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Contents

1 Acknowledgments

We are thankful to the entire Global Adaptation Mapping Initiative (GAMI) team, led by Dr. Lea Berrang-Ford for providing us the database (articles) for the meta-analysis, which were then coded for assessing the effectiveness of water-related adaptation responses. We are thankful to Valeria Fanghella for preparing Figure 2 of this report. We are also thankful to 28 coders who helped code all the papers and to the SysREV coding platform designers for their help and assistance with numerous queries that we had. Names of all coders are included as co-authors/contributors. We would like to thank the Australian Centre for International Agricultural Research (ACIAR) for providing funding for conducting this meta-review. A part of this analysis has been used for Chapter 4 (Water) of the IPCC AR6 WGII report and the associated Summary for Policymakers. All usual disclaimer applies.

2 Executive summary

Anthropogenic climate change impacts every aspect of water security through changes in water availability and quality, increases in water-induced disasters, and changes in ecosystems and their services. In response to climate and non-climate induced water insecurity, people and governments around the world are undertaking various adaptation responses. While there are thousands of case studies of current implemented adaptation responses to water insecurity, there is a lack of synthesized understanding about the effectiveness of these responses in reducing risks.

In this report, we describe our meta-review methodology for assessing the outcomes of current water-related responses. For assessing the outcomes of current adaptation responses, we use a database of 1819 documented case studies of adaptation across all sectors published since 2014. Of these, only 359 (19.7%) case studies assess the effectiveness of current water-related adaptation responses. Outcomes are measured across 6 dimensions and an adaptation response is deemed to be "beneficial" in reducing climate or related risks if the study documents a positive outcome on any of these six "outcome" indicators. These are: (1) the response led to positive economic/financial outcomes; (2) positive water-related outcomes; (3) positive environmental/ecological outcomes; (4) positive outcomes for vulnerable populations; (5) positive institutional or sociocultural outcomes; and (6) positive outcome on any other parameter not captured by the above five indicators. Using these criteria, 319 out of 359 (88.9%) studies that documented water-related adaptation were deemed to be "effective" in reducing risks. However, only 64 (17.8%) of those studies were of "high" enough quality to causally link adaptation response with the outcome, while the rest failed to do so, making the evidence base even smaller. Overall, only 64 out of 1819 studies (3.5%) of all studies provide an assessment of the benefitsof adaptation response with a high degree of rigour.

A majority (~81%) of the adaptation responses were about adaptation in the agriculture sector, followed by adaptations in water-related disasters sector, and urban and peri-urban water use. About one-third, of the adaptation responses which were found to be "effective", were also deemed to be maladaptive, especially if it involved intensification that needed fertilizers and pesticides or water-intensive crop varieties. The majority of the water adaptation responses are about incremental adaptation, that is adaptation that aims to improve existing ways of doing things (e.g., better crop varieties replacing older varieties), without tackling root causes of vulnerability. Cases on transformative adaptation are few and far between, and migration, and capacity building and training seem to be the only two adaptation responses that have transformative possibilities.

Similarly, a large number of case studies documented limits or barriers to adaptation, and the main barriers were deemed to be financial, or governance-related, followed by lack of information and awareness, and capacity.

Given the huge database, and that it took almost 5 out of 6 months of the project to get all the articles coded and quality checked. Thus, the analysis in this report is preliminary and limited to summary statistics.

3 Background

Water has long been recognized as being one of the first impacts in the area of climate change (Bijl et al., 2018; Gosling & Arnell, 2016; Kummu et al., 2016), as well as a central component in adaptation (GCA, 2019; GWP, 2018). Yet, there remain large gaps in our understanding of how people, especially small and marginal farmers, adapt to water-related climate change impacts (Ricciardi et al., 2020). Climate change, through variations in temperature, rainfall, and evaporation, impacts all components of the hydrological cycle, bringing about changes to river flows, aquifers, cryospheric components, and soil moisture dynamics (Jiménez Cisneros et al., 2015). Climate change is also intensifying extreme events and consequent flood and drought events. These climate-induced impacts on the hydrological cycle in turn, affect every sector of the economy, including food, health, ecosystems, cities, energy systems, and challenges the achievement of policy goals like poverty alleviation and sustainable development goals (Gain et al., 2016). Overall, the impacts of 'too little water'; 'too much water'; 'too dirty water'; and "at the wrong place" and "at the wrong time" are already being felt by a majority of the world's population and water insecurity is likely to be among the earliest manifestation of climate change that people experience in their day to day lives (Greve et al., 2018). This is in addition to water insecurity that is being already experienced by more than 4 billion people across the world, as a result of water governance and scarcity (climate and non-climate induced) issues (Gain et al., 2016; Mekonnen & Hoekstra, 2016).

Adaptation is increasingly seen as an imperative to counter climate impacts. At the latest, with the publication of the Special Report on Global Warming at 1.5°C (IPCC, 2018), it is clear that climate impacts are occurring across regions, sectors, and systems and that even at warming levels in line with temperature limits set out by the Paris Agreement, further impacts will be substantial. Water is thought to be central to adaptation. For example, water features prominently in most of the nationally determined contribution (NDCs) pledges and was identified as a top sector (118 among 137 countries) for adaptation in NDC pledges (GWP, 2018). The Global Commission on Adaptation (GCA, 2019) defines four clear action tracks on water and adaptation; namely, harness the power of nature and expand water infrastructure; cope with water scarcity by using water more productively; prepare for a changing climate by planning for floods and droughts, and improve water governance and scale-up water financing.

Overall, in response to climate and non-climate induced water insecurity, people and governments around the world are undertaking various adaptation responses involving combinations of technologies, incentives, and policies. While there are thousands of stand-

alone case studies on current implemented adaptation responses to water insecurity, there isn't enough synthesized evidence to indicate if these adaptation responses reduce climate and associated risks. In view of a lack of synthesized knowledge base on the effectiveness of current adaptation responses, we undertake a meta-review for measuring the effectiveness of water-related adaptation responses in reducing current climate and associated risks.

We define a water-related adaptation as a response that is undertaken if either the risk is water-related or the actual adaptation intervention is water-related. For example, if the risk (defined as a combination of hazard, exposure, and vulnerability) is water-related, i.e., the risk emanates from hazard and exposure caused by floods, droughts, groundwater depletion, melting of the cryosphere, soil moisture depletion, etc., and manifests itself in the form of an increased vulnerability of individuals and communities driven by constrains on water access; or if the adaptation intervention to reduce risk (water-related or otherwise) is water-related, e.g. irrigation, soil moisture conservation, rainwater harvesting, wastewater reuse, etc., then we categorize that adaptation response as a water-related adaptation response.

Defining effectiveness of current and future adaptation responses

For current adaptation responses, in line with the Global Adaptation Mapping Initiative (GAMI) (Berrang-Ford et al., 2020), we only include case studies on actual, implemented adaptation, as opposed to adaptation that has been planned, but yet to be implemented. Effectiveness is defined as the ability of the adaptation response to "reduce" or mitigate risk – where risk is defined as per IPCC definition – a combination of hazard (climate aspect) and vulnerability and exposure (human aspects). We only include studies that measure the "effectiveness" of adaptation response by using one or multiple indicators. We define any current adaptation response to be effective if it leads to positive outcomes in either one of the following indicator categories:

1. Economic and/or financial indicators, such as improvements in crop yields and resulting incomes; increase in profits, greater savings, or lesser losses from hazards, etc.;
2. Impacts on vulnerable people, e.g., on women, children, indigenous people, etc.;
3. Water-related impacts, e.g., improved water use efficiency, water saving, reduction in water withdrawals and application, etc.;
4. Ecological and environmental impacts such as lesser energy use, better soil structures, and better thermal comfort, etc.;

5. Institutional and socio-cultural impacts such as better group dynamics and action, better bargaining power among vulnerable people, strengthening of local institutions, or national policies, etc.; and
6. Any other positive impacts not captured by the above 5 indicators.

4 Objectives

1. Conduct a systematic review of documents on existing case studies of water-related adaptation responses and ascertain the extent to which these adaptation responses have been able to reduce climate-related risks;

2. Examine the enabling conditions that helped to make these adaptation responses “effective”;

3. Understand if some of the adaptation responses were “maladaptive” or if there were limits to adaptation.

5 Methodology

Meta-review protocol for coding current and future adaptation responses

We developed a methodology for assessing the effectiveness of current adaptation responses. The following sections describe this methodology in greater detail.

Steps for meta-review of current water-related responses:

The meta-review for current adaptation responses draws on the GAMI initiative for two things. First, our overall approach of meta-review is inspired and influenced by the approach of the GAMI meta-review protocol (Berrang-Ford et al., 2020). Second, we used the same set of papers as available in the GAMI database, and we used the same screening protocol as GAMI (Fischer et al., 2020). However, in addition to the 1682 unique papers from the GAMI database, we also included 137 additional papers which were cited in adaptation sub-sections of the First Order Draft of Water chapter of IPCC, Working Group II. Further details about the GAMI approach and screening protocol can be found in Berrang-Ford et al. (2020) and Fischer et al. (2020). Some (~30%) of our coding questions were common with the GAMI coding protocol (Lesnikowski et al., 2020). However, we developed our own inclusion/exclusion criteria and a separate coding protocol for the two reasons explained below.

Unlike the broader GAM initiative, where adaptation responses from all sectors are being considered, in our analysis, we are only interested in adaptation responses related to the broad water sector – including all water use sub-sectors such as water for agriculture, energy, industry, health, etc. (see definition of water-related responses above). Second, we were interested in studies that measure the effectiveness of water adaptation in reducing climate and associated risks (see definition of effectiveness above). We only include studies that measure the "effectiveness" of adaptation response by using one or multiple indicators. Therefore, we developed a separate coding protocol based on our interest in understanding the effectiveness of water-related adaptation.

Inclusion and exclusion criteria:

Given our focus on measuring the effectiveness of water-related adaptation responses, our inclusion criteria were if the:

- Paper was about water-related adaptation;
- Paper documents actual implemented case study/studies of water-related adaptation responses/interventions as opposed to planned responses/interventions;

- Paper evaluates the impact/effectiveness of that adaptation response/intervention in reducing climate and associated impacts, in credible and (semi) causal ways, including through a well-enunciated theory of change;
- The paper includes at least one tangible (either quantitative or qualitative) indicator of effectiveness. Those indicators could be economic/financial indicators; indicators on impacts on vulnerable people, water-related indicators, environmental and ecological indicators, socio-political indicators, or any other indicators not captured by the above categories;
- Paper was published in or after 2014;
- Paper has enough (at least half a page) information about the water-related adaptation response/intervention that is being coded.

To be included for full coding, a paper had to meet all six inclusion criteria. Papers that did not meet any one of these 6 criteria were coded partially for only 4 variables: description of the adaptation response; water use sub-sector relevant to that adaptation response (e.g., agriculture, energy, water for sanitation and health (WaSH), water for ecosystems, water for urban areas, etc.); location of the study (country and continent); and concluding remarks. The rest of the papers were coded for 90 questions. We describe our coding protocol and coding questions below.

Coding protocol:

Our coding protocol had seven sections. The first was the inclusion/exclusion criteria, as mentioned above. In the second section, we summarized the nature of the adaptation response. This included: category of water adaptation response (16 categories were developed); categorized them across various water use sub-sectors (agriculture, energy, WaSH, urban, ecosystems, cultural uses, water-related conflicts, etc.); scale (local, national, regional, and global) of the response; geographic location (country and continent); details about the initiator of adaptation and whether adaptation response included Indigenous and Local knowledge. The third section of the protocol coded studies based on water-related hazards (e.g., floods, droughts, extreme rainfall, groundwater depletion, melting of the cryosphere, etc.); vulnerability (how did the communities experience vulnerability), and risks. There was a total of 11 risk categories defined. Section 4 coded evidence on the effectiveness of adaptation response in reducing climate and associated risks, and coded evidence on maladaptation and co-benefits. We also coded the studies on different indicators of effectiveness as described earlier. We coded the papers based on the evidence provided in the paper, and kept coder interpretation of the results to a minimum, to avoid potential misinterpretation. Each paper was coded by two or more coders. Section 5 documented enabling conditions for successful adaptation and these

include information on adaptation costs and finance and on governance and political support. Section 6 classified the studies in terms of their quality. In addition to the GAMI protocol, where studies were coded using the GRADE-CERQual approach with evidence across 4 components: methodological limitations, adequacy of data; coherence, and relevance, we also classified the studies based on the rigor of attribution of adaptation outcomes to the adaptation response because of our central interest in understanding the effectiveness of adaptation. In other words, we classified the studies into 3 categories. The first category was studies that establish causal linkages between the adaptation response and outcome and called them high-quality studies. Medium quality studies were those which shows a correlation between the adaptation response and outcome but does not necessarily establish causality, while the third category (low quality studies) are those which neither establish causality, nor show any correlation between adaptation response and outcomes in tangible ways, but often provides a relatively good narrative of the pathways along which adaptation response may have been effective in reducing risks. Section 7 included only one question where the coder had to summarize the main conclusions from the study briefly. In addition to answering the question, coders were required to copy and paste relevant text from the papers to support their answers.

We summarize the main coding questions below:

Section 1 is the inclusion/exclusion criteria described above.

Section 2: Summary and categorization of water-related adaptation response/intervention, including general and geographic information:

- Brief description of the adaptation response/intervention in human systems or human-assisted responses in natural systems if it pertains to any of the water use-subsectors;
- Categorization of water response into 16 main adaptation categories: improved cultivars and agronomic practices; changes in cropping pattern and crop systems; on farm irrigation and water management; water and soil moisture conservation; collective action, policies, institutions; migration & off-farm diversification; economic/financial incentives; training and capacity building; agro-forestry and forestry adaptations; flood risk reduction measures; livestock and fishery-related; IK and LK based adaptations; urban water management; energy-related adaptations; WaSH related adaptations; any other (includes coping);
- Category/type of adaptation response: behavioral/cultural; ecosystem-based; institutional; technological/infrastructure; and any other;

- Water use sub-category where the adaptation is happening. These are: water for agriculture; water for urban and peri-urban use; water-induced disasters (floods, droughts, extreme rainfall events, etc.); water for health and sanitation; water for freshwater ecosystems; cultural uses of water; and water-related conflicts;
- Region(s) or geographic focus of adaptive responses documented: Country and continent;
- Scale of the adaptation response/intervention: local, national, regional, and global;
- Inclusion of Indigenous Knowledge & Local Knowledge (IK & LK) in adaptation response;
- Who is initiating or engaging in adaptation responses? E.g. individuals/households; civil society, government, and private sector.

Section 3: What are the hazards, vulnerabilities, and resultant risks that the adaptation response/intervention is responding to?

- What is the water-related hazard that the adaptation response responds to? The categories are cryospheric changes; changes in groundwater availability; changes in precipitation, including extreme precipitation; droughts, riverine floods, soil erosion, and sedimentation; extreme heat events and unspecified, but general climate impacts;
- What aspects of vulnerability are targeted by adaptation responses? The categories are vulnerabilities related to poverty alleviation; consumption and production; access to agricultural water; energy access, gender equality; improving health and well-being; providing access to clean water and sanitation; and reducing social vulnerabilities;
- What is the stated (or implied/assumed) risk? Coders sum up the overall risk and then categorize the risk across 11 categories, which are: risk to lives; risk to livelihoods; risks to health and well-being; economic risks; social risks; cultural risks; risks to assets, infrastructure, investments; risks to services (including ecosystems services); risks to ecosystems and species and multiple risks.

Section 4: Evidence and indicators of the effectiveness of adaptation response/intervention including mal-adaptation and co-benefits:

- Is there any evidence that adaptation response successfully reduced risk or vulnerability?
- Are indicators or measures of ‘effectiveness’ identified?

- Did the response lead to better financial/economic outcomes?
- Did the response target the vulnerable group, and if yes, is there evidence that risk for that group declined?
- Did the response lead to better hydrological (water-related) outcomes?
- Did the response lead to better ecological/environmental outcomes?
- Did the response lead to improved institutional/socio-cultural outcomes?
- Did the response lead to any other improved outcomes (not captured above)?
- Which aspect of risk (hazard, vulnerability, or exposure) is reduced due to the adaptation response?
- Is there any consideration of new risks or maladaptation?
- Is there any reference to co-benefits?

Section 5: Adaptation finance and costs, enabling conditions and limits to adaptation

- Who financed the response?
- Are the costs of the response documented?
- Is there evidence of participative/bottom-up governance?
- Is there evidence of polycentric/nested/multi-level governance?
- Is there any evidence of strong political support for the adaptation response?
- Are limits to adaptation described?
- Are these soft or hard limits?

Section 6. Assessing confidence in evidence:

- Does the study establish a causal relationship between adaptation response and outcomes?
- Does the study document correlation between the adaptation response and outcomes?
- Are there any major methodological limitations?
- Nature and type of data: qualitative, quantitative, remote sensing and GIS-based data, etc.;
- Did the document provide sufficient information to answer all these coding questions? (coherence);
- Comment on the quantity and quality of data upon which the findings are based (adequacy);
- What is the external validity of the evidence? (relevance)

Section 7. Concluding remarks:

- Any additional remarks that may have relevance for the review

Figure 1 provides a pictorial depiction of the coding protocol and figure 2 shows the country-wise distribution of 359 case studies that measure the effectiveness of current adaptation responses (Annex 1 provides a complete bibliography of the 359 studies).

Coding platform, selection of coders, coding and data cleaning

Like the GAMI, we also used the online SysREV platform for coding the papers. This online tool enables multiple coders to code simultaneously, and all results are saved on SysREV server as .csv files. The link to the SysREV project is https://sysrev.com/u/1502/p/28357.

Coders were solicited through tweets and emails sent to professional networks. We received over 100 applications from prospective coders, and chose a total of 28 coders, most of whom were early career researchers, i.e., either in the final stages of their PhD research or are post-doctoral researchers. All coders were provided with a detailed manual, and we conducted two online training sessions. The coders were first asked to code at least 20 articles on a mock online platform and were given feedback on the quality of coding, and suggestions for improvement. Thereafter, actual coding commenced from the 3rd week of March 2020 and ended in early July 2020. Every two weeks, the first author of this paper took stock of the coding status and provided regular feedback for reconciliation. The CSV output files were downloaded from SysREV site, and a smaller group of coders, along with the first author of this paper ensured that data was clean and complete in every respect. The cleaned data was analyzed using Excel, R Programming Software, and Stata software, and qualitative information was analyzed using NVIVO software.

Section 1	Section 2:	Section 3	Section 4	Section 5	Section 6
Inclusion/Exclusion	Adaptation response	Hazard, vulnerability,risk	Effectiveness	Enabling conditions and limits	Data & Methods
Bollean & String	Boolean/categorical/string	Boolean/categorical/string	Mostly Boolean & Strings	Boolean/categorical/string	Mostly Boolean & Strings
Requires user consensus	User consensus not needed	User consensus not needed	Requires user consensus	User consensus not needed	User consensus not needed
Water-related adaptation	Describe water-adaptation	Hazard	Evaluate effectiveness	Bottom-up participative goernance	Confidence in methods
Case study of implemented response	Categorize water adaptation into 16 sub-categories	Vulnerability/exposure	Indicators of effectiveness	Polycentric governance	Type of data
Evaluates "effectiveness"	Category of response	Risk	Economic/Financial	Political support	Adequacy in data
Has at least 1 out of 6 effectiveness indicators	"Water use" subsectors	Categorize risk into 10 sub-categories	Impact on vulnerable groups	Limits to adaptation	Coherence of evidence
Published in or after 2014	Location		Water related outcomes		Relevance of evidence
Sufficient for coding	Scale of response		Ecological/environmental outcomes		Attribution of causality -- Is adaptation response to risk reduction causal?
	Indigenous & Local Knowledge		Social/cultural/institutional outcomes		
	Who responds/who intiated?		Any other outcomes		
			Which aspect of risk (hazard/vulberability/exposure) is reduced?		
	Water chapter codes		Maladaptation & Co-benefits		
	GAMI derived codes		Adaptation cost & Finance		

Figure 1. Main coding questions. Cells highlighted in green are the same as GAMI codes, while those in blue are unique to this meta-review exercise. The second row from the top describes the different sections of the coding protocol, the third row from the top mentions the type of data in that section (Boolean = Yes/No; Categorical= coders have to choose among several pre-defined categories and string= quotes from papers); and the fourth row from top shows if the answer requires user consensus or not. This means that for the answers to be counted, all coders must agree on the correct Yes/No answer. If answers differ, coders would consult each other, revisit their respective codes, and would arrive

at a consensus. In questions that did not require consensus, we considered the answer of the coder who answered “yes” to that question and provided supporting quotations from the paper for the same. We assumed that it is more probable to miss coding an indicator, than to code it incorrectly, especially when for every indicator coded, there has to be a supporting statement.

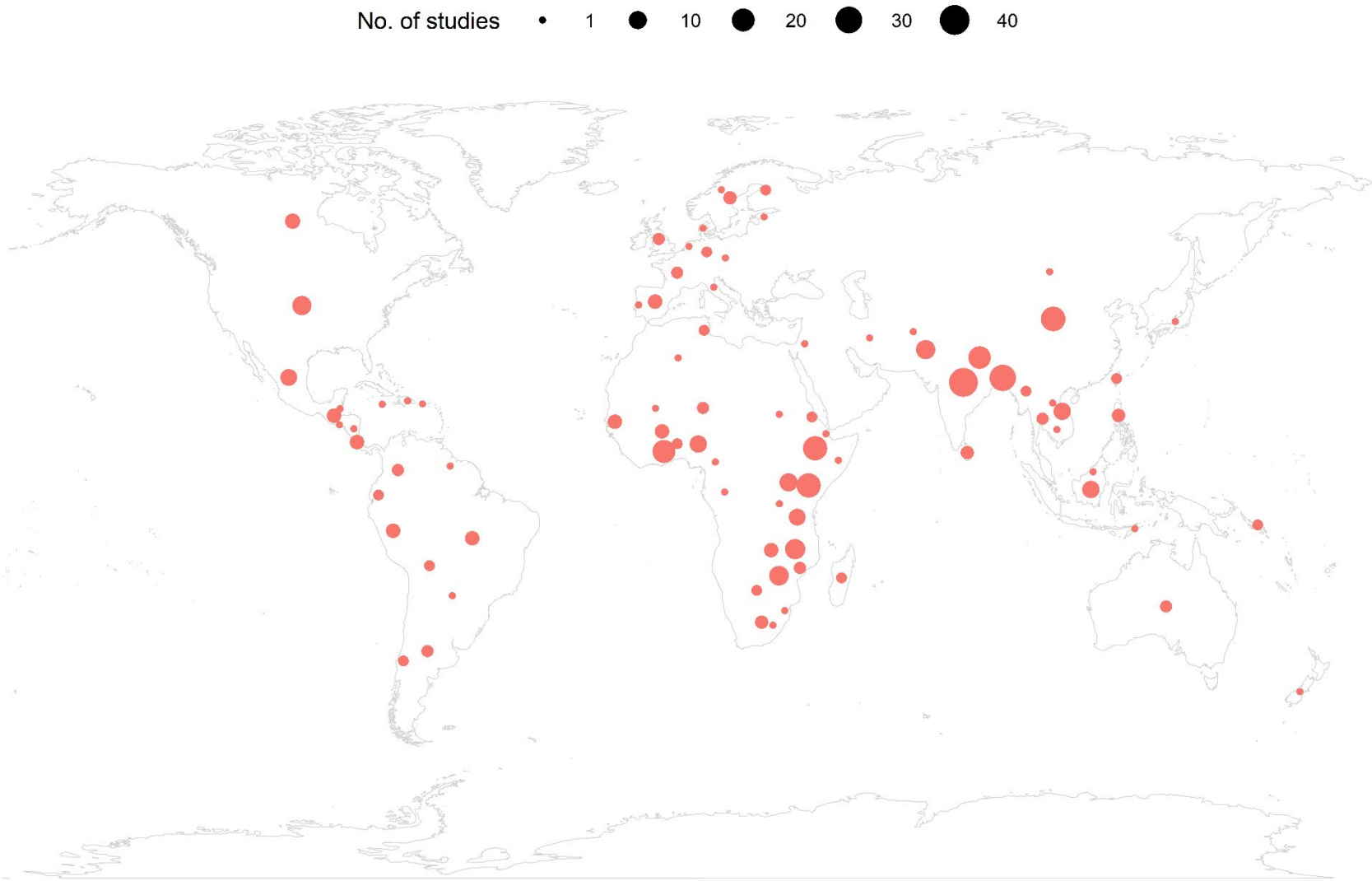

Figure 2. World map showing the number of documented case studies of current adaptation responses (total n=359) in each country.

6 Achievements against activities and outputs/milestones

Objective 1: To …

Sr. no.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Create a database of relevant articles that deal with adaptation responses (this is a global database covering all regions of the world);	Two databases (1 for excluded case studies and another for included case studies) were created in excel	30/07/2020	This database was mostly derived from GAMI database, even though we added some additional literature based on separate searches.
1.2	Use inclusion/exclusion criteria (explained in further details in the methodology section) to identify studies for further review;	Same as above	30/11/2020	
1.3	Code the studies using a coding schema to extract needed information on the effectiveness of the adaptation response;	Same as above	30/11/2020	

PC = partner country, A = Australia

Objective 2: To …

Sr. no.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Analyze results, and write a report documenting all water-related adaptation interventions that have been found to be effective in reducing climate-related risks.	A methodology paper submitted to Climate and Development Journal (also a part of this report) This report	15/12/2020 18/01/2021 Revised on 29/08/2021	Submitted to Climate and Development Journal, under review
2.2				
2.3				

PC = partner country, A = Australia

7 Key results and discussion

Summary results for current adaptation effectiveness

A total of 359 out of 1819 papers (~19.7%), published on or after 2014, satisfied all inclusion criteria and measured the effectiveness of adaptation response (see figure 3). The studies were identified along the 16 major categories of adaptation responses and Table 1 provides further details.

Table 1. Number of datapoints* per adaptation options identified from the 359 studies that measure the effectiveness of current water-related adaptation options

Sr. No.	Category of the water adaptation response	Description of the water adaptation response	No. of case studies (data points) which measure the effectiveness of these responses
1	Changes in cropping pattern and crop systems	Changes in cropping pattern; Changes in timing of sowing and harvesting; On farm diversification.	145
2	Improved crop cultivars and agronomic practices	Improved crop cultivars; Improved agronomic practices	139
3	Irrigation and water management practices	Irrigation; On-farm water management; Water-saving technologies.	115
4	Water and soil conservation	Water and soil conservation measures; Water harvesting; Water shed conservation programs; Revival of water bodies.	102
5	Migration and off-farm diversification	Spontaneous migration; Employment and remittances; Planned relocation; Off farm diversification	92
6	Collective action, policies, and institutions	Collective action and cooperation; Community-based adaptation; Local institutions; Water dispute resolution; Institutional and policy reforms.	95
7	Economic and financial incentives	Insurance; Micro-finance and credit programs; Social safety nets; Subsidies and incentives; Water markets and tariffs; Payment for ecosystems services.	54
8	Training and capacity building	Information, training, and capacity building; Behavioral changes.	57
9	Flood risk reduction measures include	Non-structural measures; Structural measures; Early warning systems; Flood resilient housing;	40

		Wetland restoration.	
10	Urban water management	Urban water management; Green infrastructure; Desalinization.	20
11	WaSH related adaptations	Hand washing and hygiene; Safe drinking water and sanitation	5
12	Agro-forestry and forestry-related responses	Agro-forestry related measures; Forestry related measures;	56
13	Livestock and fishery-related	Livestock related; Fishery related.	63
14	IK and LK based adaptations	Use of Indigenous, local and traditional knowledge	41
15	Energy-related adaptations	Hydropower related; Other renewable energy-related.	8
16	Any other including coping strategies	Reduction in consumption, selling of assets, etc.	20

* Number of data points is larger than the total number of studies, as one paper can document more than one adaptation response.

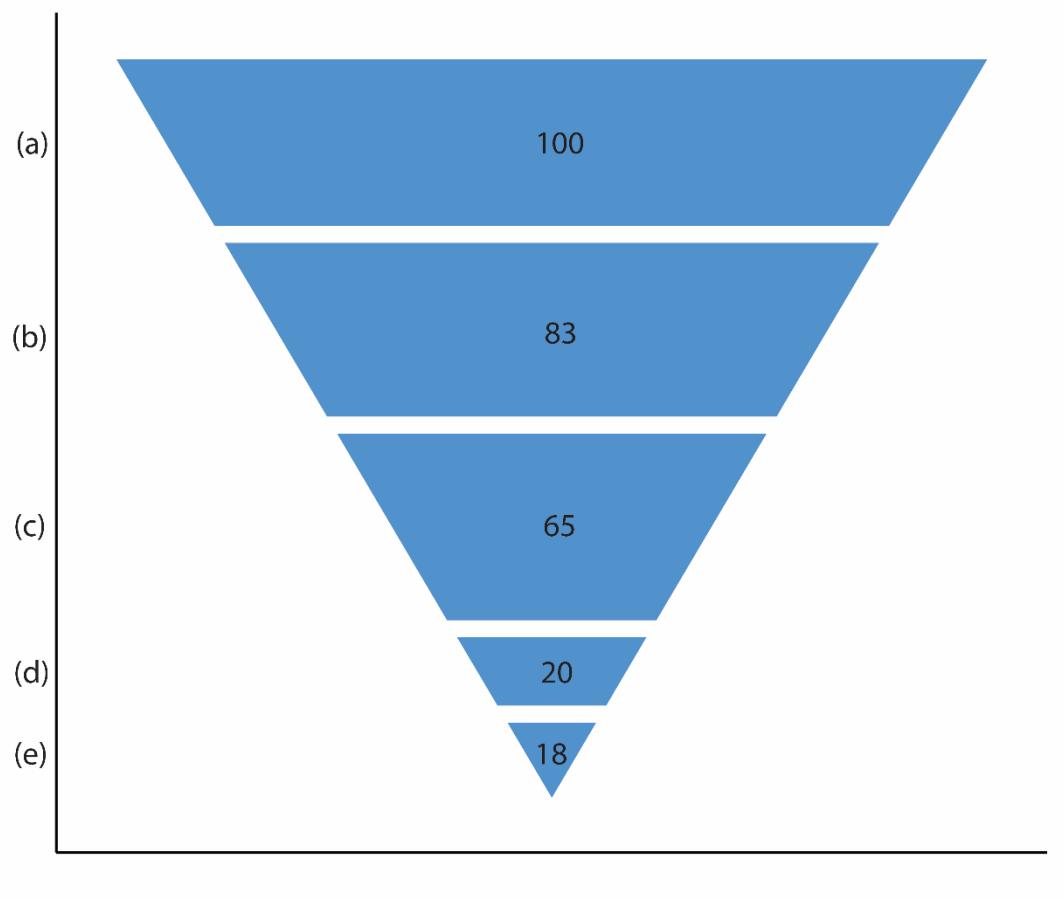

Figure 3. Inverted pyramid diagram to show the nestedness of total studies reviewed and found to be effective a) The total number of studies in the adaptation meta-review database (n=1819) equivalent to 100%, b) percentage of studies on water-related adaptation responses implemented or otherwise; c) the percentage of studies on implemented water-related adaptation responses; d) the percentage of studies that fulfills all inclusion criteria and measures effectiveness of adaptation response in reducing impacts; e) the percentage of

case studies which are found to be effective in reducing climate and associated impacts. All the numbers in the figure are in percentages.

More than 80% of all adaptation-related case studies published since 2014 are about water-related adaptation, that is, the adaptation was in response to a water-related hazard e.g. droughts, floods, rainfall variability, groundwater depletion, melting of the cryosphere, soil moisture changes, etc.; or the adaptation response itself was water-focused e.g. irrigation, soil moisture conservation; rainwater harvesting; wetlands conservation etc. However, only 18% (359 out of 1819 studies) of these studies measured the effectiveness of adaptation in reducing climate and associated impacts, and out of those 88.9% (319 out of 359 studies) also found the adaptation response to be effective in reducing climate and associated impacts. (Figures 3 and 4). Of the 319 studies which found any of the above-mentioned water adaptation responses to be effective, 84% of responses/interventions, were found to be effective because those had positive economic/financial outcomes; 48% had positive water-related outcomes; 41% had positive institutional/political outcomes; while only 36% and 40% respectively had positive environmental/ecological outcomes and positive outcomes for vulnerable groups.

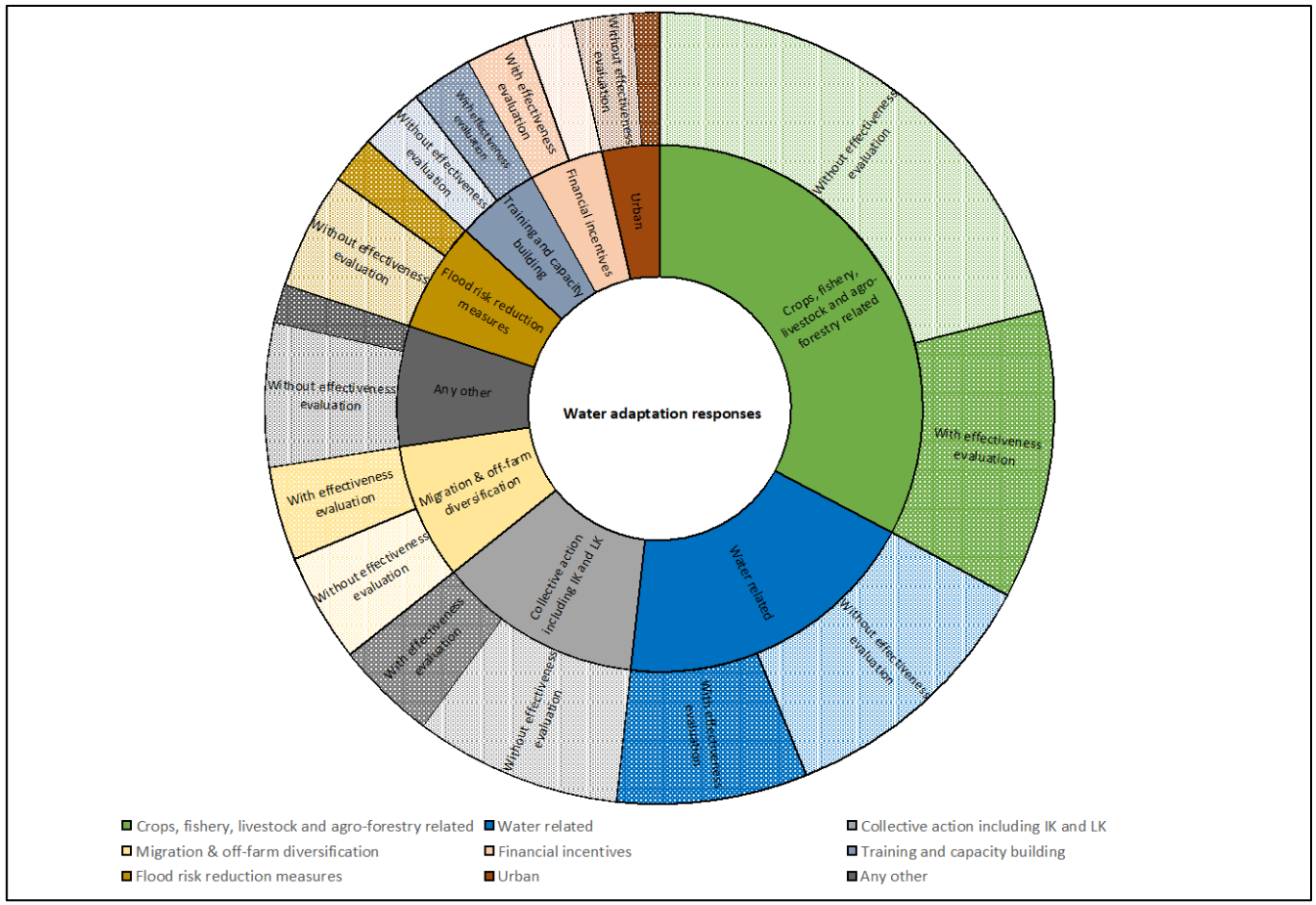

Figure 4. Distribution of different categories of water adaptation responses and proportion of studies that measure the effectiveness of adaptation response. This pie-chart includes all cases of implemented water-related adaptation case studies i.e., category c of Figure 4, irrespective of whether or not they evaluated the effectiveness of that response. Coloured wedges show a category of adaptation. For example, the blue wedge shows all water-related adaptation responses. Lightly shaded wedges outside the bold coloured wedge show the proportion of studies in that particular category that does not measure the effectiveness of the adaptation response; while the dark shaded wedges show the proportion of studies that measure the effectiveness of adaptation response in reducing climate and associated impacts. Adaptation categories are mentioned in the previous section.

Most of the water-related adaptation responses are documented from Asia, followed by Africa (Figure 5), while the majority of the adaptation action happens in the agriculture sector, followed by water-related disasters, urban-peri urban space, and in WaSH sectors (Figure 6).

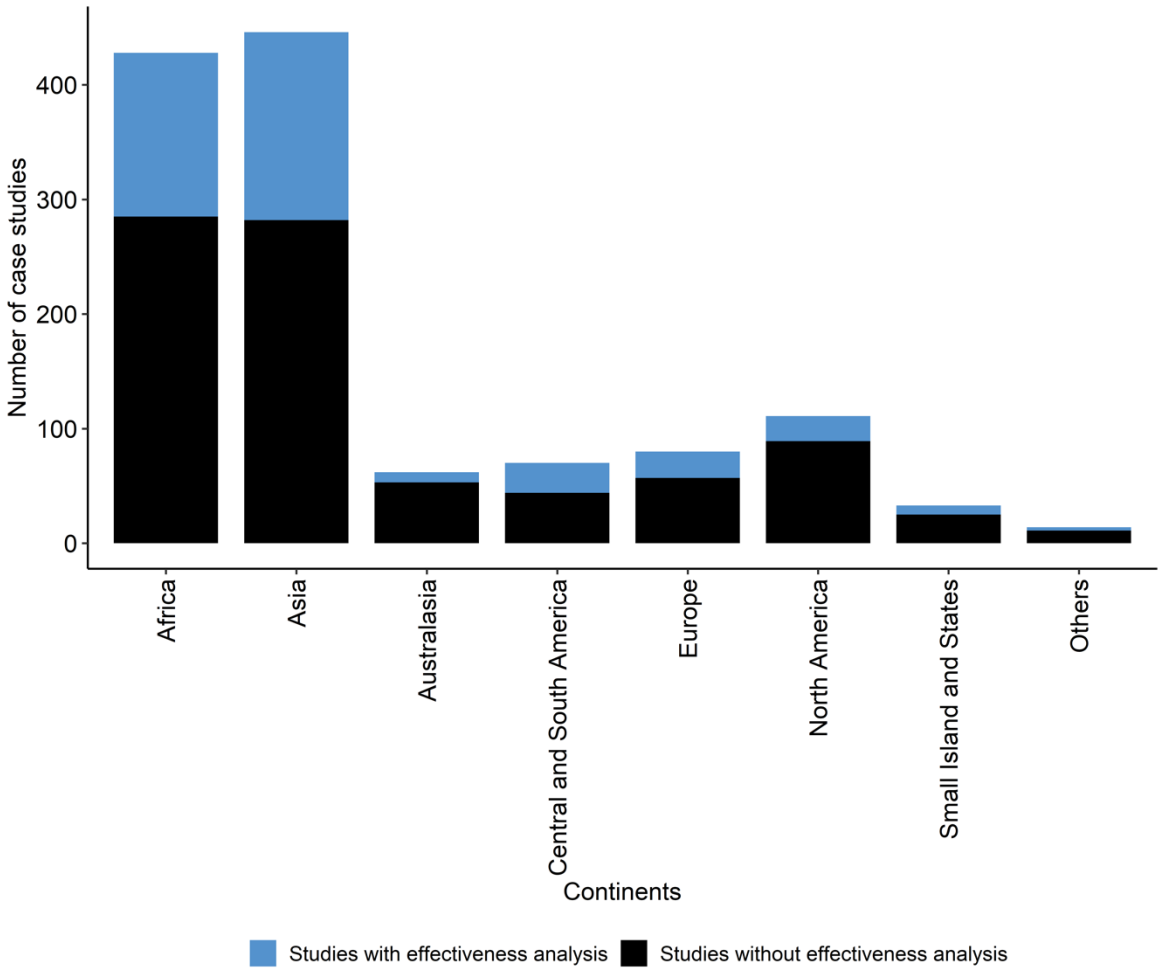

Figure 5. Location of the case studies. The majority of the case studies are from Asia and Africa, and only a small proportion of all studies include effectiveness analysis

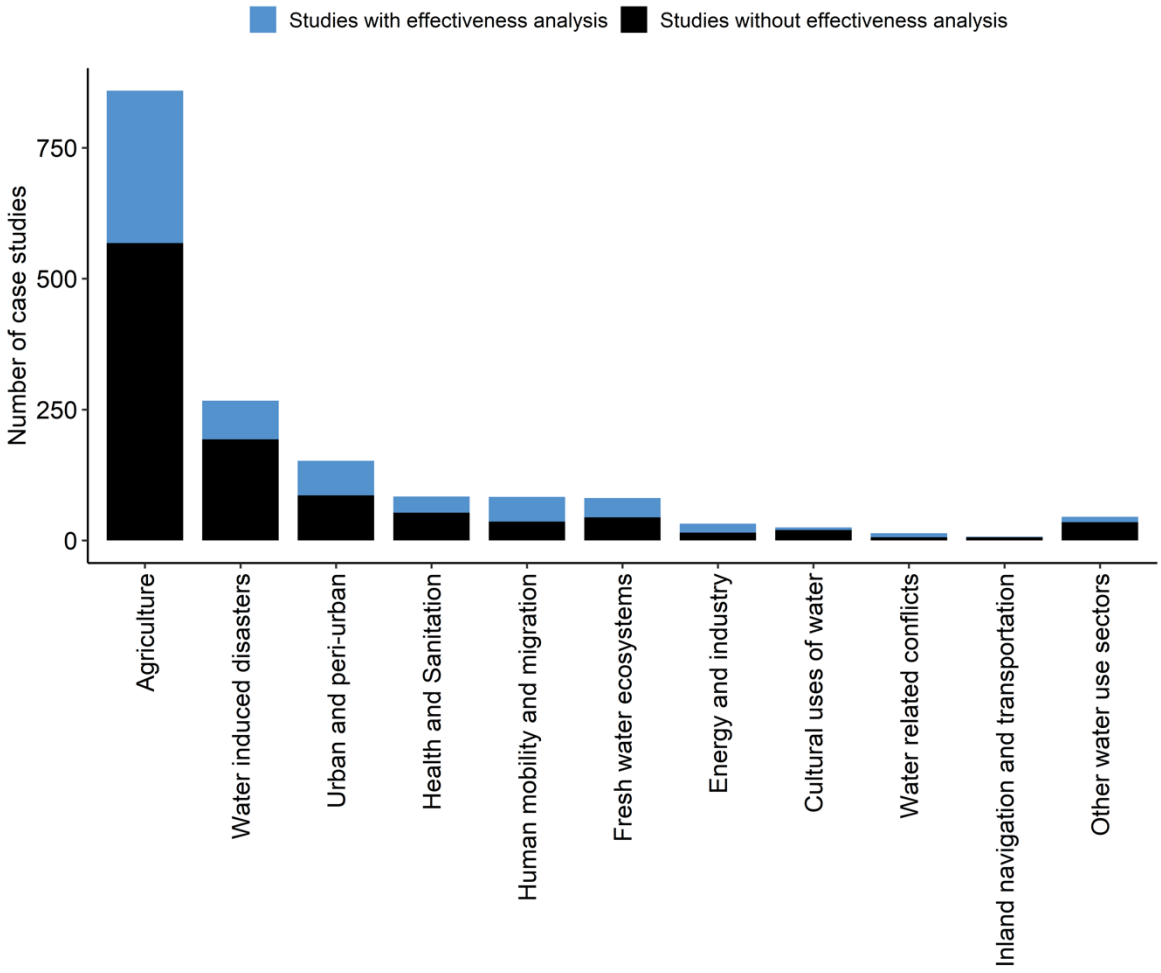

Figure 6. Sectoral distribution of the case studies.

In the following subsections, we will discuss summary results from 4 main sectors, namely, agriculture, water-induced disasters, urban and peri-urban, and water for human migration and mobility.

Table 2 shows a snapshot of studies that document the effectiveness of adaptation responses to various hazards. Effectiveness is measured along with various indicators, such as economic/financial; hydrological; ecological/environmental; institutional/socio-cultural, or any other kinds of impacts not captured by the above five indicators.

Table 2. Some examples of adaptation responses and their outcomes that reduce negative climate and associated impacts.

Hazard	**Adaptation responses**	**Outcome type**	**Adaptation outcome**	**Reference**
Droughts, floods, and general climate impacts in Nepal	Improved crop cultivars, agronomic practices, irrigation, soil water conservation measures	Economic and financial outcomes	Farming households that adapted, produced about 33% more rice than households that did not adapt, after controlling for all heterogeneity.	Khanal et al. (2018)
Increased rainfall variability in India	Farmer's training on agronomic measures, e.g. alternate drying and wetting AWD, modified system of rice intensification MSRI, and direct-seeded rice DSR		The capacity building and water-saving increased crop yields by 960kg/ha; 930 kg/ha and 770 kg/kg through the adoption of AWD, MSRI, and DSR respectively. The three practices have increased farmers' income and decreased the cost of cultivation by up to US$169/ha.	Kakumanu et al. (2019)
Droughts in North China Plains	Irrigation		Adding one extra irrigation could increase wheat yield by up to 12.8% in a severe drought year.	Wang et al. (2019)
Soil degradation; extreme rainfall events high run-off causing erosion in Mali	Soil and water conservation using contour ridges and improved millet and sorghum cultivars		Millet grain yield in 2012-14 was statistically higher in contour ridge terrace plots compared to the control with yield differences ranging from 301kg/ha in 2012 to 622 kg/ha in 2013. Improved varieties produced on average 55% more yield than the local ones.	Traore et al. (2017)
Drought, floods, hailstorm, and erratic rainfall, Ethiopia	On farm agricultural water management		The net revenue from adopting a combination of agricultural water management and modern seeds or inorganic fertilizer is significantly higher by 7600 and 1500 Birr/ha respectively than adopting modern seeds or inorganic fertilizer alone.	Teklewold et al. (2017)
Droughts and general climate impacts, South Africa	Crop insurance and irrigation		Farmers who insured their farm business, and had access to irrigation, had relatively higher net revenue than those who did not after controlling for other factors.	Elum et al. (2018)

Hazard	Adaptation responses	Outcome type	Adaptation outcome	Reference
Droughts and floods in Kenya	Migration		Remittance income enables uptake of costlier adaptation measures such as a change in livestock species, which also have higher returns for households.	Ng'ang'a et al. (2016)
Droughts in Nigeria	Drought-tolerant varieties		Per capita food expenditure of those who adopted drought-tolerant maize was significantly lower than those who did not.	Wossen et al. (2017)
Water quality deterioration due to floods in Bangladesh	Water, sanitation and health WaSH program	Impacts on vulnerable groups	Children: Prevalence of childhood diarrhea reduced by 35% in midline prevalence 8.9% and by 73% in end line prevalence 3.6% compared to baseline prevalence 13.7%.	Dey et al. (2019)
Droughts in Zimbabwe	Adoption of drought-tolerant maize varieties by small holder farmers		Smallholder farmers: Smallholder farmers practicing conservation agriculture CA were found to be as likely to adopt drought tolerant maize varieties as other farmers and benefit from increased yields and incomes.	Makate et al. (2017)
Historically widespread and severe droughts in Ethiopia in 1999, 2002, 2003, 2005, and 2008.	Government safety net program called Productive Safety Net Program PSNP		Poor households: PSNP transfers reduces chronic poverty level from 15.7% to 10.6% and increases the share of never poor from 11.5% to 15.8%.	(Gao & Mills, 2018)
Soil degradation and rainfall variability in Tanzania	Conservation agriculture	Water-related impacts	Relative to conventional farming, rainwater use efficiency was higher by 36 to 47 % in plots that followed conservation agricultural practices.	Kimaro et al. (2016)
Droughts in Kenya	Water harvesting structures, e.g. sand dams		Sand dams increase groundwater storage in riverbanks by up to 40% which is maintained throughout the year	Ryan & Elsner (2016)
Millennium drought in Australia	Water trading		Irrigation application rates fell in the dairy industry from 4.2 million liters/ha in 2000–2001 to 3.5 million liters/ha in 2005–2006	Kirby et al. (2014)

Hazard	Adaptation responses	Outcome type	Adaptation outcome	Reference
General climate impacts in Italy	Precision agriculture and low-cost soil moisture monitoring		Water productivity yield per unit of water was more than double in plots with water-saving techniques, as compared to control plots	Masseroni et al. (2015)
Rainfall variability and extreme rainfall events in Mexico	Improved agronomic practices, including zero tillage	Ecological and environmental outcomes	Zero tillage leads to a significant decline in energy use for farming, hence has high mitigation co-benefits	Torres et al. (2019)
General climate impacts, including rainfall variability in Brazil	Agro-forestry systems as land use in rural municipalities		Plants planted as a part of agro-forestry program provides thermal comfort to both animals and humans	Schembergue et al. (2017)
Drought in 2015 in Ethiopia	Contour ridge terraces as soil water conservation measure		Contour ridge terraces primarily controlled water runoff and soil erosion and acted as a buffer during the 2015 Ethiopian drought	Kosmowski (2018)
Drought and rainfall variability in Pakistan	Climate-smart agricultural practices	Institutional and sociocultural outcomes	Farmers who adopted climate-smart practices also tended to form better relationships with local extension agents and reached out to them more frequently.	Imran et al. (2019)
Droughts, Mexico	Strengthening of local water users' associations through external assistance programs		Local water user associations were able to reduce water abstractions during years of severe droughts.	Villamayor-Tomas & García-López (2017)
Rainfall variability in Niger	Community-based adaptation and through adaptation learning programs		Stronger social networks where women were able to take decisions	Vardakoulias & Nicholles (2015)

Source: An expanded version of this table appears in Chapter 4, IPPC AR6, WGII Report (Second Order Draft) and is currently open for expert review.

Summary results for agriculture-related adaptation responses

Over 81% (291 papers out of 359 papers) document agriculture-related responses, and hence, most of the responses in Table 1 were found to be relevant for the agriculture sector. Figure 7 shows the incidence of various adaptation responses in agriculture and their relative importance. This follows the overall results presented in the previous section.

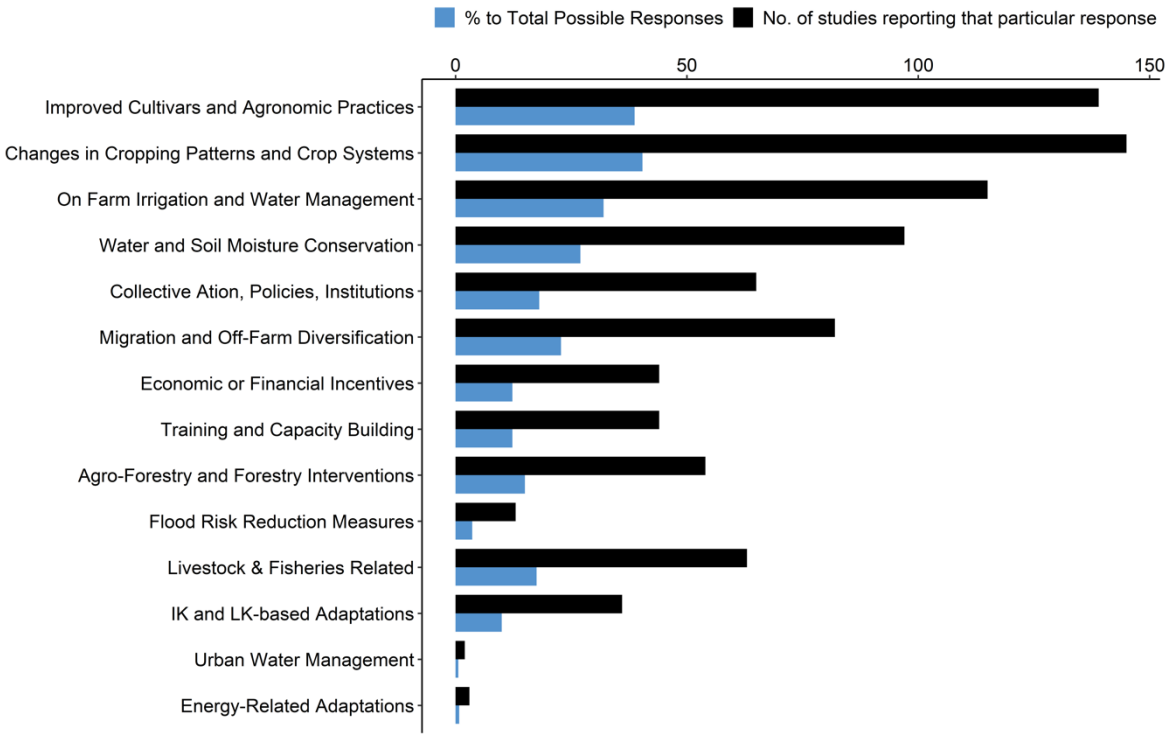

Figure 7. Adaptation responses in the agriculture sector

Droughts, changes in precipitation, and general climate impacts were the top three hazards faced by farmers and the majority of the adaptation responses mentioned above were in response to these waters related hazards (Table 3).

Table 3. Hazards to which farmers are responding

S.No.	Hazards	Number of responses
1	Drought	245
2	Precipitation change	194
3	General climate impacts	173
4	Extreme heat	102
5	Inland and riverine floods	86

6	Soil erosion and sediment load change	46
7	Coastal hazards	44
8	Groundwater availability change	34
9	Storms	27
10	Pests	20

Geographically, most of the documented adaptation responses are from Africa and Asia as shown in the Figure 8. The top five countries from which these responses are documented are India (32), Bangladesh (25), China (24), Ethiopia (20), Kenya (18), and Nepal (15).

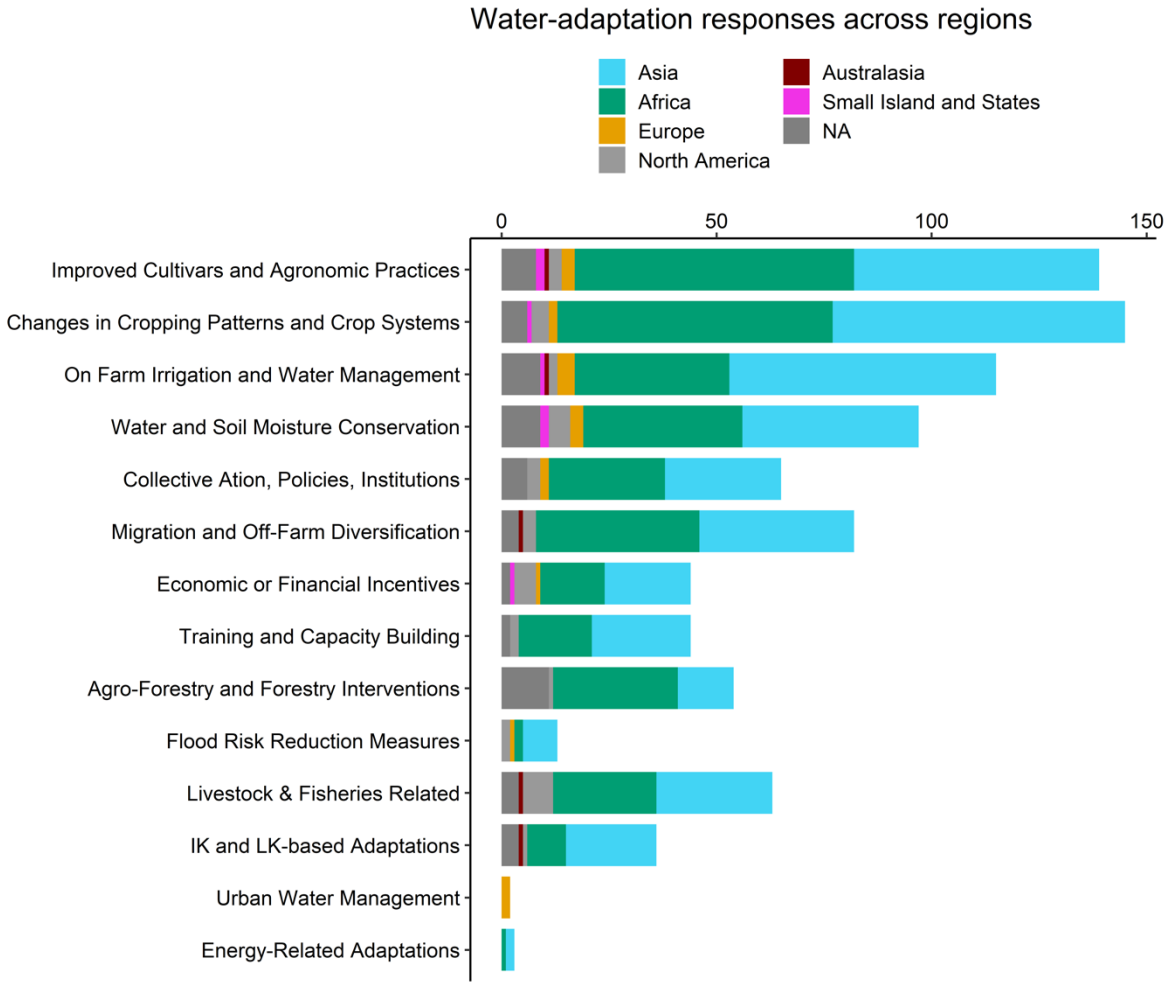

Figure 8. Geographical distribution of agricultural-related adaptation responses

Most adaptation responses are forged and implemented at the local level. Of the 291 documented case studies that are related to agricultural adaptation responses, 236 case

studies mentioned local responses, which were implemented by farmers, households, and local governments, while 82 of these case studies documented responses that were national in scale. Local knowledge and indigenous knowledge (IK and LK) played an important role in shaping these adaptation responses. Of the 291 case studies, approximately half (141) mentioned that adaptation response was based on local knowledge, and another 31 case studies documented the use of Indigenous knowledge in crafting adaptation response. The majority of the adaptation responses are being undertaken by households and individuals, and this is followed by government action at all levels, while the role of the private sector is still quite negligible, despite the vast amounts of literature that discusses the need for private sector investments in forging adaptation action (Table 4).

Table 4: Who is adapting to, or initiating adaptation responses in the agriculture sector?

S.No.	Who is adapting/initiating adaptation?	Number of Responses
1	Individual and households	236
2	Government (national)	82
3	Civil society (sub-national/local)	67
4	Civil society (international/multinational/national)	41
5	Government (local)	41
6	International or multinational governance institutions	32
7	Government (sub-national)	23
8	Others	18
9	Private sector (SME)	12
10	Private sector (corporations)	8
11	Not assessed/Not available/Not known	1

Not all adaptation responses in the agriculture sector have an explicit focus on vulnerable people, but when they do, majority of these responses actually target small and marginal farmers, followed by low-income/poor households, and women (Table 5).

Table 5. Which vulnerable group was targeted by the adaptation response?

Sr. No.	Category of people targeted by adaptation response	Number of responses
1	Small and marginal farmers	124
2	Low-income/Poor	51
3	Women	44
4	Indigenous people	22
5	Farmers without land rights	14
6	Others	14
7	Landless labourers	9
8	Youth and children	9
9	Ethnic/religious minorities	8
10	Migrants	7
11	Elderly	3
12	People with disability	2

The majority of the adaptation responses are undertaken to reduce risks related to livelihoods and economic risks, but rarely the focus is on unidimensional risk. Instead, most adaptation initiatives are geared towards reducing multiple risks as shown in the Table 6.

Table 6: What kinds of risks did the adaptation response address?

S.No.	What are the risks?	Number of responses
1	Risk to livelihoods	233
2	Multiple risks	229
3	Economic risks	225
4	Risks to health and well-being	73
5	Social risks	24
6	Risks to services (including ecosystems services)	24

S.No.	What are the risks?	Number of responses
7	Risks to ecosystems and species	21
8	Cultural risks	17
9	Risks to assets, infrastructure, investments	13
10	Risk to lives	11
11	Risk not clearly stated	9

Finally, we were interested in understanding if these adaptation responses were effective in reducing climate and associated risks (also see Table 6). We see that a majority of risk reduction was related to improvements in crop yields, and incomes, followed by positive water impacts, such as efficient water use. However, downstream impacts of local (plot)-level water interventions have rarely been documented (Table 7).

Table 7. The aspects of effectiveness measured and their frequency of incidence

Sr. No.	Indicators of effectiveness	Number of cases that measure an aspect of effectiveness	Number of cases where risk has been reduced
1	Economic- Financial outcomes	226	226
2	Water-related outcomesWater-related	126	126
3	Impacts on vulnerable groups	107	107
4	Ecological-environmental outcomes	98	98
5	Institutional/sociocultural outcomes	93	93
6	Any other outcomes	58	56
7	Downstream/watershed level impact	28	27

Summary results for adaptation responses to water-related disasters

After agriculture, the next most frequent water sub-sector where adaptation responses are documented are related to water disasters. Inland riverine floods and droughts are the two most important disasters identified in the studies against which adaptation responses are forged. The majority of drought-related adaptations are in the agriculture sector, while adaptations for floods are also in non-agricultural contexts, such as urban flooding. Flood

risk reduction measures, including both structural and non-structural measures, are two of the most important adaptation responses, followed by collective actions, policies, and institutions, such as laws and policies for flood protection. Water and soil conservation measures are also documented in the context of droughts, while training and capacity building (mostly flood preparedness measures) are relatively well documented too. Table 8 lists the top 8 adaptation responses, and their effectiveness in reducing water disaster-related risks, while Table 9 lists the major adaptation categories with some examples of actual adaptation responses.

Table 8. Top eight adaptation responses used to address water-related disasters

Sr. No.	Name of the adaptation category	Number of responses	Reduces risk (or is effective in reducing risk)	% to total
1	Flood Risk Reduction Measures	40	31	77.5
2	Collective Ation, Policies, Institutions	29	25	86.2
3	Migration and Off-Farm Diversification	16	13	81.2
4	Changes in Cropping Patterns and Crop Systems	15	14	93.3
5	Water and Soil Moisture Conservation	15	15	100
6	Training and Capacity Building	15	14	93.3
7	Agro-Forestry and Forestry Interventions	14	14	100
8	Economic or Financial Incentives	12	12	100

Table 9: Categories of adaptation responses that address water-related disasters

Sr. No.	Adaptation category	Examples	# Responses
1.	Adaptation category: Behavioral/cultural	Remittances, financial support, constructing traditional structures, alternate livelihoods	38
2.	Adaptation category: Ecosystem-based	Water and soil moisture conservation, crop rotation, agroforestry and forestry interventions, traditional combined fishing and paddy farming methods, SUDS (Sustainable Urban Drainage Systems), mangrove restoration, Room for the River	25
3.	Adaptation category: Institutional	National Disaster Risk Reduction Policies and Plans, institutional guidelines, public awareness programs, sharing knowledge and resources, self-organization of communities	37
4.	Adaptation category: Technological/infrastructure	Flood barriers, and flood-proof housing, Urban infrastructure, and planning, waterproofing, barriers and other infrastructural solutions, farming technology for productivity improvement, land use planning, fisheries technology	47

The majority of the documented cases are also from Asia, closely followed by Africa (Figure 8).

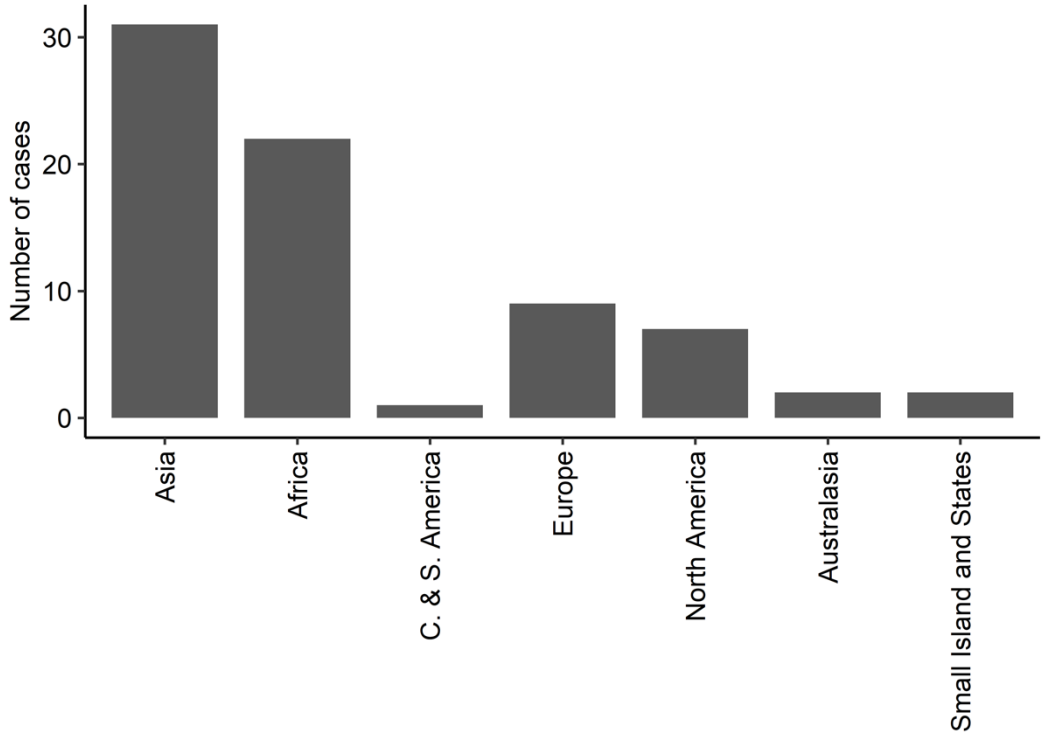

Figure 8. Number of case studies from different continents

Again, just like in the agriculture sector, the majority of the responses have been initiated by households and individuals, but very closely followed by government actions and initiatives, while private sector action does not seem to be very prominent (Table 10).

Table 10. Who is adapting or initiating to water-related disasters?

Sr. No.	Who is adapting/initiating adaptation?	# of responses
1.	Individual and households	42
2.	Government (national)	33
3.	Civil society (sub-national/local)	31
4.	Government (local)	22
5.	Civil society (international/multinational/national)	17
6.	Government (sub-national)	16
7.	International or multinational governance institutions	11

Sr. No.	Who is adapting/initiating adaptation?	# of responses
8.	Others	6
9.	Private sector (SME)	4
10.	Private sector (corporations)	2
11.	Not assessed/Not available/Not known	0

The majority of these adaptations have reduced vulnerability and exposure, rather than the possibility of hazard per se, as hazard reduction is contingent upon successful mitigation.

Enabling conditions for effective adaptation

We coded three important enabling conditions, namely, participative governance, polycentric multilevel nested governance, and strong political will. Of the 319 case studies which were deemed to be "effective" in reducing climate and related risks, 116 of those reported instances of community participation and some mechanisms of participative governance, and another 65 reported polycentric and multi-level governance structures.

Table 11. Cross-tabulation of cases which were deemed to be effective and ineffective in reducing risks, with enabling conditions

Number of case studies which report (number of cases/% to total):	**Participative governance (number of cases/% to total)**	**Polycentric governance (number of cases/% to total)**	**Strong political will (number of cases/% to total)**
Effective in reducing risk (319/88.9%)	116 (36.4% of cases which were deemed to be effective)	65 (20.4% of cases which were deemed to be effective)	104 (32.6% of cases which were deemed to be effective)

Not effective in reducing risk (40/11.1%)	5 (12.5% of the cases which were not deemed to be effective)	5 (12.5% of cases which were not deemed to be effective)	11 (27.5% of cases which were not deemed to be effective)

For example, in Buena Milpa agricultural development project in conflict-affected Guatemala, a commission of natural resource management was established in each of the 68 communities and these were integrated into an overarching organization called Coordinadora de Comisiones de Recursos Naturales (COCOREMA). The members of the COCOREMA were responsible for developing an annual plan for the management of the natural reserve and presented it to the municipal authorities as well as the rest of the 68 commissions for their approval. COCOREMA played a crucial role in the mediation and communication between local traditional authorities and municipal authorities and provided an excellent example of both participative and multi-layered government (Hellin et al., 2018). Strong political will for the formulation of adaptation response and its implementation is also noted in 104 out of the 319 case studies which were deemed to be "effective". Further in-depth analysis is needed for unpacking these enabling conditions.

Maladaptation and limits to adaptation

An adaptation response can be effective in reducing climate and associated risks in the immediate short term but could also be maladaptive in the long term. Of the 319 case studies where adaptation response was found to be effective, 115 (36%) of those also mentioned the possibility that those responses can be maladaptive. Examples include increased use of fertilizer (Khanal et al., 2018) and herbicides (Kakumanu et al., 2019)to increase crop production in Nepal and India; and use of improved millets to increase production in Sahel, while knowing that shift to more water-intensive variety of millet under a changing condition may be detrimental to their livelihoods in years of rainfall failure (Lalou et al., 2019).

Of the 359 case studies that documented the effectiveness of adaptation response, as many as 262 (73%) studies also pointed out the limits to adaptation. The majority (199 out of 262) of these studies mentioned "soft" limits to adaptation, which includes limits or barriers such as poor governance, lack of capacity, knowledge, and information, and economic and financial constraints to adapt, while only 22 studies mentioned "hard" limits

to adaptation and included issues like borewells turning dry due to groundwater over-exploitation, or melting or surging of glaciers that destabilizes irrigation systems in the mountains. Further, the majority of the studies (151 out of 262) found poor governance to be the main barrier to adaptation, followed by a lack of information and awareness.

Other aspects of adaptations

Of the 359 case studies that documented the effectiveness of adaptation response, one-fifth (21.7%) also documented co-benefits in terms of carbon storage and sequestration.

the Additionally, about 50 (14%) out of the 359 studies documented evidence of gender equity and social justice.

Observations on quality of studies

As mentioned earlier, we classified the studies into 3 categories, high, medium, and low (see the section on methodology for definitions). Only 64out of 359 fully coded studies were deemed to be “high” quality, whereas 146 were of medium quality and 149 were deemed ‘low’ quality. This shows that high-quality studies are relatively less in number and more work needs to be done to causally link the adoption of an adaptation response to its effectiveness.

Impacts

7.1 Scientific impacts – now and in 5 years

To the best of our knowledge, this is the first comprehensive compilation of all water-related adaptation cases studies globally. We hope to publish a series of 5-10 papers in the coming year and take full advantage of the database. The papers so published, and the open-access database (after 1 year) will remain an important source of knowledge on adaptation responses and it's effectiveness. Results from this study have been used in Chapter 4 of the IPCC, and IPCC chapters often set the scientific agenda for climate-related studies.

7.2 Capacity impacts – now and in 5 years

Not applicable. This project was not about capacity building, though results, particularly those showing that training and capacity building are effective adaptation measures, may lead to more investments in capacity building in the developing countries. A total of 28 young coders contributed to the coding exercise, and roughly 50% of them are from the global South.

7.3 Community impacts – now and in 5 years

Not applicable. This is a desk review project and does not intend to have community-level impacts. Most of the impacts are expected to be in the scientific domain.

7.3.1 Economic impacts

NA

7.3.2 Social impacts

NA

7.3.3 Environmental impacts

NA

7.4 Communication and dissemination activities

Given the short duration of the project (only 6 months), separate communication and dissemination activities were not planned.

8 Conclusions and recommendations

This study managed to create a huge database where 1819 studies were coded. Of these, 359 studies were coded fully across 100 plus variables as these had documented the effectiveness of adaptation responses in reducing risks. The excluded studies, which did not measure effectiveness, were also coded across 10 variables. Given the short duration of the study (6 months) and that it took almost the entire time to code the papers, and do quality controls, the analysis in this report is mostly limited to summary statistics.

8.1 Conclusions

These are some of our high-level conclusions:

First, the majority (~81%) of climate adaptation responses are about water, that is, either the hazard is water-related, or the response is water-related or both. Water, therefore, is central to adaptation.

Second, while there are thousands of documented cases of adaptation, only around a quarter of them actually measure the effectiveness of adaptation in reducing risk, and only a very small percentage of those studies (~18%) measure effectiveness using appropriate methodologies that can link adaptation response with effectiveness in a rigorous and defensible way. This is a cause of concern because we do not know if the investments in water-related adaptations are bearing fruit.

Third, a majority of the water-related adaptation responses are about incremental adaptations, i.e., adaptations that aim to improve existing ways of doing things (e.g. better crop varieties replacing older varieties), without tackling the root causes of vulnerability. Transformative adaptations are few and far between, and migration, capacity building, and training seem to be the only two adaptation responses that have transformative possibilities.

Fourth, the majority of the water-related adaptation responses are in the agricultural sector, followed by adaptation in water-induced disasters sector. This makes sense because agriculture is the main consumptive water user, and water-induced disasters are one of the most important causes of loss of lives, livelihoods, and property worldwide.

An “effective” adaptation can also be maladaptive in the long run and there are several barriers or limits to adaptation. Most of these barriers or limits are “soft” limits and possibly can be overcome with investments in capacity building and better governance.

Hard limits to adaptation have not yet been reached in most locations, except perhaps in some of the small island states and in the remote mountains where the melting of the cryosphere has meant that every source of water has been compromised.

8.2 Recommendations

The main recommendation from our short 6-month study is that, while larger patterns of adaptation and centrality of water in adaptation are quite clear, more time and effort are needed to get an in-depth understanding of several unanswered questions. For example, the authors have not yet been able to delve fully into the coded papers and answer some of the more interesting questions, such as: Which among the adaptation responses seem to be most effective in reducing risks?; Are adaptation responses more likely to be successful when several adaptation responses are adapted simultaneously or in isolation?; What are the enabling conditions that differentiate a successful adaptation response from a not-so-successful adaptation response?, etc. These questions need further analysis of the database.

Findings from this study can also inform future adaptation projects. Given how few of these adaptation projects are actually assessed in terms of their effectiveness, and how often the outcomes are also maladaptive, requires rethinking the way adaptation investments are done and monitored.

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9.2 List of publications produced by project

10 Appendixes

10.1 Appendix 1:

Annex 1: List of 359 case studies that measure effectiveness of current water-related adaptation responses

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10.2 Appendix 2:

1. The manual for coders in excel document (attached separately)