazards) at the same time as not including these specific health outcomes in the review.

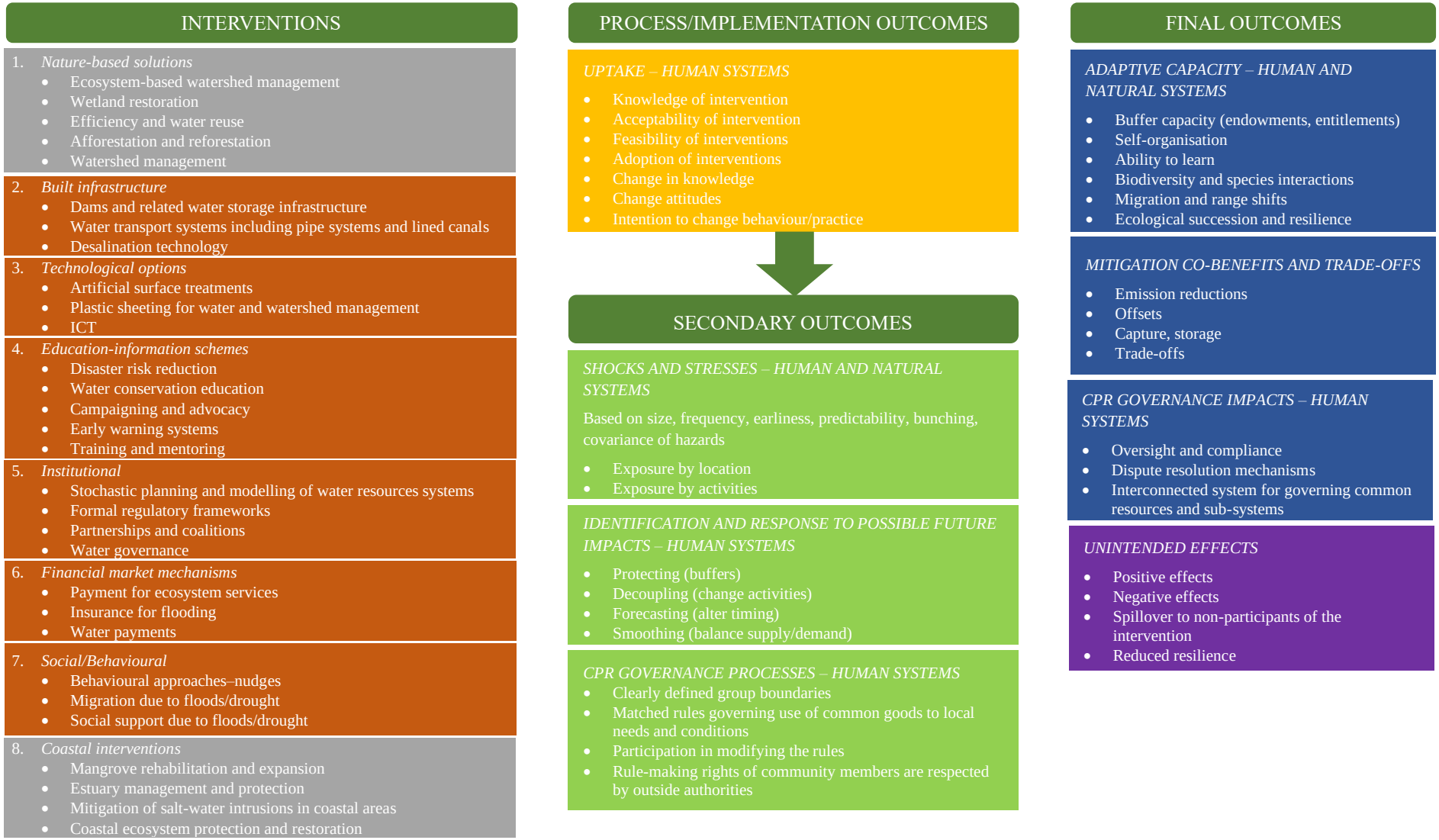
II. METHODS

A. THE OVERALL SYSTEMATIC REVIEW DESIGN APPROACH

This assignment entailed producing a full SR compliant with the guidelines for conducting systematic reviews set by the Campbell Collaboration (2020) and 3ie's guidelines for reviews in international development. We drafted a detailed review protocol according to Campbell Corporation's guidelines[8]. A versatile software solution that provides flexibility in the backend as well as the frontend of the evidence mapping tool was applied to integrate the knowledge management aspect of the evidence review and allowed the visualization of the evidence base in the form of an evidence gap map (EGM). The EGM mapped evidence from impact evaluations across eight coastal and terrestrial water sector interventions indicated in the ToC section below. Its main objective was to indicate the overall nature and size of the available evidence base and facilitate the identification of areas for synthesis. The final EGM presented to GCF included a total of 172 studies, including one linked study. The EGM was applied instrumentally to guide discussions about which areas of the evidence base to use for synthesis, as well as what would be the most effective synthesis method to answer the review question. Following a meeting with the engagement committee and continued engagement with GCF to jointly identify the relevant areas of evidence for the SR, the synthesis gaps and stakeholders' interest steered the focus of the review to the six intervention types. These intervention types covered four broad categories, namely, built infrastructure, nature-based options, institutional interventions, and financial/market mechanisms. A total of 103 studies included these intervention types. We conducted a statistical meta-analysis for the effects of (i) water-efficient irrigation systems (built infrastructure); (ii) ecosystem-based watershed management (nature-based options); (iii) development of formal regulatory framework (institutional); (iv) establishment of user-based organizations (institutional); (v) payments for ecosystem services (financial/market mechanisms); and (vi) insurance for losses due to flood and drought (financial/market mechanisms). The meta-analysis focused on the impact of these interventions only on adaptive (buffer) capacity and adoption of interventions, involving 40 studies.

[8] Details on the theory of change, intervention-outcome framework, inclusion/exclusion criteria, the search strategy, screening, and data management are provided in the protocol. See Independent Evaluation Unit (2023).

Figure 1. Theory of change



An effectiveness review was conducted to answer the review question about the extent to which these coastal and terrestrial water sector interventions impact adaptive capacity and adoption of interventions in developing countries. Therefore, the SR only includes primary studies that measure the effects of interventions and have designs that can reliably attribute observed effects to these applied interventions on adaptive capacity and the adoption of interventions. Individual effects are synthesized into overall estimates of treatment effects using statistical meta-analysis.

1. Intervention-outcome framework for the review

The intervention-outcome framework was used to structure and visualize the evidence base, and the ToC directly influences its design. Comprehensive details of the intervention-outcome framework are provided in the SR protocol.

2. Criteria for inclusion and exclusion of studies in the review

To systematically synthesize literature on the effectiveness of the eight intervention types, an underlying focus on coastal and terrestrial water sector interventions in achieving desired outcomes has guided the scope of the review. Formally, we adopted the PICOS framework to develop our inclusion criteria. Full details of the inclusion criteria for the SR are highlighted in the SR protocol (Independent Evaluation Unit, 2023). The inclusion criteria define the precise characteristics of the studies that are included in the SR. All evidence not meeting these criteria was excluded from this review.

3. Searching for evidence

A comprehensive search strategy was developed to search for qualifying research literature studies to identify all available evidence relevant to the review question and be included in the SR. The protocol outlines the search strategy, including sources (databases and repositories), backward and forward searches, search terms, the combination of search terms, and results from the search and screening process.

B. Data collection and analysis

1. Selection of studies

Review management software, EPPI Reviewer 4, from the Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI), was used to manage the entire screening process. All potentially relevant citations gathered from the academic sources noted in the protocol were imported into EPPI Reviewer 4. Search results from organizational websites and the citation searches were captured in MS Word, and only studies deemed to be relevant for the map were then captured on EPPI Reviewer 4. Any grey literature not already on EPPI Reviewer was captured manually by the software. Before proceeding with screening, all duplicates of titles were excluded from the review using EPPI Reviewer 4's duplicate control function.

A manual screening process to assess eligibility was carried out on EPPI Reviewer 4. At the title and abstract screening level, we carried out a manual double screening exercise to assess the eligibility of studies using the inclusion criteria highlighted in the protocol. Decisions made about each citation were recorded on EPPI Reviewer 4. To ensure quality and consistency in the screening process, a set of 1,500 studies were double screened at the title and abstract levels. Two reviewers screened this common sample of all study abstracts. During the training, the researchers' results were compared and any discrepancies in coding decisions were discussed where necessary, including clarification of

the inclusion criteria. The individual screening was only permissible once a similarity index of the screening exercise reached 95 per cent.

Following the completion of the screening of the title and abstracts, we conducted a full-text screening of each study that met the inclusion criteria at the title and abstract screening stage. During this stage, two reviewers independently screened studies remaining from the title and abstract screening stage in detail against the protocol and independently decided whether to include or exclude the study. Any disagreements between reviewers were reconciled through the supervision of a senior review team member. The individual screening was only permissible once a similarity index of the screening exercise reached 95 per cent. The output of this stage was a set of studies deemed suitable for inclusion in the review. The screening process at the title and abstract was reported using the PRISMA[9] flow chart below.

The EGM mapped evidence from impact evaluations across eight coastal and terrestrial water sector interventions. The EGM presented to GCF included a total of 172 studies. The EGM guided discussions about which evidence base areas to use for the synthesis. The review team consulted with the advisory group to identify the relevant areas of evidence for the SR. The synthesis gaps and stakeholders' interest directed the focus of the meta-analysis to six intervention types; (i) water-efficient irrigation systems; (ii) ecosystem-based watershed management; (iii) development of formal regulatory frameworks; (iv) establishment of user-based organizations; (v) payments for ecosystem services; and (vi) insurance for losses due to flood and drought.

2. Data extraction and management

We used a predefined data extraction tool to extract data systematically and transparently from the included primary studies. The coding tool highlighted in Appendix 3 was translated into EPPI Reviewer 4 to extract information that is required for the SR and synthesis. The data was entered directly into Excel, with full-text reports examined and studies coded on variables related to:

- Descriptive data, including authors, publication date, status and other information to characterize the study, including study design, country, type of intervention and outcome, population and context.
- Methodological information, analysis method and type of comparison.
- Quantitative data for outcome measures, including outcome descriptive information, sample size in each intervention group, outcomes means and standard deviations, and test statistics (e.g. t-test, F-test, p-values, 95 per cent confidence intervals).[10]
- Information on intervention design, including how the intervention incorporates participation, participant adherence, contextual factors, and programme mechanisms, including implementation fidelity.

3. Assessment of risk of bias in included studies

We applied a critical appraisal tool to assess the trustworthiness of the impact evaluations included in the SR. Trustworthiness refers to the level of confidence that the impact evaluation's findings are rigorous, credible and likely to reflect the results of the evaluated interventions rather than the influence of the applied study design and research conduct. To assess the risk of bias in the primary studies, we adapted the Cochrane risk of bias tool for randomized and non-randomized studies (Sterne and others, 2016), shown in Appendix 4. We have previously used and adopted this risk of

[9] PRISMA stands for preferred reporting items for SRs and meta-analyses. More information is available at http://prisma-statement.org/PRISMAStatement/PRISMAStatement.aspx.
[10] To extract this information for statistical meta-analysis, the data extraction tool was translated into Excel.

bias tool in international development reviews (Stewart and others, 2015; Rebelo Da Silva and others, 2017). Sterne and others (2016) used a domain-based risk of bias tool covering the following six indications of trustworthiness: (i) selection bias; (ii) confounding bias; (iii) bias due to departures from applied interventions; (iv) bias due to missing data; (v) bias due to measurement of outcomes; and (vi) bias due to selection of the reported result. Each domain of bias received a low, moderate, high or critical risk of bias rating, allowing for a transparent calculation of the overall risk of bias score for each study. Studies with a critical risk of bias were included in the review but excluded from the synthesis. The critical appraisal tool used to assess studies for the SR is presented in Appendix 4 and was piloted using a similar approach to that used for piloting the data extraction tool. Two reviewers independently assessed each study before comparing their decisions. A third reviewer was consulted when the initial two reviewers disagreed about the risk of bias rating for a particular study.

4. Measures of treatment effect – Methods for handling dependent effect sizes

a. Criteria for the determination of independent findings

Complex data structures are a common occurrence in meta-analyses of impact evaluations. There are numerous scenarios through which these complex structures with dependent effect sizes might occur. For example, there could be several publications that stem from one or several studies based on the same data set. Some studies might have multiple treatment arms that are all compared to a single control group. Other studies may report outcome measurements from several time points or use multiple outcome measures to assess related outcome constructs. All such cases yield a set of statistically dependent effect size estimates (Borenstein and others, 2009).

The research team assessed the extent to which relationships exist across the studies included in the review and avoided double-counting identical evidence by linking papers before data analysis. Where several publications reported on the same effect, we used effect sizes from the most recent publication. We used information provided in studies to support these assessments, such as sample sizes, programme characteristics and key implementing and/or funding partners.

We extracted effects reported across different outcomes or subgroups within a study. Where information was collected on the same programme for different outcomes at the same or different periods, information on the full range of outcomes over time was extracted. Where studies reported effects from multiple model specifications, we adopted the author's preferred model specification. If this was not stated or was unclear, the specification with the most controls was used. Where studies reported multiple outcomes or evidence according to subgroups of participants, we recorded and reported data on relevant subgroups separately. Further information on criteria for determining independent effect sizes is presented in the protocol for this SRs.

b. Effect size calculations

Quantitative data for outcome measures, including outcome descriptive information, sample size in each intervention group, outcome means and standard deviations, and test statistics (e.g. t-test, F-test, p-values, 95 per cent confidence intervals) was extracted using Excel. Effect size data was stored and any necessary cleaning was conducted in Excel. Following the screening and descriptive data extraction process to ensure consistency in coding quality, two reviewers piloted the effect size data extraction tool, working independently on a random sample (10 per cent) of included studies to test the tool across a range of the included impact evaluation designs and methods. We aimed to achieve a minimum Kappa statistic score of 0.90 following a round of repeating the process for the tool to be finalized. After the piloting stage, the remaining studies were coded by individual

reviewers and all extracted data was checked by a third reviewer. Further information on effect size calculations is presented in the protocol for this SR.

5. Unit of analysis issues

Unit of analysis errors can arise when the unit of allocation of a treatment is different to the unit of analysis of effect size estimate, and this is not accounted for in the analysis (e.g. by clustering standard errors at the level of allocation). Further information on unit of analysis issues is presented in the protocol for this SR.

6. Assessment of heterogeneity

To visibly examine variability in the effect size estimates, we used forest plots to display the estimated effect sizes from each study along with their 95 per cent confidence intervals. Subsequently, and acknowledging the limitations of quantification of heterogeneity and the different strengths of statistical approaches, the following tests for heterogeneity were conducted:

Calculation of the Q – statistic as a statistical test of heterogeneity (Hedges and Olkin, 1985).

Calculation of the $I^2$and Tau^2($\hat{\tau}^2$) statistic to provide estimates of the magnitude of the variability across study findings caused by heterogeneity (Higgins and Thompson, 2002; Higgins and others, 2003; Borenstein and others, 2009).

In addition, we explored heterogeneity using moderator analysis in meta-regression specifications where there were at least four studies in each category and significant heterogeneity. It has been suggested that a minimum of 10 studies are required for moderator analysis (Borenstein and others, 2009), but there are no hard and fast rules. Nevertheless, we ensured that for categorical moderators, a minimum of two studies existed in each category per moderator variable for meaningful moderator analysis.

7. Assessment of reporting biases

When the nature and direction of results influence the dissemination of research findings, this leads to reporting biases. Positive and statistically significant results that show an intervention works are more likely to be published and more likely to be published rapidly, usually in English. Further, there is a high probability they will be published more than once and appear in high-impact journals, and are therefore more likely to be cited by others. In SRs, the contribution made to the totality of the evidence by studies with non-significant results is the same made by studies with statistically significant results. Funnel plots are used to test for reporting biases. However, the general rule is that they are utilized only when there are at least 10 studies included in the meta-analysis. This is because, with fewer studies, the power of the tests is too low to distinguish chance from real asymmetry (Higgins, 2019). To reduce the possibility of publication bias, we searched for and included unpublished studies in this review. Whenever feasible, we also tested for the presence of publication bias using funnel plots and statistical tests. Specifically, the rank correlation test (Begg and Mazumdar, 1994) and the regression test (Sterne and Egger, 2005), using the standard error of the observed outcomes as predictor, were used to check for funnel plot asymmetry.

8. Data synthesis

The included studies in the review cover six selected interventions of interest to GCF, namely:

- Ecosystem-based watershed management
- Water-efficient irrigation systems

- Development of formal regulatory framework
- Insurance for losses due to flood and drought
- Establishment of user-based organizations
- Payments for ecosystem services

The minimum criteria were used only to combine studies using meta-analysis when we identified two or more effect sizes using a similar outcome construct and where the comparison group stated was judged to be similar across the effects, which is like the approach taken by Wilson, Weisburd and McClure (2011). In terms of outcomes, nine outcome indicators for adaptive capacity covered in the meta-analyses include:

- Income
- Crop yield
- Consumption and expenditure
- Income growth
- Water consumption
- Dietary diversity
- Food security
- Poverty levels
- Adoption of interventions

Hence, we combined studies in the same analysis when they evaluated the same intervention type and the same type of outcome measure. We used the *metan* package in Stata 18 software to conduct the meta-analyses. The amount of heterogeneity (i.e. $\hat{\tau}^2$), was estimated using the DerSimonian-Laird estimator (DerSimonian and Laird, 1986). In addition to the estimate of $\hat{\tau}^2$, the Q-test for heterogeneity (Cochran, 1954) and the I^2 statistic (Higgins and Thompson, 2002) are reported. Where there were too few studies or included studies were considered too heterogeneous in terms of interventions or outcomes, we presented a discussion of individual effect sizes along the causal chain through a narrative synthesis.

9. SUBGROUP ANALYSIS AND INVESTIGATION OF HETEROGENEITY

Whenever feasible, we conducted moderator analyses to explain variations in effect sizes. Moderators are variables such as socioeconomic context and population characteristics, measured at baseline, that interact with treatment to change the outcome for each group (Pincus and others, 2011). Following the PROGRESS-PLUS approach (Gough, Oliver and Thomas, 2017), we utilized moderators according to three broad categories of extrinsic, methodological and substantive characteristics. Specifically, these categories include:

- Extrinsic characteristics: funder of the study (e.g. non-governmental organization versus private sector versus government investments), publication type, publication date.
- Methodological characteristics: study design, risk of bias, evaluation period, length of intervention.
- Substantive characteristics: participant characteristics (gender, age, socioeconomic status), context (geographical setting), intervention type, intervention length, type of implementing agency.

10. SENSITIVITY ANALYSIS

To test the robustness of the results of the meta-analysis, several sensitivity analyses were conducted. Broadly, this involves collecting data on and assessing the sensitivity of findings to the methods of the primary studies and the methods of the review. We anticipated that the included studies would vary methodologically and, therefore, conducted sensitivity analyses to examine the influence of these variations on the summary measures. These analyses offered possible explanations for the differences between studies when interpreting the results. The main objective of the sensitivity analysis is to provide an informal, visual comparison for determining if the results of our meta-analyses are sensitive to the study design and the review team's methodological decisions.

11. STRENGTH OF THE EVIDENCE ASSESSMENT

The SR's last research step was to conduct a Grading of Recommendations, Assessment, Development and Evaluations (GRADE) review that reported on the evidence base's overall strength. This step is distinct from the critical appraisal step. It considered additional factors in assessing the overall body of evidence and how much trust can be placed in its ensuing recommendations. Appendix 5 presents the GRADE results for each meta-analysis conducted.

III. RESULTS

In this section, we report descriptive results from the review to provide an overview of its characteristics and distribution of evidence base across all interventions. We start by providing the results of the search and screening of the literature, followed by a section that summarizes the characteristics of the included studies.

A. DESCRIPTION OF STUDIES: SEARCH RESULTS AND CHARACTERISTICS OF THE EVIDENCE BASE

1. RESULTS OF THE SEARCH

Our exhaustive search for studies indexed in scientific databases and grey literature sources was conducted in June 2023. As the PRISMA[11] diagram below shows, the search strategy returned a total of 19,345 records (Figure 2). These were derived from 56 different sources, compromising 10 scientific databases of research studies (18,456 citations), 46 grey literature sources (295 citations), and backward and forward searches (597). The grey literature searches generated 161,571 hits across the 46 websites through the application of key search terms, iterated depending on the functionality of each website. However, following the recommendations presented in Haddaway and others (2015), we deliberately screened the first 1,000 article titles for each website, resulting in the generation of 295 relevant studies.[12] All search hits were imported into EPPI Reviewer 4 to facilitate data storage and management. Only those hits found to be relevant after initial screening were entered into EPPI Reviewer 4 manually. Grey literature searches were not included.

After removing duplicates from the total of 18,751 records generated from academic and grey literature searches, as shown in Figure 2, 16,146 records were left for screening at the title and abstract level. As noted above, to enable ex-post validation of screening consistency, approximately 10 per cent (1,500) of the 16,146 studies were retained for double screening at title and abstract. Around 95 per cent of these studies were screened consistently by all screeners. Individual screening was then carried out for the remaining studies. After screening on title and abstract, most studies were excluded due to non-relevance to the topic (n=13 366). A total of 1,122 studies were excluded due to a lack of any intervention or an intervention that met the inclusion criteria. Exactly 374 studies were excluded on population, 238 due to their study design, 179 due to irrelevant outcomes, and 221 studies were identified as duplicates. Precisely 31 studies were excluded based on their publishing date. After screening all records at the title and abstract stage, we identified 615 studies to review at the full-text level.

We then retrieved the full texts of the remaining 615 studies and screened these against our inclusion criteria. This screening led to the exclusion of a further 493 studies. The main reason for exclusion on full-text is due to a lack of intervention or the presence of an intervention that does not meet the inclusion criteria (n=252); for example, studies examining water, sanitation and hygiene interventions (often referred to as WASH). We also excluded many studies relating to irrelevant study design (n=169). Precisely 28 studies were excluded on population and 28 due to irrelevant outcomes. Two studies were identified as duplicates, while two studies were excluded based on their

[11] PRISMA stands for preferred reporting items for SRs and meta-analyses. More information is available at http://prisma-statement.org/PRISMAStatement/PRISMAStatement.aspx.

[12] Haddaway and others (2015) suggest that searches of articles from grey titles focus on the first 200 to 300 results. Our decision to screen the first 1,000 results was considerably higher as we aimed to be as exhaustive as possible in locating grey material.

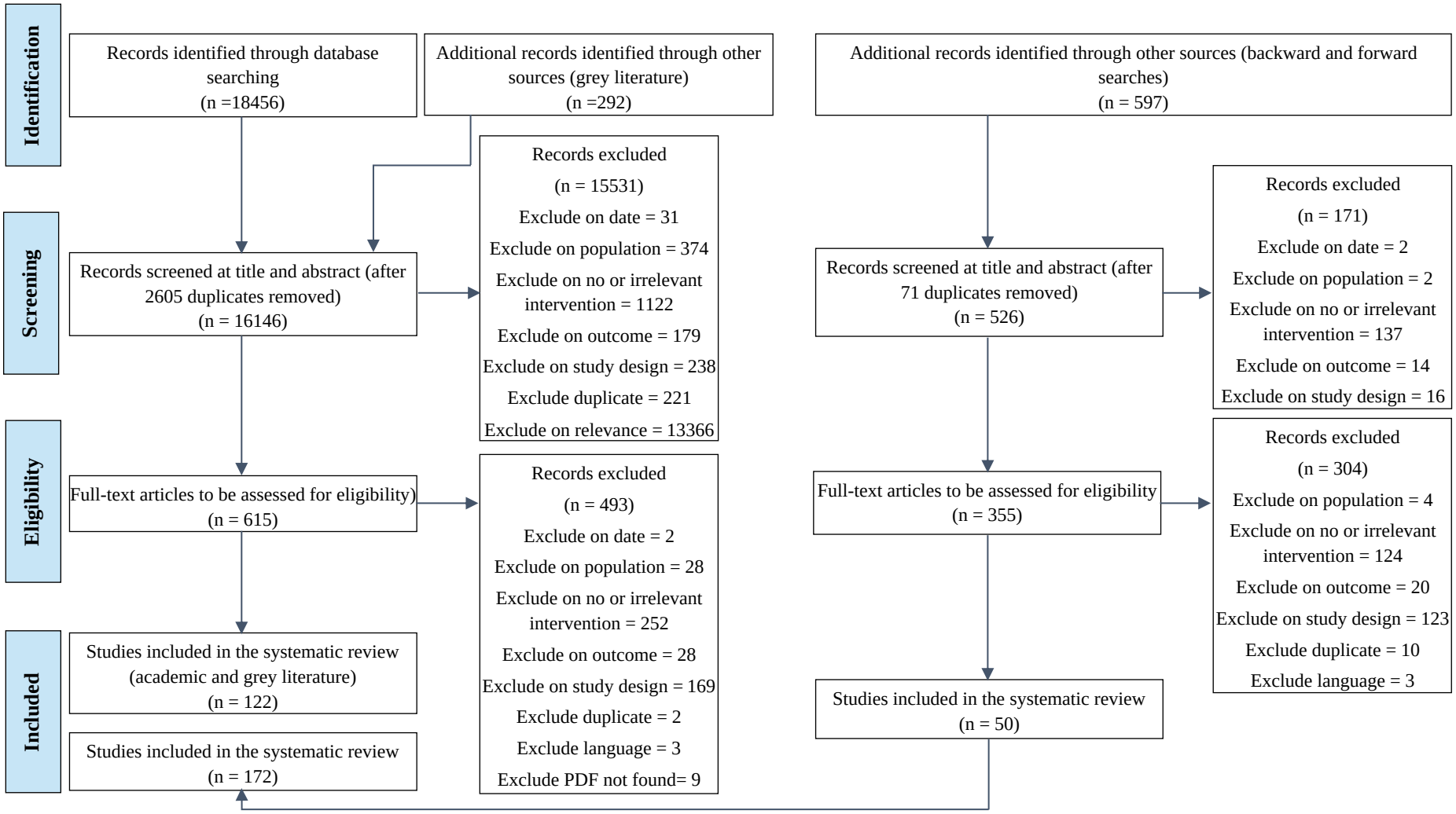
publishing date. Nine studies were excluded as the full texts could not be found, and three studies were excluded as they were not published in English.

Our backward citation searches searched through the reference lists of included studies. Forward citation searches using Google Scholar to find papers that cite the included studies[13] were conducted in July 2023. As shown in Figure 2, the backward and forward searches generated 597 studies. We removed a total of 71 duplicates, and 526 records were left for screening at the title and abstract level. Of these, 137 studies were excluded due to a lack of any intervention or intervention that met the inclusion criteria. Exactly 16 studies were excluded due to their study design; 114 studies were excluded due to irrelevant outcomes. Two studies were excluded based on their publishing date. The same number of studies were excluded based on population. After screening all the records at the title and abstract level, we identified 355 studies to review at the full-text level.

After retrieving the full texts of the remaining 355 studies and screening these against our inclusion criteria, a further 301 studies were excluded mainly due to a lack of intervention or the presence of an intervention that does not meet the inclusion criteria (n=124) and study design (n=123). Exactly 20 studies were excluded due to irrelevant outcomes. Ten studies were identified as duplicates. Four studies were excluded based on population, and 21 studies were excluded as the full texts could not be found. Three studies were excluded due to the publication's language. The final number of studies that made it into the SR was 172, made up of 171 unique studies and one linked study.

[13] Included studies refer to studies in cells identified for meta-analysis from the academic and grey literature searches.

Figure 2. PRISMA diagram



2. CHARACTERISTICS OF INCLUDED STUDIES

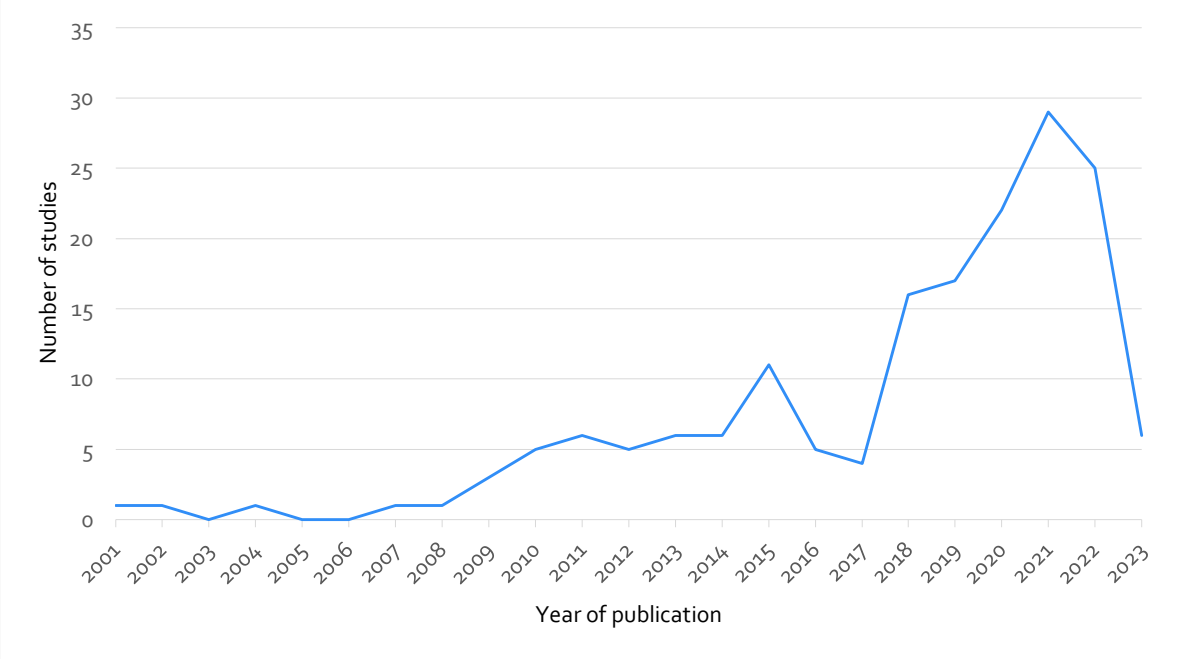
a. Publication trend over time

Figure 3 reports the publication trend of the studies included in the SR over time. In line with this review's specific focus on interventions that commenced on or after the year 2000, the earliest included publication was Middlestadt and others (2001). The most recent studies were Dai and others (2023), Fishman, Giné and Jacoby (2023), Huang (2023), Nepal and others (2023), Yang and Xu (2023a), and Yang and Xu (2023b). The annual number of publications saw a steady increase over the years, with 118 publications (69 per cent of the total) published between 2016 and 2022. The year of 2021 ranked as the year with the highest number of studies published, with 29 publications.

b. Geographic distribution

The included studies retained after the screening process were geographically diverse (see Figure 4 and Figure 5) and representative of developing contexts around the globe. The studies were conducted across 65 countries.[14] Thirty-one per cent (n=53) of the studies were conducted in Sub-Saharan Africa, 32 per cent (n=55) in East Asia and the Pacific, and seven per cent (n=12) in Latin America and the Caribbean. Twenty-two per cent of studies were carried out in South Asia (n=37), and six per cent in the Middle East and North Africa (n=10). Two per cent (n=4) were conducted in Europe, and only one study was undertaken in North America. As shown in Figure 6, most of these interventions were carried out in lower-middle-income countries (n=71; 41 per cent) and upper-middle-income countries (n=64; 37 per cent). The remaining interventions were conducted in low-income countries (n=38; 22 per cent) and high-income countries (n=1; 0.6 per cent).

Figure 3. Publication trend over time



[14] As explained above, we define developing countries as those included as non-Annex I countries within the Kyoto Protocol. We sub divide this category into low-income countries, lower-middle-income countries and upper-middle-income-countries when describing the geographical distribution of included studies and within the meta-analyses. This is to offer greater detail to the reader to supplement the main UNFCCC categorisation as determined in the Kyoto Protocol.

Figure 4. Geographic spread of included studies

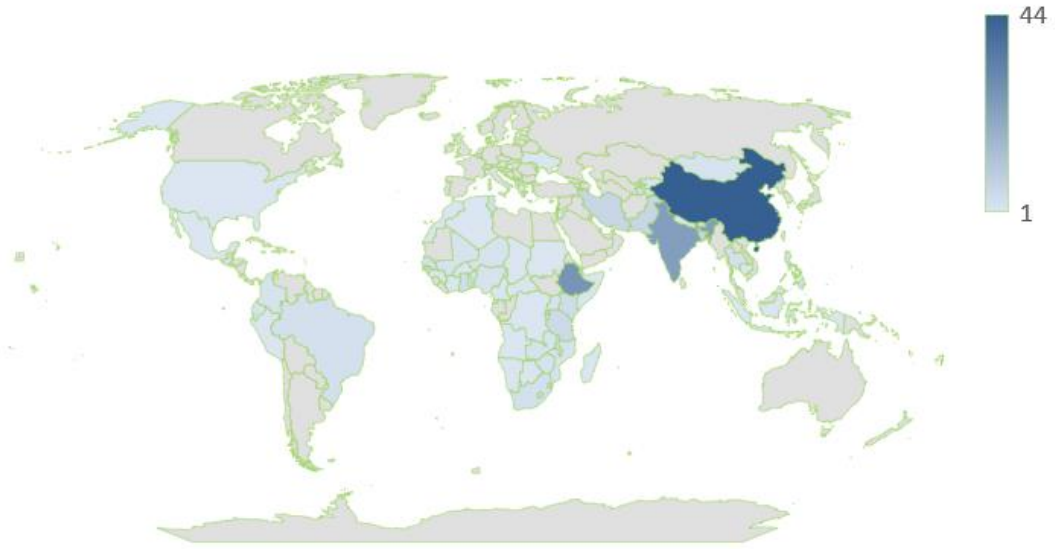


Figure 5. Distribution of studies by region

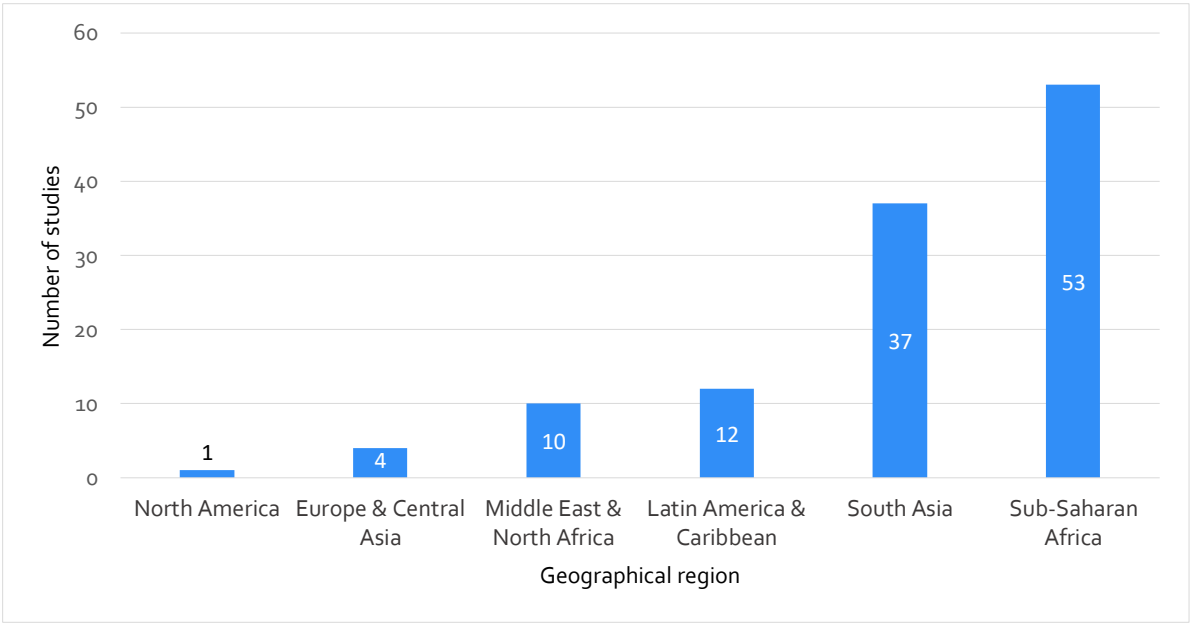
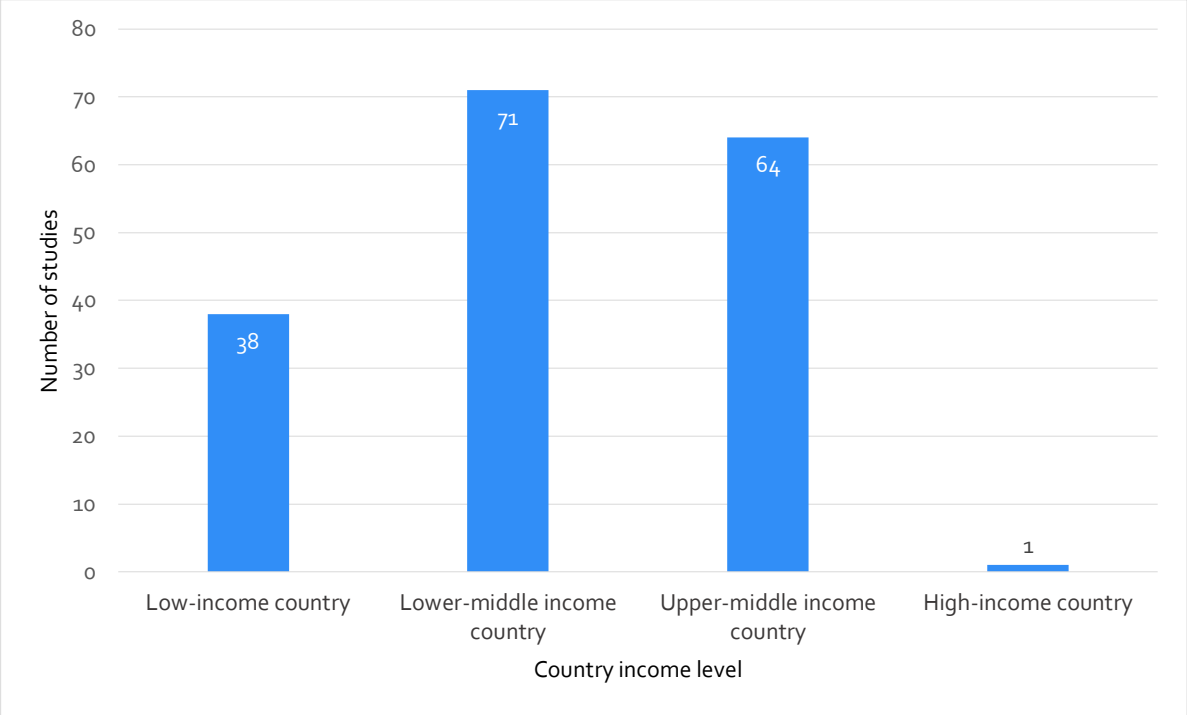


Figure 6. Distribution of studies by country sub-category



c. Interventions

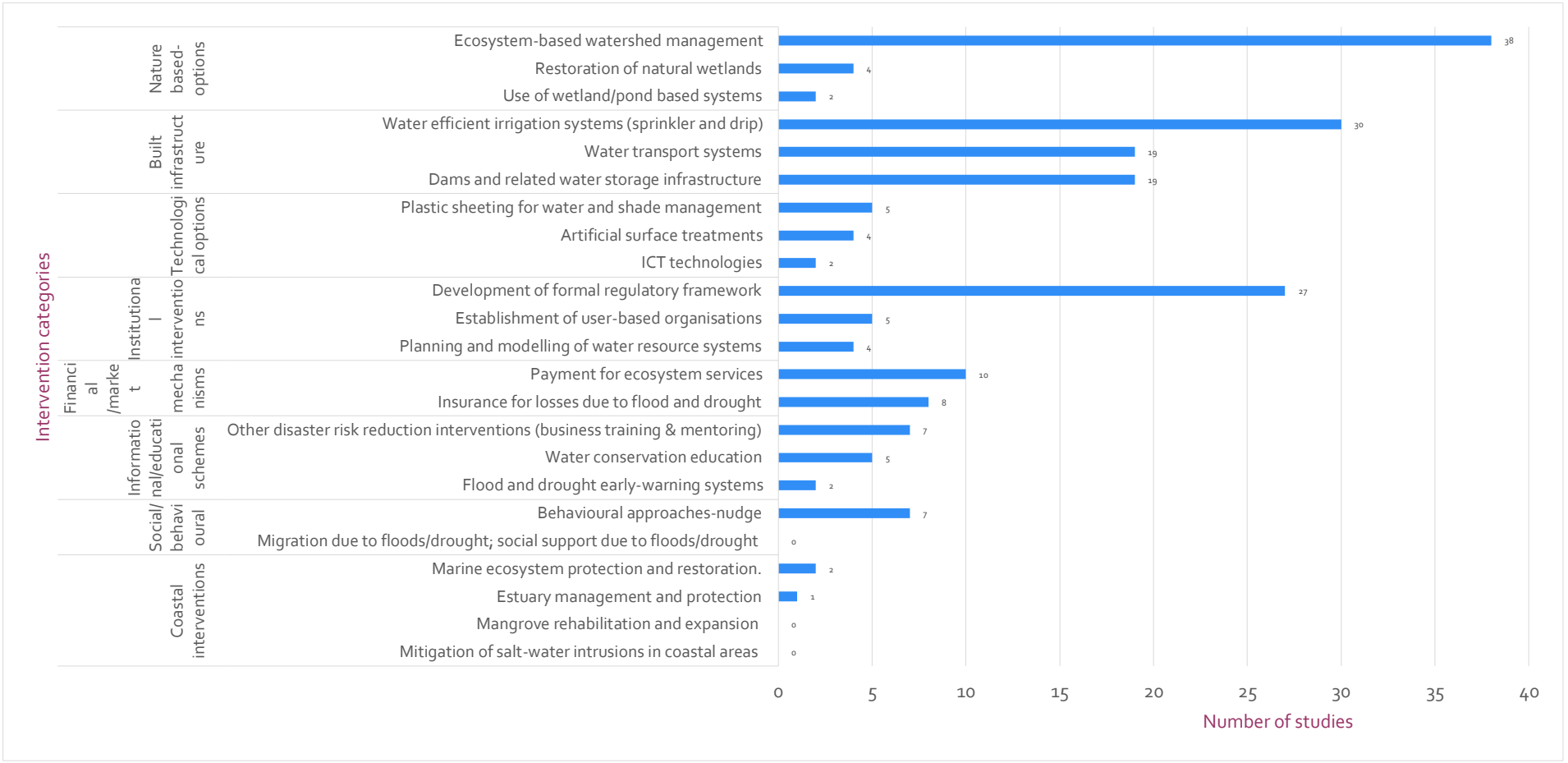
Figure 7 shows the number of studies across the eight coastal and terrestrial water sector intervention categories covered in this SR. The most frequently assessed interventions are ecosystem-based watershed management (nature-based options; n =38) followed by water-efficient irrigation systems (built infrastructure; n = 30) and the development of formal regulatory frameworks (institutional interventions; n = 25). The least reported interventions were behavioural and coastal interventions, which were reported in seven and three studies, respectively. There is limited reported evidence about technological interventions and informational/educational schemes.[15]

d. Outcomes

Figure 8 shows the outcomes of interest reported in the included studies. The most reported outcome is adaptive capacity, specifically buffer capacity (n=121). The second most reported outcome is the adoption of interventions, which falls within the process and implementation group of outcomes of (n=50). The third most reported outcome is ecological succession and resilience (n=28), which falls in the adaptive capacity group, followed by changed attitudes (=26) from within the process and implementation. The least reported outcomes are negative effects (unintended effects; n=1) and exposure by location (shocks and stresses; n=4).

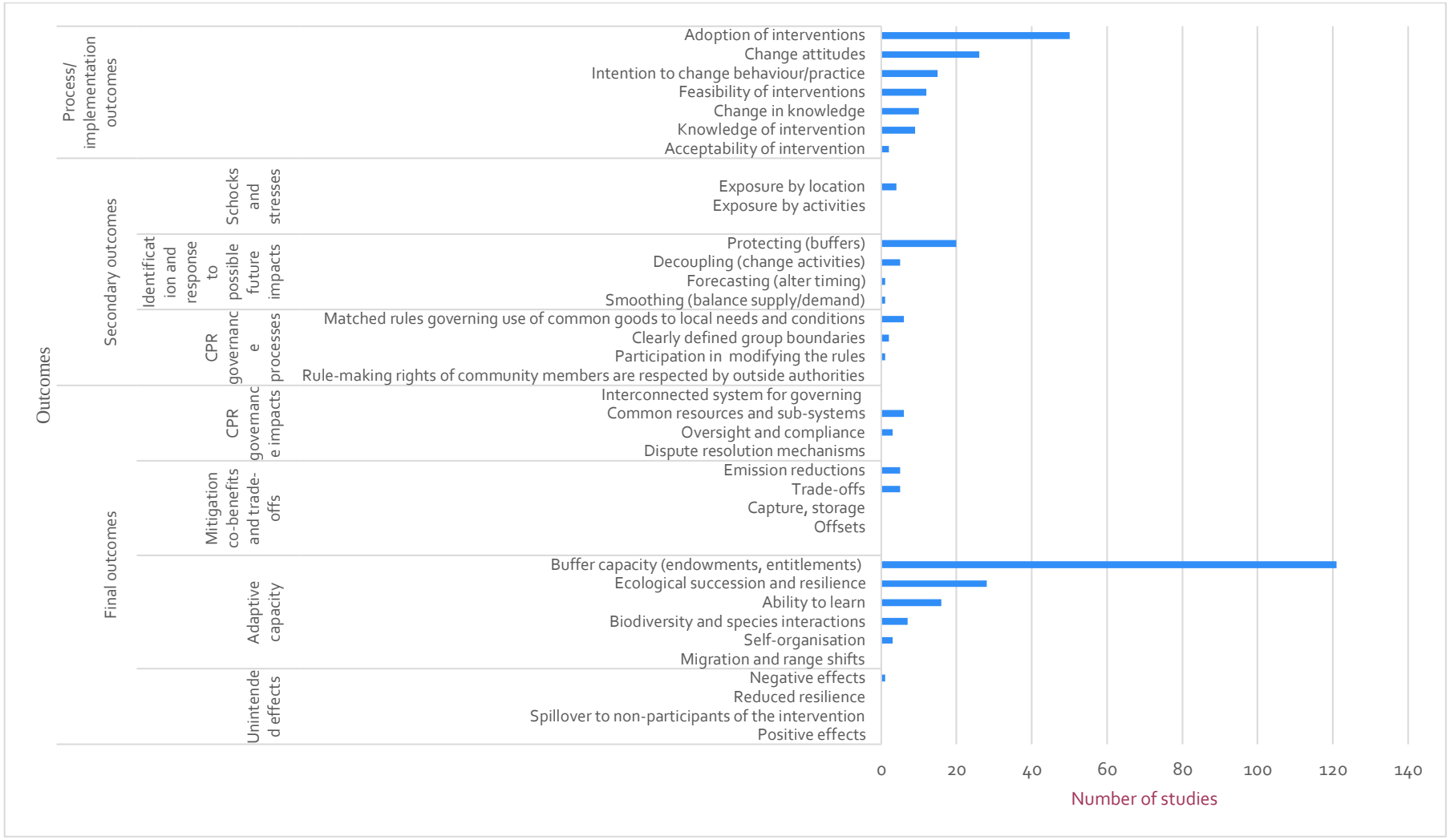
[15] As explained in the protocol for this systematic review, we do not use any restrictions related to intervention-level characteristics, such as modality, intensity, duration or complexity of delivery. In addition, we do not exclude studies based on restrictions related to sample size, ensuring the review captures pilot-scale interventions that often focus on newer, more innovative approaches.

Figure 7. Overview of included intervention[16] types



[16] Studies can report multiple interventions, leaving the cumulative total that does not necessarily match the number of included studies.

Figure 8. Overview of included outcomes[17]

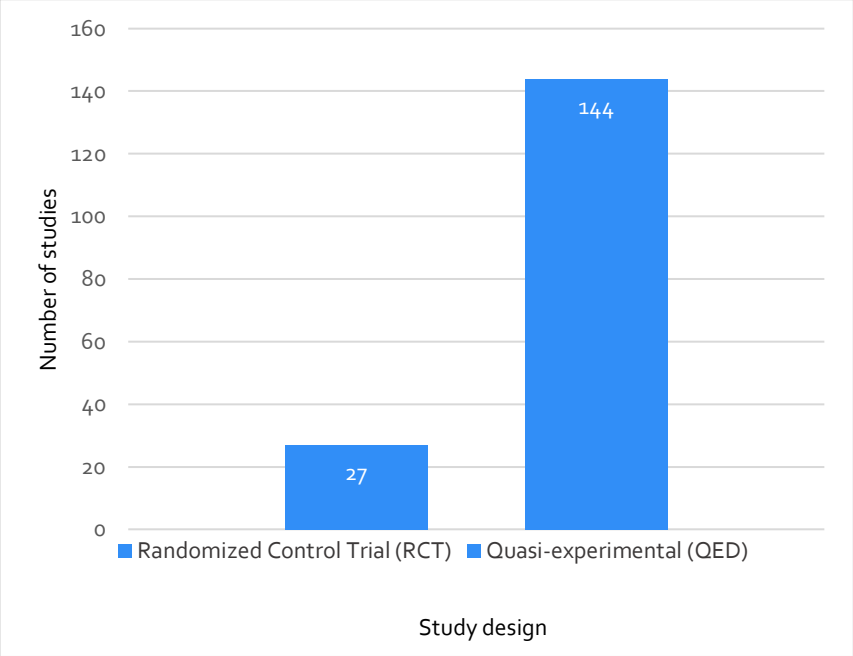


[17] Studies can report multiple outcomes, leaving the cumulative total to not necessarily match the number of included studies.

e. Study design of included studies

Of the 171 included unique studies, a large majority adopt quasi-experimental designs (QEDs) (144), whereas 27 are randomized controlled trials (RCTs) (Figure 9). A vast majority of the included studies (n=117) do not specify the intervention's follow-up period[18] due to the nature of the intervention. For example, an intervention involving the implementation of water-efficient irrigation systems identified in the evidence base does not have an end date as these structures are permanent. Hence, the point of the end of the intervention cannot be determined. Thus, the follow-up period cannot be stipulated. Twelve per cent (n=21) of the included studies have a follow-up period of over 25 months, 10 per cent of included studies have a follow-up period of under a month, five per cent of included studies (n=9) follow-up at seven to 12 months, two per cent of the studies included (n=4) have a follow-up period of 19 to 24 months, and approximately two per cent of the included studies follow-up at between one to six months. Only one study had a follow-up period of 13 to 18 months (n=1).

Figure 9. Study design of included studies



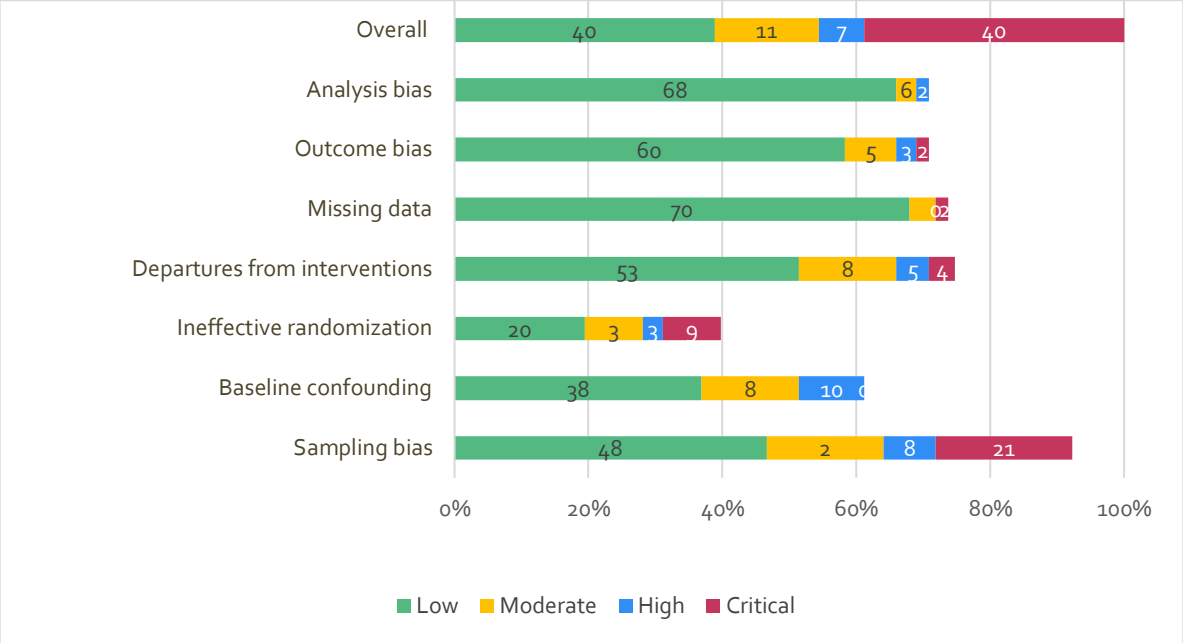
3. RISK OF BIAS IN INCLUDED STUDIES

The risk of bias tool aims to assess the risk of bias in each included study covering four broad intervention categories selected for synthesis, as noted above. These intervention categories are built infrastructure, nature-based options, institutional interventions and financial/market mechanisms. These intervention categories are represented by a total of 103 studies. Figure 10 below provides a summary of the full risk of bias ratings of the included studies. Forty per cent (40/103) of the included studies were assessed to be of low risk of bias. Forty studies received a critical risk of bias rating and were excluded from the synthesis. The critical risk of bias assessment is largely due to sampling bias (n=21).

[18] Follow-up is the length of period between the end date of the intervention and the date at which the outcomes are measured.

Eleven studies were rated as having a moderate risk of bias, and seven studies were found to have a high risk of bias, raising concerns about the reliability of the impact estimates. Throughout the synthesis, we indicate the underlying risk of bias in the studies included in the different analyses.

Figure 10. Overview of risk of bias assessment



4. SYNTHESIS OF RESULTS

In this section, we report the results of our synthesis of the selected coastal and terrestrial water sector interventions on adaptive (buffer) capacity and adoption of interventions. The synthesis is based on the results of the 40 studies assessing the impact of the six interventions, broadly categorized into four domains: built infrastructure, nature-based options, institutional, and financial/market mechanisms. A study could assess more than one outcome indicator if it featured an outcome in that category. Hence, some studies appear in more than one of these outcome categories. The selection of saturated cells is based on the observation that a significant portion of the studies reviewed for these interventions employed well-defined methodologies to measure adaptive (buffer) capacity and the adoption of interventions. This facilitated the collection of statistical information for calculating effect sizes. In addition, the selection of cells was determined by feedback from the advisory group for this evidence review.

We conducted meta-analyses in our SR to examine the overall effects of:

- Water-efficient irrigation systems (six meta-analyses)
- Ecosystem-based watershed management (three meta-analyses)
- Development of formal regulatory framework (three meta-analyses)
- Insurance for losses due to flood and drought (three meta-analyses)
- Establishment of user-based organizations (one meta-analysis)
- Payments for ecosystem services (one meta-analysis)

These meta-analyses focused on the impact of these interventions on adaptive (buffer) capacity and the adoption of interventions, involving a total of 40 studies. The indicators for adaptive capacity in the meta-analyses include:

- Income (five meta-analyses)
- Crop yield (four meta-analyses)
- Consumption and expenditure (two meta-analyses)
- Income growth (one meta-analysis)
- Water consumption (one meta-analysis)
- Dietary diversity (one meta-analysis)
- Food security (one meta-analysis)
- Poverty levels (one meta-analysis)
- Adoption of interventions (one meta-analysis)

We also conducted a narrative synthesis in these interventions for studies that do not constitute the same intervention and outcome combinations. We report the effects of these interventions using narrative synthesis based on a structured summary of findings tables. In total, we report 17 meta-analyses and one narrative synthesis for the above intervention groupings.

IV. RESULTS OF THE META-ANALYSIS

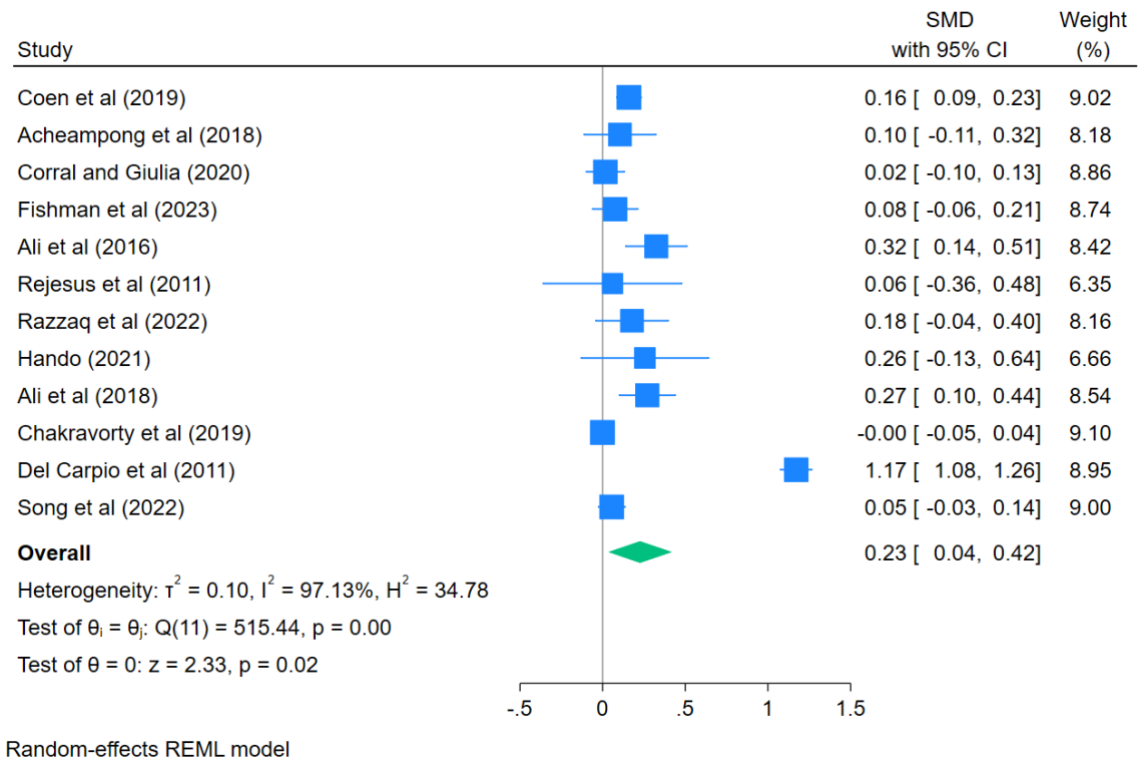
In this section, we report the results of our quantitative analysis of the effects using statistical meta-analysis and narrative synthesis. Our analysis is structured around the four intervention categories, namely built infrastructure, nature-based options, institutional interventions, and financial/market mechanisms. Using meta-analysis and narrative synthesis, we specifically explore the effectiveness of the interventions on buffer capacity and adoption of interventions.

A. INTERVENTION 1: BUILT INFRASTRUCTURE

1. EFFECTS OF WATER-EFFICIENT IRRIGATION SYSTEMS ON INCOME

We included a total of k = 12 studies, including two RCTs and 10 quasi-experimental designs. We assessed seven studies as having a low risk of bias and the remaining five studies as having a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.23 (CI: 0.04 to 0.42). The pooled effect estimate is therefore statistically significant (z=2.33, p<0.02). This implies that water-efficient irrigation system interventions have a significant positive effect on income. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 11 below. According to the Q-test, the meta-analysis results are subject to a significant degree of heterogeneity (Q (11) =51.44, p=0.00, $\hat{\tau}^2$=0.10, I^2=97.13 per cent), and the confidence intervals of all but one study overlap. To assess the robustness of the identified effect, we next report the results of our sensitivity and moderator analyses, which investigate whether the observed overall effect might be driven by variables other than the applied water-efficient irrigation systems interventions. A funnel plot of the estimates is shown in Figure 12. Neither the rank correlation nor the regression test indicated any funnel plot asymmetry (p= 0.1926 and p= 0.7697, respectively. Applying the GRADE framework, the evidence on the effects of water-efficient irrigation systems on income is of very low quality (see Appendix 3).

Figure 11. Meta-analysis of water-efficient irrigation systems on income



In our meta-analysis on water-efficient irrigation systems on income, we combined results from two RCTs and 10 quasi-experimental designs. The results of the meta-analysis were sensitive to the applied study design (Q=4.88; p=0.03), with the quasi-experimental designs yielding a higher pooled effect estimate. While we observed that a lower risk of bias led to larger effects, testing for the significance of this difference in effect sizes established that variances in the quality of studies did not influence the overall results of the meta-analysis (Q= 1.46; p=0. 0.23). We found that the results are sensitive to follow-up. The effects are largest for a study with a follow-up period of less than one month, followed by studies with an unspecified follow-up period and lowest for studies with a follow-up period of one to six months (Q=501.52; p=0.02).

Sensitivity analysis of water-efficient irrigation systems on income

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and follow-up period). For example, a more rigorous evaluation approach might yield systematically different effect sizes from those with a less robust evaluation design. We investigated the sensitivity of our pooled effect estimate to the above design factors. Table 1 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features. Differences in the pooled effect size for each variable could indicate that the overall results of the meta-analysis are sensitive to the design variable under investigation.

Figure 12. Funnel plot of water-efficient irrigation systems on income

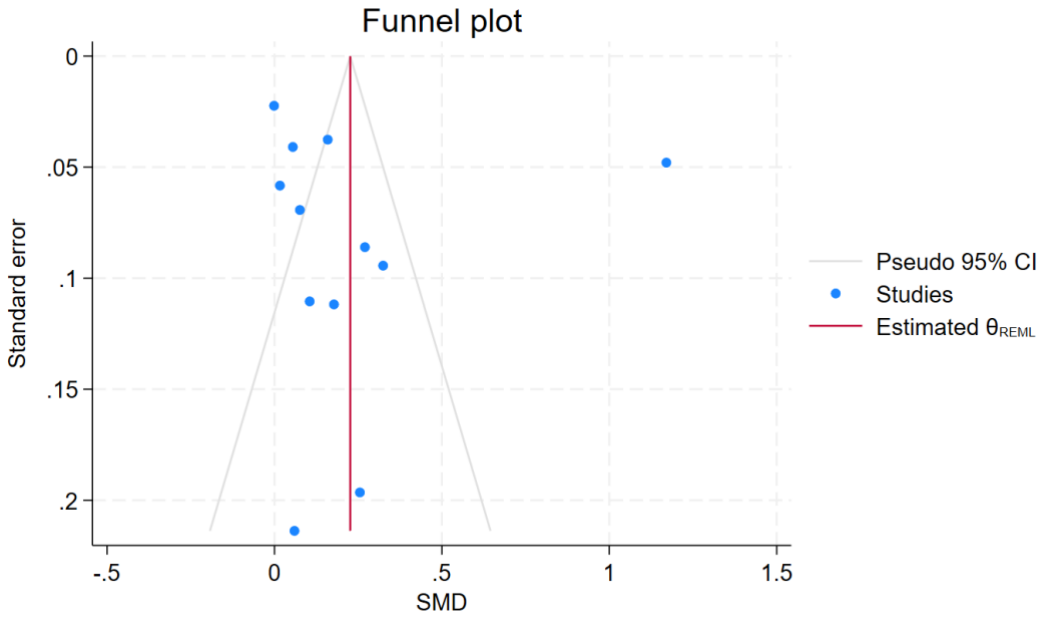


Table 1. Sensitivity analysis of water-efficient irrigation systems on income

VARIABLE	SMD*	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all studies	0.23	0.04 to 0.42	4.88	0.1	97.13%	0.03		
Design			4.88			0.03		Sensitive
RCT	0.01	-0.04 to 0.06	1.12	0.00	10.84%	0.72	2	
Quasi-experimental design	0.27	0.04 to 0.49	408.88	0.12	96.32%	0.02	10	
Risk of bias			1.46			0.23		Not sensitive
Low risk of bias	0.3	-0.00 to 0.61	495.55	0.16	98.37%	0.05	7	
Moderate risk of bias	0.1	-0.01 to 0.22	8.32	0.01	60.49	0.07	5	
High risk of bias	N/A	No observations						
Period of follow-up			501.52			0.02		Sensitive
<1 month	1.17	1.08 to 1.26	0.00	0.00	0.00	0.00	1	
1–6 months	-0.00	-0.05 to 0.04	0.00	0.00	0.00	0.96	1	
7–12	0.02	-0.10 to	0.00	0.00	0.00	0.78	1	

VARIABLE	SMD*	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
months		0.13						
13-18 months	N/A	No observations						
19-24 months	N/A	No observations						
>25 months	0.14	0.07 to 0.21	1.11	0.00	10.02%	0.00	2	
Not specified	0.17	0.07 to 0.27	11.01	0.01	45.85%	0.00	7	

Abbreviations: SMD stands for Standardized Mean Difference.

Moderator analysis of water-efficient irrigation systems on income

In addition to assessing whether variables relating to study design influenced the robustness of the meta-analysis, we further conducted moderator analyses on a combination of extrinsic characteristics and substantive characteristics listed in Table 2. A context characteristic, such as income, may influence the intervention effects. For example, programmes in upper-middle-income countries might be more effective than those in low-income countries, and so forth. We had sufficient data to test all moderators for this intervention type and investigated variables related to publication type and date, implementing agency type, length of exposure to the intervention and context characteristics of the intervention that might systematically moderate intervention effects identified in the meta-analysis (Table 2).

When reporting the moderator analysis, we used the same structure as in the sensitivity analysis based on an observational overview table followed by a one-way Restricted Maximum Likelihood (REML) model.[19] Table 2 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the moderator variables under investigation. Differences in the pooled effect size for each variable could indicate that the overall results of the meta-analysis are sensitive to the moderator variable under investigation, which is then formally tested in the REML model. We had sufficient data to test all moderators for this intervention and outcome group and investigated variables related to publication type and date, intervention length, provision of incentives, implementing agency type and context characteristics of the intervention that might systematically moderate intervention effects identified in the meta-analysis (see Table 2).

Publication date, country income group, and whether the programme participants received incentives to participate did not significantly influence the results of our meta-analysis. However, publication type, the location (country and region) of the programme, the implementing agency type and length of intervention influenced the results of our meta-analysis. Regarding publication type, academic journal articles yielded larger effects than research reports. Country-wise, we observed larger effects in Peru, followed by Pakistan and Ethiopia, while the smallest effects were observed in Bangladesh. In terms of region, the effects were larger in Latin America and the Caribbean relative to East Asia and Pacific, South Asia and Sub-Saharan Africa. We observed the largest effects for programmes that were implemented by international aid agencies, followed by interventions implemented by for-profit firms and in programmes that have no specific

[19] Restricted Maximum Likelihood is a statistical method used for estimating the parameters of linear mixed-effects models and variance components.

implementing agency. The least number of effects were observed in programmes implemented by government agencies.

Table 2. Moderator analysis of water-efficient irrigation systems on income

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all studies	0.23	0.04 to 0.42	2.84	0.01	55.85 %	0.09	12	
Publication type			2.84			0.09		Sensitive
Academic journal	0.29	0.04 to 0.53	368.1	0.13	95.44 %	0.02	9	
Research report	0.06	-0.05 to 0.16	13.57	0.01	83.22 %	0.27	3	
Publication date			8.81			0.18		Not sensitive
2011	0.63	-0.45 to 1.72	25.71	0.59	96.1%	0.00	2	
2016	0.32	0.14 to 0.51	0.00	0.00	0.00%	0.00	1	
2018	0.20	0.04 to 0.38	1.39	0.00	28.09 %	0.01	2	
2020	0.08	-0.08 to 0.23	13.41	0.01	92.54 %	0.34	2	
2021	0.06	-0.12 to 0.25	1.36	0.01	26.32 %	0.51	2	
2022	0.07	-0.01 to 0.16	1.06	0.00	6.01	0.09	2	
2023	0.08	-0.06 to 0.21	0.00	0.00	0.00	0.27	1	
Length of intervention			21.34			0.00		Sensitive
<1 month	N/A	No observations						
1-6 months	-0.00	-0.05 to 0.04	0.00	0.00	0.00	0.96	1	
7-12 months	N/A	No observation						
13-18 months	N/A	No observations						
19-24 months	N/A	No observations						
>25 months	0.26	-0.11 to 0.63	414.8	0.2	98.62	0.16	6	
Not specified	0.24	0.14 to 0.33	2.72	0.00	0.00	0.00	5	
Country			514.43			0.00		Sensitive
Bangladesh	0.00	-0.05 to 0.04	0.06	0.00	0.00	0.96	1	
China	0.05	-0.03 to 0.14	1.34	0.00	0.00	0.18	1	
Ecuador	0.02	-0.10 to 0.13	0.28	0.00	0.00	0.78	1	

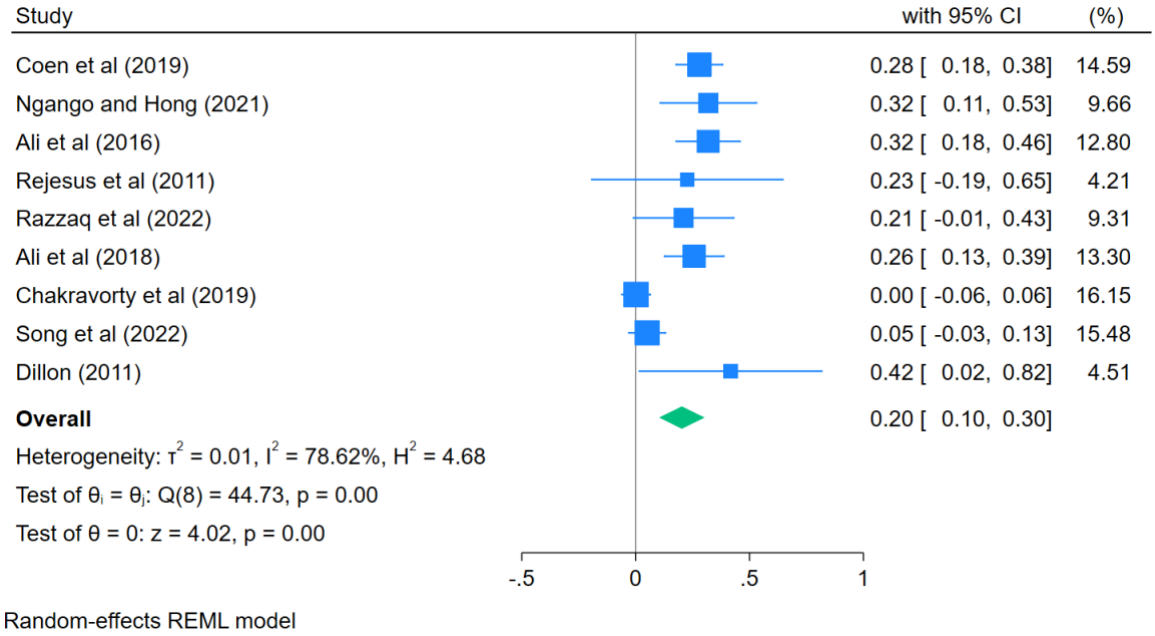
VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Ethiopia	0.26	-0.13 to 0.64	1.3	0.00	0.00	0.19	1	
Ghana	0.10	-0.11 to 0.32	0.95	0.00	0.00	0.34	1	
India	0.08	-0.06 to 0.21	1.10	0.00	0.00	0.27	1	
Pakistan	0.27	0.16 to 0.37	4.82	0.00	0.00	0.00	3	
Peru	1.17	1.08 to 1.26	24.41	0.00	0.00	0.00	1	
Philippines	0.06	-0.36 to 0.48	0.28	0.00	0.00	0.78	1	
Senegal	0.16	0.09 to 0.23	4.23	0.00	0.00	0.00	1	
Region			4.6			0.2		Sensitive
East Asia and Pacific	0.06	-0.02 to 0.13	0.00	0.00	0.00	0.17	2	
Middle East and North Africa	N/A	No observations						
Europe and Central Asia	N/A	No observations						
Latin America and Caribbean	0.59	-0.54 to 1.73	233.74	0.66	99.57 %	0.3	2	
South Asia	0.15	0.02 to 0.28	21.42	0.02	78.09 %	0.02	5	
Sub-Saharan Africa	0.16	0.09 to 0.23	0.47	0.00	0.00	0.00	3	
Not specified	N/A	No observations						
Income group			0.84			0.66		Not sensitive
Low-income country(s)	0.26	-0.13 to 0.64	0.00	0.00	0.00	0.19	1	
Lower-middle-income country(s)	0.14	0.05 to 0.22	29.42	0.01	71.29 %	0.00	8	
Upper-middle-income country(s)	0.41	-0.33 to 1.16	372.42	0.43	99.45 %	0.27	3	
High-income country(s)	N/A	No observations						
Incentives			1.70			0.19		Not sensitive
No	0.24	0.03 to 0.45	513.7	0.11	97.39 %	0.02	11	
Yes	0.08	-0.06 to 0.21	0.00	0.00	0.00	0.27	1	
Implementing agency			376.7			0.00		Sensitive
Government agency	0.02	-0.09 to 0.13	0.04	0.00	0.00	0.73	2	

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Academic institutions	N/A	No observations						
Charitable or private foundation	N/A	No observations						
For-profit firm	0.14	0.07 to 0.21	1.11	0.00	10.02	0.00	2	
International aid agency	1.71	1.08 to 1.26	0.00	0.00	0.00	0.00	1	
International financial institution	N/A	No observations						
Non-profit organization	N/A	No observations						
Not specified	0.14	0.04 to 0.25	22.79	0.01	76.22 %	0.01	7	

2. EFFECTS OF WATER-EFFICIENT IRRIGATION SYSTEMS ON CROP YIELD

Nine studies reported the impact of water-efficient irrigation systems on crop yield (k=9 studies), including one RCT and eight quasi-experimental designs. We assessed six studies as having a low risk of bias and the other three as having a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.20 (CI: 0.10 to 0.30). This is statistically significant (z=4.02, p<0.00), indicating that water-efficient irrigation systems interventions present a large positive and statistically significant effect on crop yields. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 13. According to the Q-test, there was a significant amount of heterogeneity in the true outcomes (Q (8) =44.73, p=0.00, $\hat{\tau}^2$=0.01, I^2=78.62 per cent). To assess the robustness of the identified effect, we report the results of our sensitivity and moderator analyses, which investigate whether the observed overall effect might be driven by variables other than the applied water-efficient irrigation systems interventions. With nine studies, tests of publication bias are not valid. Applying the GRADE framework, the evidence on the effects of water-efficient irrigation systems on crop yield is of moderate quality (see Appendix 3).

Figure 13. Meta-analysis of water-efficient irrigation systems on crop yield



Sensitivity analysis of water-efficient irrigation systems on crop yield

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and follow-up period). Table 3 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features. Differences in the pooled effect size for each variable could indicate that the overall results of the meta-analysis are sensitive to the design variable under investigation. In our meta-analysis of water-efficient irrigation systems on crop yield, we combined results from one RCT and eight quasi-experimental designs. The results of the meta-analysis were sensitive to the applied study design (Q=17.29; p=0.00), and we observed larger effects from quasi-experimental designs relative to the RCT.

Regarding pooling studies with different risks of bias, we observed that a lower risk of bias led to larger effects than studies with a moderate risk of bias. However, testing for the significance of this difference in effect sizes established that variances in the quality of studies did not influence the overall results of the meta-analysis (Q=0.07; 0.79). We further tested if differences in the period of follow-up systematically affected the pooled effect size and found that the results were sensitive to follow-up. The effects are higher for a study with a follow-up period of less than a month compared to a follow-up period of one to six months and unspecified periods of follow-up (Q=27.17; p=0.00).

Table 3. Sensitivity analysis of water-efficient irrigation systems on crop yield

VARIABLE	SMD	95% CI	Q	TAU²	I²	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all studies	0.20	0.10 to 0.30	44.73	0.01	78.62%	0.00	9	
Design			17.29			0.00		Sensitive
RCT	0.00	-0.06 to 0.06	-0.00	0.00			1	
Quasi-	0.24	0.14 to 0.33	21.45	0.01	60.94%	0.00	8	

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
experimental design								
Risk of bias			0.07			0.79		Not sensitive
Low risk of bias	0.22	0.09 to 0.34	33.94	0.02	77.84%	0.00	6	
Moderate risk of bias	0.18	-0.02 to 0.38	10.79	0.02	77.90%	0.00	3	
High risk of bias	N/A	No observations					0	
Period of follow-up			27.17			0.00		Sensitive
<1 month	0.28	0.18 to 0.38	0.00	0.00			1	
1–6 months	0.00	-0.06 to 0.06	-0.00	-0.00			1	
7–12 months	N/A	No observations						
13–18 months	N/A	No observations						
19–24 months	N/A	No observations						
>25 months	N/A	No observations					0	
Not specified	0.23	0.12 to 0.34	18.11	0.01	60.06	0.01	7	

Moderator analysis of water-efficient irrigation systems on crop yield

We then assessed whether a range of moderators influenced the robustness of the meta-analysis of water-efficient irrigation systems on crop yield. We had sufficient data to test all moderators for this intervention and outcome group and investigated a range of variables. These variables included publication type and date, intervention length, provision of incentives to participants and implementing agency type. They also included context characteristics of the intervention that might systematically moderate intervention effects identified in the meta-analysis (see Table 4). We find that context is a significant moderator, such as country, region and income group. Specifically, among the seven countries where evaluations were conducted, the largest effects were realized in Mali, followed by Rwanda, Senegal, Pakistan and the Philippines. The smallest effects were observed in Bangladesh and China. Regionally, this translates into Sub-Saharan Africa witnessing the largest effects, followed by South Asia and then East Asia and the Pacific. Correspondingly, the same pattern is noticed for income group, with the largest effects being realized in a low-income country. Publication type and date, length of intervention, incentivizing participants to participate and implementing agency type are not significant moderators.

Table 4. Moderator analysis of water-efficient irrigation systems on crop yield

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all	0.20	0.10 to 0.30	44.73	0.01	78.62%	0.00	9	

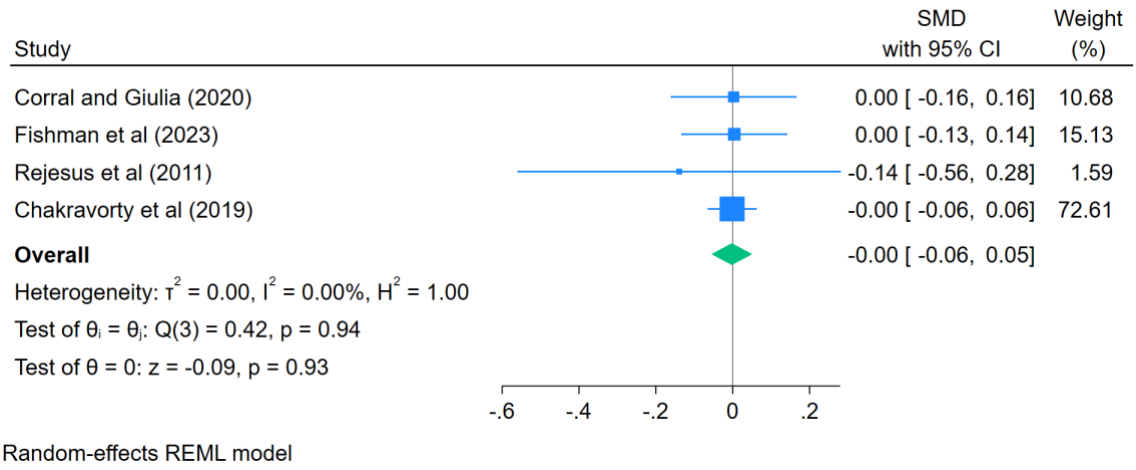
VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
studies								
Publication type			0.37			0.54		Not sensitive
Academic journal	0.23	0.12 to 0.32	18.11	0.01	60.06%	0.01	7	
Research report	0.14	-0.13 to 0.41	20.99	0.04	95.24%	0.00	2	
Publication date			7.41			0.19		Not sensitive
2011	0.33	0.04 to 0.62	0.41	0.00	0.00%	0.52	2	
2017	0.32	0.18 to 0.46	0.00	0.00		0.00	1	
2019	0.12	-0.13 to 0.37	12.10	0.03	91.73%	0.00	2	
2020	0.28	0.18 to 0.38	0.00	0.00			1	
2021	0.32	0.11 to 0.53	0.00	0.00	0.00%		1	
2022	0.10	-0.05 to 0.24	1.79	0.01	44.24	0.18	2	
Length of intervention			1.05			0.59		Not sensitive
<1 month	N/A	No observations					0	
1–6 months	0.14	-0.17 to 0.45	7.99	0.04	87.48%	0.00	2	
7–12 months	N/A	No observations					0	
13–18 months	N/A	No observations					0	
19–24 months	N/A	No observations					0	
>25 months	0.20	0.03 to 0.37	14.03	0.02	75.16	0.00	4	
Not specified	0.27	0.19 to 0.36	0.77	0.00	0.01	0.68	3	
Country			43.96			0.00		Sensitive
Bangladesh	0.00	-0.06 to 0.06	0.00	0.00			1	
China	0.05	-0.03 to 0.13	-0.00	0.00.			1	
Mali	0.42	0.02 to 0.82	0.00	0.00			1	
Pakistan	0.27	0.19 to 0.36	0.77	0.00	0.01%		3	
Philippines	0.23	-0.19 to 0.65	0.00	0.00			1	
Rwanda	0.32	0.11 to 0.53	0.00	0.00			1	
Senegal	0.28	0.18 to 0.38	-0.00	0.00			1	
Region			15.34			0.00		Sensitive
Middle East and North Africa	N/A	No observations						
East Asia and Pacific	0.06	-0.02 to 0.14	0.65	0.00	0.00%	0.42	2	

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Sub-Saharan Africa	0.29	0.20 to 0.38	0.49	0.00	0.00%	0.78	3	
Europe and Central Asia	N/A	No observations						
Latin America and Caribbean	N/A	No observations						
South Asia	0.19	0.03 to 0.34	25.42	0.02	83.18	0.00	4	
Not specified	N/A	No observations						
Income group			10.25			0.01		Sensitive
Low-income country(s)	0.34	0.15 to 0.53	0.18	0.00	0.00	0.67	2	
Lower-middle-income country(s)	0.21	0.09 to 0.32	36.09	0.01	78.60	0.00	6	
Upper-middle-income country(s)	0.05	-0.03 to 0.13	0.00	0.00			1	
High-income country(s)	N/A	No observations						
Incentives			1.14			0.29		Not sensitive
No	0.19	0.09 to 0.30	41.24	0.02	80.37%	0.00	8	
Yes	0.32	0.11 to 0.53	0.00	0.00			1	
Implementing agency			2.07			0.36		Not sensitive
Academic institution	N/A	No observations						
Government agency	0.30	0.11 to 0.49	0.15	0.00	0.00%	0.70	2	
Charitable or private foundation	N/A	No observations						
For-profit firm	0.28	0.18 to 0.38	-0.00	0.00			1	
International aid agency	N/A	No observations						
International financial institution	N/A	No observations						
Non-profit organization	N/A	No observations						
Think tank	N/A	No observations						
Not specified	0.17	0.05 to 0.30	28.86	0.02	83.39%	0.00	6	

3. EFFECTS OF WATER-EFFICIENT IRRIGATION SYSTEMS ON THE ADOPTION OF INTERVENTIONS

We included k = 4 studies in the meta-analysis of the impact of water-efficient irrigation systems on the adoption of interventions. In terms of design, the analysis includes two RCTs and two quasi-experimental designs. We assessed two studies as having a low risk of bias and two studies as having a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.00 (CI: -0.06 to 0.05). This is statistically insignificant (z=-0.09, p<0.93), indicating that water-efficient irrigation systems interventions have zero and statistically insignificant effect on the adoption of interventions. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 14. According to the Q-test, there was no significant amount of heterogeneity in the true outcomes (Q (3) =0.42, p=0.94, $\hat{\tau}^2$=0.00, I^2=0.00 per cent). Given that the meta-analysis only includes four studies, moderator analyses were not possible. However, we conducted a sensitivity analysis to test if the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). With four studies, tests of publication bias are not valid. Applying the GRADE framework, the evidence on the effects of water-efficient irrigation systems on adoption of interventions of low quality (see Appendix 3).

Figure 14. Meta-analysis of water-efficient irrigation systems on adoption of interventions



Sensitivity analysis of water-efficient irrigation systems on adoption of interventions

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). Table 5 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features. In our meta-analysis on water-efficient irrigation systems on adoption of interventions, we combined results from two RCTs and two quasi-experimental designs. The results of the meta-analysis shown in Table 5 below indicate that quasi-experimental studies, studies with moderate risk of bias and a study with an unspecified follow-up period have larger effects, but this influence is not statistically significant. In sum, the results of the meta-analysis were not sensitive to the applied study design, risk of bias and period of follow-up.

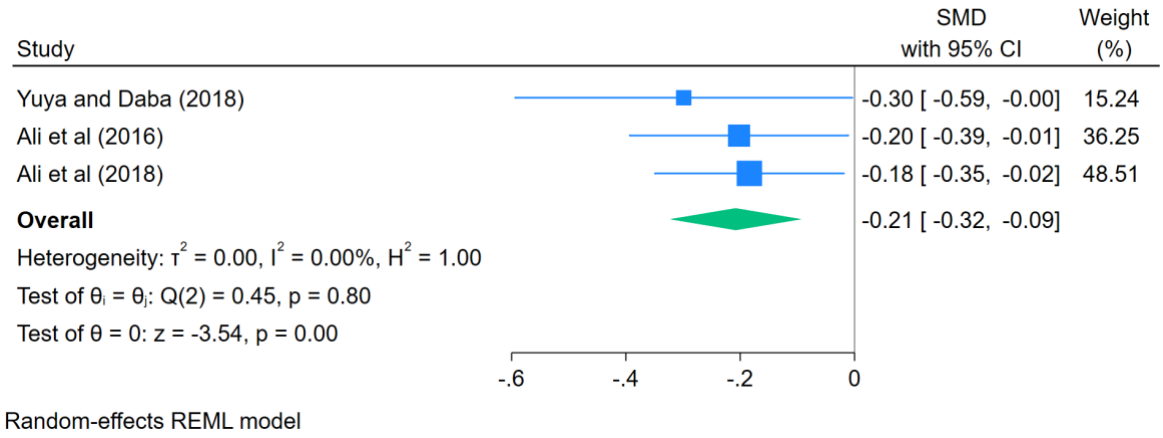
Table 5. Sensitivity analysis of water-efficient irrigation systems on adoption of interventions

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all studies	-0.00	-0.06 to 0.05	0.03	0.00	0.00	0.85	4	
Design			0.03			0.85		Not sensitive
QED	-0.02	-0.17 to 0.14	0.38	0.00	0.00	0.84	2	
RCT	-0.00	-0.06 to 0.06	0.01	0.00	0.02	0.99	2	
Risk of bias			0.03			0.85		Not sensitive
Low risk of bias	-0.00	-0.06 to 0.06	0.01	0.00	0.02	0.99	2	
Moderate risk of bias	-0.02	-0.17 to 0.14	0.38	0.00	0.00	0.84	2	
Period of follow-up			0.42			0.94		Not sensitive
<1 month								
1–6 months	-0.00	-0.06 to 0.06	0.00	0.00	0.00	0.96	1	
7–12 months	0.00	-0.16 to 0.16	0.00	0.00	0.00	0.97	1	
>25 months	0.00	-0.13 to 0.14	0.00	0.00	0.00	0.95	1	
Not specified	-0.14	-0.56 to 0.28	0.00	0.00	0.00	0.51	1	

4. EFFECTS OF WATER-EFFICIENT IRRIGATION SYSTEMS ON POVERTY LEVELS

Three studies reported the impact of water-efficient irrigation systems on poverty (k = 3 studies), including two RCTs and one quasi-experimental design. We assessed two of the studies as having a low risk of bias and the other as having a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=-0.21 (CI: -0.32 to -0.09). Therefore, the pooled effect estimate is statistically significant (z=-3.54, p<0.00), implying that water-efficient irrigation systems do have a minimizing and statistically significant effect on poverty levels. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 15. Considering the small number of studies, this result should be interpreted with caution. According to the Q-test, there was no significant amount of heterogeneity in the true outcomes (Q (2) =0.45, p=0.80, $\hat{\tau}^2$=0.00, I^2=0.00 per cent). Given that the meta-analysis only includes three studies, moderator analyses were not possible. However, we conducted a sensitivity analysis to test if the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). As already noted, with three studies, tests of publication bias are not valid. The GRADE framework rated the evidence on the effects of water-efficient irrigation systems on poverty levels as being of moderate quality (see Appendix 3).

Figure 15. Meta-analysis of water-efficient irrigation systems on poverty levels



Sensitivity analysis of water-efficient irrigation systems on poverty levels

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). The results of the meta-analysis shown in Table 6 indicate that quasi-experimental studies and studies with a low risk of bias have larger effects, but this influence is not statistically significant. There is insufficient data in each category to perform sensitivity analysis on the period of follow-up, as all the studies are categorized as having an unspecified follow-up period.

Table 6. Sensitivity analysis of water-efficient irrigation systems on poverty levels

VARIABLE	SMD	95% CI	Q	TAU²	I²	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all studies	0.21	-0.32 to -0.09	0.43	0.00	0.00	0.51	3	
Design			0.43			0.51		Not sensitive
RCT	-0.19	-0.32 to -0.07	0.02	0.00	0.01%	0.00	2	
Quasi-experimental design	-0.30	-0.59 to -0.00	0.00	0.00	0.00	0.05	1	
Risk of bias			0.01			0.94		Not sensitive
Low risk of bias	-0.21	-0.36 to -0.07	0.44	0.00	0.00	0.00	2	
Moderate risk of bias	-0.20	-0.39 to -0.01	0.00	0.00	0.00	0.04	1	
Period of follow-up	Lack of sufficient evidence in each category for sensitivity analysis on this variable.[20]							N/A
<1 month	N/A	No observations						
1–6 months	N/A	No						

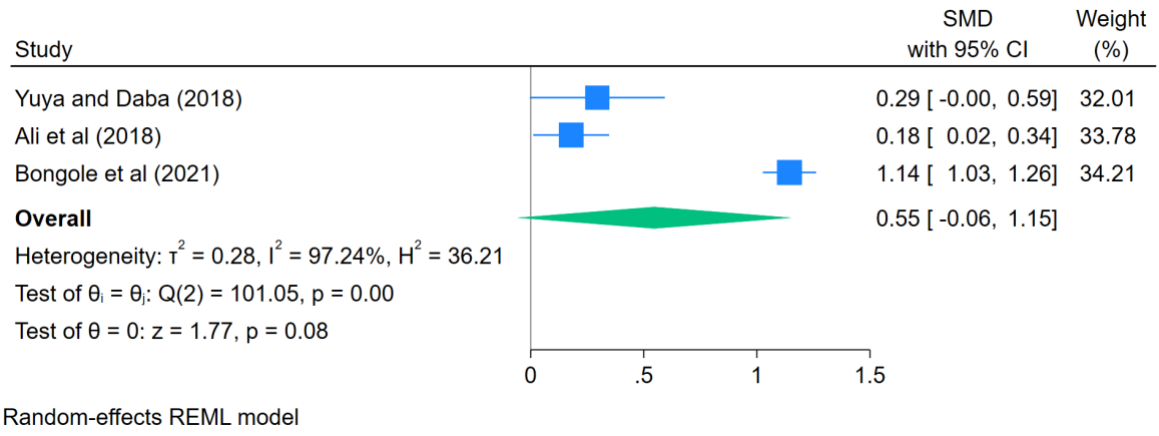
[20] All studies do not specify the follow-up period.

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
		observations						
7–12 months	N/A	No observations						
13–18 months	N/A	No observations						
19–24 months	N/A	No observations						
>25 months	N/A	No observations						
Not specified	0.21	-0.32 to -0.09	0.43	0.00	0.00	0.51	3	

5. EFFECTS OF WATER-EFFICIENT IRRIGATION SYSTEMS ON FOOD SECURITY

We identified and included a total of three studies k = 3 studies – all quasi-experimental studies – that assessed the impact of water-efficient irrigation systems on food security. Two studies were assessed as having a low risk of bias, and one study as having a moderate risk. The pooled effect estimate based on the random-effects model was $\hat{\mu}$= 0.55 (CI: -0.06 to 1.15). This is statistically significant only at the 10 per cent level (z=1.77, p<=0.08), indicating that water-efficient irrigation systems present a sizeable positive but statistically significant effect on food security. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 16. According to the Q-test, there was a significant amount of heterogeneity in the actual outcomes (Q (2) =101.05, p<0.00, $\hat{\tau}^2$=0.28, I^2=97.24 per cent). Given that the meta-analysis only includes three studies, moderator analyses were not possible. However, we conducted a sensitivity analysis to test if the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). As mentioned, tests of publication bias are not valid with only three publications. The GRADE quality of evidence assessment indicates that evidence of the effects of water-efficient irrigation systems on food security is very low quality (see Appendix 3).

Figure 16. Meta-analysis of water-efficient irrigation systems on food security



Sensitivity analysis of water-efficient irrigation systems on food security

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). Table 7 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features. In our meta-analysis of water-efficient irrigation systems on food security, we combined results from two RCTs and one quasi-experimental design. The results indicate that RCTs and studies with a moderate risk of bias have larger effects, and this influence is statistically significant. Hence, the results of the meta-analysis were sensitive to the applied study design and the risk of bias. There is insufficient data in each category to perform sensitivity analysis on the period of follow-up, as all the studies are categorized as having an unspecified follow-up period.

Table 7. Sensitivity analysis of water-efficient irrigation systems on food security

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Water-efficient irrigation systems: all studies	0.55	-0.06 to 1.15	1.62	0.28	97.24%	0.2	3	
Design			1.62			0.08		Sensitive
RCT	0.73	-0.10 to 1.56	27.78	0.35	96.40%	0.09	2	
Quasi-experimental design	0.18	0.02 to 0.34	0.00	0.00	0.00	0.03	1	
Risk of bias			101.05			0.00	3	Sensitive
Low risk of bias	0.21	0.06 to 0.35	0.00	0.00	0.00	0.00	2	
Moderate risk of bias	1.14	1.03 to 1.26	0.00	0.00	0.00	0.00	1	
High risk of bias	N/A							
Period of follow-up	Lack of sufficient evidence in each category for sensitivity analysis on this variable.[21]							N/A
<1 month	N/A	No observations					0	
1–6 months	N/A	No observations					0	
7–12 months	N/A	No observations					0	
13–18 months	N/A	No observations					0	
19–24 months	N/A	No observations					0	
>25 months	N/A	No observations					0	

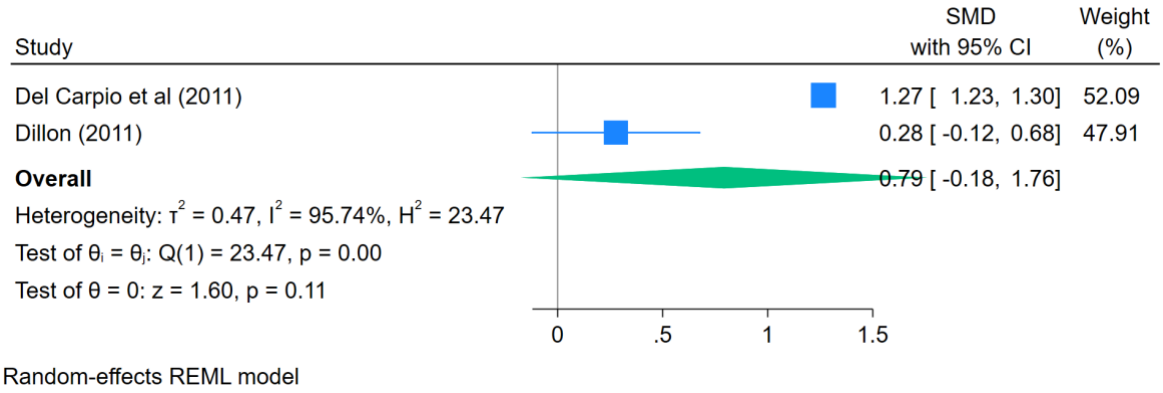
[21] All studies do not specify the follow-up period.

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Not specified	0.55	-0.06 to 1.15	1.62	0.28	97.24%	0.2	3	

6. EFFECTS OF WATER-EFFICIENT IRRIGATION SYSTEMS ON CONSUMPTION/EXPENDITURE

Two studies (k = 2) reported the impact of water-efficient irrigation systems on consumption and expenditure. Both studies are quasi-experimental designs and were assessed as having a low risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$= 0.79 (CI: -0.18 to 1.76). This is statistically insignificant (z=1.60, p<=0.11), indicating that water-efficient irrigation systems present a sizeable positive but statistically insignificant effect on consumption and expenditure. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 17. According to the Q-test, there was a significant amount of heterogeneity in the actual outcomes (Q (1) =23.47, p<0.001, $\hat{\tau}^2$=0.47, I^2=95.74 per cent). Given there were only two studies, sensitivity and moderator analyses were not possible, and tests of publication bias were not valid. The GRADE quality of evidence assessment indicates that evidence of the effects of water-efficient irrigation systems on consumption and expenditure is very low quality (see Appendix 3).

Figure 17. Meta-analysis of water-efficient irrigation systems on consumption/expenditure



B. INTERVENTION 2: NATURE-BASED OPTIONS

1. EFFECTS OF ECOSYSTEM-BASED WATERSHED MANAGEMENT ON CROP YIELD

We identified and included a total of k = 8 studies – all quasi-experimental studies – that assessed the impact of ecosystem-based watershed management on crop yield. Six studies were assessed as having a low risk of bias, one as having a high risk of bias and one a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.21 (CI: 0.03 to 0.38). This is statistically significant (z=2.35, p<0.02), indicating that ecosystem-based watershed management interventions resulted in a small positive and effect on crop yield. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 18 below. According to the Q-test, there is a significant amount of heterogeneity in the true outcomes (Q (7) =169.47, p=0.00, $\hat{\tau}^2$=0.06, I^2=97.24 per cent), and the confidence intervals of the one study

do not overlap. To assess the robustness of the identified effect, we next report the results of our sensitivity and moderator analyses. These investigate whether the observed overall effect might be driven by variables other than the applied reminder interventions. With eight studies, tests of publication bias are not valid. Applying the GRADE framework, the evidence on the effects of ecosystem-based watershed management on crop yield is of low quality (see Appendix 3).

Sensitivity analysis of ecosystem-based watershed management on crop yield

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). An overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features is presented in Table 8. The meta-analysis on ecosystem-based watershed management on crop yield combines results from eight quasi-experimental designs. The results of the meta-analysis shown in Table 8 indicate that a study with a high risk of bias has larger effects relative to studies with a moderate risk of bias and a study with a low risk of bias, but this influence is not statistically significant. Regarding follow-up, studies that did not specify the follow-up period have larger effects compared to a study with a follow-up period of more than 25 months. There is insufficient data in each category to perform sensitivity analysis on the study design, as all the studies are categorized as quasi-experimental designs.

Figure 18. Meta-analysis of ecosystem-based watershed management on crop yield

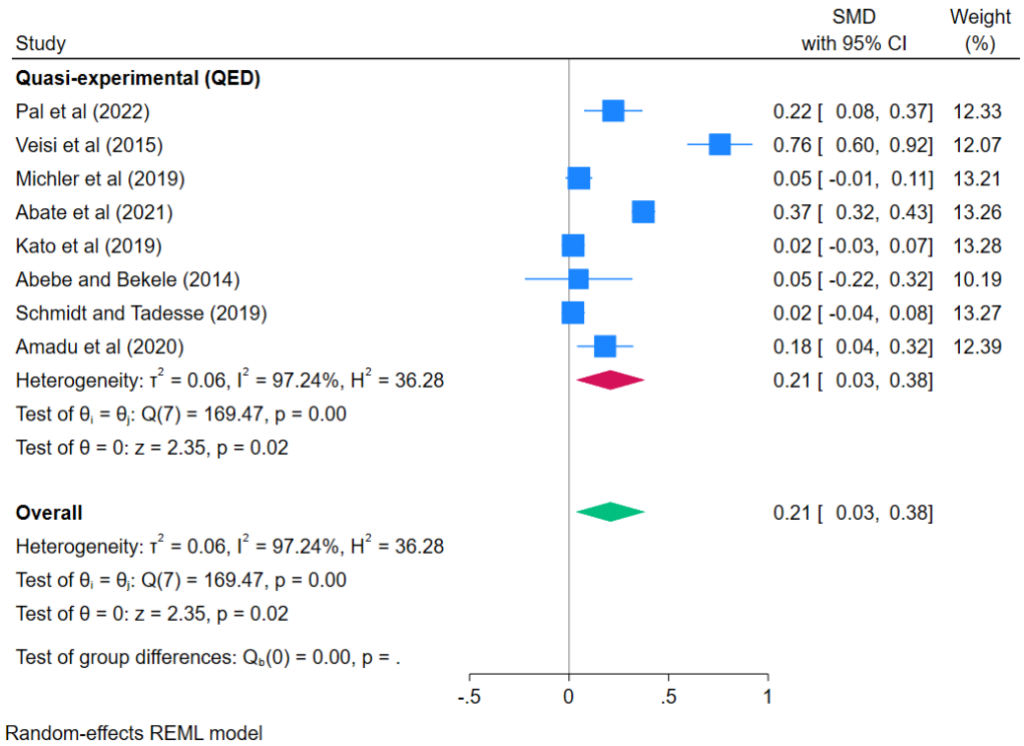


Table 8. Sensitivity analysis of ecosystem-based watershed management on crop yield

VARIABLE	SMD	95% CI	Q	TAU²	I²	P-VALUE (Q)	SAMPLE	SENSITIVITY
Ecosystem-based watershed management: all studies	0.21	0.03 to 0.38	169.47	0.06	97.24%	0.00	8	
Design	Lack of sufficient evidence in each category for moderator analysis							N/A

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
RCT	N/A	No observation						
Quasi-experimental design	0.21	0.03 to 0.38	169.47	0.06	97.24%	0.00	8	
Risk of bias			86.28			0.00		Sensitive
Low risk of bias	0.07	0.1 to 0.14	11.24	0.00	67.04%	0.05	6	
Moderate risk of bias	0.37	0.32 to 0.43	0.00	0.00			1	
High risk of bias	0.76	0.60 to 0.92	0.00	0.00			1	
Period of follow-up			4.53			0.03		Sensitive
<1 month	N/A	No observations					0	
1–6 months	N/A	No observations					0	
7–12 months	N/A	No observations					0	
13–18 months	N/A	No observations					0	
19–24 months	N/A	No observations					0	
>25 months	0.02	-0.04 to 0.08		0.00			1	
Not specified	0.24	0.05 to 0.43	146.18	0.06	96.91%	0.00	7	

Moderator analysis of ecosystem-based watershed management on crop yield

Following our sensitivity analysis of ecosystem-based watershed management on crop yield, we assessed if a range of moderators influenced the robustness of the meta-analysis of ecosystem-based watershed management on crop yield. We had sufficient data to test all moderators for this intervention and outcome group and investigated a range of variables. These variables included publication type and date, intervention length and the provision of incentives to participants. Other variables examined included the implementing agency type and the context characteristics of the intervention that might systematically moderate intervention effects identified in the meta-analysis (see Table 9). We found that publication type and date, length of intervention, context (country and region) and implementing agency type are significant moderators.

Regarding publication type, academic journal articles yield larger effects than research reports. In terms of publication date, the largest effects were observed for a study published in 2015, followed by a study published in 2021. The smallest effects were observed in 2019. Considering the length of intervention, the largest effects were observed for studies that do not specify intervention length as compared to studies with an intervention length of more than 25 months.

Among the five countries where evaluations were conducted, the largest effects were realized in Iran, followed by India, Malawi and Ethiopia. The smallest effect was observed in Zimbabwe.

Regionally, this translates to the Middle East and North Africa witnessing the largest effects relative to South Asia and Sub-Saharan Africa. We observed that a study whose programme was implemented by a combination of a government agency and an international financial institution yields the largest effects relative to a study implemented by a government agency only and studies implemented by academic institutions. Country income group and incentivizing participants to participate are not significant moderators.

Table 9. Moderator analysis of ecosystem-based watershed management on crop yield

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Ecosystem-based watershed management: all studies	0.21	0.03 to 0.38	169.47	0.06	97.24%	0.00	8	
Publication type			4.61			0.03		Sensitive
Academic journal	0.26	0.05 to 0.48	143.49	0.07	97.54%	0.00	6	
Research report	0.02	-0.03 to 0.07	0.04	0.00	0.00%	0.85	2	
Publication date			145.64			0.00		Sensitive
2014	0.05	-0.22 to 0.32	0.00	0.00			1	
2015	0.76	0.80 to 0.92	0.00	0.00			1	
2019	0.03	-0.01 to 0.07	0.48	0.00	0.07%	0.49	2	
2020	0.18	0.04 to 0.32	0.00	0.00			1	
2021	0.37	0.32 to 0.43	0.00	0.00			1	
2022	0.11	-0.09 to 0.31	6.71	0.02	85.09%	0.01	2	
Length of intervention			6.89			0.01		
<1 month	N/A	No observations						
1–6 months	N/A	No observations						
7–12 months	N/A	No observations						
13–18 months	N/A	No observations						
19–24 months	N/A	No observations						
>25 months	0.04	0.01 to 0.07	5.05	0.00	0.02%	0.28	5	
Not specified	0.45	0.14 to 0.75	25.98	0.07	95.09%	0.00	3	
Country			66.25			0.00		Sensitive
Ethiopia	0.12	-0.6 to 0.31	102.4	0.03	0.00%	0.00	4	
India	0.22	0.08 to 0.37	0.00	0.00		0.00	1	

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Iran	0.76	0.60 to 0.92	0.00	0.00			1	
Malawi	0.18	0.04 to 0.32	0.00	0.00			1	
Zimbabwe	0.05	-0.1 to 0.11	0.00	0.00			1	
Region			40.93			0.00		Sensitive
Middle East and North Africa	0.76	0.60 to 0.92	0.00	0.00			1	
East Asia and Pacific	N/A	No observations						
Sub-Saharan Africa	0.12	-0.00 to 0.22	108.30	0.02	93.92%	0.00	6	
Europe and Central Asia	N/A	No observations						
Latin America and Caribbean	N/A	No observations						
South Asia	0.22	0.08 to 0.37	0.00	0.00			1	
Not specified	N/A	No observations						
Income group			0.83			0.36		Not sensitive
Low-income country(s)	0.13	-0.01 to 0.28	102.91	0.02	94.45%	0.00	5	
Lower-middle-income country(s)	0.34	-0.08 to 0.76	66.00	0.13	97.27%	0.00	3	
Upper-middle-income country(s)	N/A	No observations						
High-income country(s)	N/A	No observations						
Incentives			0.06			0.81		Not sensitive
No	0.21	0.01 to 0.41	169.10	0.07	97.87%	0.00	7	
Yes	0.18	0.04 to 0.32	0.00	0.00			1	
Implementing agency			104.84			0.00		Sensitive
Academic institution	0.02	-0.02 to 0.06	0.04	0.00	0.00%	0.98	3	
Government agency	0.22	0.08 to 0.37	0.00	0.00			1	
Government agency and international financial institution	0.37	0.32 to 0.43	-0.00	0.00			1	
Not specified	0.40	-0.29 to 1.09	65.07	0.25	98.46%	0.90	2	

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Charitable or private foundation	N/A	No observations						
For-profit firm	N/A	No observations						
International aid agency	N/A	No observations						
International financial institution	N/A	No observations						
Non-profit organization	0.18	0.04 to 0.32	0.00	0.00			1	
Think tank	N/A	No observations						

2. EFFECTS OF ECOSYSTEM-BASED WATERSHED MANAGEMENT ON INCOME

We identified and included a total of k =7 studies – all quasi-experimental studies – that assessed the impact of ecosystem-based watershed management on crop yield. Six studies were assessed as having a low risk of bias and one a moderate risk. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.11 (CI: -0.01 to 0.23). This is statistically significant and differed significantly from zero (z=1.87, p<0.06), indicating that ecosystem-based watershed management interventions resulted in a small positive and statistically significant effect on income but only at the 90 per cent level. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 19 below.

According to the Q-test, there is a significant amount of heterogeneity in the true outcomes (Q (6) =41.35, p=0.00, $\hat{\tau}^2$=0.02, I^2=80.45 per cent), and the confidence intervals of all studies overlap. To assess the robustness of the identified effect, we next report the results of our sensitivity and moderator analyses, which investigate if the observed overall effect might be driven by variables other than the applied reminder interventions. Tests of publication bias are not valid when applied to only seven studies. Applying the GRADE framework, the evidence on the effects of ecosystem-based watershed management on income is of low quality (see Appendix 3).

Sensitivity analysis of ecosystem-based watershed management on income

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). Table 10 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features. The meta-analysis combines results from seven quasi-experimental designs. The results of the meta-analysis shown in Table 10 indicate that studies with moderate risk of bias have larger effects relative to studies with low risk of bias, but this influence is not statistically significant. There is insufficient data in each category to perform sensitivity analysis on the study design and period of follow-up, as all the studies are categorized as quasi-experimental designs and do not specify the period of follow-up, respectively.

Figure 19. Meta-analysis of ecosystem-based watershed on income

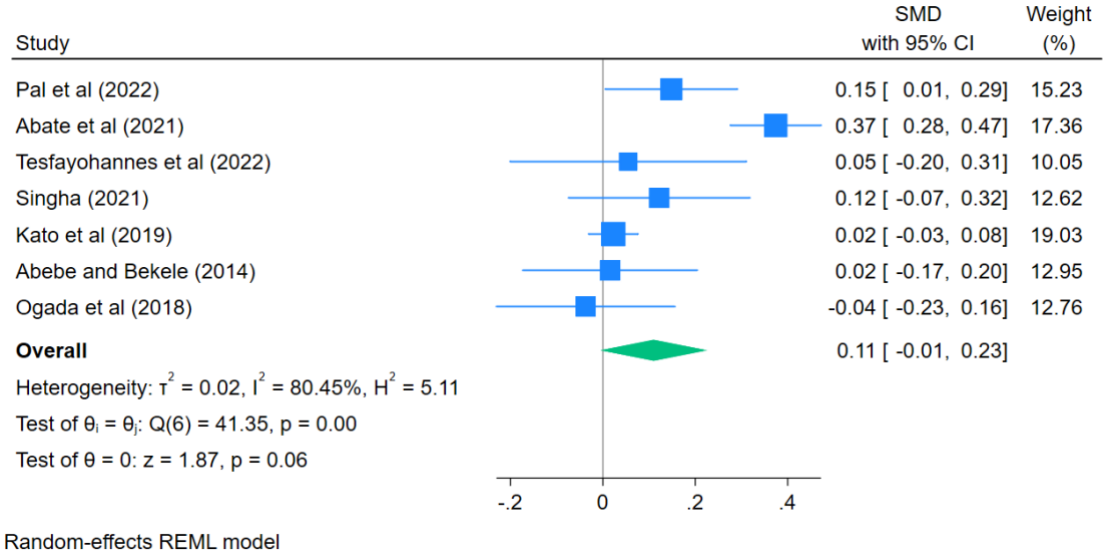


Table 10. Sensitivity analysis of ecosystem-based watershed management on income

VARIABLE	SMD	95% CI	Q	TAU²	I²	P-VALUE (Q)	SAMPLE	SENSITIVITY
Ecosystem-based watershed management: all studies	0.11	-0.01 to 0.23	41.35	0.02	80.45%	0.00	7	
Design	Lack of sufficient evidence in each category for moderator analysis							N/A
RCT	N/A	No observations						
Quasi-experimental design	0.11	-0.01 to 0.23	41.35	0.02	80.45%	0.00	7	
Risk of bias			0.82			0.36		Not sensitive
Low risk of bias	0.05	-0.03 to 0.13	2.67	0.00	28.93%	0.026	3	
Moderate risk of bias	0.14	-0.05 to 0.34	18.52	0.03	79.00%	0.00	4	
High risk of bias	N/A	No observations						
Period of follow-up	Lack of sufficient evidence in each category for moderator analysis[22]							N/A
<1 month	N/A	No observations						
1–6 months	N/A	No observations					0	
7–12 months	N/A	No observations					0	

[22] All studies do not specify the follow-up period.

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
13–18 months	N/A	No observations					0	
19–24 months	N/A	No observations					0	
>25 months	N/A	No observations					0	
Not specified	0.11	-0.01 to 0.23	41.35	0.02	80.45%	0.00	7	

Moderator analysis of ecosystem-based watershed management on income

Following our sensitivity analysis of ecosystem-based watershed management on income, we assessed whether a range of moderators influenced the robustness of the meta-analysis of ecosystem-based watershed management on income. We had sufficient data to test most moderators for this intervention and outcome group and investigated variables related to publication type and date, intervention length, implementing agency type and context characteristics of the intervention that might systematically moderate intervention effects identified in the meta-analysis (see Table 11). We found that only the country of investigation and implementing agency type are significant moderators. Regarding country, the largest effects were observed in India as compared to an evaluation carried out in Ethiopia and an evaluation conducted across Ethiopia, Kenya, Tanzania and Uganda. We observed that a study whose programme was implemented by a combination of a government agency and international financial institution yields the largest effects relative to studies implemented by a government agency only, a study implemented by academic institutions, and a study that does not specify the implementing agency type. There is insufficient data in each category to perform moderator analysis on the provision of incentives to participants, as no incentives were provided to participants across all the studies.

Table 11. Moderator analysis of ecosystem-based watershed management on income

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Ecosystem-based watershed management: all studies	0.11	-0.01 to 0.23	41.35	0.02	80.45%	0.00	7	
Publication type			2.14			0.14		Not sensitive
Academic journal	0.13	-0.00 to 0.26	23.93	0.02	73.37%	0.00	6	
Research report	0.02	-0.03 to 0.08	0.00	0.00			1	
Publication date			6.09			0.19		Not sensitive
2014	0.02	-0.17 to 0.20	-0.00	0.00			1	
2018	-0.04	-0.23 to 0.16	0.00	0.00			1	
2019	0.02	-0.03 to 0.08	0.00	0.00			1	
2021	0.26	0.02 to 0.51	5.09	0.03	80.35%	0.02	2	

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
2022	0.13	0.00 to 0.25	0.39	0.00	0.00%	0.53	2	
Length of intervention			2.14			0.14		Not sensitive
<1 month	N/A	No observations					0	
1–6 months	N/A	No observations						
7–12 months	N/A	No observations					0	
13–18 months	N/A	No observations					0	
19–24 months	N/A	No observations					0	
>25 months	0.02	-0.03 to 0.08	0.00	0.00			1	
Not specified	0.13	-0.00 to 0.26	23.93	0.02	73.37%	0.00	6	
Country			66.25			0.00		Sensitive
Ethiopia	0.13	-0.6 to 0.31	38.93	0.03	89.74%	0.00	4	
Ethiopia, Kenya, Tanzania and Uganda	-0.04	-0.23 to 0.16	0.00	0.00			1	
India	0.14	0.02 to 0.25	0.05	0.00	0.00%	0.83	2	
Region			0.18			0.67		Not sensitive
Middle East and North Africa	N/A	No observations						
East Asia and Pacific	N/A	No observations						
Sub-Saharan Africa	0.10	-0.06 to 0.26	40.70	0.03	87.11%	0.00	5	
Europe and Central Asia	N/A	No observations						
Latin America and Caribbean	N/A	No observations						
South Asia	0.14	0.02 to 0.25	0.05	0.00	0.00%	0.83	2	
Not specified	N/A	No observations						
Income group			2.46			0.29		Not sensitive
Low-income country(s)	0.13	-0.06 to 0.31	38.93	0.03	89.74%	0.00	4	
Low- and lower-middle-income country(s)	0.04	-0.23 to 0.16	0.00	0.00			1	

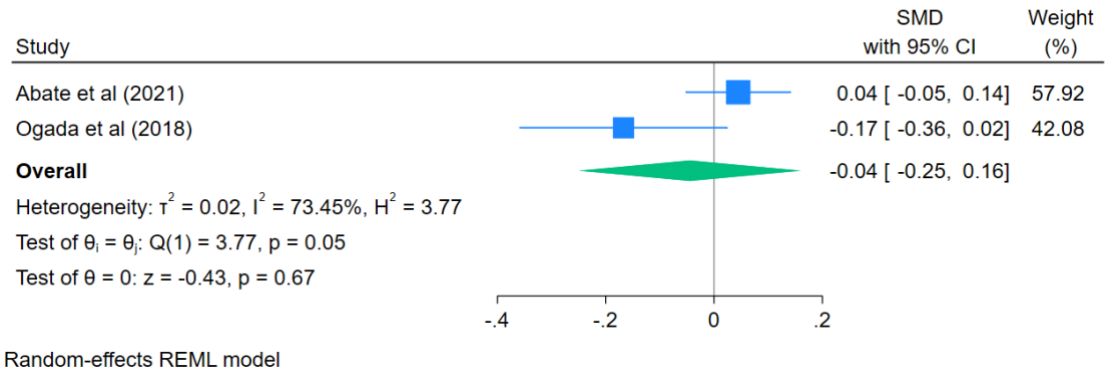
VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Lower-middle-income country(s)	0.14	0.02 to 0.25	0.05	0.00	0.00%	0.83	2	
Upper-middle-income country(s)	N/A	No observations						
High-income country(s)	N/A	No observations						
Incentives	Lack of sufficient evidence in each category for moderator analysis							
No	0.11	-0.01 to 0.23	41.35	0.02	80.45%	0.00	7	
Yes	N/A	No observations						
Implementing agency			40.95			0.00		Sensitive
Academic institution	0.02	-0.03 to 0.08	0.00	0.00			1	
Government agency	0.12	0.02 to 0.23	0.39	0.00	0.01%	0.82	3	
Not specified	0.02	-0.17 to 0.20	0.00	0.00			1	
Government agency and international financial institution	0.37	0.28 to 0.47	0.00	0.00			1	
Charitable or private foundation	N/A	No observations						
For-profit firm	N/A	No observations						
International aid agency	N/A	No observations						
International financial institution	N/A	No observations						
Non-profit organization	0.04	-0.23 to 0.16	0.00	0.00			1	
Think tank	N/A	No observations						

3. EFFECTS OF ECOSYSTEM-BASED WATERSHED MANAGEMENT ON DIETARY DIVERSITY

Two studies reported the impact of ecosystem-based watershed management on dietary diversity (k = 2 studies). Both were quasi-experimental designs and were assessed as having a low risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$= -0.04 (CI: -0.25 to 0.16). This is statistically insignificant (z=-0.43, p<=0.67) and indicates that ecosystem-based watershed management interventions present a small negative but statistically insignificant effect on dietary

diversity. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 20. Given the small number of studies, this result should be interpreted with caution. According to the Q-test, there was no significant amount of heterogeneity in the true outcomes (Q (1) =3.77, p=0.05, $\hat{\tau}^2$=0.02, I^2=73.45 per cent). Given there were only two studies and no heterogeneity among the effects, sensitivity and moderator analyses were not possible. Tests of publication bias were not valid, given the small number of studies included in the analysis. The GRADE quality of evidence assessment indicates that evidence on the effects of ecosystem-based watershed management on dietary yield is of low quality (see Appendix 3).

Figure 20. Meta-analysis of ecosystem-based watershed management on dietary diversity



4. NARRATIVE SYNTHESIS OF ECOSYSTEM-BASED WATERSHED MANAGEMENT ON ADOPTION

We also investigated whether a narrative synthesis of ecosystem-based watershed interventions is feasible for interventions and outcome combinations not covered in the meta-analysis. However, these studies could not be synthesized due to heterogeneity in the outcome types. This can be seen in Table 12, which provides a narrative overview of the individual studies and key findings on impact.

Table 12. A narrative synthesis of ecosystem-based watershed management on adoption

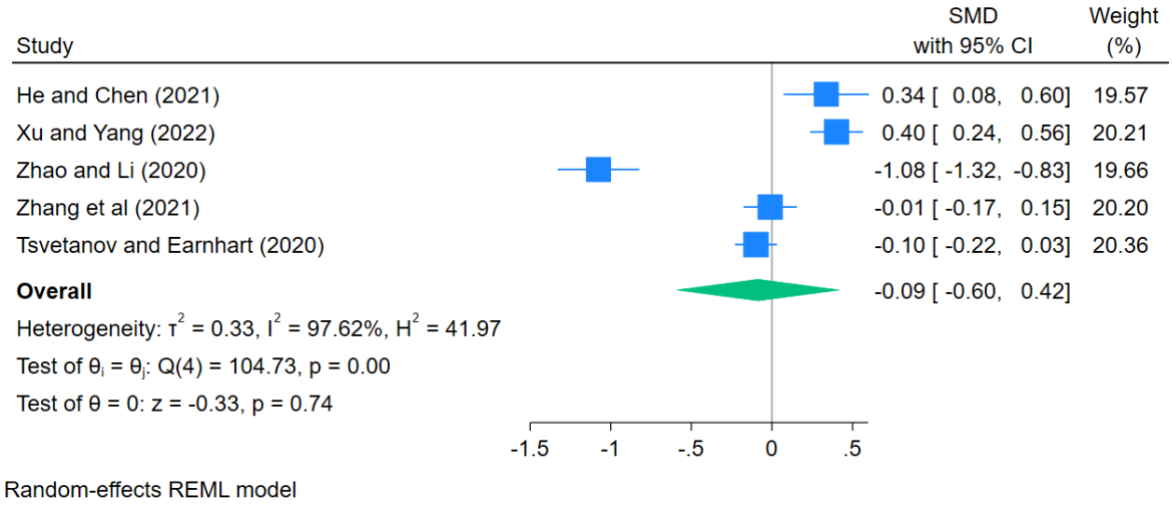
STUDY	INTERVENTION TREATMENT COMPONENTS	CONTEXT	FINDINGS
Kato and others (2019) High risk of bias	Ecosystem-based watershed management	Sub-Saharan Africa: Malawi Income group: Low-income country	There was increased adoption of sustainable land management investments and practices, specifically overall soil and water conservation investments (SMD: 0.2562, CI: 0.18-0. 0.33).
Amadu and others (2020) High risk of bias	Ecosystem-based watershed management	Sub-Saharan Africa: Malawi Income group: Low-income country	There was a significant statistical increase in the adoption of non-woody plants (SMD: 0.5851, CI: 0.4434 to 0.7268), woody plants (SMD: 1.0256, CI: 0.8781 to 1.1731) and assisted regeneration groups (SMD: 0.7091, CI: 0.5661 to 0.8522).

C. INTERVENTION 3: INSTITUTIONAL INTERVENTIONS

1. EFFECTS OF THE DEVELOPMENT OF FORMAL REGULATORY FRAMEWORKS ON WATER CONSUMPTION

Five studies reported the impact of the development of formal regulatory frameworks on water consumption (k = 5 studies), all being quasi-experimental designs. We assessed six studies as having a low risk of bias and the other three as having a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=-0.09 (CI: -0.60 to 0.42). This is statistically insignificant (z=o.33, p<0.74), indicating that the development of formal regulatory frameworks presents a small negative and statistically insignificant effect on water consumption. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 21. According to the Q-test, there was a significant amount of heterogeneity in the true outcomes (Q (4) =104.73, p=0.00, $\hat{\tau}^2$=0.33, I^2=97.62 per cent). To assess the robustness of the identified effect, we report the results of our sensitivity and moderator analyses, which investigate whether the observed overall effect might be driven by variables other than the applied water-efficient irrigation systems interventions. With only five studies, tests of publication bias are not valid. Applying the GRADE framework, the evidence on the effects of water-efficient irrigation systems on income is of very low quality (see Appendix 3).

Figure 21. Meta-analysis of the development of formal regulatory frameworks on water consumption



Sensitivity analysis of the development of formal regulatory frameworks on water consumption

We investigated whether the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). Table 13 presents an overview of how the meta-analysis results vary if different groups of studies are combined according to the above design features. The meta-analysis combines results from five quasi-experimental designs. The results of the meta-analysis shown in Table 13 indicate that a study with a follow-up of more than 25 months has a larger effect relative to, firstly, a study with a follow-up period of 19 to 24 months and, secondly, studies that do not specify the follow-up period, with the effect being statistically significant. There is insufficient data in each category to perform sensitivity

analysis on the study design and risk of bias as all the studies are categorized as quasi-experimental designs and low risk of bias, respectively.

Table 13. Sensitivity analysis of the development of formal regulatory frameworks on water consumption

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Development of formal regulatory framework: all studies	-0.09	-0.06 to 0.42	104.74	0.33	97.62	0.00	5	
Design	Lack of sufficient evidence in each category for moderator analysis							N/A
RCT	N/A	No observations						
Quasi-experimental design	-0.09	-0.06 to 0.42	104.73	0.33	97.62	0.00	5	
Risk of bias	Lack of sufficient evidence in each category for moderator analysis							N/A
Low risk of bias	-0.09	-0.06 to 0.42	104.73	0.33	97.62	0.00	5	
Moderate risk of bias	N/A	No observations						
High risk of bias	N/A	No observations						
Period of follow-up			96.30			0.00		Sensitive
<1 month	N/A	No observations					0	
1–6 months	N/A	No observations					0	
7–12 months	N/A	No observations					0	
13–18 months	N/A	No observations					0	
19–24 months	0.40	0.24 to 0.56	0.00	0.00			1	
>25 months	-1.08	-1.32 to -0.83	0.00	0.00			1	
Not specified	0.05	-0.19 to 0.29	8.74	0.04	82.74	0.01	3	

Moderator analysis of the development of formal regulatory frameworks on water consumption

We then assessed whether a range of moderators influenced the robustness of the meta-analysis of the development of formal regulatory frameworks on water consumption. We had sufficient data to test most moderators for this intervention and outcome group and investigated variables related to publication date, intervention length, implementing agency type and contextual characteristics of the intervention that might systematically moderate intervention effects identified in the meta-analysis (see Table 14). We find that only publication date and implementing agency type are significant moderators. The largest effects were observed in a study published in 2022 relative to studies published in 2021 and 2020. Regarding implementing agency type, the largest effect was observed for studies implemented by government agencies compared to studies that do not specify the

implementing agency type. There was insufficient data in each category to perform moderator analysis on the provision of incentives to participants as all the studies are academic journal articles.

Table 14. Moderator analysis of the development of formal regulatory frameworks on water consumption

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Development of formal regulatory framework: all studies	-0.09	-0.06 to 0.42	104.73	0.33	97.62%	0.00	5	
Publication type	Lack of sufficient evidence in each category for moderator analysis							N/A
Academic journal	-0.09	-0.06 to 0.42	104.73	0.33	97.62%	0.00	5	
Research report	N/A	No observations						
Publication date			5.34			0.07		Sensitive
2020	-0.58	-1.54 to 0.38	47.22	0.47	97.88%	0.00	2	
2021	0.15	-0.19 to 0.49	4.98	0.05	79.90%	0.03	2	
2022	0.40	0.24 to 0.56	-0.00	0.00			1	
Length of intervention			2.46				0.12	Not sensitive
<1 month	N/A	No observations					0	
1–6 months	N/A	No observations					0	
7–12 months	N/A	No observations					0	
13–18 months	N/A	No observations					0	
19–24 months	N/A	No observations					0	
>25 months	-0.19	-0.80 to 0.41	96.86	0.37	98.16	0.00	4	
Not specified	0.34	0.08 to 0.60	0.00	0.00			1	
Country			0.00			0.97		Not sensitive
China	-0.08	-0.75 to 0.58	102.29	0.45	97.79	0.00	4	
United States of America	-0.10	-0.22 to 0.03	-0.00	0.00			1	
Region			0.00			0.97		Not sensitive

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
East Asia and Pacific	-0.08	-0.75 to 0.58	102.29	0.45	97.79	0.00	4	
North America	-0.10	-0.22 to 0.03	-0.00	0.00			1	
South Asia	N/A	No observations						
Sub-Saharan Africa	N/A	No observations						
Income group			0.00			0.97		Not sensitive
Low-income country(s)	N/A	No observations						
Lower-middle-income country(s)	N/A	No observations						
Upper-middle-income country(s)	-0.08	-0.75 to 0.58	102.29	0.45	97.79%	0.00	4	
High-income country(s)	-0.10	-0.22 to 0.03	-0.00	0.00			1	
Incentives			0.00			0.97		Not sensitive
No	-0.08	-0.75 to 0.58	102.29	0.45	97.79%	0.00	4	
Yes	-0.10	-0.22 to 0.03	0.00	0.00			1	
Implementing agency			5.01			0.03		Sensitive
Academic institution	N/A	No observations						
Government agency	-0.39	-1.05 to 0.27	55.43	0.33	97.80%	0.00	3	
Charitable or private foundation	N/A	No observations						
For-profit firm	N/A	No observations						
International aid agency	N/A	No observations						
International financial institution	N/A	No observations						
Non-profit organization	N/A	No observations						
Think tank	N/A	No observations						

VARIABLE	SMD	95% CI	Q	TAU^2	I^2	P-VALUE (Q)	SAMPLE	SENSITIVITY
Not specified	0.38	0.25 to 0.52	0.17	0.00	0.00%	0.68	2	

2. EFFECTS OF DEVELOPMENT OF FORMAL REGULATORY FRAMEWORKS ON CROP YIELD

We included k = 2 studies in the analysis of the effect of developing a formal regulatory framework on yield. Both were quasi-experimental studies and were assessed as having a low risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.07 (CI: -0.04 to 0.18). This pooled effect estimate is therefore statistically insignificant (z=1.17, p=0.24), indicating that the development of formal regulatory frameworks presents a small positive and statistically insignificant effect on crop yield. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 22. Given the small number of studies, this result should be interpreted with caution. According to the Q-test, there was no significant amount of heterogeneity in the true outcomes (Q (1) =1.31, p=0.25, $\hat{\tau}^2$=0.00, I^2=23.85 per cent). With only two studies and given there was no significant heterogeneity among the effects, sensitivity and moderator analyses were not possible, and tests of publication bias were not valid. Applying GRADE indicates that the evidence on the effects of developing a formal regulatory framework on crop yield is of low quality (see Appendix 3).

3. EFFECTS OF DEVELOPMENT OF FORMAL REGULATORY FRAMEWORKS ON INCOME GROWTH

Only two quasi-experimental studies reported the impact of the development of a formal regulatory framework on income growth, thus we included k = 2 studies in the analysis. We assessed one of the studies as having a low risk of bias and the other as having a high risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.84 (CI: 0.38 to 1.30). The pooled effect estimate is therefore statistically significant (z=3.560.93, p<0.0035). Therefore, developing a formal regulatory framework presents a large positive and statistically significant effect on income growth. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 23.

However, given the small number of studies with one having a high risk of bias, this result should be interpreted with caution. According to the Q-test, there was no significant amount of heterogeneity in the true outcomes (Q (1) =1.59, p=0.21, $\hat{\tau}^2$=0.06, I^2=37.19 per cent). With only two studies, and given there was no heterogeneity among the effects, sensitivity and moderator analyses were not possible, and tests of publication bias were not valid. The GRADE quality of evidence assessment indicates that evidence on the effects of developing a formal regulatory framework on income growth is of very low quality (see Appendix 3).

Figure 22. Meta-analysis of formal regulatory framework on crop yield

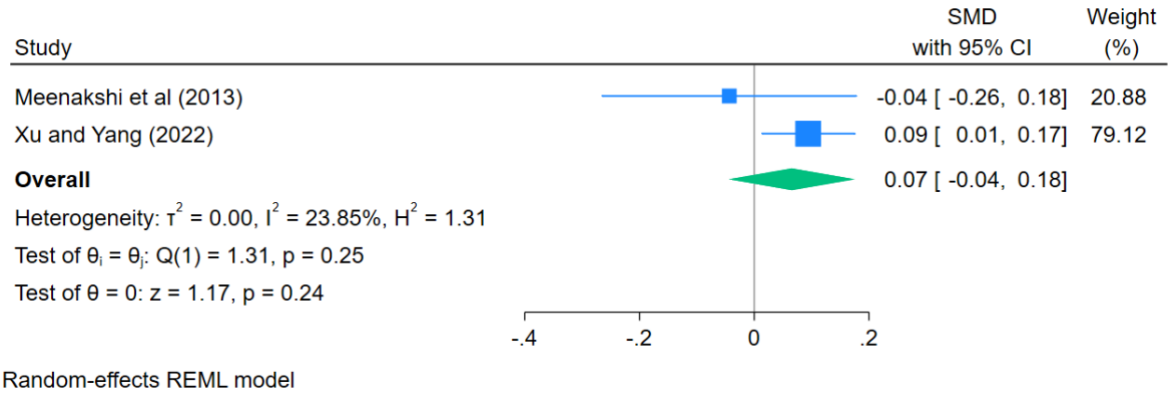
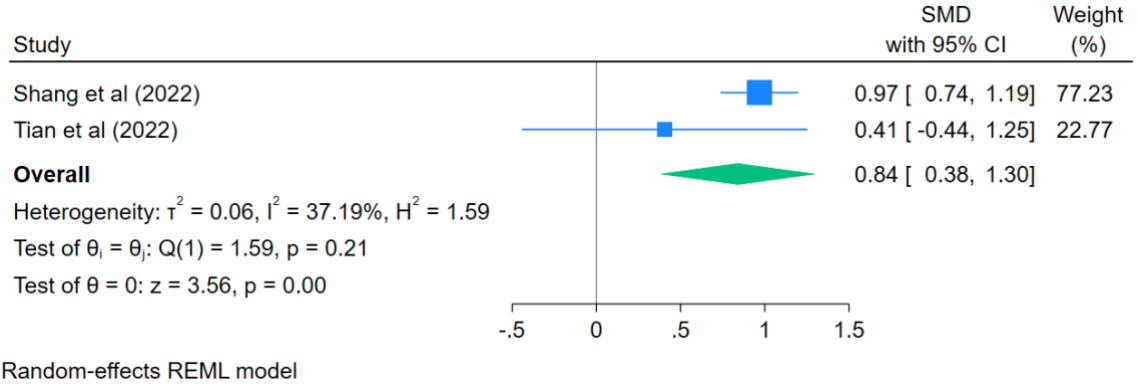


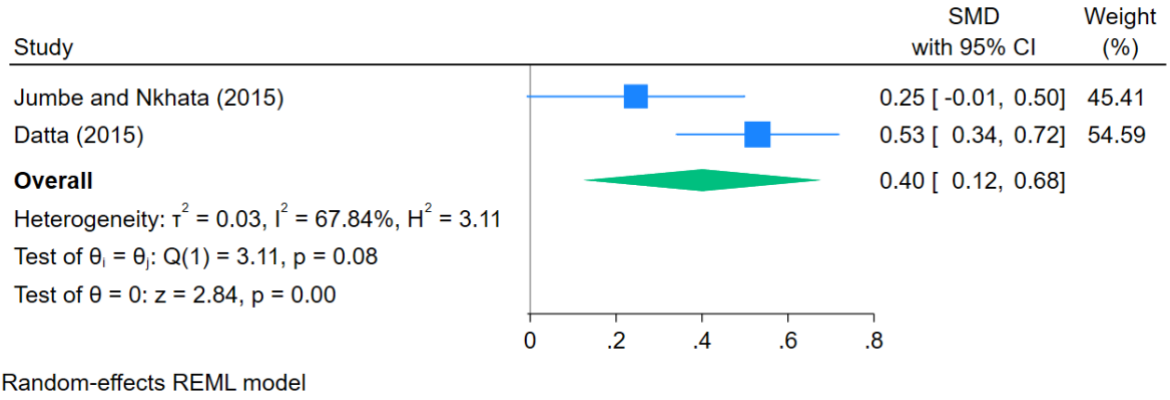
Figure 23. Meta-analysis of the development of formal regulatory frameworks on income growth



4. EFFECTS OF ESTABLISHMENT OF USER-BASED ORGANIZATIONS ON INCOME

Two studies, k = 2, were included to estimate the effect of establishing user-based organizations on income. Both studies are quasi-experimental study designs. One was assessed as having a low risk of bias and the other as a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.4 (CI: 0.12 to 0.68). Therefore, the pooled effect estimate is statistically significant (z=2.84, p<0.001). A forest plot showing the observed outcome and the estimate based on the random-effects model is shown in Figure 24. Given the small number of studies, this result should be interpreted cautiously. According to the Q-test, there was a borderline significant heterogeneity in the actual outcome (Q (1) =3.11, p=0.08, $\hat{\tau}^2$=0.03, I^2=67.84 per cent). With only two studies, sensitivity and moderator analyses were not conducted, and tests of publication bias would have been invalid. Applying GRADE indicates that the evidence on the effects of the establishment of user-based organizations on income is of very low quality (see Appendix 3).

Figure 24. Meta-analysis of the establishment of user-based organizations frameworks on income

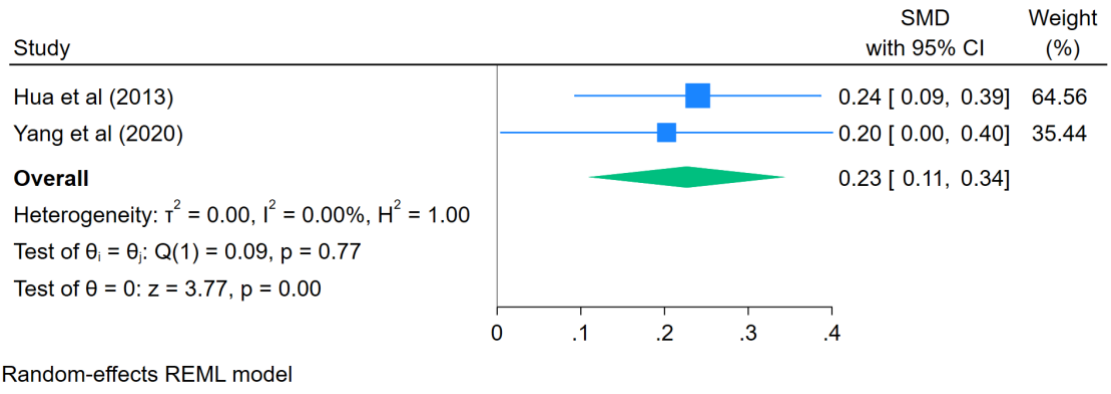


D. INTERVENTION 4: FINANCIAL/MARKET MECHANISMS

1. EFFECTS OF PAYMENT FOR ECOSYSTEM SERVICES ON INCOME

Only two quasi-experimental studies reported the impact of payment for ecosystem services on income, thus we included k = 2 studies in the analysis. One study was assessed as having a low risk of bias and the other a high risk. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.23 (CI: 0.11 to 1.34). Therefore, the pooled effect estimate is statistically significant (z=3.77, p <0.001). Thus, payment for ecosystem services intervention has a significant positive effect on income. A forest plot showing the observed estimate based on the random-effects model is shown in Figure 25. However, given the small number of studies, this result should be interpreted cautiously. According to the Q-test, the actual outcomes had no significant heterogeneity (Q (1) =0.09, p=0.77, $\hat{\tau}^2$=0.00, I^2=0.00 per cent). With only two studies and the absence of heterogeneity among the effects, sensitivity and moderator analyses were not conducted, and tests of publication bias would have been invalid. The GRADE quality of evidence assessment indicates that evidence of the impacts of payment for ecosystem services on income is very low quality (see Appendix 3).

Figure 25. Meta-analysis of payment for ecosystem services on income



2. EFFECTS OF INSURANCE FOR LOSSES DUE TO FLOOD AND DROUGHT SERVICES ON CROP YIELD

Two studies, k = 2, were included to estimate the effect of insurance for losses on yield. One study is an RCT and the other is a quasi-experimental study. One study was assessed as having a low risk of bias and the other as a moderate risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=0.06 (CI: -1.36 to 1.49). Therefore, the pooled effect estimate is statistically insignificant (z=0.09, p<0.93). A forest plot showing the observed outcome and the estimate based on the random-effects model is shown in Figure 26. Given the small number of studies, this result should be interpreted cautiously. According to the Q-test, there was a significant heterogeneity in the actual outcome (Q (1) =132.21, p<0.001, $\hat{\tau}^2$=1.05, I^2=99.24 per cent). With only two studies, sensitivity and moderator analyses were not conducted, and tests of publication bias would have been invalid. Applying GRADE indicates that the evidence on the effects of insurance for losses due to flood and drought on crop yield is of very low quality (see Appendix 3).

3. EFFECTS OF INSURANCE FOR LOSSES DUE TO FLOOD AND DROUGHT SERVICES ON INCOME

Two studies reported the impact of insurance for losses due to flood and drought on income (k = 2 studies), one RCT and a quasi-experimental study. Both studies were assessed as having a low risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$= 0.68 (CI: -0.10 to 1.46) and is therefore statistically insignificant (z=171, p<=0.09). This indicates that insurance for losses due to flood and drought interventions presents a large positive but statistically insignificant effect on income. A forest plot showing the observed outcomes and the estimate based on the random-effects model is shown in Figure 27. Given the small number of studies, this result should be interpreted with caution. According to the Q-test, there was a significant amount of heterogeneity in the true outcomes (Q (1) =38.07, p=0.00, $\hat{\tau}^2$=0.31, I^2=97.37 per cent) and the confidence intervals do not overlap. Given there were only two studies, sensitivity and moderator analyses were not conducted, and tests of publication bias would have been invalid given the small number of studies included in the analysis. The GRADE quality of evidence assessment indicates that evidence on the effects of insurance for losses due to flood and drought on income is of very low quality (see Appendix 3).

Figure 26. Meta-analysis of insurance for losses due to flood and drought on crop yield

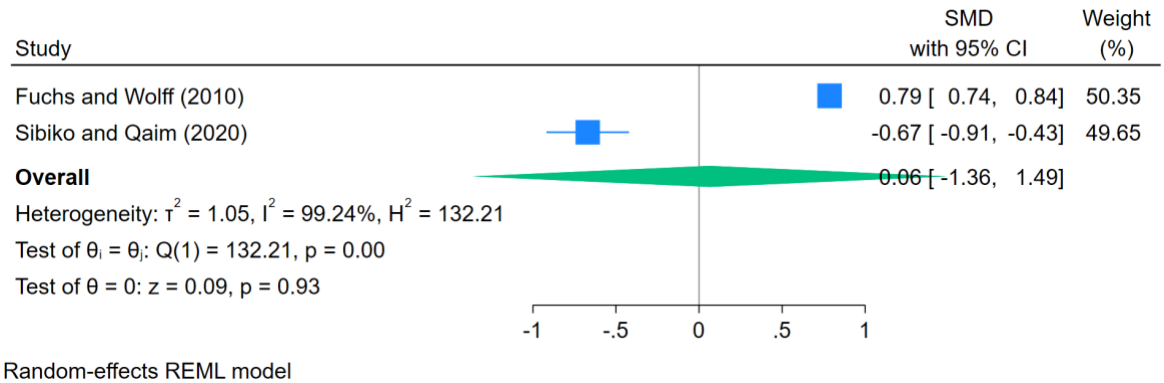
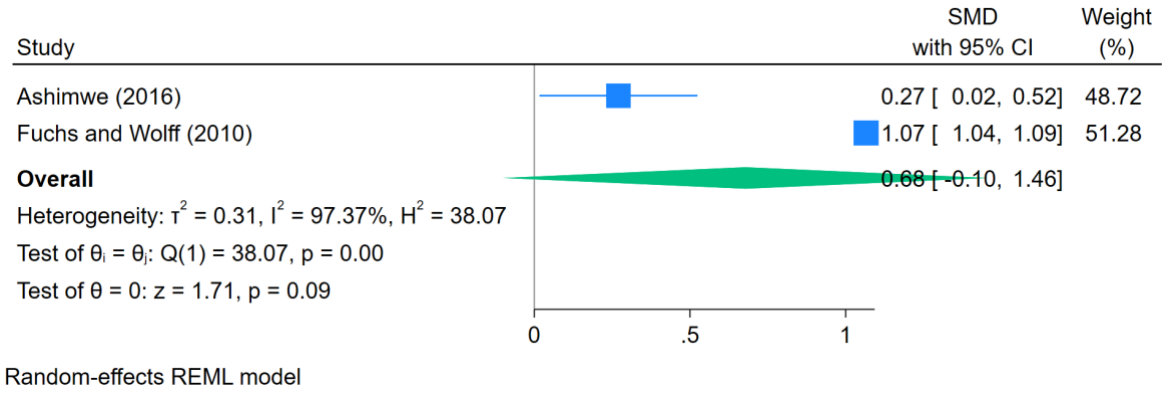


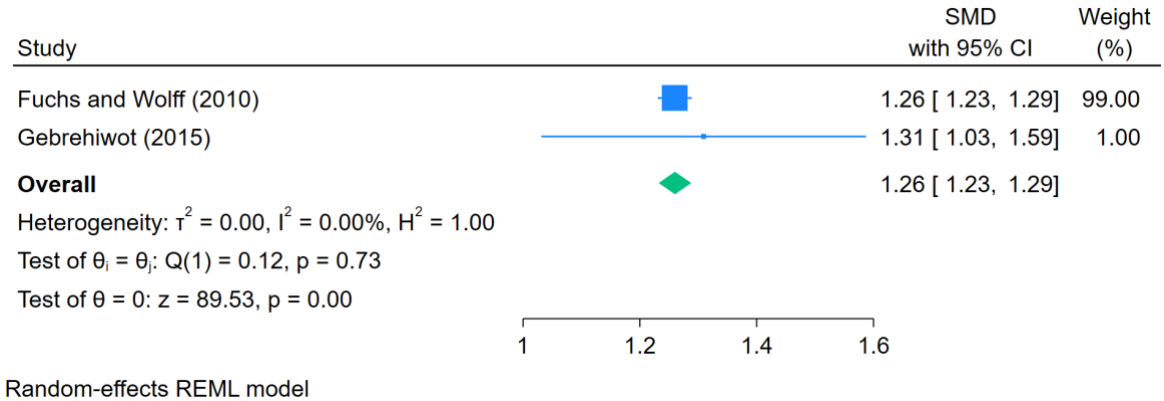
Figure 27. Meta-analysis of insurance for losses due to flood and drought on income



4. EFFECTS OF INSURANCE FOR LOSSES DUE TO FLOOD AND DROUGHT SERVICES ON CONSUMPTION AND EXPENDITURE

We included k = 2 studies to analyse the effect of insurance for losses due to flood and drought on expenditure, one RCT and another quasi-experimental study. One of the studies was evaluated as having a low risk of bias and the other a high risk of bias. The pooled effect estimate based on the random-effects model was $\hat{\mu}$=1.26 (CI: 1.23 to 1.29). Therefore, the pooled effect estimate is statistically significant (z=89.53, p<0.001). A forest plot showing the observed outcome and the estimate based on the random-effects model is shown in Figure 28. Given the limited number of studies, it is important to interpret this result with caution. According to the Q-test, there was no significant heterogeneity in the actual outcome (Q (1) =0.12, p=0.73, $\hat{\tau}^2$=0.00, I^2=0.00 per cent). With only two studies and given there was no significant heterogeneity among the effects, sensitivity and moderator analyses were not conducted, and tests of publication bias would have been invalid. Applying GRADE to assess the quality of evidence regarding the effects of the insurance for losses due to flood and drought on expenditure is of low quality (see Appendix 3).

Figure 28. Meta-analysis of insurance for losses due to flood and drought on consumption and expenditure



E. SUBGROUP ANALYSIS AND INVESTIGATION OF HETEROGENEITY

We conducted moderator analyses on a combination of extrinsic and substantive characteristics, namely, publication type and date, length of intervention, context (country, region, country income group), presence of incentives in the intervention, and implementing agency type. Our threshold for conducting moderator analysis referred to a minimum of five studies included in each meta-analysis. Moderator analysis was carried out in five meta-analyses: water-efficient irrigation systems on income (n=12), water-efficient irrigation systems on crop yield (n=9), ecosystem-based watershed management on crop yield (n=8), ecosystem-based watershed management on income (n=7), and the development of a formal regulatory framework on water consumption (n=5). Across the five meta-analyses, the significant moderator variables are publication type and date, context (country, region, country income group), length of intervention, presence of incentives in the intervention, and implementing agency type.

Across the five meta-analyses, we find a clear pattern in the influence of implementing agency type (4/5) and contextual characteristics – specifically country (4/5) and region (3/5) – on the robustness of the meta-analysis, as these variables are significant in both meta-analysis and the robustness of the meta-analysis. The patterns also show that overall publication type year (2/5), length of intervention (2/5), and country income group (1/5) have limited influence on the robustness of the meta-analysis, whereas the presence of incentives in the intervention did not influence the robustness of the results (0/5). No clear patterns are identified regarding the influence of publication type as this variable was sensitive in two meta-analyses and lacked influence in two meta-analyses. In one meta-analysis, we lacked sufficient data to assess the influence of publication type.

F. SENSITIVITY ANALYSIS

In the sensitivity analysis, we investigated if the variance in effect sizes might be caused by factors related to the applied evaluation design (i.e. study type, risk of bias and period of follow-up). We conducted sensitivity analysis in eight of the 17 meta-analyses where three or more studies were included in the meta-analysis.

Sensitivity analysis was possible in the following eight meta-analyses: water-efficient irrigation systems on income (n=12), water-efficient irrigation systems on income (n=9), water-efficient irrigation systems (n= 4), water-efficient irrigation systems on food security (n= 3 studies), water-efficient irrigation on poverty (n=3), ecosystem-based watershed management on income (n= 7), ecosystem-based watershed management on yield (n=8) studies and development of a formal regulatory framework on water consumption (n=5).

In three of the eight meta-analyses, conducting sensitivity analysis on the study design variable was not feasible as the meta-analysis included only quasi-experimental designs. It was also not feasible to conduct sensitivity analysis on the follow-up in three studies, given that the studies had unclear periods of follow-up. Regarding study design within the remaining five meta-analyses where moderator analysis was possible, these variables influence the robustness of the meta-analysis in three meta-analyses. The same pattern is witnessed for the follow-up moderator.

Finally, while sensitivity analysis using a risk of bias as a moderator was possible in all meta-analyses (n = 8), this variable influenced the robustness of results in only three meta-analyses.

V. DISCUSSION

A. OVERALL COMPLETENESS AND APPLICABILITY OF EVIDENCE

Using a water sector lens, we can examine the results of this SR in terms of types of coastal and terrestrial water sector interventions, types of outcomes, and in relation to the ToC. The present review addressed those interventions that, after evaluation, qualified for inclusion in a SR according to the inclusion criteria set. The interventions that qualified were only a small set drawn from a much wider population of coastal and terrestrial water sector interventions. Because of the inclusion criteria, many of the large family of water resource intervention types initially identified were excluded from the SRs, such as wetland conservation, restoration and use, and forest management.

We conducted 17 meta-analyses and reported significant results from 12 meta regressions. Water-efficient irrigation systems and ecosystem-based management stand out as valuable tools for enhancing income and crop yield, warranting specific attention. That said, it is valuable to offer a transparent assessment of the completeness of the evidence base.

The interventions with the highest number of studies that did qualify for inclusion involved using built infrastructure to support water-efficient irrigation. This indicates that many of these studies reviewed were conducted using well-defined methodologies that are regularly applied as a part of wider investigations into the impact of agricultural practices. Another set of interventions with a relatively high number of inclusions addressed the nature-based approach, characterized by ecosystem-based watershed management. While eight studies qualified for inclusion based on the criteria applied, closer analysis showed that, by virtue of the broad definitions of the intervention and the wide diversity of circumstances in which the interventions were implemented, many similar interventions were not strictly comparable. Most were rather generic land or agricultural management interventions conducted within the geographical boundaries of a watershed.

As expressed by one of the study authors (Michler and others, 2019)

> "… Conservation agriculture (CA) is based on three practices promoted as a means for sustainable agricultural intensification: minimum tillage, mulching with crop residue, and crop rotation. The goal of these practices is to increase yields through improvements in soil fertility and reduce risk to yields from rainfall shocks."

Similarly, Abate and others (2021) characterized the programme evaluated in their study as

> "… promoting greater community participation, the CBINReMP provided support to watershed communities for the restoration of degraded soils and water sources, rehabilitation of forests, as well as in obtaining access to secure land titles and practices for climate change adaptation. The project further provided support towards diversification of incomes in off-farm activities and incentives for women's empowerment and youth employment."

For one potentially important intervention, insurance for losses due to flood and drought, four qualifying studies were identified that addressed three different outcomes (crop yield, expenditure

incurred and income received). While the sample size is too small to draw robust conclusions, the fact that the outcomes from crop insurance were consistent with the expectations should be noted.[23]

The difficulties created by an over-wide definition of interventions were illustrated by the few studies that sought to review the impact of generic "regulatory interventions". Thus, Tvetanov and Earnhart (2020) considered the outcome of regulations governing the use of existing water rights in the USA. They found that when supported by payment for the 'retirement' of water use rights (effectively a payment for ecosystem services foregone), regulations governing water use were very effective for groundwater but not for surface water. Another study in this category (He and Chen, 2021) considered the variable outcomes of regulatory interventions to mitigate water quality deterioration.

A further study, classified as a regulatory intervention, considered the outcome of a requirement for urban users to pay for watershed services (Zhang and others, 2021). In that case, it was found that the intervention negatively affected per capita GDP in the urban area involved. However, the two studies that were specifically characterized as evaluations of the outcomes of payment for ecosystem services interventions came to the opposite conclusion. In both cases, the outcomes were significant and positive. However, their relevance is limited since both were from the same country (China) and reflected location specific opportunities that are unlikely to be widely replicated in this review's geographic coverage.

What is demonstrated is that identifying effective interventions that achieve the generic goal of providing evidence on the effectiveness of water sector interventions requires a precise characterization of the specific goal, a clear understanding of the context in which it is to be achieved, and clear identification of specific context-relevant interventions that may contribute to the goal's achievement.

1. TYPES OF OUTCOMES – BUFFER CAPACITY AND ADOPTION

The outcomes from the types of interventions that were identified in this review are mixed. Outcomes from irrigation-related interventions include expected production-related outcomes (increased yields and incomes). Where social impacts were considered, food security and expenditure rose while poverty fell. Only four of the 12 irrigation water-efficiency studies considered whether the interventions resulted in their further adoption. In all cases, results were inconclusive. The eight studies that considered ecosystem-based watershed management interventions presented similar outcomes. While four of the studies (Pal and others, 2022; Veisi and others, 2015; Abate and others, 2021; Amadu and others, 2020) reported increases in crop yields, the interventions in three cases were multi-factorial, meaning several inputs were provided to recipients. Only in the case of Abate and others (2021) was water management a primary intervention (land levelling to ensure better distribution of available water). Of the seven studies in which income outcomes were considered, only two studies indicated significant positive outcomes (Pal and others, 2022; Abate and others, 2021).

The four studies that considered insurance for losses due to flood and drought illustrated the value of evaluating more tightly defined interventions. The two studies that considered yield showed contrasting yield outcomes. This is to be expected since crop insurance aims to encourage a greater degree of risk-taking by protecting in the event of low yields due to climatic variation. The two studies that considered production expenditure both reported increased expenditure, an outcome

[23] In one study that showed the most positive effect size, the authors made the caveat that an apparently successful intervention may promote concentration on a mono-crop type of economy that reduced rather than increased resilience to future climate or market shocks.

expected to be incentivized by insurance provision. Finally, the two studies that considered the farmers' income showed significant increases.

2. Relation to the theory of change

For a comprehensive perspective on these findings, it is worthwhile revisiting the ToC outlined in the protocol for this SR (as detailed above). We analyse how the coastal and terrestrial intervention categories align with the outcomes specified in the ToC and their relevance to the meta-analysis. Regarding interventions, the available evidence predominantly pertains to terrestrial water sector interventions. Due to a scarcity of evidence on coastal interventions, conducting a meta-analysis was not feasible. These intervention categories for the SR encompassed only four of the potential eight intervention categories: nature-based options, built infrastructure, institutional interventions, and financial/market mechanisms. Notably, the most extensive meta-analysis focused on built infrastructure and nature-based options. Within these interventions, the evidence included in the meta-analysis is confined to specific types. Regarding nature-based options, the meta-analysis exclusively considers ecosystem-based watershed management, while built infrastructure primarily centres on water-efficient irrigation systems. As for institutional interventions, the evidence refers to formal regulatory frameworks, while financial/market mechanisms encompass payment for ecosystem services and insurance for flooding.

Similarly, the evidence incorporated in this review predominantly overlooks other sub-outcomes in the process and implementation category, along with secondary and final outcomes associated with common pool resource (CPR) governance processes. Additionally, secondary outcomes falling under subcategories like shocks and stresses, identification, response to potential future impacts, and mitigation co-benefits (a subcategory of final outcomes), receive limited attention in the available evidence. The information regarding unintended consequences is limited. Nevertheless, it is worth noting that, in terms of outcomes, this review significantly addresses the process and implementation outcome, specifically adoption, and the final outcomes related to adaptive (buffer) capacity as outlined in the ToC.

B. Quality of the evidence

Based on an extensive search of both academic and grey literature, our SR identified a heterogeneous evidence base of coastal and terrestrial water sector interventions in developing countries that includes 172 studies. Following consultations with the engagement committee advisory group and continued engagement with GCF to jointly identify the SR's relevant evidence areas, the synthesis gaps and stakeholders' interest steered the review's focus to the six intervention types. These intervention types covered four broad categories, namely built infrastructure, nature-based options, institutional interventions, and financial/market mechanisms and are represented in 103 studies. Regarding the quality of the individual studies included in the review and selected for meta-analysis, the identified evidence base was of mixed quality. Of the 103 studies remaining after the selection of interventions for meta-analysis, 56 studies were judged to be of either low or moderate risk of bias, while 47 studies were considered to have either a high or critical risk. Of these, 40 studies were excluded as they were deemed to have a critical risk. The most rigorous synthesis comprised the effects of water-efficient systems interventions on income (n=12); water-efficient systems interventions on crop yield (n= 9), ecosystem-based watershed management on crop yields (n=8), and ecosystem-based watershed management on income (n=7). Consequently, this presents an opportunity to conduct an extensive synthesis of the effectiveness of these interventions on the respective outcomes.

To formally assess the overall quality of the evidence base, we apply the GRADE framework, which combines the risk of bias rating of the included studies with an assessment of the consistency, precision, and directness of the included evidence base. The GRADE framework originated in the medical sciences and places a premium on closed experimentation. In this respect, the GRADE framework sets a very high bar by elevating experimental studies, which are much more challenging in the social sciences, and places a stringent and comprehensive set of criteria to assess the overall quality of the evidence base. Applying the GRADE framework, we are unsurprised to find that, due to the strict criteria, the overall quality of the evidence included in our 17 meta-analyses was low (see Appendix 3). Only the quality of evidence included in the meta-analysis on water-efficient irrigation systems interventions of crop yield and poverty levels was of moderate quality. All other syntheses were based on low quality evidence (n=5) and very low quality (n=10). In summary, through using the GRADE framework and in common with most systematic reviews in the social sciences, the heterogeneous, low quality nature of the evidence base limits the findings of our SR. We are only able to reach cautious conclusions regarding the evidence presented. As professional evaluators, we recognise that, in common with most systematic reviews in the social sciences, the low quality of the evidence base limits the conclusions that can be drawn from the included studies.

C. LIMITATIONS AND POTENTIAL BIASES IN THE REVIEW PROCESS

Referring again to the ToC, we see that the review examined a limited set of coastal and terrestrial water sector interventions and outcomes. The ToC presents eight categories of coastal and terrestrial water sector interventions: (i) nature-based options; (ii) built infrastructure; (iii) technological options; (iv) coastal interventions; (v) informational/educational schemes; (vi) institutional interventions; (vii) financial market mechanisms; and (viii) social/behavioural interventions. These interventions are linked to numerous outcomes, including seven process/implementation outcomes and 10 secondary outcomes (divided into two shocks and stresses, four identification and response to possible future impacts outcomes, and four CPR governance processes). In addition, this outcome group also included 13 final outcomes of adaptive capacity (six types), mitigation co-benefits and trade-offs (three types), and CPR governance impacts (four types). However, it is important to note that the primary outcome focus area of the review is adaptive capacity proxy and mitigation co-benefits. Our meta-analysis largely concerns the impacts of the stated interventions on the former outcomes and not the latter, due to the lack of sufficient evidence. The specific terrestrial water sector interventions analysed in the review comprise four of the eight categories: (i) nature-based options; (ii) built infrastructure; (iii) institutional interventions; and (iv) financial market mechanisms. There is room for further exploration in other intervention categories, and it is important to recognize there may be additional promising coastal and terrestrial water sector interventions not considered in this review.

The second set of limitations relates to the design and implementation of our SR. In terms of review design, our SR subscribed to an aggregative review approach aiming to use statistical meta-analysis to synthesize the results of a homogeneous body of interventions and outcomes. To attain this objective, the scope of the SR was narrow in terms of the included study designs and the synthesis question of interest; that is, which interventions work and to what effect. This narrow scope, by implication, excludes qualitative evidence on contextual factors that might mitigate intervention effects and causal pathways.

In conducting the SR, we applied a range of quality assurance mechanisms to limit potential biases in the research process introduced by the review team. Firstly, the SR design and process occurred before conducting the review and were outlined in a protocol to adequately define the review's scope and ensure its transparency and replicability (Konci and others, 2023). Secondly, throughout

the review process we had guidance from a multidisciplinary advisory group engaged through a co-production model, which was particularly useful in identifying areas for synthesis such that it meets stakeholders' priorities. Thirdly, our SR was based on an exhaustive search of academic and grey literature. Fourth, we applied a structured coding and risk of bias tool to assess the trustworthiness of the included studies and to extract relevant information for the synthesis in a transparent and consistent manner. Lastly, we assessed the quality of our meta-analyses using moderator and sensitivity analyses. In sum, we are confident we have applied reasonable measures to reduce the potential bias in the design and conduct of this SR.

D. AGREEMENTS AND DISAGREEMENTS WITH OTHER STUDIES OR REVIEWS

As expected, the significant role of built infrastructure, including water-efficient irrigation systems and nature-based solutions, particularly ecosystem-based management interventions is shown from the results of this review. These are among the most extensively studied interventions in the terrestrial water sector realm, especially in agriculture. Water-efficient irrigation systems and measures for conserving soil and water have frequently been used to enhance crop yields, income and overall consumption. A substantial body of literature exists on this subject. The SR's conclusion that water-efficient irrigation systems and ecosystem-based management show reasonable effectiveness in boosting income and crop yields aligns with the broader body of literature. However, a notable discrepancy arises from the review's inability to conduct a meta-analysis for coastal interventions due to a dearth of suitable studies for synthesis. Among these interventions, payment for ecosystem services stands out as a widely adopted approach, with numerous successful instances across different countries, particularly in terms of income-generation.

Our findings largely mirror this broader landscape. For instance, one global meta-analysis found that irrigation system interventions led to a significant increase in maize yield and water productivity (Zheng and others, 2019). However, in a different study, non-continuous[24] flooding resulted in reduced rice yield and lower methane (CH_4) emissions, albeit with an increase in nitrous oxide (N_2O) emissions from rice paddies. This mixed pattern underscores the necessity for organizing evidence and practices, particularly in the context of coastal interventions and mitigation co-benefits outcomes in developing nations. Finally, while the evidence regarding payment for ecosystem interventions considered in this review may not be robust, there is a wealth of literature documenting successful interventions in various other domains.

[24] These techniques have been labelled with terms like alternate wetting and drying, sporadic watering, and mid-season drainage (Jiang and others, 2019).

VI. CONCLUSIONS AND IMPLICATIONS FOR PRACTITIONERS

Water-efficient irrigation systems and ecosystem-based management interventions to promote income and crop yield should continue to be considered as effective tools to promote income and crop yield and should receive continued consideration. Two sets of interventions were identified that had a significant number of studies. In both sets, water management interventions were part of broader programmes involving a range of other interventions, without which the impact of water-related interventions may not be fully demonstrated. In the case of water-efficient irrigation studies, these interventions are implicit and are held constant in assessing the impact of the water-related intervention. In the case of the ecosystem-based watershed management studies, the designs explicitly focus on interventions that may not be exclusively water-related, but which are undertaken within the physical geography of a "watershed". While both sets of interventions may have water-related outcomes (e.g. on water quality or flows), their impacts were not systematically considered as primary outcomes. This highlights the difficulty of conceptualizing in a structured manner the complexity of the many relationships between water resources and society. This complexity has many causes, including the diversity of interactions between society and water, the multiplicity of physical contexts in which water resources are found and the varying intricacies of the societies themselves.

Rising population numbers and climate change's severe impacts have heightened the demand for sustainable agriculture. Water, now widely considered a scarce global resource, is predominantly utilized by agriculture. Enhancing the efficiency of irrigation water usage and improving crop productivity represent significant priorities within the agricultural industry. Effective irrigation management yields various advantages, including conserving fresh water and energy, decreasing nutrient run-off, enhancing crop yields and quality, and optimizing investment returns. Clearly, effective irrigation management is a highly viable solution to the worldwide threat of freshwater scarcity.

Ecosystem-based management in agricultural production involves using and maintaining natural ecosystems to support and enhance farming practices. This approach recognizes the interconnectedness of ecological processes and aims to harmonize agricultural activities with their surrounding environment. It emphasizes sustainable practices that promote crop yields and livestock production and safeguard biodiversity, soil health and water resources. By leveraging the services provided by natural ecosystems, such as pollination, pest control and nutrient cycling, ecosystem-based management can lead to more resilient and productive agricultural systems in the long run.

For policy purposes, this complexity and diversity point to the need for a nuanced analysis of the specific concerns to be addressed. Policy and technical options for using, managing and protecting water resources should consider the context of the wider challenges of economic, social and environmental policy. The challenge for practitioners is often to identify the set of interventions that may be appropriate for successfully addressing the challenges faced in their context and then to identify the approaches that may support their specific objectives.

APPENDICES

Appendix 1. INTERVENTION TYPES AND RELATED ACTIVITIES

INTERVENTION TYPE	DEFINITION	EXAMPLES[25]
Nature-based options	Activities that use ecosystems and biodiversity and sustainable management, conservation, and restoration of ecosystems to achieve water security goals[26].	Restoration of natural wetlands. Use of wetland/pond-based systems for water quality management and wastewater treatment. Ecosystem-based watershed management, including afforestation and reforestation and remediation and control of land erosion.
Built infrastructure	Activities that include structural components built to achieve water security goals.	Dams and related water storage infrastructure. Desalination plants. Water transport systems, including pipe systems and lined canals. Water-efficient irrigation systems (sprinkler and drip). *Rainwater harvests tanks[27].
Technological options	Activities that apply specific technologies to support the achievement of water security goals.	Information and communication technologies. Plastic sheeting for water and shade management. Artificial surface treatments. *Smart water metres[28]. *Monitoring networks.
Informational/ educational schemes	Activities that aim to inform and educate water managers and users to influence behaviour.	Water conservation education. Flood and drought early-warning systems. Other disaster risk reduction interventions (business training and mentoring).
Institutional interventions	Activities that involve the development of institutional arrangements (including organizations, regulatory and operational frameworks) to support the achievement of water security goals.	Development of a formal regulatory framework to govern water resource use, management, and protection. Establishment of user-based organizations to manage CPR (e.g. farmers' water user associations, catchment management institutions etc.). Planning and modelling of water resource systems to guide their development and operation. *Smart Decision support system systems. *Water user association.
Financial/market mechanisms	Activities that include financial transactions or are market-driven.	Payment for ecosystem services, including user payment schemes. Insurance for losses due to flood and drought.
Social/ behavioural	Activities that include social support and change or behavioural change.	Behavioural approaches-nudges. Migration due to floods/drought; social support due to floods/drought. *Catchment management plan.

[25] Denotes examples of interventions per category provided by the advisory group.
[26] Readers are also directed to definitions of nature-based options such as from the International Union for the Conservation of Nature.
[27] Excludes WASH related intervention types.
[28] Excludes WASH related intervention types.

Intervention type	Definition	Examples[25]
Coastal interventions	Activities in the coastal environment and at the coastal/land interface.	Mangrove rehabilitation and expansion. Estuary management and protection. Mitigation of saltwater intrusions in coastal areas. Coastal ecosystem protection and restoration.

Appendix 2. DEFINITIONS OF OUTCOMES

OUTCOME		DEFINITION
Process/implementation outcomes		
Uptake – Human systems	Knowledge of the intervention	Awareness of the intervention and its objectives
	Acceptability of intervention	Perceptions about the intervention
	Feasibility of interventions	Whether an intervention was implemented as planned
	Adoption of interventions	Adoption of intervention activities
	Change in knowledge	Acquisition of knowledge following the intervention
	Change attitudes	Perceptions of the environment and developmental matters
	Intention to change behaviour/practice	Future plans to modify behaviour towards the environment
Secondary outcomes		
Shocks and stresses – Human and natural systems (based on size, frequency, earliness, predictability, bunching, covariance of hazards)	Exposure by location	These outcomes relate to the ability of targeted groups to address shocks and stressors while minimizing permanent, adverse effects on their longer-term livelihood security. These outcomes include those related to disaster risk reduction and disaster risk management approaches. Increased/decreased exposure/asset specificity
	Exposure by activities (e.g. markets)	
Identification and response to possible future impacts – Human systems	Protecting (defence mechanisms)	Measures to protect against (water-related) disaster risks
	Decoupling (change activities)	Change in activities or shifting of their location to minimize potential shock or stress
	Forecasting (alter timing)	Providing information that identifies and informs the need for future action
	Smoothing (balance supply/demand)	Storage or rationing to enable consistent and predictable provision of a good or service
CPR governance processes – Human systems	Clearly defined group	Identification of the societal grouping/s who use a shared resource
	Rules governing the use of common goods	Institutional arrangements for using CPR developed and agreed upon among the communities of users
	Participation in modifying the rules	Established mechanisms to resolve conflicts between existing and potential users over access to and use of CPR
	Outside authorities respect the rule-making rights of community members	The institutional framework that confirms the scope and limits of action of CPR governance institutions and provides for oversight and intervention to resolve conflicts between stakeholders
Final outcomes		
Adaptive capacity –	These outcomes relate to the ability of targeted groups to make proactive and informed decisions about alternative livelihood strategies based on an understanding of changing	

OUTCOME	DEFINITION	
Human and natural systems	conditions The adaptive capacity of natural systems refers to their ability to adjust and respond to changing environmental conditions, including those associated with climate change	
	Buffer capacity (endowments, entitlements)	Buffer capacity refers to the capacity to cushion change and to use emerging opportunities to achieve better livelihood outcomes
	Self-organization	The ability of social actors to determine their own rules that affect them in a collective process of social cooperation within an overarching framework of public governance
	Ability to learn	The acquisition of new knowledge and skills and the capacity to act on them
	Biodiversity and species interactions	High biodiversity provides a greater pool of genetic variation and ecological interactions, which can enhance the resilience of ecosystems to climate change
	Migration and range shifts	Natural systems can respond to climate change by shifting their geographic ranges or expanding into new areas that offer more suitable conditions. This movement allows species to track suitable climates and maintain viable populations
	Ecological succession and resilience	Natural systems can undergo ecological succession, where species composition and community structures change over time. This process allows for adaptation and resilience as new species are introduced or existing species adapt to new conditions. The ability of a system to resist, absorb, accommodate, adapt to, transform, and recover from external impacts in a timely and efficient manner
Mitigation co-benefits and trade-offs – Human and natural systems	Changes in emissions	GHG emissions avoided, reduced, or increased
	Offsets	Value of offset credits verified and validated
	Capture, storage	Amount of GHG sustainably captured or sequestered
	Trade-offs/opportunity costs	Opportunity costs of interventions incurred, including spatial and socioeconomic impacts
CPR governance processes – Human systems	Oversight and compliance	Systems established to monitor the behaviour of the CPR group
	Dispute resolution mechanisms	Effective mechanisms in place for dispute resolution are accessible and affordable
	Interconnected system for governing common resources and subsystems	Institutional arrangements that recognize and provide linkages for the governance and management of activities in interconnected resource subsystems

Appendix 3. DATA EXTRACTION TOOL

DESCRIPTION	QUESTION
Date when the form was completed	Date when the form was completed
ID of the person extracting data	ID of the person extracting data
Report identification	
Publication title	Title of publication
Publication ID	EPPI ID
Author details	Surname of first author
Publication date	Year (letter - if more than one study from that author and that year)
Publication type	What is the impact evaluation publication type? ☐ Academic journal article ☐ Research report ☐ Government report ☐ Dissertation/thesis ☐ Online book chapter
Funding agency name	Who is funding the evaluation/study? Please add the name of the agency funding the evaluation.
Funding agency type	Type of agency funding the evaluation/study: ☐ Academic institution ☐ Charitable or private foundation ☐ For-profit firm ☐ Government agency ☐ International aid agency ☐ International financial institution ☐ Non-profit organization ☐ Not specified
Independence of evaluation	What level of independence is there between the implementing agency and study team? ☐ Funding and author team independent of implementers/funders of programme ☐ Funding independent of implementers/funders of programme, but includes authors from funder/implementer ☐ Evaluation funded and undertaken by funders/implementers ☐ Unclear
Independent data collection	Has an independent party collected the data? ☐ Yes ☐ No ☐ Not clear
Conflict of interest	Is there a potential conflict of interest associated with the study which could influence the collected/reported results? (e.g. Is there a declaration of conflict of interest? Are any of the authors connected in any way to the funding or implementing institution?) ☐ Yes ☐ No

DESCRIPTION	QUESTION
	☐ Not clear
Comments on conflict of interest	If yes, please add a reason for your answer to whether there is a conflict of interest.
Language of publication	Language of publication of the impact evaluation (e.g. Spanish, English etc.)
Other methods	If the impact evaluation addresses questions other than effectiveness, note the questions and methods used here.
Linked studies	If there is any study linked to this one, add the reference.
Context	
Country	List countries the study was conducted in.
Detailed location	If provided, give detailed information on where the study occurred within a country (e.g. regions/districts covered).
Region	Select region(s) the study was conducted in. For more information regarding the region classification, see http://data.worldbank.org/country.
Income category	Select the income classification of the country at the time of the study.
Sector	Choose sector options below: ☐ Agriculture ☐ Education ☐ Energy and extractives ☐ Forestry ☐ Financial ☐ Industry and trade/services ☐ Information and communication ☐ Public administration ☐ Transportation ☐ Environmental and disaster management
Intervention information	
Programme or project name	State the programme or project name. If there is no name, list the location.
Study design	Select the type of study: ☐ Randomized controlled trial ☐ Regression discontinuity ☐ Matching/Propensity Score Matching (PSM) ☐ Instrumental Variable/2SLS ☐ Difference in Difference ☐ Interrupted Time series analysis ☐ Controlled Before and After ☐ Heckman ☐ Fixed effects or random-effects estimation ☐ Natural experiment
Estimation methods	Brief description of the estimation methods.
Commentary on methods (if multiple methods are selected)	State here if multiple methods are selected.

DESCRIPTION	QUESTION
Multi-component intervention	Is more than one intervention subcode applied to this intervention? ☐ Yes (go to question 2) ☐ No (code as "No") Is each intervention subcode evaluated independently (i.e. separate effect sizes estimated for each intervention subcomponent, e.g. 2x2 design, separate evaluations reported in one study)? - If yes, code as "Multiple components, but evaluated separately" - If no, code as "Multiple components, not evaluated separately" ☐ Multiple components, but evaluated separately ☐ Multiple components, not evaluated separately ☐ No
Number of treatment arms	State the number of treatment arms.
Treatment ID	Please create an ID for each treatment of the intervention. 'Treatment' is defined here by 'treatment arms' (i.e. the combination of intervention components received by an arm of the evaluation). For example, in a case where there are three (3) intervention components A, B, and C, with two (2) treatment arms A+B and A+C, this would be coded on separate rows as: Treatment 1 Component A Treatment 1 Component B Treatment 2 Component A Treatment 2 Component C In cases where the intervention is the same (e.g. A+B and A+B), but the delivery mechanism is different (e.g. by community elders versus by teachers), code as separate treatments. When a study does not have a 'pure control', in which the comparison arm receives some intervention components, that comparison is coded as another treatment arm, even if that arm measures no outcomes as a treatment.
Component ID	Please create a component ID for each component of the intervention. Component IDs need to be consistent across treatments. For example, if a component is repeated across treatments, it should have the same component ID. For example, in a case where there are three (3) intervention components A, B, and C, with two (2) treatment arms A+B and A+C, this would be coded on separate rows as: Treatment 1 Component A Treatment 1 Component B Treatment 2 Component A Treatment 2 Component C Component IDs should be captured alphabetically.
Intervention type	Select the intervention type: ☐ Nature-based solutions ☐ Built infrastructure ☐ Technological options ☐ Informational/educational schemes ☐ Institutional ☐ Financial market mechanisms ☐ Social/behavioural ☐ Coastal interventions

DESCRIPTION	QUESTION
Other (add new if it does not fit existing categories)	If you are certain the intervention does not fit within any of the previously defined classifications of coastal and terrestrial water sector interventions, code the intervention here, otherwise leave it blank. When developing a name, either use a description from the study or, if unclear, code it as a non-coastal/terrestrial intervention.
Description of intervention(s)	Write a short paragraph to describe the intervention type and characteristics. The description should be as detailed as possible. Add page numbers.
Objectives of intervention	State any objectives stated in the study or other document.
Scale of implementation	At which level the intervention implemented? ☐ Individual ☐ Household ☐ Firm ☐ Community ☐ District/region ☐ National
What intervention (if any) did the comparison group receive?	☐ No treatment ☐ As usual ☐ Alternative intervention ☐ Other ☐ Unclear
Intervention implementing agency name	Who is implementing the intervention? State the name (and department) of the implementing agency.
Intervention implementing agency type	Type of agency for the implementation of the intervention: ☐ Academic institution ☐ Charitable or private foundation ☐ For-profit firm ☐ Government agency ☐ International aid agency ☐ International financial institution ☐ Non-profit organization ☐ Not specified
Intervention funding agency name	Who is funding the intervention? State the name (and department) of the funding agency.
Intervention funding agency type	Type of funding/financial institution for the implementation of the intervention: ☐ Academic institution ☐ Charitable or private foundation ☐ For-profit firm ☐ Government agency ☐ International aid agency ☐ International financial institution ☐ Non-profit organization ☐ Not specified
Intervention target group	What were the characteristics of the beneficiaries targeted by the intervention? Were the characteristics of beneficiaries used to target the intervention? Open answer.

DESCRIPTION	QUESTION
Target population gender	Indicate the gender of the targeted population: ☐ Female ☐ Male ☐ Female and male ☐ Unclear
Target population age	Indicate the population either ☐ Children <18 ☐ Young adults (18-35) ☐ Adults (36-65) ☐ Elderly (65+) ☐ Mixed ☐ Not specified
Target population income	Indicate the target population income: ☐ Low ☐ Middle ☐ Diverse ☐ Not specified
Target population living environment	State the target population's living environment between: ☐ Protected area ☐ Non-protected area ☐ Both
Targeting methods	How were beneficiaries targeted for the programme (e.g. how was the targeting implemented)?
Target population-specific restrictions	Please provide details. In some instances, the target population is restricted to exclude population members that are difficult or impossible to interview.
Intervention starts	Start date (if not stated, state study date) of intervention.
Intervention end	State end date (if ongoing state ongoing).
Intervention length/exposure to intervention (in months)	Start intervention length (months).
Evaluation period (in months)	The total number of months elapsed between the end of the intervention and the point at which an outcome measure is measured post-intervention or as a follow-up measurement. If less than one month, use decimals (e.g. one week would be 25).
Consideration of equity	Does the study consider equity? ☐ Yes ☐ No
Equity focus[7]	How does the study consider equity? ☐ Intervention targets vulnerable population ☐ Subgroup analysis by sex ☐ Subgroup analysis (other than sex) ☐ Heterogeneity analysis (other than subgroup) ☐ Equity-sensitive analytical framework ☐ Equity-sensitive methodology ☐ Equity-sensitive research process ☐ Measures effects on an inequality outcome

DESCRIPTION	QUESTION
	☐ Research ethics informed by equity
Equity dimension	What dimension(s) of equity does the study consider? ☐ Age (e.g. old or young age, but only if it provides arguments) ☐ Conflict-affected ☐ Culture (includes language) ☐ Disability (medical, physical, neurological, mental disorders) ☐ Education ☐ Ethnicity ☐ Head of household (female or male) ☐ HIV/AIDS (people with or at risk of HIV) ☐ Land size ☐ Land ownership ☐ Place of residence (rural, urban, peri-urban, informal dwellings) ☐ Refugees ☐ Religion ☐ Socioeconomic status (income or poverty status) ☐ Social capital ☐ Sex (includes the use of the term gender meaning the biological sex of a person) ☐ Sexual orientation ☐ Sexual identity ☐ Other (vulnerable groups not typified by any of the above). Answers might include orphans, sex workers, survivors of sexual violence etc. ☐ Not applicable
Process and implementation	
Information about programme take-up	Is there any information about programme take-up? Take-up refers to participation in a programme among those who are eligible. Commentary by authors should be used when information on programme take-up etc., is not supported by some form of research/when the authors do not report that/how they collected data to assess these areas. ☐ Yes, commentary from author ☐ Yes, formally assessed ☐ No
Methods of assessing take-up	Which methods are used to assess programme take-up? ☐ Observation by intervention staff ☐ Reporting by participants ☐ Other ☐ Commentary from author ☐ Not measured
Results of the take-up assessment	What is the result/information provided for the programme take-up assessment? Open answer
Information about programme adherence (among beneficiaries)	Is there any information about programme adherence (how well the participants stuck to the programme requirements) among beneficiaries? Commentary by authors should be used when some form of research does not back up information on programme adherence etc., or when the authors do not report that/how they collected data to assess these areas. ☐ Yes, commentary from author

DESCRIPTION	QUESTION
	☐ Yes, formally assessed ☐ No
Methods of assessing adherence	Which methods are used to assess programme adherence for beneficiaries? This includes dropout rates and adherence to appointments, etc. ☐ Observation by intervention staff ☐ Reporting by participants ☐ Other ☐ Commentary from author ☐ Not measured
Results of the adherence assessment	What is the result/information provided of the assessment of programme adherence? Open answer
Information about implementation fidelity/intervention delivery quality (among implementers)	Is there any information on implementation fidelity and intervention delivery quality? Commentary by authors should be used when information on programme adherence etc., is not backed up by some form of research/when the authors do not report that/how they collected data to assess these areas. ☐ Yes, commentary from author ☐ Yes, formally assessed ☐ No
Methods of assessing intervention fidelity	Which methods are used to assess implementation fidelity/intervention delivery quality by the implementing partner: ☐ Observation by intervention staff ☐ Reporting by participants ☐ Other ☐ Commentary from author ☐ Not measured
Results of the intervention fidelity assessment	What is the result/information derived from assessing implementation fidelity/intervention delivery quality? Open answer
Incentives	Were incentives provided to intervention participants? ☐ Yes ☐ No ☐ Not clear
Other descriptions of process/implementation factors	Any other description of process/implementation factors not covered above. Open answer
Results: barriers and facilitators	Report here any material relevant to causal mechanisms and barriers and enablers. Open answer
Cost	Are any unit cost data/cost-effectiveness estimates provided? ☐ Return on investment analysis ☐ Cost-effectiveness ☐ Cost-benefit ☐ Cost only ☐ No cost data

DESCRIPTION	QUESTION
Cost details	If yes, report any unit cost details and/or total cost. Please also report the year and currency.
External validity	
Length of study	Length of study in months (Where study length is not reported, code as length of intervention and include a note in brackets) Number of months, if not reported N/A
Efficacy or effectiveness trial	Was the intervention implemented under "real world" conditions? By real world, we mean a programme implemented independently of the evaluation, either by a government, non-governmental organization or international agency ☐ Yes ☐ No ☐ N/A
Personnel implementing the programme	Who was in charge of implementing the programme? ☐ PI/researchers (study authors) ☐ Implementing agency staff ☐ External agency (e.g. survey firm) ☐ Others ☐ Not clear
Author discussion of external validity	Do the authors discuss or explicitly address generalisability/applicability? ☐ Yes ☐ No
Outcome information	
Outcome type	Select the outcome type: *Process/implementation outcomes* ☐ Uptake – Human systems *Secondary outcomes* ☐ Shocks and stresses – Human and natural systems ☐ Identification and response to possible future impacts – Human systems ☐ CPR governance processes – Human systems *Final outcomes* ☐ Adaptive capacity – Human and natural systems ☐ Mitigation co-benefits and trade-offs ☐ CPR governance impacts – Human systems
Outcome indicator description	Extract the exact name of the indicator used as the dependent variable in the analysis. Use this open answer field to enter, in the author's own words, a description of the outcome in a sentence or so. Be selective and concise with the excerpts transcribed to ensure accurate and precise descriptions of the outcome. Include page numbers with every excerpt extracted.
Outcome timing	☐ Less than 1 year ☐ 1 to 3 years ☐ More than 3 years ☐ Not clear
Timing of outcome measurement	☐ Only after ☐ Before and after ☐ Not clear

DESCRIPTION	QUESTION
Unintended outcomes	State any unintended outcomes highlighted in the study.
Effective size calculations	
Treatment ID	Indicate the relevant treatment ID linked to the relevant effect size.
Outcome type	Select the outcome used to extract effect size data.
Post-intervention or change from baseline?	☐ Post-intervention ☐ Change from baseline
Nature of the measures/estimate type	Type of data for this effect size: ☐ Continuous ☐ Dichotomous outcome - proportions ☐ Hand calculated data ☐ Regression data
Direction of the effect	☐ Effect favours treatment ☐ Effect favours comparison ☐ Zero effect ☐ Unclear
Reverse sign (i.e. decrease is good)	Record no if an increase is good, record yes if a decrease is good and the sign needs to be reversed. ☐ Yes ☐ No
Unit of analysis	☐ Individual ☐ Household ☐ Firm ☐ Community ☐ District/region ☐ Unclear
When measuring this outcome, were there any differences between the treatment group participants and the comparison?	☐ Yes ☐ No
Effect is statistically significant?	☐ Yes ☐ No ☐ Unclear
Treatment sample size	Insert treatment sample size here.
Control sample size	Insert control sample size here.
Subgroup	Is this analysis of a subgroup? ☐ Yes ☐ No
If yes to subgroup, describe the subgroup if applicable	Free text, describe the subgroup if applicable (e.g. boys, girls).
Source	Which page(s) contain the effect size data? Note the page number, table number, column and row used to extract the data.
The following group of questions only applies if the Nature of the Measures is "Continuous"	
Treatment group mean	Insert numerical value.

DESCRIPTION	QUESTION
Comparison group mean	Insert numerical value.
Are the means reported above adjusted?	☐ Yes ☐ No
Treatment group standard deviation	Insert numerical value.
Comparison group standard deviation	Insert numerical value.
Treatment group standard error	Insert numerical value.
Comparison group standard error	Insert numerical value.
t-value from an independent t-test	Insert numerical value.
The following group of questions only applies if the Nature of the Measures is "Dichotomous"	
Treatment group number of participants who experienced a change	Insert numerical value.
Comparison group number of participants who experienced a change	Insert numerical value.
Treatment group proportion of participants who experienced a change	Insert numerical value.
Comparison group proportion of participants who experienced a change	Insert numerical value.
Are the proportions above adjusted for pre-test variables?	☐ Yes ☐ No
Logged odds ratio	Insert numerical value.
Standard error of logged odds ratio	Insert numerical value.
Logged odds ratio adjusted?	☐ Yes ☐ No
Chi-square with df=1 (2 by 2 contingency table)	Insert numerical value.
Correlation coefficient	Insert numerical value.
The following group of questions only applies if Nature of the Measures is "Hand calculated data"	
Hand calculated d-type effect size	Insert numerical value.
Hand calculated error of the d-type effect size	Insert numerical value.
Hand calculated odds ratio effect size	Insert numerical value.
Hand calculated odds ratio standard error	Insert numerical value.

DESCRIPTION	QUESTION
Intermediate outcomes or themes (knowledge, skills)	State intermediate outcomes or themes here.
Questions applying to all studies	
Are there results coming from regressions?	☐ Yes ☐ No
Sample size	Insert sample size here.
The following group of questions only applies if results are coming from regressions	
Method: econometric model?	State the econometric model.
Standard deviation effect	Insert numerical value.
Effect (mean)	Insert numerical value.
Controls	Insert numerical value.
Standard deviation: Y	Insert numerical value.
Standard deviation: X	Insert numerical value.
β (beta)	Insert numerical value.
Standard error β (beta)	Insert numerical value.
Degrees of freedom	Insert numerical value.
Data type	☐ Panel ☐ Cross section ☐ Time series

Appendix 4. CRITICAL APPRAISAL TOOL

METHODOLOGICAL APPRAISAL CRITERIA	RESPONSE		
	YES	NO	COMMENT
(If randomized control trial, start after confounding bias. For all other study designs, start here.) **I. Bias in the selection of participants for the study** Are participants selected in a way that minimizes selection bias? *Appraisal indicators* Consider whether:			
1) There is an adequate description of how and why the sample was chosen (i.e. identified/selected/recruited).			
2) There is an adequate sample size to allow for representative and/or statistically significant conclusions.			
3) Participants in the control group were sampled from the same population as that of the treatment.			
4) The group allocation process minimized the potential risk of bias (e.g. using computer algorithms).			
5) The selection of participants for the study (or the analysis) is based on participant characteristics observed after the start of the intervention.			
Low risk of bias / Moderate risk of bias / High risk of bias / Critical risk of bias / Worth continuing? Y/N			
II. Bias due to confounding Is confounding potentially controllable in the context of this study? *Appraisal indicators* Consider whether:			
1) There is potential for confounding the effect of the intervention in this study. If yes, provide examples of confounding domains in the comment box.			
2) Where matching was applied and, if so, whether it featured sufficient criteria.			
3) Where relevant, the authors conducted an appropriate analysis that is controlled for all potential/remaining critical confounding domains after matching had been applied.			
4) The authors avoided adjusting for variables identified after administering the intervention.			
5) The treatment and control groups are comparable after matching/controls have been completed. Select one of the following: - No statically significant differences - Statistically significant difference - Negligible descriptive differences - Significant descriptive differences			
Low risk of bias / Moderate risk of bias / High risk of bias / Critical risk of bias / Worth continuing? Y/N			

METHODOLOGICAL APPRAISAL CRITERIA	RESPONSE		
	YES	NO	COMMENT
(If randomized control trial, skip I + II (above) and start here.) **III. Bias due to confounding (because of ineffective randomization)** Is the allocation of treatment status truly random? *Appraisal indicators* Consider whether:			
1) Eligibility criteria for study entry are specified.			
2) There is a clear description of the randomization process and whether the methods are robust.			
3) The unit of randomization and number of participants is clearly stated (pay special attention to treatment and control locations/balance).			
4) Characteristics of both baseline and end line samples are provided, and the treatment and control groups are comparable at the end line. Select one of the following: - No statically significant differences - Statistically significance difference - Negligible descriptive differences - Significant descriptive differences			
Low risk of bias / Moderate risk of bias / High risk of bias / Critical risk of bias / If there is a critical risk of bias, treat it as a non-random study			
IV. Bias due to departures from intended interventions Was the intervention implemented as laid out in the study protocol? *Appraisal indicators* Consider whether:			
1) The critical co-interventions were balanced across intervention and control groups.			
2) Treatment switches were low enough not to threaten the validity of the estimated effect of the intervention.			
3) Implementation failure was minor and unlikely to threaten the validity of the estimated effect of the intervention.			
4) It is possible that the intervention was taken by the controls (contamination and possible crossing-over).			
5) It is possible that knowledge of group allocation affects how the two study groups are treated during the delivery and evaluation of the intervention.			
Low risk of bias / Moderate risk of bias / High risk of bias / Critical risk of bias / Worth continuing? Y/N			
V. Bias due to missing/incomplete data (attrition) Are the intervention and control groups free of critical differences in participants with missing/incomplete data? *Appraisal indicators* Consider whether:			
1) Outcome data are reasonably complete (80 per cent or above).			

METHODOLOGICAL APPRAISAL CRITERIA	RESPONSE		
	YES	NO	COMMENT
2) If the level of attrition (or other forms of missing/incomplete data) is more than 20%, are the reasons for the missing data reported?			
3) If the level of attrition (or other forms of missing/incomplete data) is more than 20%, do the authors demonstrate the similarity between remaining participants and those lost to attrition and is the proportion of participants with missing/incomplete data and reasons for missing/incomplete data similar across groups?			
4) If the level of attrition (or other forms of missing/incomplete data) is more than 20%, were appropriate statistical methods used to account for missing data? (e.g. sensitivity analysis)			
5) If it is impossible to control for missing/incomplete data, are outcomes with missing/incomplete data excluded from the analysis?			
Low risk of bias / Moderate risk of bias / High risk of bias / Critical risk of bias / Worth continuing? Y/N			
VI. Bias in measuring outcomes Are measurements appropriate, e.g. clear origin or validity known? *Appraisal indicators* Consider whether:			
1) There was an adequate period for follow-up.			
2) The outcome measure (e.g. employment status, income) was clearly defined and objective.			
3) Outcomes were assessed using standardized instruments and indicators.			
4) Outcome measurements reflect what the experiment set out to measure.			
5) The methods of outcome assessment were comparable across groups.			
6) Were outcome assessors aware of the intervention received by study participants?			
Low risk of bias / Moderate risk of bias / High risk of bias / Critical risk of bias / Worth continuing? Y/N			
VII. Bias in the selection of results reported Are the reported outcomes consistent with the proposed outcomes at the protocol stage? *Appraisal indicators* Consider whether:			
1) It is unlikely that the reported effect estimate has been selected for publication because it is a particularly notable finding among numerous exploratory analyses.			
2) It is unlikely that the reported effect estimate is prone to selective reporting from among multiple outcome measurements within the outcome domain.			
3) It is unlikely that the reported effect estimate is prone to selective reporting from among multiple analyses of the outcome measurements, including subgroup analysis.			
4) If subgroup/ancillary/adjusted analyses are presented, are these pre-specified or exploratory?			
5) The analysis includes an intention to treat analysis. (If so, was this appropriate and were appropriate methods used to account for missing data?)			
6) Do the authors report on all variables they aimed to study (as specified in their			

Methodological appraisal criteria				Response		
				Yes	No	Comment
protocol or study aims/research questions)?						
Low risk of bias	Moderate risk of bias	High risk of bias	Critical risk of bias	Worth continuing? Y/N		

Appendix 5. GRADING OF RECOMMENDATIONS ASSESSMENT, DEVELOPMENT AND EVALUATION EVIDENCE PROFILE OF META-ANALYSIS

Intervention category (outcomes)	Quality assessment					Pooled effect	GRADE result
	No. of studies (design)	Limitations	Inconsistency	Indirectness	Imprecision		
Water-efficient irrigation systems							
Adaptive (buffer) capacity: income	12 (2 RCTs)	Very serious limitation	Very serious inconsistency	No serious indirectness	No serious imprecision	0.23 (0.04, 0.42)	□□□□ Very low
Adaptive (buffer) capacity: crop yield	9 (1 RCT)	Very serious limitation	No serious inconsistency	No serious indirectness	No serious imprecision	0.20 (0.10, 0.30)	□□□□ Moderate
Process/implementation: adoption of interventions	4 (2 RCTs)	Serious limitation	No serious inconsistency	Serious indirectness	No serious imprecision	0.00 (-0.06, 0.05)	□□□□ Low
Adaptive (buffer) capacity: poverty levels	3 (2 RCTs)	Serious limitation	No serious inconsistency	No serious indirectness	No serious imprecision	0.21 (-0.32, -0.09)	□□□□ Moderate
Adaptive (buffer) capacity: food security	3 (0 RCTs)	Very serious limitation	Very serious inconsistency	No serious indirectness	Serious imprecision	0.55 (-0.06, 1.15)	□□□□ Very low
Adaptive (buffer) capacity: consumption/expenditure	2 (0 RCTs)	Very serious limitation	Very serious inconsistency	No serious indirectness	Very serious imprecision	0.79 (-0.18, 1.76)	□□□□ Very low
Ecosystem-based watershed management							
Adaptive (buffer) capacity: crop yield	8 (0 RCTs)	Very serious limitation	Serious inconsistency	No serious indirectness	No serious imprecision	0.21 (0.03 to 0.38)	□□□□ Low
Adaptive (buffer) capacity: income	7 (0 RCTs)	Very serious limitation	Very serious inconsistency	Very serious indirectness	No serious imprecision	0.11 (-0.01, 0.23)	□□□□ Very low

Intervention category (outcomes)	Quality assessment					Pooled effect	GRADE result
	No. of studies (design)	Limitations	Inconsistency	Indirectness	Imprecision		
Adaptive (buffer) capacity: dietary diversity	2 (0 RCTs)	Very serious limitation	No serious inconsistency	No serious indirectness	No serious imprecision	-0.04 (0.25, 0.16)	⨁⨁◯◯ Low
Development of formal regulatory frameworks							
Adaptive (buffer) capacity: water consumption	5 (0 RCTs)	Very serious limitation	Very serious inconsistency	No serious indirectness	Very serious imprecision	-0.09 (-0.60, 0.42)	⨁◯◯◯ Very low
Adaptive (buffer) capacity: crop yield	2 (0 RCTs)	Very serious limitation	No serious inconsistency	No serious indirectness	No serious imprecision	0.07 (-0.04, 0.18)	⨁⨁◯◯ Low
Adaptive (buffer) capacity: income growth	2 (0 RCTs)	Very serious limitation	Serious inconsistency	No serious indirectness	Serious imprecision	0.84 (0.38, 1.30)	⨁◯◯◯ Very low
Establishment of user-based organizations on income							
Adaptive (buffer) capacity: income	2 (0 RCTs)	Very serious limitation	No serious inconsistency	No serious indirectness	Serious imprecision	0.4 (0.12, 0.68)	⨁◯◯◯ Very low
Payment for ecosystem services							
Adaptive (buffer) capacity: income	2 (0 RCTs)	Very serious limitation	No serious inconsistency	No serious indirectness	Very serious imprecision	0.23 (0.11, 1.34)	⨁◯◯◯ Very low
Insurance for losses due to flood and drought services							
Adaptive (buffer) capacity: crop yield	2 (1 RCT)	Very serious limitation	Very serious inconsistency	No serious indirectness	Very serious imprecision	0.06 (-1.36, 1.49)	⨁◯◯◯ Very low
Adaptive (buffer) capacity: income	2 (1 RCTs)	Very serious limitation	No serious inconsistency	No serious indirectness	Very serious imprecision	0.68 (-0.10, 1.46)	⨁◯◯◯ Very low
Adaptive (buffer) capacity: consumption and expenditure	2 (1 RCTs)	Very serious limitation	No serious inconsistency	No serious indirectness	No serious imprecision	1.26 (1.23, 1.29)	⨁⨁◯◯ Low

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