



The role of indigenous knowledge and local knowledge in water sector adaptation to climate change in Africa: a structured assessment

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Received: 4 August 2021 / Accepted: 6 February 2022 / Published online: 1 April 2022
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Abstract

Evidence is increasing of human responses to the impacts of climate change in Africa. However, understanding of the effectiveness of these responses for adaptation to climate change across the diversity of African contexts is still limited. Despite high reliance on indigenous knowledge (IK) and local knowledge (LK) for climate adaptation by African communities, potential of IK and LK to contribute to adaptation through reducing climate risk or supporting transformative adaptation responses is yet to be established. Here, we assess the influence of IK and LK for the implementation of water sector adaptation responses in Africa to better understand the relationship between responses to climate change and indigenous and local knowledge systems. Eighteen (18) water adaptation response types were identified from the academic literature through the Global Adaptation Mapping Initiative (GAMI) and intended nationally determined contributions (iNDCs) for selected African countries. Southern, West, and East Africa show relatively high evidence of the influence of IK and LK on the implementation of water adaptation responses, while North and Central Africa show lower evidence. At country level, Zimbabwe displays the highest evidence (77.8%) followed by Ghana (53.6%), Kenya (46.2%), and South Africa (31.3%). Irrigation, rainwater harvesting, water conservation, and ecosystem-based measures, mainly agroforestry, were the most implemented measures across Africa. These were mainly household and individual measures influenced by local and indigenous knowledge. Adaptation responses with IK and LK influence recorded higher evidence of risk reduction compared to responses without IK and LK. Analysis of iNDCs shows the most implemented water adaptation actions in academic literature are consistent with water sector adaptation targets set by most African governments. Yet only 10.4% of the African governments included IK and LK in adaptation planning in the iNDCs. This study recommends a coordinated approach to adaptation that integrates multiple knowledge sources, including IK and LK, to ensure sustainability of both current and potential water adaptation measures in Africa.

Keywords IPCC · Africa · Climate risk · Water adaptation responses · Indigenous knowledge and local knowledge

Handled by Leslie Mabon, The Open University, United Kingdom.

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Introduction

Climate hazards are projected to intensify in the twenty-first century with severe risks projected for both humans and ecosystems (IPCC 2018b; Global Risk Report 2021). African countries have contributed relatively little to the greenhouse gas emissions causing climate change, but face many of the most severe risks in key sectors, including water, food systems, economies, health, and biodiversity (Niang et al. 2014). Anthropogenic climate change has already increased the likelihood of extreme climate change and variability in Africa, such as the 2015–2017 Cape Town drought (Otto et al. 2018; Pascale et al. 2020). Climate change adaptation

is thus essential in order to manage current impacts and reduce future risks.

Understanding which adaptation actions are being implemented, how, and the effectiveness of specific responses for reducing risk is crucial for adaptation planning (Owen 2020; Berrang-Ford et al. 2021b; Williams et al. 2021). The Intergovernmental Panel on Climate Change (IPCC) defines climate adaptation in human systems as “the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities” (IPCC 2018a, p 542). Since the publication of the IPCC 5th Assessment Report (AR5) in 2014, there has been a substantial increase in peer-reviewed publications documenting evidence of the impacts of climate change and climate change adaptation responses, with the greatest increase evident in the literature on Africa (Berrang-Ford et al. 2021b; Callaghan et al. 2021; Sietsma et al. 2021). This growing literature record has improved information on where and how adaptation is taking place, including possible maladaptation threats. It has shown that for Africa most human responses to climate change are taken incrementally by individuals, while planned adaptation is considered to be limited, fragmented, and poorly governed (Berrang-Ford et al. 2021b; Sietsma et al. 2021).

However, little is known in Africa about what effect indigenous knowledge (IK) and local knowledge (LK) are having on climate change adaptation actions. Indigenous knowledge refers to the understanding, skills, and philosophies developed by societies with long histories of interaction with their natural surroundings (IPCC 2018b). Local knowledge refers to the understanding and skills developed by individuals and populations, specific to the place where they live (IPCC 2018b). IK and LK systems in Africa are central to managing resources, particularly during periods of resource scarcity (Leal Filho et al. 2021), and thus important to broader and more effective implementation of climate change adaptation options. For example, despite being climate change literate and having access to radios, it is common for communities across Africa to use IK to make important livelihood decisions, such as deciding on planting dates (Kaganzi et al. 2021). Further, the highly context-specific nature of adaptation has led scholars to highlight the need for inclusion of IK and LK for enhanced efficacy of adaptation projects due to their social acceptability and rich understanding of local environmental parameters (Nyong et al. 2007; Makondo and Thomas 2018; Leal Filho et al. 2021). Consequently, a range of localised case studies have highlighted the importance of IK and LK for coping responses and adaptation scalability (Nkomwa et al. 2014; Kanda et al. 2017; Mwaniki and Stevenson 2017; Opare 2018; Williams et al. 2020). Recent IPCC Special Reports for AR6 highlight the potential role IK and LK can play to reduce climate risks to natural and managed ecosystems (IPCC 2018b, 2019a, b).

This role of indigenous and local people has been recognised by the Green Climate Fund, Global Environment Facility, and International Climate Initiative as key to facilitating adaptation with important stakeholders and framing adaptation and financing of projects in Africa (United Nations Environment Programme 2021). Further, the necessity to consider the role of IK and LK systems in climate adaptation was established in the IPCC-AR5 (IPCC 2014) citing the lack thereof in previous IPCC Assessments (Ford et al. 2016). The IPCC AR6 Special Reports have also highlighted how crucial IK and LK is to climate adaptation especially for regions, like Africa, and the importance of IK and LK in knowledge co-production for effective climate adaptation across sectors and regions (Abram et al. 2019). A synthesis of the inclusion of IK and LK in climate change adaptation across Africa is crucial to policymakers for several reasons, including (1) assessing which adaptation actions include IK and LK and where these are being implemented, (2) assessing the effectiveness of adaptation options that include IK and LK for reducing risk, (3) assessing the adaptation gap in Africa, and (4) prioritising the distribution of limited financial resources to adaptation options and guiding decisions on adaptation funding from multilateral funders.

Here, we begin to fill these knowledge gaps by reviewing evidence of the use of IK and LK in the implementation of water adaptation responses across Africa and provide the first regional assessment on the role of IK and LK in adaptation responses related to water in Africa. Water is a key resource linking multiple different sectors (e.g. food, energy, health) in climate adaptation (United Nations Economic Commission for Europe 2009; UN Water 2013; Global Water Partnership 2018). We identify several IK and LK-informed adaptation measures and unpack how IK and LK possessed by communities is used in the implementation of water adaptation responses across Africa. Mapping where this adaptation is taking place is vital for planning and feasibility assessment of the water adaptation measures, including the different types of knowledge being used for decision making during adaptation. We therefore relate these observations of local and incremental responses to climate change to planned adaptation at the National level through analysis of intended nationally determined contributions (iNDCs) and discuss the role that IK and LK currently plays in key policy tools used to shape climate adaptation.

Methods

We conducted a structured assessment (Kofod-Petersen 2012) of the academic literature published between 2013 and 2019, aligned with the timeframe of the IPCC 6th Assessment. The data used was obtained from the Global Adaptation Mapping Initiative (GAMI), a global dataset with 1682

coded articles on human adaptation to climate change. GAMI articles were retrieved from three online libraries: Web of Sciences, Medline, and Scopus. Over 48,000 articles were screened through supervised machine learning tools aided by physical human screening. A total of 2032 articles were retrieved from the screening stage and deemed potentially eligible for data extraction. The final coding resulted in the processing of 1682 articles which had evidence of human climate adaptation responses implemented globally. Further details on how the articles were retrieved, the screening process (machine learning plus human screening), and coding are provided in Berrang-Ford et al. (2021b) with accompanying protocols by Berrang-Ford et al. (2021a), Fischer et al. (2021), and Lesnikowski et al. (2021). The inclusion and exclusion criteria for the articles used in the GAMI are explained in Fischer et al. (2021), particularly, documents that reported responses that constituted adaptation based on a strict definition of the term as behaviours that directly aimed to reduce risk or vulnerability. Articles that were theoretical, or assessments of potential or future adaptation, were excluded to maintain the empirical foundation of observed responses to climate change.

The GAMI dataset has been used to provide global, regional, and sectoral reviews of adaptation feasibility (Williams et al. 2021), policy tools to support climate adaptation (Ulibarri et al. 2021), responses to climate-related water scarcity (Leal Filho et al. 2022), equity in adaptation (Araos et al. 2021), health effects of adaptation (Scheelbeek et al. 2021), constraints and limits to adaptation (Thomas et al. 2021), adaptation to extreme heat (Turek-Hankins et al. 2021), adaptation in conflict affected areas (Sitati et al. 2021), and a systematic global stocktake of evidence of human adaptation to climate change (Berrang-Ford et al. 2021b). Our assessment here focuses on water sector responses within the five hundred and seventy (570) articles on the region of Africa. These articles are drawn from the global GAMI dataset of 1 682 articles with evidence of human adaptation responses to climate change. We assessed the evidence and role of IK and LK on the implementation of the adaptation responses. Articles that were included in the IK and LK assessment were selected based on these criteria: articles that include specific words—“indigenous knowledge”, “local knowledge”, “traditional knowledge”, “traditional ecological knowledge”, and “local or traditional institutions” in the article text linked to adaptation responses implemented or in specific adaptation responses (see Fig. 1). This was based on IPCC framing of the IK and LK systems and practices for climate change adaptation in AR6 (Abram et al. 2019). Although useful for clarity in discussion, the IPCC definitions of IK and LK are not commonly used in the African literature on climate change adaptation. In the latter case, IK and LK is commonly collapsed into terms,

like “traditional knowledge”, “indigenous knowledge systems”, or “local and indigenous knowledge” where the IPCC distinction is lost or considered by a particular study as too strict for the African context where constructions of “local” or “indigenous” can be problematic. The IPCC’s four evidence levels—strong, high, medium, and low—are used throughout the study to describe the evidence levels for both water adaptation responses and IK and LK in the articles across Africa sub-regions (Mastrandrea et al. 2011) (Supplementary Material 2—SM2. Table 7).

Framing water adaptation responses

To extract relevant water adaptation responses from the GAMI dataset, we developed criteria based on a broad definition of water adaptation responses using the United Nations Economic Commission for Europe (2009) framing of water adaptation responses, the IPCC (2018a) framing of adaptation options, and also the face value reporting of adaptation responses in the articles. We included water adaptation responses as responses or actions that were undertaken to reduce the risk that is water related, for example, the risk that emanates from hazard and exposure caused by floods, droughts, groundwater depletion, and soil moisture reduction (e.g. groundwater abstraction or mulching). Then we also included water adaptation responses in terms of actual adaptation interventions that were water related in their implementation, for example, practices, such as irrigation, soil moisture conservation, rainwater harvesting, and wastewater reuse.

Data extraction

Data extraction in GAMI was guided by an adaptation typology designed to characterise who is responding, what responses are being observed, what the extent of the adaptation-related response is, and whether adaptation-related responses are reducing vulnerability and/or risk. A detailed codebook for data extraction is available in the Supplemental Material of Berrang-Ford et al. (2021b). The screening of adaptation responses for this review used the filter selection in excel and content analysis in Nvivo 12 following the criteria for systematic reviews in Vaismoradi et al. (2013). Key word analysis focused on water in the sector analysis and specific water adaptation responses (e.g. irrigation, water harvesting, water conservation, and water management). For assessing the role of IK and LK, we further developed extension codes to the existing GAMI codes (SM3—Table 10) attributing the nature and form of IK and LK based on the systematic mapping approach set by Petzold et al. (2020).

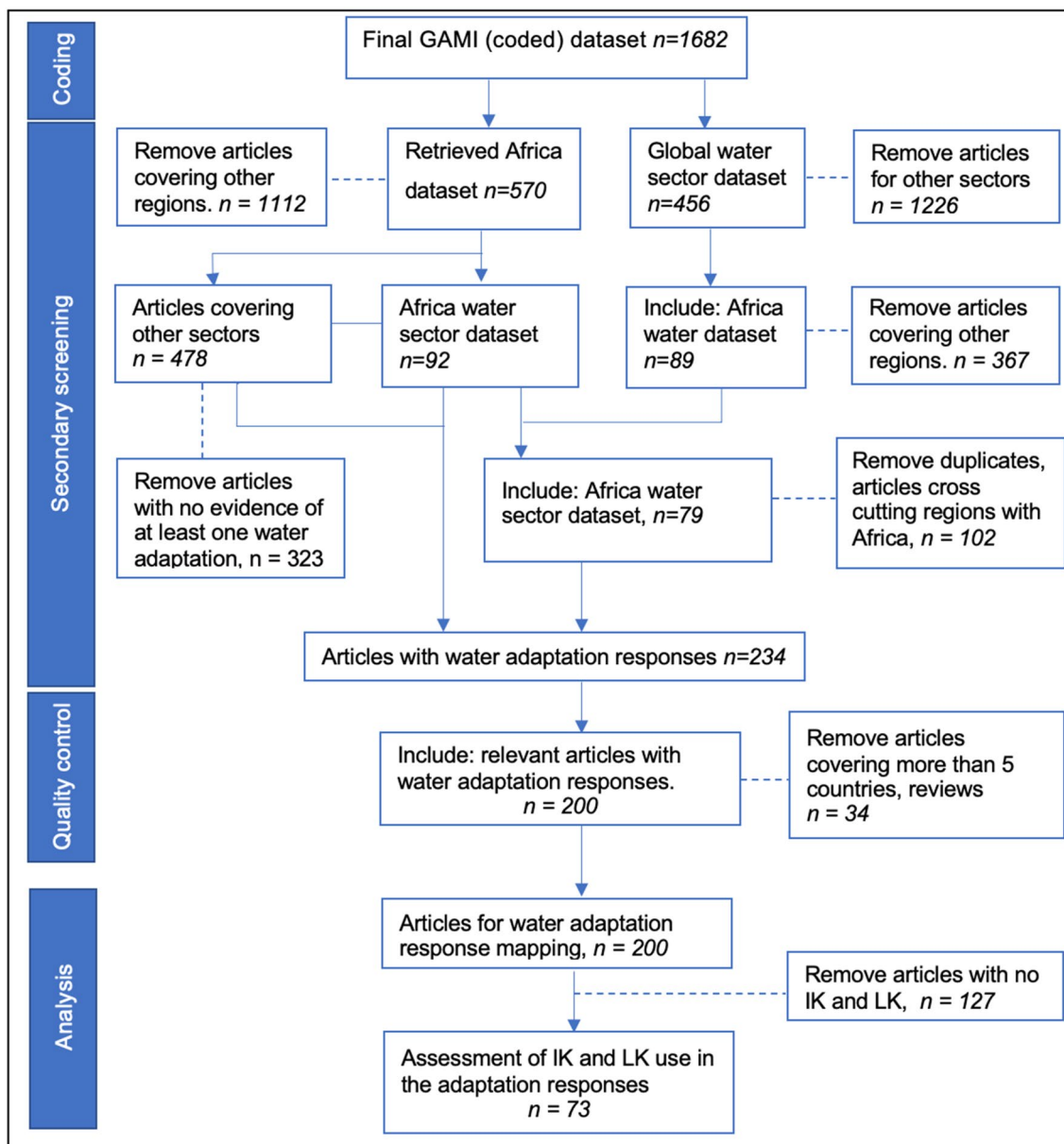


Fig. 1 Flowchart of the procedure used in this study. Developed after Haddaway et al. (2018) ROSES (Reporting standards for Systematic Evidence Syntheses) for conducting environmental systematic

reviews and systematic maps procedure. Key: Means articles removed from the assessment

Analysis of water adaptation responses and role of IK and LK

We performed qualitative assessment through content analysis of adaptation responses text following the procedure in Vaismoradi et al. (2013) in Nvivo 12. Based on the framing of water adaptation responses presented in Sect. 2.1, we developed five categories of water adaptation responses: water adaptation responses in agriculture, domestic and potable water management responses,

ecosystem-based responses, grey infrastructure development responses and policy, and strategy and enabling conditions responses.

The attributes of IK and LK were adapted from Petzold et al. (2020) (see SM3 Table 10 on the definition of attributes of IK and LK in the articles). The interactions of local and indigenous people with other adaptation actors (local government, national government, civil society, multilateral organisations) were assessed to ascertain the level of inclusion and influence of local people in both

planning and implementation of adaptation responses. The assessment further explored instances where climate risk reduction was associated with evidence of indigenous and local knowledge to elicit efficacy of the IK and LK for adaptation.

IK and LK and African governments iNDCs

Finally, to assess the role of African governments on framing the water sector adaptation to climate risks and the inclusion of IK and LK in adaptation planning by governments, thematic content analysis of the first iNDCs pledges submitted by African governments (2015–2019) to UNFCCC was done using the approach sets in Vaismoradi et al. (2013, 2016). Analysis of iNDCs is important as they embody efforts by each country to reduce national emissions and adapt to the impacts of climate change (Biesbroek et al. 2022),¹ Our assessment focused on water sector adaptation targets under the adaptation theme per country and whether IK and LK was integrated in long-term adaptation plans. Fifty-two iNDCs were retrieved, but only 36 were considered (those submitted in English). iNDCs submitted in Spanish and French languages were excluded due to lack of French and Spanish speakers among the author team; also iNDCs submitted by small island Africa states were removed because we followed the AR6 five African regions (see Sect. 2.1).

Limitations

The GAMI dataset used does not consider grey literature, such as government reports, policies, patents including the National Adaptation Plans of Action (NAPA), and country's climate change adaptation strategies as well as relevant multilateral organisation reports—the UN, United Nations Environment Programme (adaptation gap reports), World Bank, Global Environment Facility, or Green Climate Fund. While GAMI provides an unmatched quantity of literature on adaptation, we acknowledge that considering other reports from grey sources could provide further information, particularly concerning adaptation feasibility at future global warming levels. These reports contain important information on country level adaptation and specific measures that will complement the assessment of scientific literature here. Future studies should consider other sources of data such as grey literature to complement assessment of the scientific literature.

¹ <https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs>.

Results

Analysis of 570 articles on climate change adaptation in Africa identified the range of sectors within which human responses to climate change have been recorded in the peer-reviewed literature, including agriculture, domestic use, ecosystem-based responses, grey water infrastructure development, and policy enabling conditions. Our analysis identified 200 articles with evidence of water adaptation responses to climate change in Africa. Of the 200 articles, 73 articles (36.5%) had evidence of the use of IK and LK in the implementation of the responses. Of these 73 articles with IK and LK use, 67.1% indicate evidence of risk reduction associated with the adaptation responses. Key actors and attributes of IK and LK are identified, together with gaps in both. Finally, given the role of IK and LK in water adaptation responses, analysis of the iNDCs highlights the lack of consideration of IK and LK by African governments in national adaptation planning.

The geographical distribution of the evidence of water adaptation responses and IK and LK

The majority of adaptation measures (76.5%) were in response to droughts and precipitation variability (63.5%) (Fig. 2). The articles with water adaptation responses were distributed among 31 African countries (Fig. 2). Southern, East, and West Africa have high evidence for both water adaptation responses and water adaptation measures where IK and LK was used. There is low evidence in Central and North African regions. Ethiopia had the highest evidence of water adaptation responses followed by Ghana and Kenya, respectively. South Africa, Nigeria, Tanzania, Zimbabwe, and Uganda had medium evidence with article range between 9 and 19 articles. There is high evidence of the use of IK and LK in water adaptation in Ghana, Kenya, and Zimbabwe (Fig. 2). Zimbabwe indicates the highest number of articles with IK and LK (77.8%), followed by Ghana (53.6%), Kenya (46.2%), and South Africa with 31.3%. According to response types, many of the adaptation responses were behavioural/cultural and technological/infrastructural (Table 1). Linking the adaptation response types with IK and LK, results show that 92% of the IK and LK influenced adaptation responses were associated with behavioural/cultural responses followed by technological/infrastructural (76%) and then ecosystem-based responses (68%). Technological responses were more linked to how communities use IK and LK to implement local irrigation practices during periods of water stress and in the off-season. Institutional responses were the least with 33.3% of the responses linked to institutionally implemented adaptation.

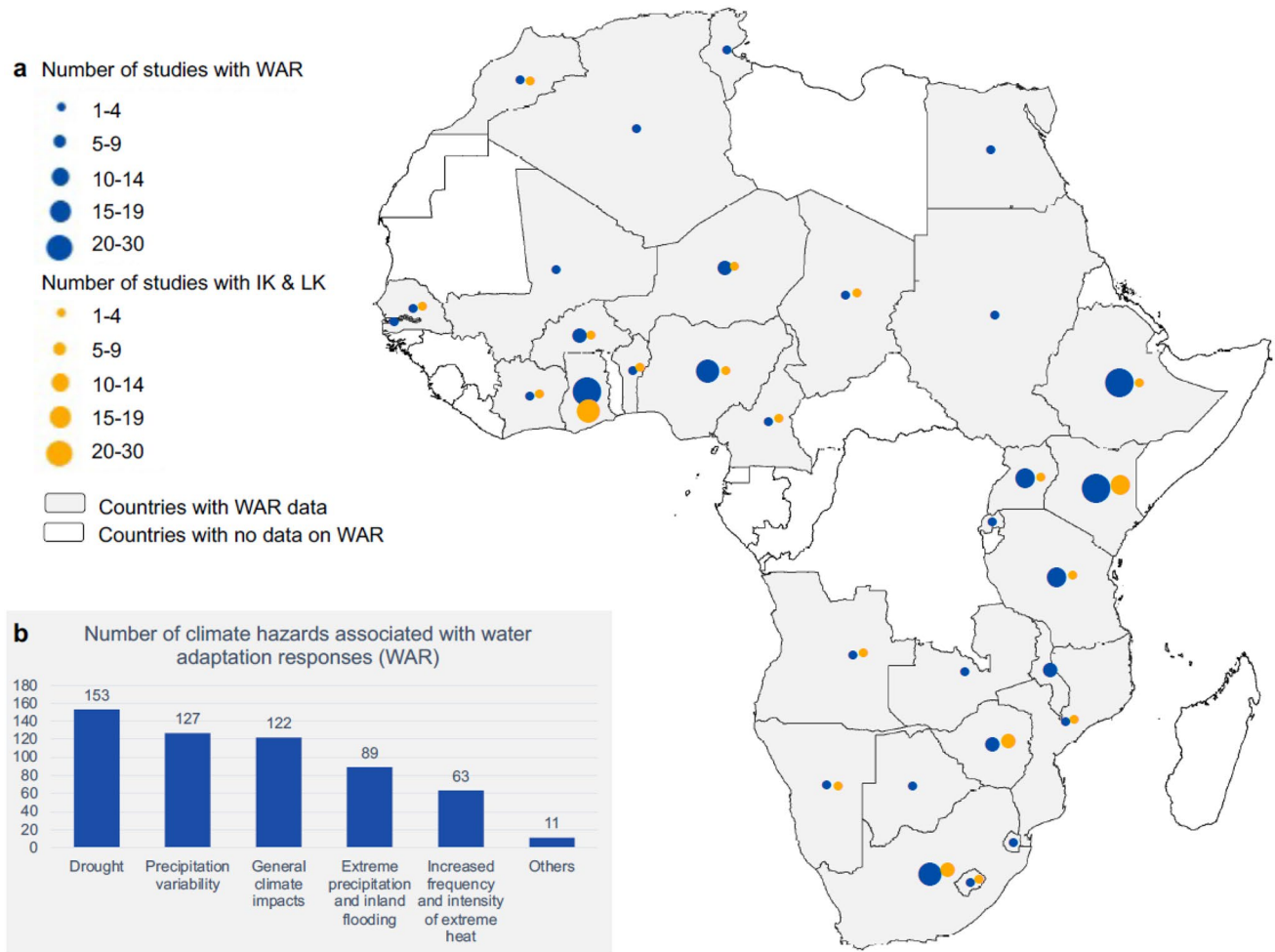


Fig. 2 Evidence of water adaptation measures implemented in Africa and the role of IK and LK. **a** Geographic distribution of evidence of water adaptation responses (WAR) (blue dots) and the water

adaptation responses influenced by IK and LK (orange dots) in Africa between 2013 and 2019. **b** Climate hazards that are responded to in the articles

Table 1 Types of adaptation responses recorded in the literature

Adaptation responses	Count	Proportion	IK and LK associated	Proportion (%)
Behavioural/cultural	169	81%	69	92
Ecosystem-based	141	70.1%	51	68
Institutional	60	29.9%	25	33.3
Technological/infrastructure	160	79.6	57	76

The distribution of water adaptation response types

We identified 18 types of water adaptation responses implemented in Africa across sectors (Table 2). The geographic distribution of these water adaptation responses shows that literature on water sector adaptation in Africa is not evenly distributed across the continent and not evenly distributed across different types of adaptation. The majority of the articles were drawn from literatures covering food, fibre, and other ecosystems (73%) and

poverty, livelihoods, and sustainable development sectors (64.5%) (SM 2 Table 9). Irrigation is the most implemented response recorded in 47% of the articles. This includes the increased use of water saving irrigation methods, such as drip irrigation which is widely implemented across Africa, including in some parts of North Africa. Rainwater harvesting was the second most implemented response (36.3%). Rainwater harvesting was implemented through a diversity of technologies, which include in situ measures, rooftop water collection, valley tanks, pitting,

Table 2 Assessment of the water adaptation responses across sub-regions of Africa and the evidence of IK and LK per adaptation response

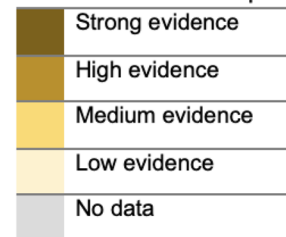
Category	Specific water adaptation responses	Africa regions					IK and LK				
		SA	EA	WA	NA	CA	SA	EA	WA	NA	CA
Water adaptation responses in agriculture	Irrigation including responses to reduce water use through technological interventions e.g., change from surface to drip irrigation.	16	37	33	6	2	9	8	8	1	2
	Rainwater/water harvesting (field in-situ responses – contours, semi-circular bunds, strip catchment, pitting -zai pits etc)	17	26	7	0	0	4	12	5	0	0
	Soil and water conservation (e.g., ditches, terracing, soil -water moisture retention strategies, moisture conservation farming).	9	24	28	3	1	1	10	10	0	1
	Increased groundwater abstraction for irrigation, livestock - wells	4	5	1	2	0	2	2	0	1	0
	Flood water control (flood water harvesting, diverting, drainage)	3	2	2	0	1	1	0	0	0	0
Domestic & potable water management adaptation responses	Rainwater harvesting include increased household bulk water storage	8	11	4	0	0	4	2	0	0	0
	Household level water management and resilience (water saving responses, reduce water usage, improve usage, improve storage during droughts and floods)	7	5	2	2	0	3	2	1	1	0
	Water markets - vending (community level water transfers), recycling, re-use.	1	2	4	1	0	1	1	1	0	0
	Increased groundwater abstraction for domestic purposes – mainly borehole drilling and deepening of wells.	6	1	0	0	0	2	2	0	0	0
	Improve drainage systems for flood water removal	4	2	3	0	0	1	1	1	0	0
	Municipal level water supply rationing	3	1	0	0	0	0	0	0	0	0
	Flood relief responses e.g., construction of raised ground platforms for houses located in flood plains, sandbags, permanent or temporary to less flood vulnerable areas.	6	4	4	0	0	1	1	1	0	0
Ecosystem based responses	Agroforestry to improve infiltration for groundwater recharge	6	11	20	1	2	1	6	7	0	2
	Protection of watersheds, catchment management, wetland restoration, mulching to increase, infiltration, soil moisture and groundwater recharge	7	8	4	0	0	3	5	4	0	0
Grey infrastructure development	Increase reservoir storage through dam construction of small, medium & large-scale (for water supply – agriculture & potable) and flood control dams, weir construction.	10	9	2	0	1	0	2	1	0	1
Policy, strategy and enabling conditions responses	Introduction of a policy, improving enabling environment for water management under climate stressed shortages, flood management plans, strategies, and other governance mechanisms.	2	1	1	2	0	0	0	0	0	0
	Implementation of IWRM plans	1	0	0	0	0	0	0	0	0	0
	Effective water tariffing.	1	0	0	0	0	0	0	0	0	0

*SA = southern Africa, EA = east Africa, CA = central Africa, WA = west Africa, NA = north Africa.

Evidence of water adaptation responses



Evidence of IK and LK per adaptation responses



*The figures are indicating the number of articles per adaptation responses per region

contour bunds, rooftop harvesting for potable water, diversion weirs for irrigation, check-dam ponds, dugouts, and shallow wells. Water conservation techniques in the agriculture sector were the third highest response recorded (31.8%). Other measures with medium evidence of

implementation include agroforestry measures to increase infiltration and groundwater recharge through forestry and catchment management. Details of the geographic distribution of specific water adaptation responses per country are presented in Fig. 1 of the SM4.

Table 3 Attributes of IK and LK used in the adaptation responses implemented in Africa

Attributes of indigenous knowledge	Number of Publications	Example	Representative study
Factual knowledge about the environment and environmental changes	22	Early warnings based on observation of the environment and natural phenomena (water wells) in Ramarumo, Kubake, and Malumeng communities in Lesotho	Kamara et al. (2019)
Factual knowledge about the use of the environment	34	Pollution of open water sources from strong winds gust and drying of water wells for disaster (droughts) early warning in Swaziland and Lesotho Indigenous soil and water conservation responses in Atankwidi basin, Ghana—communities use indigenous organic matter (<i>Nandeene, Tampugere, Na'ambea</i>) to improve soil fertility, thus increases the water retention capacity of their soils Use traditional knowledge for water conservation in Ghana	Kamara et al. (2019) Derbile (2013) Ahmed et al. (2016)
Cultural values	6	Traditional and indigenous irrigation methods The <i>Zunde raMambo</i> (the chief's granary)—a traditional social security arrangement designed to protect vulnerable groups and those affected by disasters such as floods and drought practised by local and indigenous people in Muzarabani, Zimbabwe	Ologeh et al. (2018) Mavhura (2017a, b)
Governance and social capital	15	Communities use social networking to build safety nets for adaptation in Ghana Use of societal customs, traditions, rules, laws to increase societal resilience to water stress caused by droughts in Swaziland and Lesotho Traditional authorities assign higher ground areas that people gather during floods in Kenya	Ahmed et al. (2016) Kamara et al. (2019) Thorn et al. (2015)
Others	4	Rain seeking ceremonies in Zimbabwe	Bhatasara (2017)

IK and LK role in water adaptation responses

Out of the 200 articles with water adaptation responses, 36.5% (73) of the articles had evidence of the use of IK and LK in the implementation of the adaptation responses. Attribution of the IK and LK used by communities in response to the impacts of climate change shows that 45.3% of this knowledge was factual knowledge about the use of the environment, and 30.1% of the knowledge was factual knowledge about environmental changes (Table 3). Both types of factual knowledge triggered behavioural changes, a shift in practices and technological interventions using indigenous knowledge by farmers and communities. Of the articles with evidence of IK and LK use, 67.1% recorded risk reduction compared to 60.6% for the articles without IK and LK (Table 4).

The role of governments on framing water sector adaptation

More than 90% of the African governments have clear water sector adaptation targets. Table 5 shows a breakdown of the water sector targets in iNDCs submitted by African

governments and the acknowledgement of IK and LK in planned adaptation. Only 5 (10.4%) African governments (Benin, Burkina Faso, Somalia, South Africa, and Zimbabwe) acknowledged and included IK and LK in their long-term adaptation planning. About 33.3% of the African governments are planning to expand irrigation capacity through increasing irrigation infrastructure and improving efficiency of irrigation systems; 72% of the governments are

Table 4 Risk reduction for adaptation responses with evidence of IK and LK vs adaptation responses without evidence of IK and LK

Category	Evidence of risk reduction		Number of publications
	Yes	No	
Evidence of indigenous and local knowledge	49 (67.1%)	24 (32.9%)	<i>n</i> = 73
No evidence of indigenous and local knowledge	77 (60.6%)	49 (39.4%)	<i>n</i> = 127

Table 5 iNDCs water adaptation goals for African governments and the acknowledgment of IK and LK in adaptation planning

Country	Country water sector adaptation priorities and evidence of IK and LK inclusion		
	Water governance priorities	Grey water infrastructure development priorities	Acknowledged IK and LK in adaptation planning
Algeria	•		
Angola	•	•	
Benin	•	•	•
Botswana		•	
Burkina Faso	•	•	•
Burundi		•	
Central A. Republic	•	•	
Chad	•	•	
Djibouti		•	
Egypt		•	
Eritrea		•	
Ethiopia		•	
Gambia	•	•	
Ghana	•	•	
Guinea		•	
Guinea-Bissau		•	
Kenya	•		
Lesotho	•	•	
Liberia	•	•	
Malawi	•	•	
Morocco		•	
Mozambique	•	•	
Namibia		•	
Nigeria		•	
Rwanda	•	•	
Somalia	•	•	•
South Africa	•	•	•
Sudan	•	•	
Swaziland	•	•	
Tanzania	•	•	
Togo	•	•	
Tunisia		•	
Uganda	•	•	
Zambia	•	•	
Zimbabwe	•	•	•

prioritising investments in grey infrastructure development to increase reservoir capacity and storage of rainfall through rainwater harvesting, large-scale multipurpose dams, reservoir improvement, and monitoring; and 53% of the countries target improved water sector governance systems through policy, integrated management plans, strategies, sustainable water resources development that promotes ecosystem-based management responses, and other soft path adaptation responses.

Discussion

The assessment identified and mapped the influence of IK and LK in the implementation of the water sector adaptation responses across human responses to climate change implemented in Africa, and recorded in peer-reviewed

literature between 2013 and 2019. Consistent with previous studies (Berrang-Ford et al. 2021b; Leal Filho et al. 2022), droughts and precipitation variability (153 and 127 papers, respectively) were the most frequently responded to climate hazards in Africa (see Fig. 2). Overall, there is high evidence of water adaptation responses implemented in the east, west, and southern African regions and little evidence in North and Central Africa. These results are consistent with reviews of responses to climate-related water scarcity in Africa (Leal Filho et al. 2022), as well as reviews of climate change research funding for Africa (Overland et al. 2021).

Communities across Africa are using IK and LK to inform decisions influencing the implementation of the adaptation responses. Knowledge on scalability of these responses to regional scale is not yet established. This is partly due to lack of coordinated implementation or early stage of implementation of most water sector adaptation actions in Africa

(Berrang-Ford et al. 2021b; Leal Filho et al. 2022). Given the proposed increase of multilateral funding for adaptation 2020–2030 from the four major climate and development funders, including Green Climate Fund, Adaptation Fund, Global Environment Facility, and the International Climate Initiative, there is a window of opportunity for these measures to be scaled up through better integration of IK and LK (United Nations Environment Programme 2021).

Most of the water adaptation responses are water management actions in agriculture with 229 adaptation responses recorded in the articles (see Table 2) that were linked to farmers' and communities' agronomic practices. There is consistency between our results on IK and LK linked adaptation response type (Table 1) and IK and LK attribution (Table 3), where factual knowledge about the use of the environment records the highest. We find that where African communities are applying IK and LK, that this leads to behavioural and cultural changes in water use, management, and conservation, which is vital for climate risk adaptation particularly during drought and floods. A third of the water adaptation response articles had evidence of IK and LK use in the implementation of the adaptation responses. Our results on the distribution of literature on IK and LK use in climate adaptation extend the findings of the systematic review of Petzold et al. (2020) that observed high evidence of IK and LK in climate change adaptation in Zimbabwe and Kenya. IK and LK exists in various forms with the majority being factual knowledge about the use of the environment, followed by factual knowledge on the environment and environmental change, cultural values, and governance and social capital. Local institutions (local governance system) are recorded as informal institutions in literature despite these channels being responsible for stricter measures or bylaws, which they put in place to check both social and environmental controls at the local level in communities (Abass et al. 2018).

Adaptation responses with IK and LK over this reference period of 2013–2019 record higher evidence of risk reduction compared to responses without IK and LK (see Table 4). This is an important preliminary finding as understanding the extent to which IK and LK adaptation response contributes to climate risk reduction is critical to evaluate effectiveness of the responses to reduce climate risks, which is the aim of climate adaptation (Berrang-Ford et al. 2021b). Risk reduction in this study was not thoroughly assessed, both qualitatively and quantitatively. However, the results form the basis for future research to concentrate more comprehensively on risk reduction for IK and LK adaptation response types.

In the Atankwidi basin, in north-east Ghana, indigenous knowledge systems (indigenous water conservation measures) for climate adaptation record dual moderating effects on reducing the vulnerability to droughts (Derbile 2013).

Traditional adaptation measures practised by local communities provide both temporary and long-term solutions; for example, stone terraces to harvest water for irrigation have been used for 19 years, on average, by households to adapt to changing micro-environments in the Semien Mountains of Ethiopia (Yohannes et al. 2019). This illustrates how communities have developed trust in such measures; however, it is important to establish whether these long practised measures are reducing the climate risks, or whether they are creating cultural lock-ins that are increasing their vulnerability. Most of the adaptation responses in literature are highly localised and implemented to address specific situations. Scaling up of some of the knowledge and creating platforms to advance the sharing of the knowledge is key to ensure a regional transformative adaptation process. Passing on of this knowledge to future generations would also ensure sustainability of these responses; for example, communities in Kenya have passed on traditional methods of responding to floods through many generations and these strategies are integrated into daily praxis (Thorn et al. 2015).

Water adaptation responses and IK and LK

Irrigation methods is the most commonly reported adaptation response and implemented by most communities and farmers across African countries. This includes expanding the irrigation capacity in Kenya, Zimbabwe, Zambia, and Ethiopia and improving irrigation water use efficiency through adoption of efficient irrigation systems and local irrigation water saving techniques, such as drip irrigation, using local initiatives in countries such as in Morocco (Aziz and Sadok 2015), South Africa (Elum et al. 2017), and Uganda (Nakabugo et al. 2019). If scaled, improvements in irrigation efficiency in Africa's agriculture system has the potential to reduce water used by the agriculture sector especially in water-stressed regions. This can address some maladaptation concerns linked to the increased use of LK irrigation, such as the excessive abstraction of limited water resources. As many African governments pledged in their iNDCs to expand irrigation, the shift from high water demand irrigation systems to efficient, water saving irrigation systems that can adjust to future water stress is key. Government's role in promoting adoption of such technology is important; this can be through implementation of irrigation policies that enable the adoption of water saving irrigation technology and farmer support.

In many cases, farmers and communities are using indigenous knowledge to apply traditional irrigation methods during the dry season or when there is limited supply of water, e.g. use of post-inundation residual moisture as natural irrigation in Zimbabwe (Mavhura 2017a), cultivating on stream banks to increase access to irrigation water, e.g. indigenous swamp farming in Nigeria (Ologeh et al. 2018), floodplain

cultivation in Zimbabwe (Mavhura 2017a), and indigenous cultivation in wetlands to increase moisture availability in Nigeria (Ajayi 2014). However, some of these water adaptation options that are working today present maladaptation threats over the long-term, e.g. continuous water harvesting in a catchment may reduce water supply risk to the communities upstream but may have negative outcomes to the downstream communities (Singh 2018; Eriksen et al. 2021). Also, stream bank cultivation will increase the vulnerability of crops to future river flooding; wetlands often act as natural barriers to flooding, and therefore, cultivation in such areas increases flooding chances to downstream areas.

As many regions in Africa are experiencing water scarcity and insecurity linked to climate change, regions and countries are exploring alternative water sources informed by IK and LK. For example, during siting and accessing groundwater to increase their access to water resources, e.g. in Tanzania communities are using indigenous knowledge for groundwater exploring and management for drinking water that allows them to access deep aquifers (Shemsanga et al. 2018). The accessed water is also used to supplement agricultural activities through indigenous means of irrigating crop fields as practised in Ghana (Abass et al. 2018). In Dupong communities in Ghana, this extended to community members who, through their indigenous and local weather predictions, use less water, which enabled them to save enough water for other equally relevant uses during droughts and limited supply (Opare 2018). In Tanzania, pastoralists are digging watering points during periods of reduced water supply (Sangeda et al. 2013) and increasing protected well water use to improve domestic water supply especially in Zimbabwean urban areas practicing strict water rationing (Chanza 2017) as well as in rural areas (Kanda et al. 2017).

Local communities and indigenous people are using local and indigenous knowledge on water management, i.e. collection and storage during wet seasons. This involved rainy season water harvesting through indigenous means for both agricultural purposes (Mugi-Ngenga et al. 2016; Nakabugo et al. 2019), such as irrigation (Abass et al. 2018) and water for livestock by pastoralists (Filho et al. 2017; Mashizha 2019), and to increase domestic water supply by diversifying sources of potable water (Nakabugo et al. 2019). Various initiatives implemented to harvest rainwater that are influenced by IK and LK include the use of valley tanks in Uganda (Nakabugo et al. 2019), the use of water pans in Kenya (Mugi-Ngenga et al. 2016), zai pits, semi-circular bunds, and small dams in Kenya (Recha et al. 2014), contour bunds in Nigeria (Ajayi 2015), and digging dead end contours in Zimbabwe (Mupakati and Tanyanyiwa 2017). All these measures were linked to the locals' and indigenous people's factual knowledge about the environment and environmental changes and factual knowledge about the use of the environment. Water

harvesting has increased communities' resilience to water stress conditions by supplementing water for irrigation during rainy and dry seasons, thus improving food security. However, these were mostly seasonal storage options that can be badly affected during successive years of droughts as demonstrated in Ghana where ponds used by farmers to harvest water to support agricultural activities dry up easily after rainy seasons (Abass et al. 2018). Further, the scalability of some of the water harvesting technologies and practices is yet to be established. For potable water harvesting, communities used various technologies and initiatives among them the digging of pits that provide additional water to households in Ghana (Opare 2018) and hand-dug wells in Ethiopia (Yohannes et al. 2019). Potable rainwater harvesting improves household water security by supplementing existing water sources to address the water scarcity linked to climate stress (Ofoegbu et al. 2016).

Many communities in East and Southern Africa are implementing water conservation practices. These include both communities' behavioural and cultural changes and technological and infrastructure interventions related to farmers' and household agronomic practices that save water, mostly green water. Most of the water conservation technology and practices include terracing technology in Ethiopia (Cholo et al. 2018) and communities' construction of trenches for water management in Ghana and Uganda (Jost et al. 2015). Local and indigenous groups extend these practices to broader catchment management practices applying a spectrum of knowledge and initiatives. These responses improve catchment storage; the review shows that several communities in Africa are implementing ecosystem-based management responses, such as agroforestry using indigenous species, to reduce erosion, which improved water infiltration and groundwater recharge (Aimé et al. 2016; Sanogo et al. 2016; Tambo and Wünschler 2017; Awazi et al. 2019). Also, communities use traditional knowledge to manage and conserve water during water-stressed seasons (Ahmed et al. 2016).

Several regions across Africa are implementing local level water management initiatives using their traditional knowledge to manage scarce resources during periods of crisis. Some of the water management strategies implemented during droughts and water scarcity include reducing water usage, improving storage, and water re-use. Under conditions of limited access to potable water caused by droughts, communities in Benin use indigenous knowledge to treat water to increase drinking water supply (Oyerinde et al. 2017). Communities across Africa use IK and LK to implement watershed management responses to water supply shortages caused by climate seasonal variability. For example, local farmers implement catchment water conservation using local plant varieties in Mutoko, Zimbabwe (Bhatasara 2017), while in Ghana communities minimise deforestation

to improve groundwater storage through increased infiltration (Abass et al. 2018).

Limits to adaptation of IK and LK use in the water responses

To determine the sustainability and opportunities of IK and LK use in climate adaptation in Africa, it is important to discuss limits to adaptation associated with IK and LK observed in literature across Africa. 78.1% of the articles with IK and LK record limits to adaptation. A majority of these limits were linked to lack of financial resources needed for effective adaptation, lack of access to climate information to complement the indigenous knowledge, and traditional indicators used for early warning systems used by communities. Since most of the IK and LK responses were technological and behavioural/cultural responses (see Table 1), lack of human capacity was one of the main limiting factors in the implementation of labour-intensive irrigation and agriculture water conservation techniques (Yohannes et al. 2019). This is because the responses were implemented at household level relying mostly on family labour. Although these communities have relevant knowledge and practices crucial for climate adaptation, the success of labour-intensive responses depends on the family availability of the labour force. Due to factors such as limited financial resources and poverty, they cannot outsource the labour. In some cases, indigenous practices, such as *Zunde raMambo* (the chief's granary) in Zimbabwe help address labour shortages as communities gather to share labour (Mavhura 2017b) (Mavhura 2017a, b) in addressing drought effects.

The lack of access to climate information, which is critical for adaptation planning, constrained local and indigenous people (Spear and Chappel 2018; Sadiq et al. 2019; Williams et al. 2019). Language barriers also hinder the access to climate information for local and indigenous people. A lack of finance was among the important constraints to the implementation of IK and LK practices cited in the publications (Abass et al. 2018; Sadiq et al. 2019); this is due to the high cost associated with procurement of equipment that aids the success of the technology (Filho et al. 2017). Gender and cultural norms and traditional practices also hindered the implementation of some water adaptation responses. For example, the capability to collect water from outlying water sources in Ghana encountered social and cultural limitations in communities where women are not allowed to use bicycles to collect water (Opore 2018).

Integrating IK and LK in water sector adaptation

Water is the most prioritised sector by African governments for adaptation to climate change. Over 90% of African countries have water sector targets in their iNDCs. More broadly,

this aligns with trends identified in analysis of UNFCCC National Communications over the period 1994–2019 which has shown water for agriculture has become an important theme in iNDCs, particularly since 2008 for Africa and Asia (Biesbroek et al. 2022). A comparison between water sector adaptation goals in the iNDCs and the evidence of water sector adaptation responses recorded in various African countries shows a link between government policies and how various stakeholders are adapting. For example, many grey water infrastructure goals expressed in the iNDCs (increase water supply, increase irrigation capacity, rainwater harvesting infrastructure) were also the highest recorded water adaptation responses recorded in literature as evidence of how the water sector in Africa is adapting to climate change. This potentially characterises how countries will drive water sector adaptation and the influence of policy on adaptation in Africa. Yet we found IK and LK is barely included in planned adaptation, only 10.4% of the African governments acknowledge and include IK and LK in planned adaptation. Given the evidence of the high reliance of African communities on IK and LK for water sector adaptation, this is a concerning lack of consideration of IK and LK to give effect to planned responses.

The above highlights a gap in academic literature on the role of IK and LK in implementation of adaptation responses and the acknowledgment of this knowledge at a policy level by African governments through formal adaptation channels. These shortcomings, notwithstanding evidence of the role IK and LK play in water sector adaptation, cautions that planned adaptation in Africa is likely to be more broadly adopted, accepted by communities, and aligned with cultural norms if IK and LK is included. There is a window for African governments to incorporate IK and LK into national adaptation planning to increase their realisation of the adaptation goals set in the iNDCs. The use of multiple sources of knowledge (scientific, and indigenous and local knowledge) is crucial and will enhance transformational adaptation in Africa. This is also key in developing disruptive adaptation responses that effectively address the climate risk in the water sector.

Conclusion

The evidence of implementation of water adaptation responses to climate risk is growing in Africa. We identified and mapped water adaptation responses implemented across Africa and the role of IK and LK in the implementation of these adaptation responses. Irrigation, water conservation (green water), rainwater harvesting, and catchment management responses, such as the use of ecosystem-based approaches, are among the most implemented responses. The evidence of water adaptation responses and IK and LK

influence is high in East Africa—Ethiopia, Kenya, Uganda; West Africa—Ghana and Nigeria; and in Southern Africa—Zimbabwe, South Africa. There is low evidence of water adaptation responses in North and Central Africa. Knowledge on the efficacy of these responses and potential maladaptation threats from some of the adaptation practices is not yet established. This is likely because the adaptation in Africa is at the early stage of implementation (Berrang-Ford et al. 2021b). There is a need for a comprehensive approach that assesses risk reduction of IK and LK climate change adaptation response types in Africa. Our assessment shows that most of the water adaptation responses are highly localised; therefore, the aspect of scalability of the responses at regional level should be considered carefully. IK and LK in communities is important for water management and initiatives implemented by communities in Africa. However, in the current academic literature, it is evidently viewed as informal knowledge with less value. There is also a lack of coverage and respect of this knowledge in formal climate adaptation channels in African iNDCs. Analysis of African iNDCs showed that IK and LK was barely included in adaptation planning, despite Africa being one of the regions with rich IK and LK practices used for climate change adaptation. We recommend a coordinated approach that integrates multiple knowledge systems in adaptation, including local and indigenous knowledge, to ensure sustainability of both the current and proposed water adaptation responses in Africa.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11625-022-01118-x>.

Funding This work was carried out with financial support from the UK Government's Foreign, Commonwealth & Development Office and the International Development Research Centre, Ottawa, Canada.

Declarations

Conflict of interest None.

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References

- Abass R, Mensah A, Fosu-Mensah B (2018) The Role of formal and informal institutions in smallholder agricultural adaptation: the case of Lawra and Nandom Districts, Ghana West African. *J Appl Ecol* 26:56–72
- Abram, N et al (2019) Framing and context of the report. In: Pörtner H-OMasson-Delmotte DCRV, Zhai P, Tignor M, Poloczanska E, Mintenbeck K, Alegria A, Nicolai M, Okem A, Petzold J, Rama B, Weyer NM (eds) IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. In press, https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/05_SROCC_Ch01_FINAL.pdf. Accessed 25 Sept 2020
- Ahmed A et al (2016) Adaptation to climate change or non-climatic stressors in semi-arid regions? Evidence of gender differentiation in three agrarian districts of Ghana. *Environ Dev* 20:45–58. <https://doi.org/10.1016/j.envdev.2016.08.002>
- Aimé FR et al (2016) Adaptations of the agricultural calendar and agricultural techniques to climate change in the Highlands of Cameroon. In: Bryant CSM, Délusca K (eds) Agricultural adaptation to climate change. Springer, Cham, pp 199–2247
- Ajayi JO (2014) Awareness of climate change and implications for attaining the Millennium Development Goals (MDGs) in Niger Delta Region of Nigeria. *Agris on-Line Pap Econ Inf* 6(1):3–11. <https://doi.org/10.22004/ag.econ.166520>
- Ajayi JO (2015) Effects of climate change on the production and profitability of cassava in the Niger Delta Region of Nigeria. *Agris on-Line Pap Econ Inf* 7(2):3–11. <https://doi.org/10.7160/aol.2015.070201>
- Araos M et al (2021) Equity in human adaptation-related responses: a systematic global review. *One Earth* 4(10):1454–1467. <https://doi.org/10.1016/j.oneear.2021.09.001>
- Awazi NP, Tchamba MN, Avana TML (2019) Climate change resiliency choices of small-scale farmers in Cameroon: determinants and policy implications. *J Environ Manag* 250:109560. <https://doi.org/10.1016/j.jenvman.2019.109560>
- Aziz L, Sadok W (2015) Strategies used by the saffron producers of Taliouine (Morocco) to adapt to climate change. *J Alpine Res* 103–2:1–13. <https://doi.org/10.4000/rga.2902>
- Berrang-Ford L et al (2021a) the Global adaptation mapping initiative (GAMI): part 1—introduction and overview of methods. *Nat Protoc Exchange*. <https://doi.org/10.21203/rs.3.pex-1240/v1>
- Berrang-Ford L et al (2021b) A systematic global stocktake of evidence on human adaptation to climate change. *Nat Clim Change* 11(11):989–1000. <https://doi.org/10.1038/s41558-021-01170-y>
- Bhatasara S (2017) Towards a sociology of adaptation to rainfall variability in Rural Zimbabwe: the case of Charewa in Mutoko. *Fudan J Hum Soc Sci* 10(4):547–568. <https://doi.org/10.1007/s40647-017-0177-8>
- Biesbroek R et al (2022) Policy attention to climate change impacts, adaptation and vulnerability: a global assessment of National Communications (1994–2019). *Clim Policy* 22(1):97–111. <https://doi.org/10.1080/14693062.2021.2018986>
- Callaghan M et al (2021) Machine-learning-based evidence and attribution mapping of 100,000 climate impact studies. *Nat Clim Change* 11(11):966–972. <https://doi.org/10.1038/s41558-021-01168-6>
- Chanza N (2017) Limits to climate change adaptation in Zimbabwe: Insights, experiences and lessons. In: Leal Filho W, Nalau J (eds) Limits to climate change adaptation. Springer International Publishing, pp 109–127
- Cholo T, Fleskens L, Sietz D, Peerlings J (2018) Is land fragmentation facilitating or obstructing adoption of climate adaptation measures in Ethiopia? *Sustainability* 10(7):2120. <https://doi.org/10.3390/su10072120>

- Derbile EK (2013) Reducing vulnerability of rain-fed agriculture to drought through indigenous knowledge systems in north-eastern Ghana. *Int J Clim Change Strateg Manag* 5(1):71–94. <https://doi.org/10.1108/17568691311299372>
- Elum ZA, Modise DM, Marr A (2017) Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. *Clim Risk Manag* 16:246–257. <https://doi.org/10.1016/j.crm.2016.11.001>
- Eriksen S et al (2021) Adaptation interventions and their effect on vulnerability in developing countries: help, hindrance or irrelevance? *World Dev* 141: <https://doi.org/10.1016/j.worlddev.2020.105383>
- Filho WL et al (2017) Climate change responses among the Maasai Community in Kenya. *Clim Change* 145(1–2):71–83. <https://doi.org/10.1007/s10584-017-2087-9>
- Fischer AP et al (2021) The global adaptation mapping initiative (GAMI): part 2—screening protocol. *Nat Protoc Exchange*. <https://doi.org/10.21203/rs.3.pex-1241/v1>
- Ford JD et al (2016) Including indigenous knowledge and experience in IPCC assessment reports. *Nat Clim Change* 6(4):349–353. <https://doi.org/10.1038/nclimate2954>
- Global Risk Report (2021) World Economic Forum, Geneva. <https://reports.weforum.org/global-risks-report-2021/>. Accessed 14 Mar 2021
- Global Water Partnership (2018) Preparing to adapt: the untold story of water in climate change adaptation processes. Stockholm, 1–20. <https://www.gwp.org/globalassets/global/events/cop24/gwp-ndc-report.pdf>. Accessed 27 June 2021
- Haddaway NR, Macura B, Whaley P, Pullin AS (2018) ROSES Reporting standards for Systematic Evidence Syntheses: Pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Environ Evid* 7(1):4–11. <https://doi.org/10.1186/s13750-018-0121-7>
- IPCC (2014) Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea MD, White LL (eds) Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1132. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIA_R5-PartA_FINAL.pdf. Accessed 21 Feb 2021
- IPCC (2018a) Annex I: Glossary. In: Matthews JBR (ed) Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (ed) pp 541–562. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_AnnexI_Glossary.pdf. Accessed 16 Oct 2020
- IPCC (2018b) Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (ed) In press. <https://www.ipcc.ch/sr15/download/>. Accessed 16 Oct 2020
- IPCC (2019a) Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In: Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner HO, Roberts DC, Zhai P, Slade R, Connors S, van Diemen R, Ferrat M, Haughey E, Luz S, Neogi S, Pathak M, Petzold J, Portugal Pereira J, Vyas P, Huntley E, Kissick K, Belkacemi M, Malley J (eds) In press. <https://www.ipcc.ch/srcccl-report-download-page/>. Accessed 16 Oct 2020
- IPCC (2019b) IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. In: Pörtner H-O, Masson-Delmotte DCRV, Zhai P, Tignor M, Poloczanska E, Mintenbeck K, Alegría A, Nicolai M, Okem A, Petzold J, Rama B, Weyer NM (ed), In press. <https://www.ipcc.ch/srccoc/>. Accessed 16 Oct 2020
- Jost C et al (2015) Understanding gender dimensions of agriculture and climate change in smallholder farming communities. *Clim Dev* 8(2):133–144. <https://doi.org/10.1080/17565529.2015.1050978>
- Kaganzi KR et al (2021) Local perceptions of climate change and adaptation responses from two Mountain Regions in Tanzania. *Land* 10(10):999. <https://doi.org/10.3390/land10100999>
- Kamara JK, Agho K, Renzaho AMN (2019) Understanding disaster resilience in communities affected by recurrent drought in Lesotho and Swaziland—a qualitative study. *PLoS ONE* 14(3):e0212994. <https://doi.org/10.1371/journal.pone.0212994>
- Kanda A, Murongazvombo M, Ncube F (2017) Adapting household water use in rural Zimbabwe. *Int J Environ Stud* 74(3):471–485. <https://doi.org/10.1080/00207233.2017.1319622>
- Kofod-Petersen A (2012) How to do a structured literature review in computer science
- Leal Filho W et al (2021) Impacts of climate change to African indigenous communities and examples of adaptation responses. *Nat Commun* 12(1):6224. <https://doi.org/10.1038/s41467-021-26540-0>
- Leal Filho W et al (2022) Understanding responses to climate-related water scarcity in Africa. *Sci Total Environ* 806:150420. <https://doi.org/10.1016/j.scitotenv.2021.150420>
- Lesnikowski A et al (2021) The global adaptation mapping initiative (GAMI): part 3—coding protocol. *Nat Protoc Exchange*. <https://doi.org/10.21203/rs.3.pex-1242/v1>
- Makondo CC, Thomas DSG (2018) Climate change adaptation: linking indigenous knowledge with western science for effective adaptation. *Environ Sci Policy* 88:83–91. <https://doi.org/10.1016/j.envsci.2018.06.014>
- Mashizha TM (2019) Adapting to climate change: Reflections of peasant farmers in Mashonaland West Province of Zimbabwe. *Jamba J Disaster Risk Stud* 11(1):8. <https://doi.org/10.4102/jamba.v11i1.571>
- Mastrandrea MD et al (2011) The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups. *Clim Change* 108(4):675–691. <https://doi.org/10.1007/s10584-011-0178-6>
- Mavhura E (2017a) Applying a systems-thinking approach to community resilience analysis using rural livelihoods: the case of Muzarabani district, Zimbabwe. *Int J Disaster Risk Reduct* 25:248–258. <https://doi.org/10.1016/j.ijdrr.2017.09.008>
- Mavhura E (2017b) Building resilience to food insecurity in rural communities: Evidence from traditional institutions in Zimbabwe. *Jamba-J Disaster Risk Stud* 9(1):9. <https://doi.org/10.4102/jamba.v9i1.453>
- Mugi-Ngenga EW et al (2016) Household's socio-economic factors influencing the level of adaptation to climate variability in the dry zones of Eastern Kenya. *J Rural Stud* 43:49–60. <https://doi.org/10.1016/j.jrurstud.2015.11.004>
- Mupakati T, Tanyanyiwa VI (2017) Cassava production as a climate change adaptation strategy in Chilonga Ward, Chiredzi District.

- Zimbabwe. *Jamba* 9(1):1–10. <https://doi.org/10.4102/jamba.v9i1.348>
- Mwaniki F, Stevenson RB (2017) Farmers' uses of indigenous knowledge and practices to cope with climate change in Kilifi County, Kenya. *Int J Clim Change Impacts Responses* 9(4):53–65. <https://doi.org/10.18848/1835-7156/CGP/v09i04/53-65>
- Nakabugo R, Mukwaya IP, Geoffrey S (2019). In: Bamutaze Y, Kyamanywa S, Singh BR, Nabanoga G, Lal R (eds) *Agriculture and ecosystem resilience in sub Saharan Africa: livelihood pathways under changing climate*. Springer International Publishing, Cham, pp 541–568 (ISBN 978-3-030-12974-3)
- Niang I et al. (2014) Africa. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) *Climate Change 2014: impacts, adaptation, and vulnerability. Part B: Regional Aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, pp 1199–1266. Accessed 10 Aug 2020
- Nkomwa EC et al (2014) Assessing indigenous knowledge systems and climate change adaptation strategies in agriculture: a case study of Chagaka Village, Chikhwawa, Southern Malawi. *Phys Chem Earth* 67–69:164–172. <https://doi.org/10.1016/j.pce.2013.10.002>
- Nyong A, Adesina F, Elasha BO (2007) The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitig Adapt Strat Glob Change* 12(5):787–797. <https://doi.org/10.1007/s11027-007-9099-0>
- Ofoegbu C, Chirwa PW, Francis J, Babalola FD (2016) Assessing forest-based rural communities' adaptive capacity and coping strategies for climate variability and change: the case of Vhembe district in south Africa. *Environ Dev* 18:36–51. <https://doi.org/10.1016/j.envdev.2016.03.001>
- Ologeh IO, Akarakiri JB, Adesina FA (2018) Constraints and limits to climate change adaptation efforts in Nigeria. In: Leal Filho W, Nalau J (eds) *Limits to climate change adaptation*. Springer International Publishing, Cham, pp 159–174 (ISBN 978-3-319-64599-5)
- Opare S (2018) Adaptation to climate change impacts: coping strategies of an indigenous community in Ghana to declining water supply. *Clim Dev* 10(1):73–83. <https://doi.org/10.1080/17565529.2016.1184610>
- Otto FEL et al (2018) Anthropogenic influence on the drivers of the Western Cape drought 2015–2017. *Environ Res Lett* 13: <https://doi.org/10.1088/1748-9326/aae9f9>
- Overland I et al (2021) Funding flows for climate change research on Africa: where do they come from and where do they go? *Climate Dev*. <https://doi.org/10.1080/17565529.2021.1976609>
- Owen G (2020) What makes climate change adaptation effective? A systematic review of the literature. *Glob Environ Chang* 62:102071. <https://doi.org/10.1016/j.gloenvcha.2020.102071>
- Oyerinde GT, Lawin EA, Odojin AJ (2017) Farmers' responses to changing hydrological trends in the niger basin parts of benin. *Hydrology* 4(4):52. <https://doi.org/10.3390/hydrology4040052>
- Pascale S, Kapnick SB, Delworth TL, Cooke WF (2020) Increasing risk of another Cape Town “Day Zero” drought in the 21st century. *Proc Natl Acad Sci* 117(47):29495. <https://doi.org/10.1073/pnas.2009144117>
- Petzold J et al (2020) Indigenous knowledge on climate change adaptation: a global evidence map of academic literature. *Environ Res Lett* 15(11):113007. <https://doi.org/10.1088/1748-9326/abb330>
- Recha CW, Mukopi MN, Otieno JO (2014) Socio-economic determinants of adoption of rainwater harvesting and conservation techniques in semi-arid Tharaka Sub-County, Kenya. *Land Degrad Dev* 26(7):765–773. <https://doi.org/10.1002/ldr.2326>
- Sadiq MA, Kuwornu JKM, Al-Hassan RM, Alhassan SI (2019) Assessing maize farmers' adaptation strategies to climate change and variability in Ghana. *Agriculture (switzerland)* 9(5):90. <https://doi.org/10.3390/agriculture9050090>
- Sangeda AZ, Maleko DD, Mtengeti EJ (2013) Socio-economic and ecological dimensions of climate variability and change for agro-pastoral communities in central Tanzania. *Livest Res Rural Dev* 25(12):1–12
- Sanogo K et al (2016) Farmers' perceptions of climate change impacts on ecosystem services delivery of parklands in southern Mali. *Agrofor Syst* 91(2):345–361. <https://doi.org/10.1007/s10457-016-9933-z>
- Scheelbeek PFD et al (2021) The effects on public health of climate change adaptation responses: a systematic review of evidence from low- and middle-income countries. *Environ Res Lett* 16(7):073001. <https://doi.org/10.1088/1748-9326/ac092c>
- Shemsanga C et al (2018) Indigenous knowledge on development and management of shallow dug wells of Dodoma Municipality in Tanzania. *Appl Water Sci* 8(2):59. <https://doi.org/10.1007/s13201-018-0697-7>
- Sietsma AJ, Ford JD, Callaghan MW, Minx JC (2021) Progress in climate change adaptation research. *Environ Res Lett* 16(5):54038. <https://doi.org/10.1088/1748-9326/abf7f3>
- Singh C (2018) Is participatory watershed development building local adaptive capacity? Findings from a case study in Rajasthan, India. *Environ Dev* 25:43–58. <https://doi.org/10.1016/j.envdev.2017.11.004>
- Sitati A et al (2021) Climate change adaptation in conflict-affected countries: A systematic assessment of evidence. *Discov Sustain* 2(1):42. <https://doi.org/10.1007/s43621-021-00052-9>
- Spear D, Chappel A (2018) Livelihoods on the edge without a safety net: the case of smallholder crop farming in north-central Namibia. *Land* 7(3):79. <https://doi.org/10.3390/land7030079>
- Tambo JA, Wünscher T (2017) Enhancing resilience to climate shocks through farmer innovation: evidence from northern Ghana. *Reg Environ Change* 17(5):1505–1514. <https://doi.org/10.1007/s10113-017-1113-9>
- Thomas A et al (2021) Global evidence of constraints and limits to human adaptation. *Reg Environ Change* 21(3):85. <https://doi.org/10.1007/s10113-021-01808-9>
- Thorn J, Thornton TF, Helfgott A (2015) Autonomous adaptation to global environmental change in peri-urban settlements: Evidence of a growing culture of innovation and revitalisation in Mathare Valley Slums, Nairobi. *Glob Environ Change* 31:121–131. <https://doi.org/10.1016/j.gloenvcha.2014.12.009>
- Turek-Hankins LL et al (2021) Climate change adaptation to extreme heat: a global systematic review of implemented action. *Oxf Open Clim Change* 1(1):kgab005. <https://doi.org/10.1093/oxfclm/kgab005>
- Ulibarri N et al (2021) A global assessment of policy tools to support climate adaptation. *Clim Policy* 22(1):77–96. <https://doi.org/10.1080/14693062.2021.2002251>
- United Nations Economic Commission for Europe (2009) *Guidance on water and adaptation to climate change*. United Nations Economic Commission for Europe (UNECE), pp 1–144. <https://unece.org/info/publications/pub/21691>. Accessed 10 July 2021
- United Nations Environment Programme (2021) *Adaptation Gap Report 2020*. Nairobi, p 120. <https://www.unep.org/resources/adaptation-gap-report-2020>. Accessed 23 Mar 2021
- Vaismoradi M, Turunen H, Bondas T (2013) Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nurs Health Sci* 15(3):398–405. <https://doi.org/10.1111/nhs.12048>
- Vaismoradi M, Jones J, Turunen H, Snelgrove S (2016) Theme development in qualitative content analysis and thematic analysis. *J Nurs Educ Pract* 6(5). <https://doi.org/10.5430/jnep.v6n5p100>
- UN Water (2013) *Climate change adaptation is mainly about water*. Geneva, Switzerland p 2. Accessed 12 Aug 2021

- Williams PA, Crespo O, Abu M (2019) Adapting to changing climate through improving adaptive capacity at the local level—the case of smallholder horticultural producers in Ghana. *Clim Risk Manag* 23:124–135. <https://doi.org/10.1016/j.crm.2018.12.004>
- Williams PA, Sikutshwa L, Shackleton S (2020) Acknowledging indigenous and local knowledge to facilitate collaboration in landscape approaches—lessons from a systematic review. *Land* 9(9):331. <https://doi.org/10.3390/land9090331>
- Williams PA et al (2021) Feasibility assessment of climate change adaptation options across Africa: an evidence-based review. *Environ Res Lett* 16:073004. <https://doi.org/10.1088/1748-9326/ac092d>
- Yohannes Z, Teshome M, Belay M (2019) Adaptive capacity of mountain community to climate change: case study in the Semien Mountains of Ethiopia. *Environ Dev Sustain* 22(4):3051–3077. <https://doi.org/10.1007/s10668-019-00334-3>

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