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RESEARCH ARTICLE

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Flood hazard in a semi-closed basin in northern Ethiopia: Impact and resilience

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Abstract

Even though flooding is a threat to rural communities in plains drained by ephemeral rivers, the magnitude of its impact, coping/prevention mechanisms, and the implications for river management are not well known. In this study, data were collected using a phenomenological-based research design. Field observations, a questionnaire ($n = 440$), key informant interviews (10), and one focus group discussion (with seven discussants) were used to collect the desired data from flood-prone farmers. As the results show, 42% of the respondents believe that flooding has become stronger over the past 20 years, whereas 38% believe there has been no change. As mitigation measures, 52% of the respondents suggested evacuating to neighbouring villages as the best option. Most of the damage was experienced in farmlands (including crops, either harvested or standing) and settlements. As coping mechanisms, 31% of the respondents were displaced, whereas an additional 40% were forced to construct new houses for their settlement. Chi-square testing showed that the farmers' responses statistically varied among different groups ($p < .001$). In the meantime, community participation in flood control and catchment management is important. Improving flood management knowledge and the skills of different groups in a community is equally important. In this case, a qualitative inquiry approach was a good option to assess the hydrological conditions of rivers.

KEYWORDS

dryland, flood hazard, flood mitigation, flooding impact, Raya, river management

1 | INTRODUCTION

A flood is a rise in the water level of a stream or water body to a peak from which the water level recedes at a slower rate, whereas flash flood refers to a flood of short duration with a relatively high peak discharge (WMO, 2010). Flooding becomes a hazard when it has a destructive effect on human life, health, properties, services, and so on, adversely affecting the living condition of humans. Flooding is among the most severe hazards over the globe. Severe flood events have been reported across Asia, Africa, and Europe (Merz et al., 2010). India, Bangladesh, China, Vietnam, and Pakistan are the most exposed countries for flooding. Qasim et al. (2016) reported that about 18% of Bangladesh is flooded every year. In terms of the trend of flooding, some studies reported a decreasing trend for a large number of stations in western North America and Australia, and increasing trends in parts of Europe, eastern North America, parts of South America, and South Africa (Do et al., 2017; Hoegh-Guldberg et al., 2018). Generally, studies show that since 1950 flood frequency and extreme stream flow have increased in some regions of the world (Hoegh-Guldberg et al., 2018).

In most cases of flooding impacts, the most vulnerable landscapes for flooding are low-lying areas and basins where rivers approach their base level (Nott, 2006). These areas, particularly in semi-arid regions, are subject to flash floods due to torrential rainfall and steep escarpments in their headwaters (Bull & Kirkby, 2002). One example is the Raya graben, which is located in northern Ethiopia, marginal to the Rift Valley (Demissie et al., 2017). Ephemeral rivers characterise this dryland area. An ephemeral river refers to a river that flows only in direct response to precipitation or to the flow from an intermittent spring (WMO, 2010). These rivers are most common in drylands of the earth where rainfall is scant and a moisture deficiency exists most of the time (Bryan, 1922).

Equivalent to these climate factors (Booij, 2005; Hirabayashi et al., 2013; Mallakpour & Villarini, 2015), human activities, such as agricultural practices (Mustafa, 1998; Posthumus et al., 2008), are important factors. In these human activities, development activities (infrastructure), improper channel management activities, for example, construction in flood plains, channel straightening and narrowing, are prominent factors (Berry et al., 2008; Bradford et al., 2012; Daniel et al., 2009; Demissie et al., 2015, 2017; McNamara & Keeler, 2013; McNamara & Keeler, 2013).

River flooding has both environmental and socio-economic impacts; its fatality is unquestionable (Diakakis & Deligiannakis, 2015). The environmental impacts may include pollution (carrying debris, pollutants, and nutrients), and damage to streams and riparian vegetation (Gardiner, 1994; Swanson et al., 1998). The main socio-economic impacts are loss of human life, destruction of houses, loss of livestock, inundation of croplands and destruction of irrigation canals, clogging of bridges, and destruction of rural infrastructure and facilities (Dixit, 2003; Lindsell & Prater, 2003).

This study is about flooding and flooding impacts in Ethiopia. In Ethiopia, there is a high prevelance flood hazard in many parts of the country. It is estimated that on average over 250,000 people are affected by flooding every year (GFDRR, 2019). Several flood incidences have been reported in Afar, Oromia, SNNP, and Somali regions of Ethiopia. In 2016, the deadly floods affected about 202 people (http://floodlist.com/tag/ethiopia). Recently, flash floods that struck the city of Dire Dawa on 24 April 2020 have killed four and injured several people. Historical flood records starting from the 1980s depict more than 47 flood event records affecting 2.2 million people in Ethiopia (Weldegebriel & Amphune, 2017; World Bank, 2010). However, floods can be a blessing; for example, floods are used for spate irrigation in crop farms in northern Ethiopan dryland areas (Meaza et al., 2017; Nyssen et al., 2017).

In this context, communities need to increase resilience via mitigation, adaptation, and coping mechanisms to the flood hazard (Lo & Chan, 2017). The concept "resilience" does not have a specific definition, but from a perspective of general understanding, it represents the capacity of a community exposed to a hazard to adapt by resisting or changing in order to maintain an acceptable level of functioning, organization and structure (Batica & Gourbesville, 2016; Nguyen & James, 2013; Sendzimir et al., 2007; UN-ISDR, 2004; Vis et al., 2003). In this study, resilience is the result of a community taking active steps to become flood-ready, before and after flood events, through mitigation, adaptation, and coping mechanisms in relation to flooding (Qasim et al., 2016; Vermont Government, 2019). For a better assessment of flooding risk, understanding the resilience capacity of a community is important. Resilience capacity refers to the potential ability of farmers to resist and recover in the presence of flooding hazards (Hudec et al., 2018; Kontokosta & Malik, 2018; Lengnick-Hall et al., 2011).

One reliable approach to study people's resilience to natural hazards, such as flooding, is the use of local knowledge of a community living around flood-prone areas. Huntington (2000) argued that traditional ecological knowledge has been promoted for use in scientific research and ecological understanding. Yet, the application of traditional ecological knowledge approaches have not received due attention in the study of hydro-climatological variables (Acharya & Prakash, 2019). Similarly, even though local people possess creative and strong practice-supported knowledge, this knowledge is not utilised in flood risk management (Abid et al., 2016; Castelli & Bresci, 2017; Troglic et al., 2019). Traditional ecological knowledge of the community that lives around the flood-prone areas is an important tool to understand flooding risks and flooding mitigation, adaptation, and coping mechanisms practiced by the community. For example, Castelli et al. (2018) have used community-based traditional spate irrigation in the Raya graben in northern Ethiopia.

This study appreciates the qualitative inquiry into flood conditions, impacts, present response and future flood hazard management practices. In the context of the study area where hydrological records are absent (Meaza et al., 2019), a qualitative inquiry becomes the sole option. Hence, this study assessed flood magnitude (depth and frequency), mitigation measures, and impacts using a local knowledge-based assessment approach in dryland ephemeral rivers in a closed basin in northern Ethiopia where the absence of gaged data is evident. The study addresses three major questions: (1) what are the perceived magnitudes of flooding and their causes in dryland grabens drained by flash flood ephemeral rivers? (2) What are the mitigation measures victims of flash floods prefer to use? (3) What are the magnitudes of flooding impacts and the coping mechanisms?

A better understanding of the magnitude of flash floods, the causes, mitigation measures, severity of impacts, and post flood coping mechanisms based on community-based information can provide a basis for prediction of disasters and development of contingency plans. Hence, this study is important for designing and implementing long-term adaptive and flexible intervention strategies (Woodward et al., 2011), especially in semi-arid areas of developing countries worldwide where gaged data are absent and experiences in this regard are limited. Moreover, it contributes to the knowledge base and to practices in efforts to manage flash floods in ephemeral rivers and the need for community participation in proper river basin management.

This paper is organized into five sections. This first section gives introductory concepts on the problem under investigation. It stresses the use of community-based local knowledge to understand flood magnitude, frequency, mitigation measures, flooding impacts and coping mechanisms. The second section is devoted to the methodological approaches used for data collection and analysis. It presents background information about the study area. This section also presents the socio-economic characteristics of the households included in this study. The third section presents the main findings of the study in four major categories, namely, flood magnitude and cause, flood mitigation measures, the impacts of flooding, and post flood coping mechanisms. The fourth section focuses on discussing the main findings of the study, supported by related studies worldwide. It discusses the meaning and the implications of the main findings in terms of flood risk management in the study area. Finally, the last section presents concluding remarks. It stresses that community-based local knowledge is a key for flood risk management efforts, particularly in areas where gaged data are not available or impossible to record.

2 | METHODOLOGY

2.1 | The study area

The Raya graben is a 3,600 km^2 semi-closed marginal basin along the northern branch of the Ethiopian Rift Valley. It has an almost rectangular shape stretching in a south–north direction and it is located between 12°–13° N and 39.5°–39.8° E (Figure 1). The highest mountains in the western graben shoulder peak at 4,284 m a.s.l. (Mt. Abohoy). Lower elevations (peaking at 2,335 m) characterise the eastern horsts. The graben floor lies at 1,400 and 1,500 m.

The major drainage system of the Raya graben is in the western escarpment; the eastern drainage system consists of short streams running westwards down from the horst. The graben has two outlets in the southeast direction, but most of the rivers are ephemeral, ending up in the graben bottom forming distributary systems. Ephemeral rivers refer to rivers that flow only in direct response to precipitation or to the flow from an intermittent spring, a river with short lasting flows (Hadley, 1968; WMO, 2010). Much higher flow variability, a general absence of low flows except during the recession periods immediately after moderate to high flow events characterise them (Knighton & Nanson, 1997). Distributary systems have relatively unrestricted channels, which are free to bifurcate and migrate laterally across wide areas on the plain (Billi, 2008; Demissie et al., 2015).

In the study area, the precipitation distribution is divided into three distinct seasons: (1) the dry season from October to February; (2) the low rain season from March to May separated by the dry month of June; and (3) the high rain season from July to September. The average total annual precipitation amounts to 750.4 mm, with 143 mm in the dry season, 219.9 mm in the small rain seasons, and 374.8 mm in the main rainy season in Alamata (graben bottom). In addition, a total of 889.1 mm with 147.7 mm, 200 mm, and 509.4 mm in the distinct seasons, respectively, based on precipitation of the upland rain gauges of Korem and Maychew (Demissie et al., 2017).

In the study area, various catchment rehabilitation activities have been in practice since the end of the 1980s. Both physical structures, such as stone bunds, terraces, soil bunds, trenches and check dams, and reforestation measures, including establishment of enclosures on highly degraded steep slopes have been implemented (Mengistu et al., 2005; Munro et al., 2008; Nyssen et al., 2005). Farmland dominated the study catchments, especially in the graben floor and

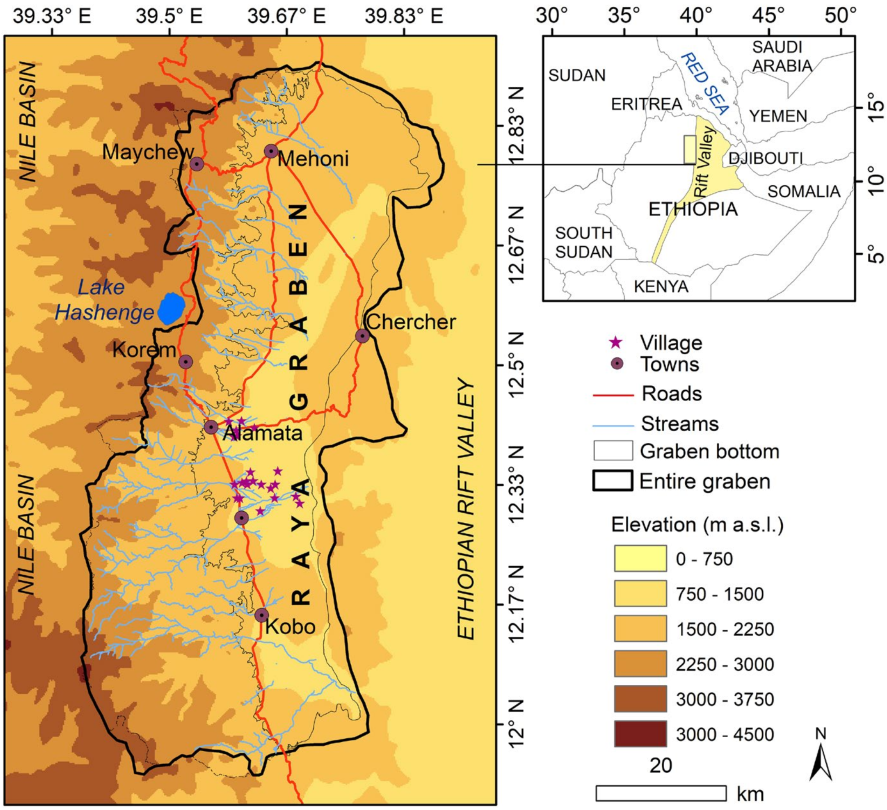

FIGURE 1 Location of the study area

bushland (dense shrub) (Annys et al., 2016; Demissie et al., forthcoming). The eroded materials from the steep escarpments are deposited as colluvium at the escarpment foot and alluvium in the graben bottom (Asfaha et al., 2016).

In one of the study rivers, a bankfull discharge of 5.4 and 589 m^3/s were estimated, virtually corresponding to a discharge with a return time of 1.58 and 2.33 years. The flow with 1.58 return time corresponds to the modal flood in the Gumbel extreme values probability curve and it is considered most effective in shaping river channel morphology and probable channel overflow (Demissie et al., 2019). Hence, in the study area flood hazards happen every 2–3 years. Due to the absence of warning a system, the people do not have sufficient response time to move their properties.

2.2 | Data collection and analysis methods

2.2.1 | Design and data collection

In this study, we used quantitative and qualitative data collection methods with a phenomenological research design. In qualitative research, commonly used approaches are ethnography, grounded theory, and phenomenology. Ethnography involves researchers using direct observation to study participants in their real-life environment over extended periods. Grounded theory, in this case, involves face-to-face interactions with respondents, such as through interviews and focus group discussions. The purpose of this method is to develop theory on the behaviors or experiences of participants. Phenomenology is similar to grounded theory in some respects, such as exploration of the behavior of respondents and data collection techniques. However, it tries to understand their subjective experiences and its purpose is to understand a concept or a phenomenon concerned with human experience and perception (Cerbone, 2010; Reiter et al., 2011; Salmon & Buetow, 2013; Sutton & Austin, 2015). As a qualitative approach, phenomenology focuses on a lived experience of individuals (Creswell, 2013). This design helps to collect data about individuals and community experiences on flood events (Caelli, 2001; Groenewald, 2004). Hence, in this study, we used phenomenology to understand the experiences, knowledge, and perceptions of local communities about flood magnitude, frequency, flood mitigation measures, flooding impacts, and coping mechanisms.

Questionnaire based surveying and sampling procedure

A questionnaire-based survey allowed data collection from farmers prone to flooding impacts, including those whose farmlands or residential areas have been destroyed, partly or fully. In the survey, we included farmers who have been frequently affected by flooding in 23 villages that are crossed by the larger rivers in the study area. We obtained the records of 512 flooding victims from district administrative offices; out of these, 440 respondents were available to participate in this study. We conducted the survey in collaboration with the administration offices and the agriculture and rural development offices of the Raya Alamata and Raya Kobo districts. Agricultural experts working in the area helped to identify the addresses of the respondents during the survey. The questionnaires consisted of 30 questions that gather data about the personal characteristics of the respondents (age, gender, marital status, family size, religion, level of education) and basic data about flooding risk (current main source of income and land holding, flood impact, coping mechanisms after the flood, prevention measures to mitigate the impact of flooding, and perception about flooding).

Out of the 440 respondents, 75% were male and 25% female (Table 1), mainly because most heads of households were male. We also had a few female-headed households (i.e. absence of a man who traditionally leads the farming operations) that completed the questionnaires The age of the respondents ranged from 18 to 97, with a mean age of 49 years and a mean standard error of 0.69. The age distribution was normally distributed. Most of the respondents (82%) were aged between 30 and 69, were married (72%), and followed Orthodox Christianity (70%). Most of the respondents were illiterate (58%), some had followed traditional education (24%), 15% of the respondents received an elementary school education (1–8 grades), and very few a high-school education (Table 1).

Most of the respondent households (77%) reported a family size of more than three (Figure 2); for most, the household size was between four and eight. Out of 440 respondents, 37.5% came to their current villages from other places within the Raya graben, and the mean distance to their original villages was 11.7 km (±0.97). The large majority 275 (62.5%) were born in the area or had lived there for more than 30 years.

Focus group discussion, key informant interviews, and sampling procedure

We conducted one focus group discussion. Discussants ($n = 7$) included young and elderly farmers, an irrigation expert, a soil and water conservation specialist, an agronomist, and a school head, and were purposively selected. Afterwards, we raised a list of questions on flood history, flood effects, flood mitigation measures, challenges of flood mitigation measures, flood adaptation measures, and actors who have been engaged in flood controlling activities. We also conducted key informant interviews with 17 local people who we met randomly during the consecutive field activities in the study area. Most of the key informants ($n = 10$) were farmers; the remainder were agricultural extension experts, natural resource experts, schoolteachers, and development agents. To obtain genuine and correct information, the focus group discussants (hereafter discussants) and the key informants were clearly told about the purpose of the study and the confidentiality of

TABLE 1 Characteristics of surveyed household heads

Characteristics	Status	*n*	%
Gender	Male	330	75.0
	Female	110	25.0
Marital status	Single	35	8.0
	Married	318	72.3
	Separated	3	0.7
	Divorced	28	6.4
	Widowed	56	12.7
Religion	Orthodox Christian	309	70.2
	Muslim	129	29.3
	Catholic	1	0.2
	Others	1	0.2
Educational status	Illiterate	254	57.7
	Traditional education	104	23.8
	1–8 grade	64	14.7
	9–12 grade	17	3.8

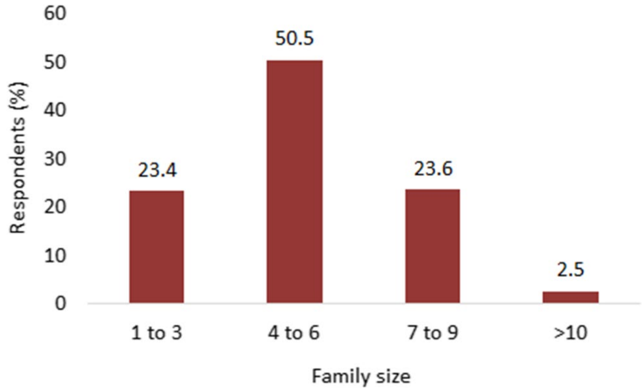

FIGURE 2 Family size distribution of respondent households

the information provided; before the interview they were told that their names would not be recorded. During the focus group discussion and the key informant interviews, we recorded responses in a notebook.

2.2.2 | Data analysis of questionnaires, focus group discussion, and interview

We checked the data for consistency and possible statistical relationships among variables were examined (Diakakis et al., 2018). Descriptive statistics and inferential tools were used to analyse the data in a more informative and quantitative manner. For descriptive statistics, we used the mean and variance of the mean (such as standard error) to understand the distribution of data for some variables. We made comparative analyses of these data to determine differences and implications. Moreover, we carried out non-parametric bivariate statistical analyses for variables that required significance of difference to be checked. For this purpose, we performed a χ^2 independence test. This test is a statistical model, which tests the association between categories of variables. We used the test to determine the association between household characteristics and coping mechanisms after flood hazards.

We analysed the qualitative data collected via focus group discussion and key informant interviews using a narrative data analysis technique. We used narrative inquiries for farmers to explain the events of flooding (trends, causes, impacts) and mitigation measures. We analysed these responses narratively to produce explanatory stories. This method involves the formulation of stories told by respondents in line with the context cases presented and experiences of the respondents who were the subject of discussion (Flick, 1998; Mello, 2002; Teddlie & Yu, 2007). Hence, qualitative analysis involves the revision of primary qualitative data gathered from the respondents. The statistical analysis was done in Stata 14. The level of confidence was 5%, as proposed by Smith (2003) and Jansen (2010).

3 | RESULTS

3.1 | Flood magnitude and causes

3.1.1 | Perceived flooding trend and dynamics

For the question related to the trend of flooding magnitude in the past 20 years, a significant proportion of the respondents (42%) believe that it is getting stronger, whereas an almost equal proportion (38%) believe that there is no change (Figure 3). Some of the respondents (20%) reported that it is indiscernible. The discussants emphasised that flooding has increased in terms of amount and frequency. An older farmer explained: "river Harosha bifurcates at the entrance of the basin floor and during the rainy season the two big branches [each having a width > 50 m] become full." Furthermore, he explained: "there has been an increase in the size of the rivers over the last three decades." In line with the trend of the flash floods in the marginal grabens, the severity of the flash floods has increased over time and destroys villages. As evidenced by the loss of different livelihood assets, the respondents said: "the magnitude of the flash flood impacts have increased over time."

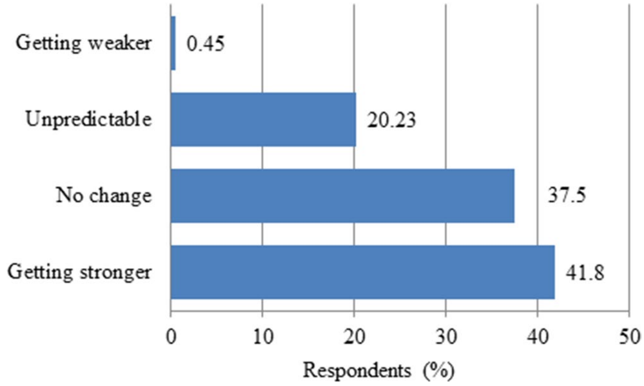

FIGURE 3 Perception of respondents on flooding trend in the study area

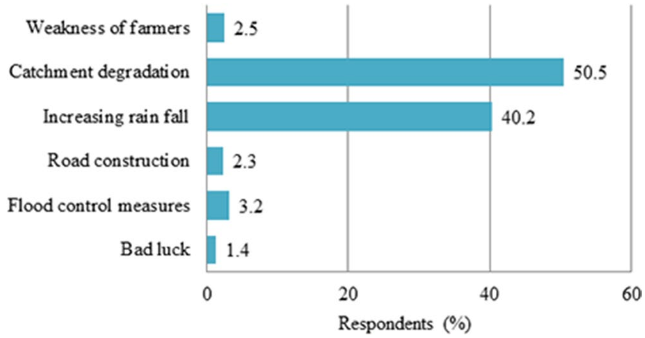

FIGURE 4 Main causes of flooding and its impacts in the study area perceived by respondents

3.1.2 | Perceived causes of flooding

Regarding the most important causes of flooding in the past 10 years, 51% of the respondents identified catchment degradation as the main cause, whereas 40% indicated that increasing rainfall is the main cause (Figure 4). They also thought that flood control measures taking place mainly on the river channels either to divert them for irrigation purposes or to control farmlands and settlements were causes. The discussants affirmed that the flood control measures carried out in the river channels are aggravating the destruction of farmland and settlement areas downstream of the measures. For example, the destruction of Gobena village was thought to be related to the channel narrowing flood control measures built 9.5 km upstream in the Gobu River. Ongoing road and railway construction in the graben bottom is also of concern to some of the respondents as it is thought to be instigating flooding hazards; this was particularly relevant to those living near such infrastructural development.

In the focus group discussion, we learned that a combination of anthropogenic and natural factors induced the floods in the Raya graben. The respondents said: "most of the flash floods (70%) are being caused by the rampant deforestation in the headwaters of the rivers. Besides, less maintenance on the physical structures and free-grazing at the headwater aggravate flash floods at the graben bottom." They also believe that farmers are making use of the fertile soil under the measures by destroying conservation measures in the headwaters. They stated that through spate irrigation canals, the floods get the chance to flow through and destroy farmlands and settlements, mainly because the spate irrigation canals are not well managed.

The discussants explained: "population growth, poor policy response to the increasing deforestation and climate change/variability are some of the drivers of the increase in flooding (vulnerability) and its impacts in the study area".

3.2 | Flood mitigation measures

Regarding the best option to protect the farmers from the impact of flooding, the majority of respondents (53%) suggested evacuating to neighbouring areas (other neighbourhoods, villages, or even districts) that do not experience

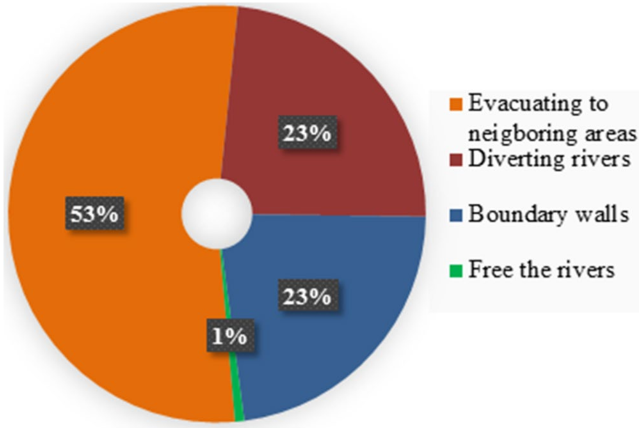

FIGURE 5 Primary flood mitigation options preferred by respondents. Neighbouring areas may be nearby neighbourhoods, but even other districts. Boundary walls refer to gabion structures and levees

flooding problems (Figure 5). Diverting the river and constructing boundary walls (such as gabion structures and levees) are the measures suggested by 24% and 23% of respondents, respectively. The discussants suggested concrete-based structures at the foot of the escarpment would be effective in reducing the ever-increasing channel widening of the rivers. Gabion check dams need to be constructed at appropriate places along the banks in consultation with local farmers. They also suggested the establishment of exclosures, afforestation and physical structures at the tributaries to enhance infiltration at the headwaters, and thereby reduce the flood volume. Furthermore, according to the discussants, proper forest management, riparian vegetation enhancement, and flood diversion at the basin floor inlet may reduce the risk of flooding. Moreover, discussants stressed: "increasing awareness and accountability of the community, reducing population pressure, and supplying alternative source of energy (to reduce deforestation) are important measures that need attention." This highlights the importance of the participation and accountability of the community in flood risk management.

We also asked respondents for their views on completely stopping flooding on the graben bottom. Most (73%) agreed to this the idea; in the focus group discussion and key informant interviews, the respondents explained that even though avoiding flooding is the priority, alternative or complementary options should be considered to maintain some water supply for their farming activities as floodwater supplements rain in the area. Yet, for some discussants, using ground water for irrigation is a worthy alternative option.

3.3 | Impacts of flooding

3.3.1 | Types and degrees of impacts

Due to flash floods that flow from the steep headwaters to the almost flat graben bottom, in addition to water inundation, large quantities of sediment are deposited on the graben floor. As a result, smallholder farmers experienced serious damage. Figure 6 shows that most of the total losses were experienced in farmlands (including crops, either harvested or standing) and settlements. Considerable proportions of respondents reported total loss of non-copped farmlands (24%), standing crops (11%), harvested crops (18%), houses (14%), and house properties (19%). Similarly, some of the respondents (33%) reported severe damage to farmland and harvested crops. Similarly, 24% of respondents experienced severe damage to their houses and household property. In addition, they experienced slight damage to animals, such as cattle, horses, goats, sheep and camels (Figure 5). The discussants explained that the flash floods threatened their lives, crops, livestock and other properties, and destroyed settlements, mainly during the past 15 years. Massive amounts of crops (on farm and storage) have also been destroyed. Moreover, about a third of the farmers' productive lands along the rivers have turned into badlands and riverbeds. Furthermore, destruction of school infrastructure, health facilities, traditional pathways and roads, and pollution of groundwater were also experienced.

Table 2 shows that on average a farmer experienced loss of nearly 2 *timad* of farmland, 1.3 *timad* of standing crops, and 1.6 Q/*timad* of harvested crops in some of the floods that happened during the five years preceding 2018. Every

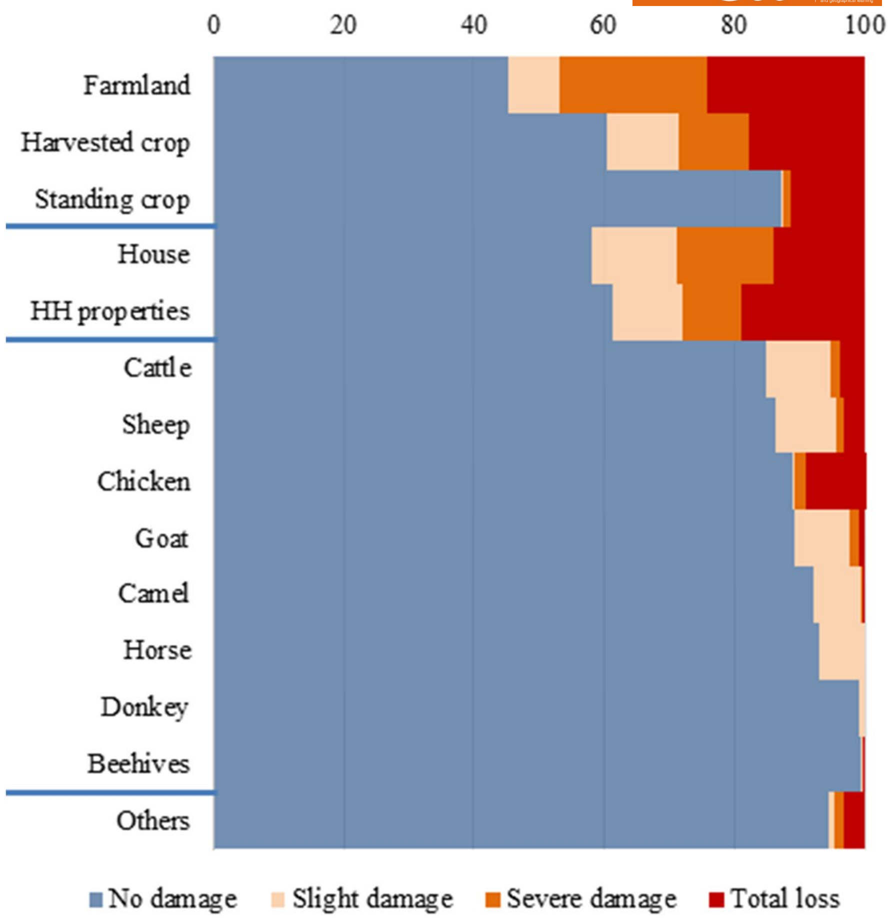

FIGURE 6 Type and severity of flood impacts experienced by survey respondents. Types of damage are categorised as farm and crops, housing, livestock, and others. In each category, items are in order of most to least affected (percentage of respondents)

TABLE 2 Average number (value) of resources the farmers lost due to flooding

Items	Mean	Standard error	Respondents (*n*)	Respondents (%)
Farmland (*timad*)	1.76	0.08	241	54.8
Standing crop (*timad*)	1.29	0.08	56	12.7
Harvested crop (quintal/*timad*)	1.6	0.14	126	28.6
House	1.14	0.03	181	41.1
Household property (US$)	250	50.00	113	25.7
Cattle	2.09	0.54	23	5.2
Camels	1.12	0.12	34	7.7
Horses	1.00	0.00	31	7.0
Donkeys	1.00	0.00	4	0.9
Goats	11.64	2.38	11	2.5
Sheep	5.58	1.16	24	5.5
Beehives	4.67	2.73	3	0.7
Chickens	11.88	1.99	52	11.8

Note: Only farmers who experienced loss were recorded (5 years preceding 2018). The animals lost were measured in numbers. The size of farmlands is in *timad*: 1 *timad* = 0.25 ha.

TABLE 3 Preferred prevention measures taken by farmers (*n* = 440; only one possible answer per category) to reduce the impact of flooding

	n	%
Protecting houses		
Dig new ditches	261	59
Make boundary wall	79	18
Keep ditches clean	34	8
Increase floor height	15	3
Move during flood season	3	1
Protecting household property		
Shift to relatives' houses	265	60
Elevate objects inside the house	155	35
Keep on floating objects	40	9
Sell property	5	1
Protecting domestic animals		
Construction of flood refuge mounds	158	36
Take to a relative in a dry village	112	25
Migrate to remote area	96	22
Move to higher ground near the village	16	4
Sell cattle	6	1
Protecting standing crops		
Dig new ditches	250	57
Make low dikes	169	38
Keep ditches clean	124	28
Harvest premature crops	23	5
Abandon	17	4
Convert to grazing land	3	1

household lost over US$250 (which is about one third of their annual per capita income) due to flood impacts. They also lost their domestic animals while grazing in the field or on their homestead (Table 2). Six of the respondents also lost one family member due to flooding; the discussants ranked this as the first critical problem because human life is not comparable with other losses.

3.3.2 | Prevention measures to mitigate impact of flooding

In the flood-prone areas on the graben bottom, where rivers deploy all their energy and destructive flash floods occur, the community takes various preventive measures before and during the flood events. We asked the respondents about the measures they take to prevent their houses, household property, domestic animals, and standing crops on farms from flooding hazards. The majority of respondents (59%) dig new ditches to protect their homesteads and stalls (Table 3). To protect their household property, 60% of respondents reported that they move their property to relatives' houses in nearby villages that are safer from flooding. Similarly, 35% of respondents place their property on roofs, walls and other standing objects. With regard to protecting domestic animals, most respondents construct livestock flood refuge mounds (36%), take them to nearby dry villages (25%), and migrate to remote areas (22%) until the flooding season ends. One of the most serious disasters farmers experience is loss of standing crops on their farmland. Hence, to protect their standing crops, 57% of respondents dig new ditches, whereas 38% make boundary walls around the flood entrance using gabion structures, stone bunds, or sand embankments.

TABLE 4 Summary of statistical testing of association between flood impact (damage) and household characteristics

	Variables	Pearson χ^2	p
Farmland damage	Marital status	32.1	.001
	Education	25.1	.05
	Family size	96.7	<.001
Standing crop damage	Age	222.4	.035
	Gender	14.5	.002
	Marital status	34.7	.001
	Family size	130.2	<.001
Harvested crops damaged	Age	309.9	.5
	Marital status	32.7	.04
	Religion	32.1	.006
	Family size	64.1	.09
Houses damaged	Age	331	.197
	Marital status	46.2	.001
Household property damaged	Gender	11.2	.01
	Marital status	23.8	.02
	Religion	35.1	<.001

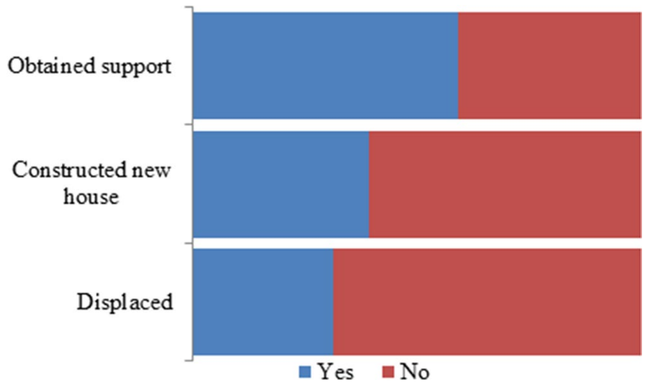

FIGURE 7 A mosaic table of the coping mechanisms of the flood affected households

3.3.3 | Association between flooding impacts and household characteristics

The study shows that some of the flooding impacts observed are associated with some of the household characteristics, such as age, gender, marital status, education or family size. We assessed the association for each impact based on the measured and expected values for experiencing different levels of damage (no damage, slight damage, severe damage, total loss) against household characteristics. For example, the test statistics for association show severity of farmland damage (measured and expected) is statistically different among households with different marital status, education level and family size (Table 4). Farmland damage is greater among farmers who are illiterate and who had traditional education. Statistically significant associations were also found for severity of damage of standing crops, harvested crops, houses and household property.

3.4 | Post flood coping

Regarding coping mechanisms after flooding, a χ^2 test showed that the responses are statistically different ($p < 0.001$). Figure 7 shows that 31% of respondents were displaced due to flooding impacts, whereas 40% of respondents were forced

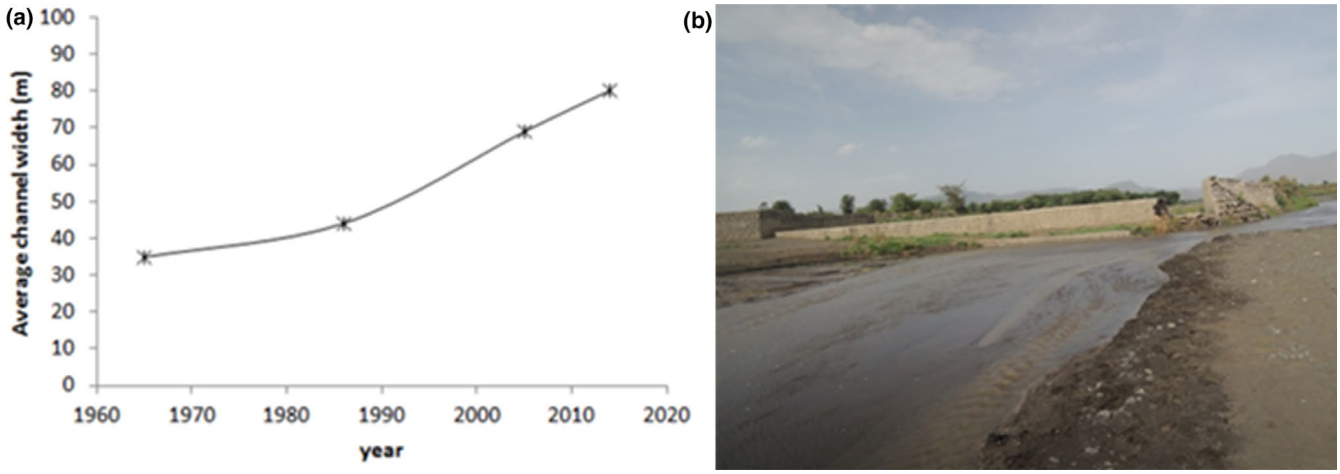

FIGURE 8 (a) Channel width changes of the Hara River between 1965 and 2014 (Demissie et al., 2019); and (b) stream direction change (Gobu River) due to a diversion structure. Flow direction is towards the back of the photo (photo taken by Biadgilgn Demissie, 2014). In the photo, the concrete walls were constructed to divert the water for spate irrigation; however, they caused a change in the direction of the river, destroying farmlands to the right of the structure

to construct a new house for their settlement. Pearson's χ^2 test does not show statistically significant differences in terms of gender and marital status in observed and expected displacement of respondents. Nevertheless, there are statistically significant differences in being displaced among respondents based on their family size ($p = 0.001$).

Out of the total respondents, 59% obtained support from different sources (families and friends, local social institutions, regional government, federal government, or NGOs). Among those who obtained support, the regional government assisted 98%, whereas families and friends assisted 48%. Insignificant proportions of victim respondents obtained support from NGOs (15%), federal government (6%) and social institutions (2%). The respondents who received support were asked to rate the level of support they obtained. In their response, 40% of respondents rated the support as low, whereas 35% rated the support as adequate. Surprisingly, only 13% of respondents rated it as high; most of these respondents obtained support from families, friends, and regional government.

4 | DISCUSSION

4.1 | Flooding trends and causes

The community claims that there is an increase in flood events (in terms of discharge and frequency), and this is also evident from changes in the stream channel forms (width, length, depth). Figure 8a shows the continuous increase in channel width of the Hara River in the study area during the past five decades. This change is in line with the claims of respondents. In support of this, the study by Castelli and Bresci (2017) in the same area depicted bank collapse as one of the major problems faced by farmers in carrying out their farming activities. Though this requires further investigation, studies by Demissie et al. (2015; 2018) could be good references of the inundation of farmlands and channel widening. In the rivers of the study area, a sudden increase in discharge characterises flash floods, the high peak of which almost coincides with the flood onset. Flow velocities can be high, in the range of 2–3 m/s with Froude numbers greater than 1, indicating a supercritical flow regime (Billi, 2011). In a close agro-ecology and geological setting, the study by Meaza et al. (2018) has also reported increases in flash flood events (in terms of quantity and frequency) in the Aba'ala limestone graben from 2015 to 2017. Furthermore, Meaza et al. (2019) reported increased flows (up to 732 m^3/s) recorded in the largest rivers (with catchment of 297 km^2) during the rainy seasons.

At the same time, an almost equal proportion of respondents claimed that there has been no change in flood events over the past 20 years. This might be due to (1) differences in the severity of flooding impacts experienced among community members, or (2) differences in perceptions on the occurrence of flooding events. These respondents claim that the increasing hazard of flooding is related to the flood control measures carried out in upstream channels rather than increases in the volume or frequency of floods. For example, the concrete wall constructed for diversion (Figure 8b) induced a change in the direction of the river and caused destruction of farmlands along its new direction. Differences in views of the local community imply further investigation is needed on the trend of flooding.

Some of the respondents reported that the flooding trend is indiscernible. This response is very interesting because it relates directly to rainfall pattern. In the study area, rainfall is highly variable during each season and over the past 30 years (Angassa & Oba, 2007; Bewket, 2009; Megersa et al., 2014; Nyssen et al., 2005; Seleshi & Zanke, 2004; Suryabhagavan, 2017). Rainfall variability is probably responsible for the unpredictable flooding behavior in the study area (though information about rainfall intensity is scarce – and how it has changed in recent decades – which may play a very important part in triggering flash floods) (Norbiato et al., 2008; Borga et al., 2014; Douinot et al., 2016).

Regarding the cause of flooding, farmers perceive that catchment degradation and increases in rainfall amount are the most important causes. However, in the study area, studies by Asfaha et al. (2015), Demissie et al. (2015, 2017), and Annys et al. (2016) confirmed that no increase in rainfall amount has occurred during the past 20 years. The same authors also reported an increase in vegetation cover in the upper catchments. Human intervention, mainly destruction of soil, water conservation measures and flood control measures in the river channels, as reported by farmers, may have aggravated the flooding situation in the study area. Some studies (Blaikie et al., 1994; Wisner et al., 2003) also claim that the social, political, and economic environment is as much a cause of disasters as the natural environment; even though very few respondents claimed that road construction is one of the most important causes of flooding. For example, in the study by Demissie et al. (2017) in the Raya graben, bridge narrowing was reported to aggravate thick sediment deposition and bridge clogging, which in effect caused bank overflow and flooding over farmlands and settlements.

4.2 | Mitigation measures in practice, success and challenges

As reported by the discussants, they implemented mitigation measures, such as biological (e.g., tree planting) and physical structures (stone terraces) in the headwaters of the rivers (Figure 9a) and gabions along the riverbanks in the graben floor (Figure 9b). Some of these mitigation measures were successful at the headwaters, yet they were insufficient to reduce the effect of flooding in the graben floor. Similarly, most of the biological and engineering works failed due to poor follow-up and maintenance. Moreover, the technical failure during construction of gabion check dams affected the sustainability of the flood mitigation measures. This is particularly attributable to failure to use the knowledge and experience of local farmers (Correia et al., 1998). In the same study area, Castelli et al. (2018) studied the need for community participation in modernising spate irrigation. For instance, most of the failures in spate irrigation systems and flood control structures were reportedly due to lack of community participation (Castelli et al., 2018).

Regarding challenges of mitigation, overall, the respondents confirmed a lack of integration among the government, experts and the community. Studies show that financing, lack of community participation, and lack of sustainability of projects might be among the challenges of flood risk management (Castelli & Bresci, 2017; Castelli et al., 2018; Trogrlić

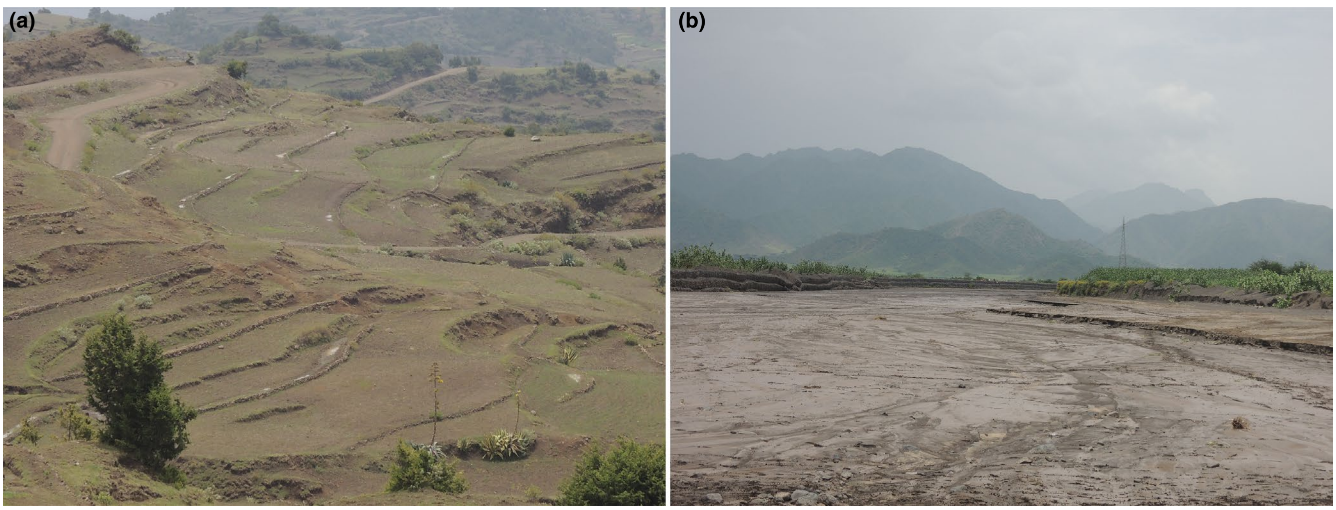

FIGURE 9 (a) Terraces in the headwaters of the Raya rivers; and (b) gabion structures in the graben bottom. Photo by Biadgilgn Demissie, 2015 et al., 2018). We learned from our study that there remains a need for outreach that increases awareness and implementation of conservation and best management practices specific to reducing flash floods. To this end, it is important to understand farmers' perspectives on what practices are effective, practical, and economically attainable (Lemke et al., 2010). Comprehensive and integrated water resource governance and flood management can be attained with a clear flood management plan that involves the community (Hartmann & Driessen, 1968; Smith et al., 2017). In the process of flood risk management, participation of the community, such as identification, analysis, treatment, monitoring and evaluation of disaster risks are vital (Castelli & Bresci, 2017; Castelli et al., 2018; Maskrey, 2011). Consideration of other experiences of flood management in other parts of the world is also recommended (Samuels et al., 2006).

4.3 | Flooding impact and prevention

It is highly probable that non-educated farmers spend more time carrying out their farm activities than those who are educated, as educated farmers have the opportunity to work on non-farm activities (Huffman, 1980; Marenya et al., 2003; Mishra & Goodwin, 1997). But the reason why non-educated farmers are more susceptible to flood damage may be due to their lower knowledge and skills about farm management (Kilpatrick, 2000; Marenya et al., 2003; Prokopy et al., 2008; Samir, 2013; Tosakana et al., 2010).

Married households seem more susceptible to damage perhaps due to extra activities at home and away from the farm, such as social activities and family affairs. Among the married households, those with smaller numbers of children were also more vulnerable to any kind of flood damage. This may perhaps be attributable to weak support or lack of support from family members as their children may be too young to help in farm management (Rob & Burton, 2006). We learned from this study that gender and religion are important indicators of flood damage. This finding is probably related to female-headed households, which are susceptible to damage due to lower capacity (physical and financial) and experience to handle farm management activities (Damisa & Yohanna, 2007; Druschke & Secch, 2014).

Overall, most of the damage experienced by farmers is related to houses and farmland. The destruction of houses and household property is a serious problem that was stressed by the respondents in the focus group discussion. The magnitude of the damage (in terms of frequency and size) may be attributable to the proximity of houses to the rivers. Farm-related damage is either destruction of farmland (partly or totally), standing crops, or harvested and piled up crops. Most of this damage affects farmlands near the river channels (Figure 10).

4.4 | Views of respondents in coping and mitigation measures

Regarding flood mitigation measures, most respondents suggested evacuating to other places (districts, neighbourhoods, or villages) as a best option. However, a study by Tempels (2015) in Europe reports that respondents in a flood risk area

FIGURE 10 (a) Farmland near stream channels destroyed by flooding and (b) villages located in the flood plains (right). Image (b) shows sediment deposition that is meters thick; the house in the center of the photo is filled up by sediment and only the thatched roof is visible above the ground. Photo by Biadgilgn Demissie, 2015 want to stay where they live. He explained that respondents more aware of flood risk are more likely to enjoy living where they live. These respondents were aware that the risk is low. However, in the Raya graben, the awareness of the community about flooding, and the availability and sustainability of flood control measures is different from Europe. Hence, in this study, the suggestion by farmers to move to other places is valid because it reflects their fear that controlling the flooding impact may not be possible. Their fear might have emanated from the experience that the existing mitigation measures are not effective enough to protect them from disasters in the future. Moreover, compared with Europe, Raya farmers have little to move; when they move, it is relatively easy to build a new house, while keeping the same farmland. Resettlement is also an option, but with careful planning and execution as multiple challenges could be introduced during planning and integration (Kita, 2017).

A significant proportion of respondents also believe that boundary walls and diverting rivers could be solutions to reducing the flooding impact. Related to this, Castelli and Bresci (2017) also reported that local communities in the same study area believe that gabion structures are stronger to protect bank collapse and hence loss of farmlands. These structures are indeed stronger than the traditional flood control measures. But previous studies by Demissie et al. (2015; 2018) and our field observation downstream of the rivers in the Raya graben show that such gabion structures lead to narrowing channels (which means increasing flow depth and velocity) and farmland destruction downstream (Billi et al., 2018; Demissie et al., 2015, 2018). Hence, freeing the rivers to follow their natural course (outside of built-up land) in the upstream areas could be a solution for flooding problems in downstream areas (Demissie et al., 2017, 2018; Ward et al., 2001). An alternative would be the construction of mounds surrounded by gabions to keep livestock safe and possibly to build homesteads; and to allow the rest of the plain to be flooded (Briggs, 2009).

Reducing the amount of flooding that comes to the graben floor through soil and water conservation measures in the headwaters could be a sustainable solution to reduce the impact of flooding in the graben floor. In line with this, other alternatives have to be in place, such as ground water irrigation schemes. These alternatives may have many advantages: (1) using the land occupied by the rivers for farming (Demissie et al., 2015); (2) reducing the huge amount of sediment dropped on farmlands (Billi, 2007; Demissie et al., 2018); and (3) achieving sustainable water availability and the introduction of modern irrigation agriculture (Howell, 2001; Loucks, 2010; Meaza et al., 2019). Avoiding spate irrigation and enhancing groundwater-based irrigation is complex in the study area because spate irrigation from floods is the main source of water for crop production (Castelli et al., 2018). Hence, the community may benefit from integrated use of both spate irrigation from rivers and ground water extraction for modern irrigation (Negash et al., 2020). In the Raya graben, many spate irrigation projects over the past 20 years have a history of failure (Castelli et al., 2018). One of the main reasons is the failure of local people participating and so using their local knowledge in spate irrigation projects (Castelli et al., 2018). The participation of the community is still important when enhancing and integrating spate irrigation with ground water irrigation schemes (Castelli et al., 2018). Involving local farmers in irrigation development processes and building a solid knowledge base is important for effective management of both irrigation and flooding problems (Castelli & Bresci, 2017; Habiba et al., 2013; Shaw, 2012).

5 | CONCLUSION

The objective of this study was to investigate the flood impacts, present responses and future flood hazard management practices in Raya graben, northern Ethiopia. Even though gaged rainfall and flow data are not available in the area to show the magnitude, frequency, impacts and possible future threats, farmers perceive that flood volume has been increasing over the past 20 years due to upper catchment degradation and increases in rainfall depth. The destruction of soil and water conservation and flood control measures along river banks have aggravated flooding in the area. Loss of standing crops and harvested crops are among the damages that farmers experience; destruction of houses and household property is also common.

This study examines the knowledge and perception of communities about the magnitude of flooding, mitigation strategies, and the impact of flooding through interviews and questionnaire-based surveys in ungaged catchments in a dryland environment. The study concludes that, for any flood management engagements, particularly in areas where gaged data are not available and even impossible to record, information obtained from communities in flood-prone areas is crucial through interview and survey methods. With the increasing impact of flood hazards, integrated flood management practices are required in the future. Importantly, developing a diverse set of flood management frameworks, and enhancing effective collaboration between the community and stakeholders are of primary importance for better flood risk management in such flash flood ephemeral river basins.

Most studies use gaged data to assess flood conditions. This study shows the importance of community knowledge-based assessment of flooding magnitude, frequency and impacts. The findings of the study add to the knowledge base on the importance of community knowledge, experience, and participation in flood risk management processes. There is no clear evidence about the increasing/decreasing trend of flood magnitude and frequency in the study area, and further studies are recommended. Similarly, the political ecology aspect of flood hazards in the study area was not addressed and further studies are required. Furthermore, the use of open access, citizen science and social media data for flood hazard and impact assessment could be options for future studies.

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REFERENCES

Abid, M., Schilling, J., Scheffran, J., & Zulfiqar, F. (2016) Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan. *Science of the Total Environment*, 547, 447–460. https://doi.org/10.1016/j.scitotenv.2015.11.125

Achary, A., & Prakash, A. (2019) When the river talks to its people: Local knowledge-based flood forecasting in Gandak River basin, India. *Environmental Development*, 31, 55–67. https://doi.org/10.1016/j.envdev.2018.12.003

Angassa, A., & Oba, G. (2007) Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. *Agricultural Systems*, 94, 715–725. https://doi.org/10.1016/j.agsy.2007.02.012

Annys, S., Demissie, B., Zenebe, A., & Nyssen, J. (2016) Land cover changes as impacted by rainfall variability in the escarpments of the Ethiopian Rift Valley". *Regional Environmental Change*, 17, 451–463. https://doi.org/10.1007/s10113-016-1031-2

Asfaha, T. G., Frankl, A., Haile, M., & Nyssen, J. (2016) Catchment rehabilitation and hydro-geomorphic characteristics of mountain streams in the western Rift Valley escarpment of northern Ethiopia. *Land Degradation & Development*, 27, 26–34. https://doi.org/10.1002/ldr.2267

Asfaha, T. G., Frankl, A., Haile, M., Zenebe, A., & Nyssen, J. (2015) Determinants of peak discharge in steep mountain catchments — Case of the Rift Valley escarpment of Northern Ethiopia. *Hydrology*, 529, 1725–1739. https://doi.org/10.1016/j.jhydrol.2015.08.013

Batica, J., & Gourbesville, P. (2016) Resilience in flood risk management - A new communication tool. *Procedia Engineering*, 154, 811–817. https://doi.org/10.1016/j.proeng.2016.07.411

Berry, R., Horritt, M., Dewar, C., Baigent, S., & Martin, J. (2008) Development of flood mapping formats for the lee catchment flood risk assessment & management study. *Irish National Hydrology Conference 2008*. County Meath, Ireland.

Bewket, W. (2009) Rainfall variability and crop production in Ethiopia: Case study in the Amhara region. In: S. Ege, H. Aspen, B. Teferra, S. Bekele (Eds.) *Proceedings of the 16th International Conference of Ethiopian Studies*. Trondheim.

Billi, P. (2007) Morphology and sediment dynamics of ephemeral stream terminal distributary systems in the Kobo Basin (northern Welo, Ethiopia). *Geomorphology*, 85, 98–113. https://doi.org/10.1016/j.geomorph.2006.03.012

Billi, P. (2008) Bedforms and sediment transport processes in the ephemeral streams of Kobo basin, Northern Ethiopia. *Catena*, 75, 5–17. https://doi.org/10.1016/j.catena.2008.04.002

Billi, P. (2011) Flash flood sediment transport in a steep sand-bed ephemeral stream. *International Journal of Sediment Research*, 26(2), 193–209. https://doi.org/10.1016/S1001-6279(11)60086-3

Billi, P., Demissie, B., Nyssen, J., Moges, G., & Fazzini, M. (2018) Meander hydromorphology of ephemeral streams: Similarities and differences with perennial rivers. *Geomorphology*, 319, 35–46. https://doi.org/10.1016/j.geomorph.2018.07.003

Blaikie, P. M., Cannon, T., Davis, I., & Wisner, B. (1994) *At risk: Natural hazards, people's vulnerability, and disasters*. Hove, UK: Psychology Press, p. 284.

Booij, M. J. (2005) Impact of climate change on river flooding assessed with different spatial model resolutions. *Hydrology*, 303(1–4), 176–198. https://doi.org/10.1016/j.jhydrol.2004.07.013

Borga, M., Stoffel, M., Marchi, L., Marra, F., & Jakob, M. (2014) Hydrogeomorphic response to extreme rainfall in headwater systems: Flash floods and debris flows. *Hydrology*, 518, 194–205. https://doi.org/10.1016/j.jhydrol.2014.05.022

Bradford, R., O'Sullivan, J., VanAm Der Craats, I., Krywkow, J., Rotko, P., Aaltonen, J. et al. (2012) Risk perception - Issues for flood management in Europe. *Natural Hazards and Earth Systems Sciences*, 12, 2299–2309. https://doi.org/10.5194/nhess-12-2299-2012

Briggs, G. (2009) *Livestock flood refuge mounds*. Industry & Investment NSW, Australia, Primefact 961, 6 p. Available from: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/304491/livestock-flood-refuge-mounds.pdf Accessed 8th April 2021

Bryan, K. (1922) Erosion and sedimentation in the Papago Country. *Bulletin United States Geological Survey*, 730-B, 88. https://doi.org/10.3133/b730B

Bull, L. J., & Kirkby, M. J. (2002) *Dryland rivers: Hydrology and geomorphology of semi-arid channels*. West Sussex, UK: John Wiley & Sons.

Caelli, K. (2001) Engaging with phenomenology: Is it more of a challenge than it needs to be? *Quantitative Health Research*, 11, 273–282. https://doi.org/10.1177/104973201129118993

Castelli, G., & Bresci, E. (2017) Participatory rural appraisal for diagnostic analysis of spate irrigation systems in Raya Valley, Ethiopia. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 118(1), 129–139.

Castelli, G., Bresci, E., Castelli, F., Hagos, E. Y., & Mehari, A. (2018) A participatory design approach for modernization of spate irrigation systems. *Agricultural Water Management*, 210, 286–295. https://doi.org/10.1016/j.agwat.2018.08.030

Cerbone, D. R. (2010) *Understanding phenomenology*. Durham, UK: Acumen Publishing Limited.

Correia, F. N., Fordham, M., Saraiva, M. D., & Bernardo, F. (1998) Flood hazard assessment and management: Interface with the public. *Water Resources Management*, 12, 209–227. https://doi.org/10.1023/A:1008092302962

Creswell, J. W. (2013) *Qualitative inquiry & research design: Choosing among the five approaches*. Thousand Oaks, CA: SAGE Publications, pp. 77–83.

Damisa, M. A., & Yohanna, M. (2007) Role of rural women in farm management decision making process: Ordered probit analysis. *World Journal of Agricultural Sciences*, 3(4), 543–546. https://dx.doi.org/10.3923/tasr.2007.241.245

Daniel, V. E., Florax, R. J., & Rietveld, P. (2009) Flooding risk and housing values: An economic assessment of environmental hazard. *Ecological Economics*, 69, 355–365. https://doi.org/10.1016/j.ecolecon.2009.08.018

Demissie, B., Amsalu, A., Tesfamariam, Z., Nyssen, J., Meaza, H., Asfaha, T. G., Zenebe, A., Gregoretti, C., & Van Eetvelde, V. (forthcoming) Landscape changes in the semi-closed Raya agricultural graben floor, northern Ethiopia. *Earth Systems and Environment*.

Demissie, B., Billi, P., Frankl, A., Haile, M., & Nyssen, J. (2017) Excessive river sedimentation at bridges in the Raya graben (northern Ethiopia). *Land Degradation & Development*, 28(946), 958. https://doi.org/10.1002/ldr.2572

Demissie, B., Frankl, A., Haile, M., & Nyssen, J. (2015) Biophysical controlling factors in upper catchments and braided rivers in drylands: The case of a marginal graben of the Ethiopian Rift Valley. *Land Degradation & Development*, 26, 748–758. https://doi.org/10.1002/ldr.2357

Demissie, B., Nyssen, J., Billi, P., Haile, M., Vaneetvelde, V., & Frankl, A. (2018) Land-use/cover changes in relation to stream dynamics in a marginal graben along the northern Ethiopian Rift Valley. *Physical Geography*, 40(1), 71–90. https://doi.org/10.1080/02723646.2018.1458577

Demissie, B., Van Eetvelde, V., Frankl, A., Billi, P., Asfaha, T. G., Haile, M., & Nyssen, J. (2019) Dynamics of ephemeral streams at the foot of degraded catchments in northern Ethiopia. *Land Degradation & Development*, 31(5), 591–606. https://doi.org/10.1002/ldr.3474

Diakakis, M., & Deligiannakis, G. (2015) Flood fatalities in Greece: 1970–2010M. *Journal of Flood Risk Management*, 10, 115–123. https://doi.org/10.1111/jfr3.12166

Diakakis, M., Priskos, G., & Skordoulis, M. (2018) Public perception of flood risk in flash flood prone areas of Eastern Mediterranean: The case of Attica Region in Greece. *International Journal of Disaster Risk Reduction*, 28, 404–413. https://doi.org/10.1016/j.ijdrr.2018.03.018

Dixit, A. (2003) Floods and vulnerability: Need to rethink flood management. *Natural Hazards*, 28, 155–179. https://doi.org/10.1023/A:1021134218121

Do, H. X., Westra, S., & Leonard, M. (2017) A global-scale investigation of trends in annual maximum streamflow. *Journal of Hydrology*, 552, 28–43. https://doi.org/10.1016/j.jhydrol.2017.06.015

Douinot, A., Roux, H., Garambois, P-A., Larnier, K., Labat, D., & Dartus, D. (2016) Accounting for rainfall systematic spatial variability in flash flood forecasting. *Journal of Hydrology*, 541, 359–370. http://dx.doi.org/10.1016/j.jhydrol.2015.08.024

Druschke, C. G., & Secch, S. (2014) The impact of gender on agricultural conservation knowledge and attitudes in an Iowa watershed. *Journal of Soil and Water Conservation*, 69(2), 95–106. https://doi.org/10.2489/jswc.69.2.95

Flick, U. (1998) *The SAGE handbook of qualitative data analysis*. London, UK: SAGE publications Ltd, p. 639.

Gardiner, J. (1994) Environmental impact of floods. In: G. Rossi, N. Harmancioğlu, & V. Yevjevich (Eds.) *Coping with floods. NATO ASI Series (Series E: Applied Sciences)*, vol. 257. Dordrecht, Netherlands: Springer.

Global Facility for Disaster Reduction and Recovery (GFDRR) (2019) *Disaster risk profile, Ethiopia. Africa disaster risk financing initiative*. Washington, DC: The World Bank Group.

Groenewald, T. (2004) A phenomenological research design illustrated. *International Journal of Qualitative Methods*, 3(1), 42–55. https://doi.org/10.1177/160940690400300104

Habiba, U., Shaw, R., & Abedin, A. (Eds.) (2013) *Disaster risk reduction approaches in Bangladesh, disaster risk reduction*. Tokyo, Japan: Springer Japan. https://doi.org/10.1007/978-4-431-54252-0

Hadley, R. F. (1968) Ephemeral streams. In: *Geomorphology. Encyclopedia of Earth Science*. Berlin, Germany: Springer. https://doi.org/10.1007/3-540-31060-6_108

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S. et al. (2013) Global flood risk under climate change. *Nature Climate Change*, 3, 816–821. https://doi.org/10.1038/nclimate1911

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I. et al. (2018) Impacts of 1.5ºC Global Warming on Natural and Human Systems. In: *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*, IPCC. https://www.ipcc.ch/sr15/chapter/chapter-3/

Howell, T. A. (2001) Enhancing water use efficiency in irrigated agriculture. *Agronomy Journal*, 93, 281–289. https://doi.org/10.2134/agronj2001.932281x

Hudec, O., Reggiani, A., & Siserova, M. (2018) Resilience capacity and vulnerability: A joint analysis with reference to Slovak urban districts. *Cities*, 73, 24–35. https://doi.org/10.1016/j.cities.2017.10.004

Huffman, W. E. (1980) Farm and off-farm work decisions: The role of human capital. *The Review of Economics and Statistics*, 62(1), 14–23. https://doi.org/10.2307/1924268

Huntington, H. P. (2000) Using traditional ecological knowledge in science: methods and applications. *Ecological Applications*, 10, 1270–1274. https://doi.org/10.1890/1051-0761(2000)010[1270:UTEKIS]2.0.CO;2

Jansen, H. (2010) The logic of qualitative survey research and its position in the field of social research methods. *Qualitative Social Research*, 11(2). https://doi.org/10.17169/fqs-11.2.1450

Kilpatrick, S. (2000) Education and training: Impacts on farm management practice. *The Journal of Agricultural Education and Extension*, 7(2), 105–116. https://doi.org/10.1080/13892240008438811

Kita, S. M. (2017) Urban vulnerability, disaster risk reduction and resettlement in Mzuzu city, Malawi. *International Journal of Disaster Risk Reduction*, 22, 158–166. https://doi.org/10.1016/j.ijdrr.2017.03.010

Knighton, A. D., & Nanson, G. C. (1997) Distinctiveness, diversity and uniqueness in arid zone river systems. In D. S. G. Thomas (Ed.), *Arid zone geomorphology: Process, form and change in drylands*, 2nd edn. (pp. 185–203). Oxford, UK: John Wiley & Sons.

Kontokosta, C. E., & Malik, A. (2018) The Resilience to emergencies and disasters index: Applying big data to benchmark and validate neighborhood resilience capacity. *Sustainable Cities and Society*, 36, 272–285. https://doi.org/10.1016/j.scs.2017.10.025

Lemke, A. M., Lindenbaum, T. T., Perry, W. L., Herbert, M. E., Tear, T. H., & Herkert, J. R. (2010) Effects of outreach on the awareness and adoption of conservation practices by farmers in two agricultural watersheds of the Mackinaw River, Illinois. *Journal of Soil and Water Conservation*, 65(5), 304–315. https://doi.org/10.2489/jswc.65.5.304

Lengnick-Hall, C. A., Beck, T. E., & Lengnick-Hall, M. L. (2011) Developing a capacity for organizational resilience through strategic human resource management. *Human Resource Management Review*, 21(3), 243–255. https://doi.org/10.1016/j.hrmr.2010.07.001

Lindsell, K. M., & Prater, S. C. (2003) Abstract on “assessing community impacts of national disasters”. *National Hazard Review*, 4(4), 176–178.

Lo, A. Y., & Chan, F. (2017) Preparing for flooding in England and Wales: The role of risk perception and the social context in driving individual action. *Natural Hazards*, 88, 367–387. https://doi.org/10.1007/s11069-017-2870-y

Loucks, D. P. (2010) Sustainable water resources management. *Journal of Water International*, 25(1), 3–10. https://doi.org/10.1080/02508060008686793

Mallakpour, I., & Villarini, G. (2015) The changing nature of flooding across the central United States. *Nature Climate Change*, 5(3), 250–254. https://doi.org/10.1038/nclimate2516

Marenya, P. P., Oluoch-Kosura, W., Place, F., & Barrett, C. B. (2003) *Education, non-farm income, and farm investment land-scarce western Kenya*. BASIS Brief No. 4.

Maskrey, A. (2011) Revisiting community-based disaster risk management. *Environmental Hazards*, 10(1), 42–52. https://doi.org/10.3763/ehaz.2011.0005

McNamara, D. E., & Keeler, A. (2013) A coupled physical and economic model of the response of coastal real estate to climate risk. *Nature Climate Change*, 3, 559–562. https://doi.org/10.1038/nclimate1826

Meaza, H., Frankl, A., Demissie, B., Poesen, J., Zenebe, A., Gebresamuel, G. et al. (2019) Water balance components of the potential agricultural grabens along the Rift Valley in northern Ethiopia. *Journal of Hydrology: Regional Studies*, 24, 100616. https://doi.org/10.1016/j.ejrh.2019.100616

Meaza, H., Frankl, A., Poesen, J., Zenebe, A., Deckers, J., Van Eetvelde, V. et al. (2017) Opportunities and challenges of natural resources for rural development in marginal grabens-a state of the art with implications for the Rift Valley system in Ethiopia. *Journal of Arid Environments*, 147, 1–16. https://doi.org/10.1016/j.jaridenv.2017.08.003

Meaza, H., Frankl, A., Poesen, J., Zenebe, A., Van Eetvelde, V., Demissie, B. et al. (2018) Water balance variability in the confined Aba’ala limestone graben of the western margin of the Danakil depression, Northern Ethiopia. *Hydrological Sciences Journal*, 63, 957–977. https://doi.org/10.1080/02626667.2018.1466055

Megersa, B., Markemann, A., Angassa, A., Ogutu, J. O., Piepho, H., & Zaráte, A. V. (2014) Impacts of climate change and variability on cattle production in southern Ethiopia: Perceptions and empirical evidence. *Agricultural Systems*, 130, 23–34. https://doi.org/10.1016/j.agsy.2014.06.002

Mello, R. A. (2002) Collocation analysis: A method for conceptualizing and understanding narrative data. *Qualitative Research*, 2(2), 231–243. https://doi.org/10.1177/146879410200200206

Mengistu, T., Teketay, D., Hulten, H., & Yemshaw, Y. (2005) The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments*, 60, 259–281. https://doi.org/10.1016/j.jaridenv.2004.03.014

Merz, B., Kreibich, H., Schwarze, R., & Thieken, A. (2010) Assessment of economic flood damage. *Natural Hazards and Earth System Sciences*, 10, 1697–1724. https://doi.org/10.5194/nhess-10-1697-2010

Mishra, A. K., & Goodwin, B. K. (1997) Farm income variability and the supply of off-farm labor. *American Journal of Agricultural Economics*, 79, 880–887. https://doi.org/10.2307/1244429

Munro, R. N., Deckers, J., Grove, A. T., Haile, M., Poesen, J., & Nyssen, J. (2008) Soil and erosion features of the Central Plateau region of Tigrai-learning from photo monitoring with 30 years interval. *Catena*, 75, 55–64. https://doi.org/10.1016/j.catena.2008.04.009

Mustafa, D. (1998) Structural causes of vulnerability to flood hazard in Pakistan. *Economic Geography*, 74, 289–305. https://doi.org/10.2307/144378

Negash, E., Gebresamuel, G., Embaye, T.-A., Nguvulu, A., Meaza, H., Gebrehiwot, M. et al. (2020) Impact of headwater hydrological deficit on the downstream flood-based farming system in northern Ethiopia. *Irrigation and Drainage*, 69(3), 342–351. https://doi.org/10.1002/ird.2413

Nguyen, K. V., & James, H. (2013) Measuring household resilience to floods: a case study in the Vietnamese Mekong River Delta. *Ecology and Society*, 18(3), 13–26. http://dx.doi.org/10.5751/ES-05427-180313

Norbiato, D., Borga, M., Degli Esposti, S., Gaume, E., & Anquetin, S. (2008) Flash flood warning based on rainfall thresholdsand soil moisture conditions: an assessmentfor gauged and ungauged Basins. *Journal of Hydrology*, 362, 274–290. https://doi.org/10.1016/j.jhydrol.2008.08.023

Nott, J. (2006) *Extreme events: A physical reconstruction and risk assessment*. New York, NY: Cambridge University Press.

Nyssen, J., Biruk, B., Tesfamariam, Z., Frankl, A., Demissie, B., Ghebreyohannes, T. et al. (2017) Geographical determinants of inorganic fertiliser sales and of resale prices in north Ethiopia. *Agricultural Ecosystem and Environment*, 249, 256–268. https://doi.org/10.1016/j.agee.2017.07.037

Nyssen, J., Vandenreyken, H., Poesen, J., Moeyersons, J., Deckers, J., Haile, M. et al. (2005) Rainfall erosivity and variability in the Northern Ethiopian Highlands. *Journal of Hydrology*, 311, 172–187. https://doi.org/10.1016/j.jhydrol.2004.12.016

Posthumus, H., Hewett, C., Morris, J., & Quinn, P. (2008) Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management*, 95, 787–798. https://doi.org/10.1016/j.agwat.2008.02.001

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D., & Baumgart-Getz, A. (2008) Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation*, 63(5), 300–311. https://doi.org/10.2489/jswc.63.5.300

Qasim, S., Qasim, M., Shrestha, R. P., Khan, A. N., Tun, K., & Ashraf, M. (2016) Community resilience to flood hazards in Khyber Pukhthunkhwa province of Pakistan. *International Journal of Disaster Risk Reduction*, 18, 100–106. https://doi.org/10.1016/j.ijdrr.2016.03.009

Reiter, S., Stewart, G., & Bruce, C. S. (2011) A strategy for delayed research method selection: Deciding between grounded theory and phenomenology. *Electronic Journal of Business Research Methods*, 9(1), 35–46.

Rob, J., & Burton, F. (2006) An alternative to farmer age as an indicator of life-cycle stage: The case for a farm family age index. *Journal of Rural Studies*, 22(4), 4485–4492. https://doi.org/10.1016/j.jrurstud.2006.02.005

Salmon, J., & Buetow, S. (2013) Transcendental phenomenology and classic grounded theory as mixed data collection methods in a study exploring fetal alcohol spectrum disorder in New Zealand. *Journal of Population Therapeutics and Clinical Pharmacology*, 20(2), 82–90.

Samir, K. C. (2013) Community vulnerability to floods and landslides in Nepal. *Ecology and Society*, 18(1), 8. http://dx.doi.org/10.5751/ES-05095-180108

Samuels, P., Klijn, F., & Dijkman, J. (2006) An analysis of the current practice of policies on river flood risk management in different countries. *Irrigation and Drainage*, 55, S141–S150. https://doi.org/10.1002/ird.257

Seleshi, Y., & Zanke, U. (2004) Recent changes in rainfall and rainy days in Ethiopia. *International Journal of Climatology*, 24, 973–983. https://doi.org/10.1002/joc.1052

Sendzimir, J., Magnuszewski, P., Flachner, Z., Balogh, P., Molnar, G., Sarvari, A., & Nagy, Z. (2007) Assessing the resilience of a river management regime: informal learning in a shadow network in the Tisza River Basin. *Ecology and Society*, 13(1), 11. http://www.ecologyandsociety.org/vol13/iss1/art11/

Shaw, R. (2012) Community-based disaster risk reduction. In: R. Shaw (Ed.), *Community-Based Disaster Risk Reduction (Community, Environment and Disaster Risk Management*, Vol. 10. Bingley: Emerald Group Publishing Limited, p. i. https://doi.org/10.1108/S2040-7262(2012)0000010027

Smith, K. (2003). *Environmental hazards: Assessing risk and reducing disaster*. London, UK: Routledge.

Smith, L., Liang, Q., James, P., & Lin, W. (2017) Assessing the utility of social media as a data source for flood risk management using a real-time modelling framework. *Flood Risk Management*, 10, 370–380. https://doi.org/10.1111/jfr3.12154

Suryabhagavan, K. V. (2017) GIS-based climate variability and drought characterization in Ethiopia over three decades. *Weather and Climate Extremes*, 15, 11–23. https://doi.org/10.1016/j.wace.2016.11.005

Sutton, J., & Austin, Z. (2015) Qualitative research: Data collection, analysis, and management. *The Canadian Journal of Hospital Pharmacy*, 68(3), 226–231. https://dx.doi.org/10.4212/cjhp.v68i3.1456

Swanson, F. J., Johnson, S. L., Gregory, S. V., & Acker, S. A. (1998) Flood disturbance in a forested mountain landscape: Interactions of land use and floods. *BioScience*, 48(9), 681–689. https://doi.org/10.2307/1313331

Teddlie, C., & Yu, F. (2007) Mixed methods sampling: A typology with examples. *Journal of Mixed Methods Research*, 1(1), 77–100. https://doi.org/10.1177/1558689806292430

Tempels, B. (2015) *Residents and flood risk management in Flanders: two worlds apart? AesOP Annual Congress 2015: Definite space, fuzzy responsibility*. Book of proceedings, pp. 2912-2927.

Tosakana, N. S. P., Van Tassell, L. W., Wulfhorst, J. D., Boll, J., Mahler, R., Brooks, E. S., & Kan, S. (2010) Determinants of the adoption of conservation practices by farmers in the Northwest Wheat and Range Region. *Journal of Soil and Water Conservation*, 65(6), 404–412. https://doi.org/10.2489/jswc.65.6.404

Troglic, R. S., Wright, G. B., Duncan, M. J., Homberg, M., Adeloye, A. J., Mwale, F. D., & Mwafulirwa, J. (2019) Characterising local knowledge across the flood risk management cycle: a case study of Southern Malawi. *Sustainability*, 11(6), 1681. https://doi.org/10.3390/su11061681

Trogrlić, R. S., Wright, G. B., Adeloye, A. J., Duncan, M. J., & Mwale, F. (2018) Taking stock of community-based flood risk management in Malawi: different stakeholders, different perspectives. *Environmental Hazards*, 17(2), 107–127. https://doi.org/10.1080/17477891.2017.1381582

UN-ISDR (2004) Available from: http://www.unisdr.org/we/inform/terminology

Vermont Government (2019) *Vermont Clean Water Initative performance report*. Available from: https://dec.vermont.gov/water%E2%80%90investment/cwi/reports Accessed 17 August 2020.

Vis, M., Klijn, F., de Bruijn, K. M., & van Buuren, M. (2003) Resilience strategies for flood risk management in the Netherlands. *International Journal of River Basin Management*, 1, 33–40. https://doi.org/10.1080/15715124.2003.9635190

Ward, J. V., Tockner, K., Uehlinger, U., & Malard, F. (2001) Understanding natural patterns and processes in river corridors as the basis for effective river restoration. *Regulated Rivers Research & Management*, 17, 311–323. https://doi.org/10.1002/rrr.646

Weldegebriel, Z. B., & Amphune, B. E. (2017) Livelihood resilience in the face of recurring floods: An empirical evidence from Northwest Ethiopia. *Geoenvironmental Disasters*, 4, 10. https://doi.org/10.1186/s40677-017-0074-0

Wisner, B., Blaikie, P., Terry, C., & Davis, I. (2003) *At risk: Natural hazards, people's vulnerability and disasters*. London, UK: Routledge, p. 471.

WMO (World Meteorological Organization) (2010) *Manual on stream gauging*. Geneva, Switzerland: WMO.

Woodward, M., Gouldby, B., Kapelan, Z., Khu, S. T., & Townend, I. (2011) Real Options in flood risk management decision making. *Journal of Flood Risk Management*, 4, 339–349. https://doi.org/10.1111/j.1753-318X.2011.01119.x

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