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Research Article

Vulnerability of Rural Households to Flooding in Gicumbi District, Rwanda in Africa

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Abstract
Rwanda is one of the African countries facing significant impacts of climate change, with frequent floods increasing rural households' vulnerability. Gicumbi, in the northern province of Rwanda, is currently the most exposed to climate hazards. The present study assessed the vulnerability of rural households to flooding in Miyove, Nyankenke, Rukomo, Byumba, Kageyo, and Ruvune in the Gicumbi district in Rwanda to flooding. Climate data was obtained from the Rwanda Meteorological Agency. Primary data was collected from 399 randomly selected households using a structured questionnaire. The vulnerability of households to flooding was assessed using the Livelihood Vulnerability Index (LVI) approach. The chi-square test was used to test the variation in households' perceptions of rainfall changes. In contrast, the Mann–Kendall test was adopted to examine the variability and trends in rainfall. Except for Byumba, the results showed that the Mulindi and Rwesero stations had the highest rainfall variability, whereas all stations showed no significant change in annual rainfall trends. The majority of households (84.9 %) perceived fluctuations in rainfall trends. However, the households' perceptions of rainfall varied significantly across the six study areas (p=0.001) and their occupations (p=0.004). Households in Miyove were the most vulnerable to floods (index: 0.123), whereas those in Byumba were the least vulnerable with high adaptive capacity. Households in Ruvune and Miyove were the most exposed and sensitive to floods, respectively. The study recommends early interventions in establishing initiatives and improved strategies to enhance the resilience and ability of rural households to adapt to floods to reduce vulnerability.

Keywords: Climate change, Flood hazard, Livelihood Vulnerability Index (LVI), Rural households, Vulnerability

INTRODUCTION

Changing climate patterns, rising sea levels, and increasingly extreme weather are devastating indicators of how quickly the climate changes and the immediate need for solutions (Pörtner *et al.*, 2022). According to Intergovernmental Panal on Climate Change (IPCC) (IPCC, 2022), extreme hydroclimatic events, such as floods and droughts, are expected to increase in frequency and severity as a result of climate change while affecting the environment, means of subsistence, and economies, especially in vulnerable regions of some African countries where the likelihood of multi-hazard events is expected to exacerbate the effects of disasters (IPCC, 2022). In Africa, the impact of climate change is becoming more pronounced, disproportionately affecting the most vulnerable, worsening food insecurity, displacing populations, and placing stress on water supplies (UNFCC, 2022). At least 71 million people from countries in Sub-Saharan Africa are estimated to experience both extreme poverty and potentially significant flood risk, thus becoming the most vulnerable to long-term negative impacts on livelihoods and well-being (Rentschler and Salhab, 2020).
Flooding is the most common natural hazard that affects people worldwide (Rentschler & Salhab, 2020). It is estimated that during flood events that occur once every 100 years, 1.47 billion people (19%) of the global population are at risk. 89 % of the 1.47 billion people at risk of flooding reside in low- and middle-income na-

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tions. At the same time, Sub-Saharan Africa accounts for 55 % of the 132 million people who are predicted to live in high-risk flood zones with extreme poverty (GCA, 2021). Rwanda is vulnerable to climate change and has experienced several climate-related hazards, including floods, landslides, and droughts, which have caused catastrophic effects, especially for people with a low capacity for adaptation and resistance to climate change (Mag, 2023). Rwanda remains extremely vulnerable to the impacts of climate change due to its significant reliance on rainfed agriculture. With more frequent and intense periods of heavy rainfall, climate change trends are projected to increase the severity and risks of flooding (WBG, 2021).

Gicumbi District is the most exposed to climate hazards and ranks second most sensitive to the effects of climate change in the northern province of Rwanda (REMA, 2019). Based on the government assessment report on climate change and its impacts on livelihoods, the north province from which the Gicumbi district is located was indicated as the most region of Rwanda at risk from disasters, particularly floods and landslides caused by variations in rainfall intensity (MIDIMAR, 2017; Nahayo *et al.*, 2019). However, studies addressing the vulnerability of households to flooding are scarce, particularly in the rural areas of the district. Since rural societies have developed unique coping strategies to address climate-induced vulnerability, conducting studies at the district or village level report yields a more precise understanding of the susceptibility faced by local communities (Poudel *et al.*, 2020). However, the lack of analytical records on how communities are vulnerable to climate treats may impede efforts to prevent disasters and maladaptation. Therefore, assessing livelihood vulnerability to climate change is desirable to identify effective adaptive livelihood strategies that balance risks and impacts to promote continuous development while adjusting adaptive capabilities to climatic shocks (Madhuri *et al.*, 2015).

Vulnerability assessment is crucial in minimising the adverse effects of disaster risks (Ullah *et al.*, 2021) while providing insights into how the climate affects the system in question (CTCN, 2018). Moreover, vulnerability assessments help determine development priorities at the national level and track advancements made in mitigating the effects of climate change and increasing adaptive capacity (REMA, 2019a). Various studies have assessed vulnerability to climate change and weather-related events concerning rural households, social groups, communities, and geographic regions. Based on the use of local-based indicators, studies indicate that the analysis of vulnerability provides a better understanding of vulnerability variations within communities and the diverse main factors (such as cultural, social, economic, physical, and institutional) influencing the vulnerability of a particular community (Ahmadi *et al.*, 2022a; Huong *et al.*, 2019; Sujakhu *et al.*, 2019; Ullah *et al.*, 2021; Wangmo *et al.*, 2023).

The concept of vulnerability, as defined by the IPCC, forms the basis of the majority of vulnerability assessments and is widely regarded as a potent analytical tool for evaluation (Adu *et al.*, 2018; Ahmadi *et al.*, 2022b; Gerlitz *et al.*, 2017; Iliyyan *et al.*, 2022; Mekonen & Berlie, 2021). While different vulnerability assessments use different index systems, most vulnerability assessments have adopted the Livelihood Vulnerability Index (LVI) (Amuzu *et al.*, 2018; Dubey & Chaturvedi, 2022; Khan *et al.*, 2022; Koirala, 2015; Sujakhu *et al.*, 2019; Suryanto & Rahman, 2019). The LVI is a composite measure of all important indicators, which are further subdivided into three IPCC vulnerability contributing factors: exposure, sensitivity, and adaptive capacity (Panthi *et al.*, 2015; Piya *et al.*, 2015; Poudel *et al.*, 2020; Hahn *et al.*, 2009). The IPCC's vulnerability framework has also become a useful instrument in research activities for vulnerability assessment. Studies indicated that the LVI and LVI-IPCC approaches are potential tools to analyse vulnerability, taking into account relevant indicators for understanding the diversity of vulnerability. Taking into account climatic exposures and adaptation strategies of households, the findings of applying LVI in two communities in Mozambique communities demonstrated that the tool was effective in capturing variations in climate vulnerability at the community level.

The potential of LVI to highlight subtle but significant disparities in particular vulnerabilities, such as food, water, and other resources, is invaluable when developing policies that can address the needs of communities that depend on resources in low-income and middle-income nations (Poudel *et al.*, 2020). Despite using LVI in Mozambique, its systematic methodology provides a practical foundation applicable to low-income and middle-income countries. Local experiences of vulnerability are universal and research has shown that levels of susceptibility to climate change vary across countries, communities, and households (Dazé, 2011). It is also critical to understand the ramifications of employing different construction techniques and metrics of input data, given the substantial influence of these factors on the outcomes of the vulnerability indices. The study employed equal weighting to avoid the drawbacks of overlooking local-level variations, such as presenting a false picture of vulnerability, especially in deprived communities. In addition, while Rwanda has taken action to evaluate vulnerability to socioeconomic and regional climate change (REMA, 2019), there is a lack of information on rural households' vulnerability to flooding particularly in the affected areas of Gicumbi district. Therefore, building on the work of Hahn *et al.* (2009), the present study applied the LVI to assess the vulnerability of rural households and determine the extent to which households are vulnerable across the selected areas in the Gicumbi district.

MATERIALS AND METHODS

Study area

The Gicumbi District is one of the five districts in the Northern Province of Rwanda. The district experiences two main seasons: dry and rainy, each divided into short and long seasons. Therefore, the district has a four -season climate: two rainy and two dry seasons. Typically, a short dry season runs from January to February, a long rainy season runs from March to May, a long dry season runs from June to August, and a minor rainy season runs from September to December and an average annual temperature of 15–16°C (District, 2022). Generally, rainfall is plenty and erratic, ranging from 1200 to 1500 mm. However, the climate is drastically changing, and the seasons are unpredictable (District, 2018). The district's relief is defined by mountains and steep slopes, with 90 % of the district being hilly. The district is situated in the northern province, where the most potentially vulnerable areas to climate change effects are located because of its mountainous topography with steep slopes (REMA, 2019a). One of the key factors contributing to the high vulnerability of the district to climate change is intense rainfall which causes severe floods and landslides. The steep topography of the district and shallow soils with limited integration of trees and shrubs within the landscape have caused significant erosion, floods, and landslides during heavy rain. Lateritic soils and granites contribute to the district's high rate of soil erosion during prolonged and intense rains (District, 2018). The primary economic activity is agriculture, which creates about 80 % of jobs. Ninety percent of the population in the district live in rural areas, where they rely on land their livelihood activities and well-being (District, 2023) like raising crops for subsistence use and sale, gathering grazing land for animals, collecting water and wood for construction, lighting, and other purposes. The district has frequently experienced floods, particularly in the six areas, Rukomo, Kageyo, Byumba, Ruvune, Miyove, and Nyankenke which were included in this study (Fig. 1).

Data collection

Both primary and secondary data were used in this study. The study's target population was households from six areas (Rukomo, Kageyo, Byumba, Ruvune, Miyove, and Nyankenke) as some of the most flood-affected areas in the Gicumbi district (Red *et al.*, 2022). Three hundred ninety-nine households were selected from the six areas for the field survey using simple random sampling (Table 1). A pilot survey of 15 participants was conducted to test the questionnaire and eliminate potential errors in the survey design. Primary data were collected from the surveyed heads of households, while another member of the same household was interviewed in the absence of the head. Through an in-depth literature review, secondary data were collected from various online published sources, including journal articles, official research reports, and dissertations. Historical rainfall data for 10 years (2011-2021) in the Gicumbi district were obtained from Rwanda Meteorological Agency. The Gicumbi district authorized the research and thereafter shared it with the local au-

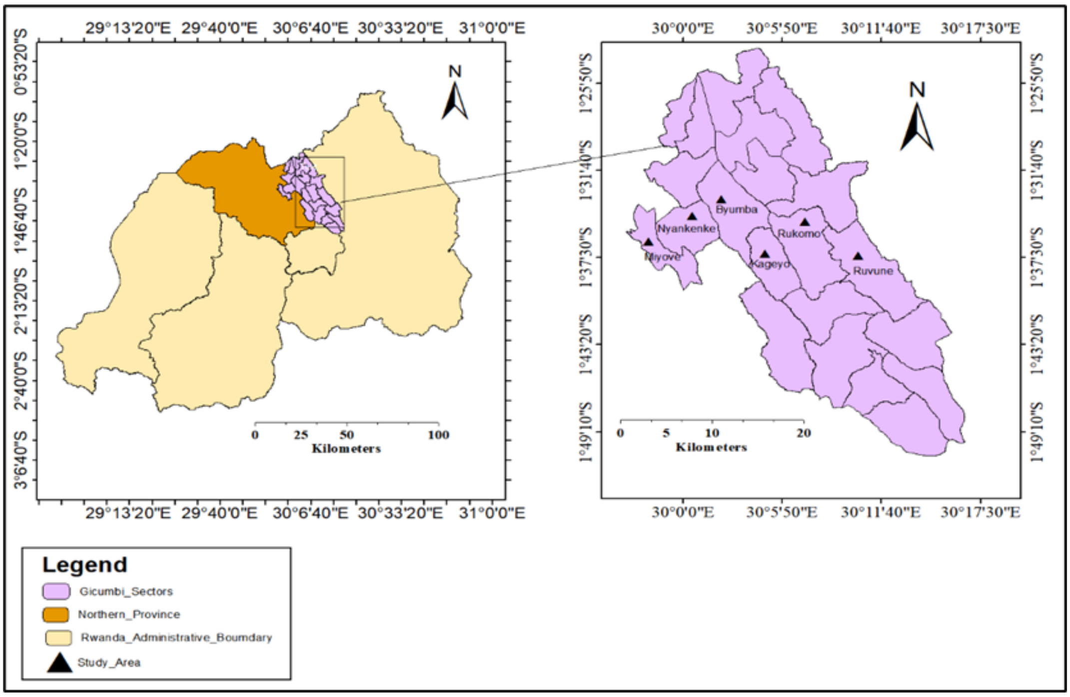

Fig. 1. *Six selected flood-affected areas in the Gicumbi district in Rwanda*

Table 1. Households surveyed in each study area of Gicumbi district

Sectors	Total population (N)	Number of households surveyed n (%)
Byumba	36,401	98 (24.5)
Kageyo	30,270	81 (20.3)
Miyove	16,299	44 (11.3)
Nyankenke	21,560	58 (14.5)
Rukomo	24,989	67 (16.7)
Ruvune	18,962	51 (12.7)
Total	148,481	399 (100)

thorities of the relevant sectors to receive additional backing. To determine the sample size, the present study considered the fourth Rwanda population and Housing Census (NISR, 2012) because the updated fifth Rwanda Population and Housing Census (NISR, 2023) had not yet been released during this study. Table 1 presents the surveyed households.

Data analysis

This study used Stata software and Microsoft Excel Spread sheet for data entry and analysis. The LVI and LVI-IPCC approaches were employed to measure the vulnerability of households. Vulnerability was examined concerning exposure, sensitivity, and adaptive capacity with corresponding measurements for each category. Before calculating the composite LVI, indicators were weighted using the balanced weighted average method. The LVI was computed to measure the vulnerability of households in each study area. Thereafter, the vulnerability indices were compared among the study areas. The LVI was first presented as a composite index with nine key components. The second method divided the components into vulnerability dimensions based on the IPCC vulnerability definition. Various indicators were selected to assess households' exposure to natural hazards and climate variability, as well as their social networks, socio-demographic status, and livelihood strategy traits that affect their capacity for adaptation and their health, food, housing means, and water resource traits that determine their sensitivity to the effects of climate change. Rainfall was the main climate parameter contributing to flooding in the Gicumbi district. The chi-square test was used to test households' perception of rainfall changes. The study adopted the Mann-Kendall statistical approach to analyse the annual rainfall distribution and identify any potential trends in the data throughout the selected study period. The Mann-Kendall test is a common statistical test used to analyse hydrological and climatologic time series (Kamal and Pachauri, 2018).

Analytical technique

Components and Indicators selection

The components and indicators used to assess the vulnerability of livelihoods to flooding were selected based on the study of Hahn *et al.* (2009) and other previous studies (Alam, 2017; Hahn *et al.*, 2009; Malakar *et al.*, 2018; Okaka and Odhiambo, 2019; Peng *et al.*, 2018; Sarker *et al.*, 2019; Sujakhu *et al.*, 2019; Yang, Guo, Deng, and Xu, 2021). With the approach developed by (Hahn *et al.*, 2009), seven major components were used, of which this study adopted and added two more developed components (housing means and natural hazards separated from climate variability), making up nine major components. Each major component considered has its corresponding indicators. Information on the indicators was collected from surveyed households. This study selected major components, such as natural hazards (particularly floods) and climate variability, to fully demonstrate the vulnerable environment concerning exposure. In addition to exposure, the components of the sensitivity and adaptive capacity dimensions were selected. The major components of the sensitivity dimension were housing means, health, food, and water. The selected significant components for the adaptive capacity dimension included sociodemographic status, social networks, and livelihood strategies. A methodological flowchart for assessing households' vulnerability to flooding adopted and modified for the study is shown in Fig. 2.

Composite Livelihood Vulnerability Index (LVI)

The balanced weighted average approach was used to weigh the indicators for the composite LVI. Since the study aimed to assess households' vulnerability to flooding at the household level, the assessment tool can be accessible to diverse users in resource-poor settings. Various studies have applied this equation (Amuzu *et al.*, 2018; Hoq *et al.*, 2021; Tran *et al.*, 2021; Venus *et al.*, 2021). Each indicator contributed equally to the overall index using this approach, although each major component contained various indicators. The average value for each major component was calculated after each indicator was standardised (Basiru *et al.*, 2022; Mai, 2022). For the present study, before calculating the average value for each major component, each indicator was standardised as an index because they were all measured using various scales such as ratios, percentages, or counts. Equation (1) was applied for the standardisation of each indicator.

Index I_a= $Ia - Imin/Imax - Imin$ Eq. 1

Where I_a represents the expected standardised value of each indicator, I_a represents the value of the original observed indicator for a particular area, and *I*min and *I*max represent the respective minimum and maximum values for that indicator. After the standardisation of

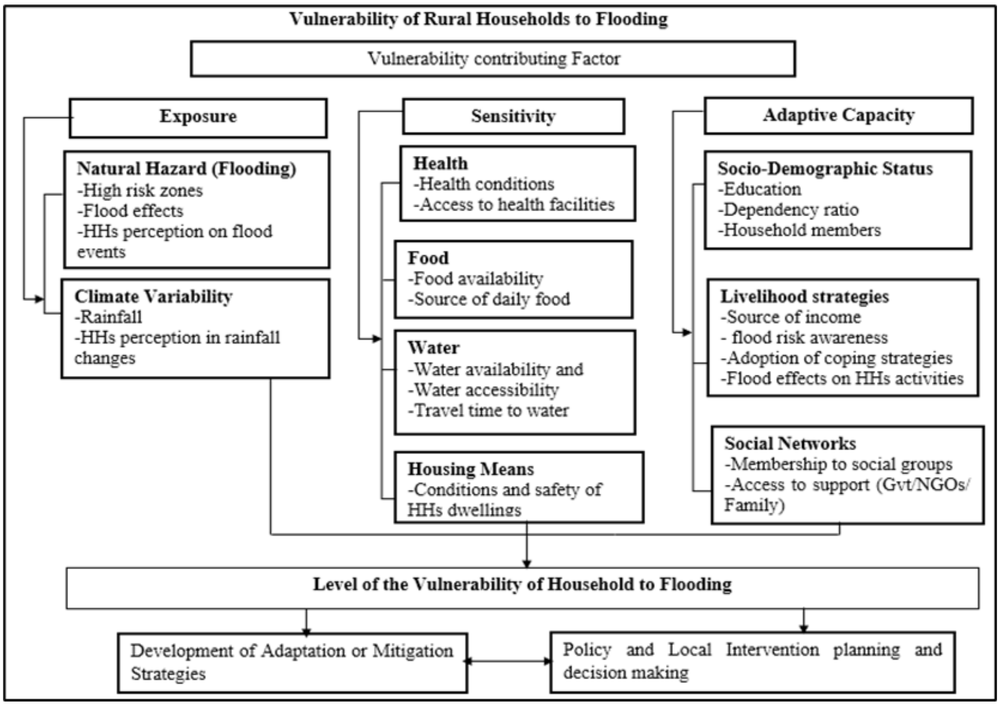

Fig. 2. *Methodological flowchart for assessing the vulnerability of households (Source: modified from Etongo and Arrisol, 2021)*

each indicator, the index of each major component was calculated using Equation (2) to obtain the average number of indicators associated with each major component, as follows:

$$MC_a = \sum_{i=1}^{n} indexIai / n \qquad \text{Eq. 2}$$

Where MC_a represents the individual major components (among all selected major components for the study) for the area a, $indexI_{ai}$ is the indicator indexed by i that constitutes each major component, and n represents the number of indicators for each major component. After the calculation of the value of each major component, the LVI at the study area level was determined by averaging all major components in each study area with the help of Equation (3) as follows:

$$LVI_a = \sum_{i=1}^{n} indexIai \, / \, \sum_{i=1}^{n} WMCi \qquad \text{Eq. 3}$$

Where, LVI*a* is LVI for the area a estimated by averaging all the weighted major components. WMC_i represents each major component's weight, determined by the total number of indicators making up the individual major components. It was also considered to ensure the equal contribution of all indicators to the overall LVI.

Calculating the LVI using the LVI-IPCC approach

The LVI-IPCC vulnerability measurement-based approach has been applied in several studies (Alam, 2017; Hahn *et al.*, 2009; Hoq *et al.*, 2021; Sarker *et al.*, 2019; Shah *et al.*, 2013). Major components of each of the three vulnerability contributing factors were considered. Each vulnerability contributing factor was calculated using Equation (4) as follows:

$$CF_a = \sum_{i=1}^{n} WMCi \; MCai \, / \, \sum_{i=1}^{n} WMCi \qquad \text{Eq. 4}$$

Where CFa represents the defined vulnerability contributing factor (exposure, sensitivity, or adaptive capacity) for the area a; MC_{ai} represents the major components for the area a indexed by i; WMC_i represents the weight of each major component; and n represents the number of major components of each contributing factor. After each vulnerability contributing factor was calculated, all three contributing factors were used to calculate the overall vulnerability index of households in each area using Equation (5) below.

$$LVI\text{-}IPCC_a = (E_a - AC_a) * S_a \qquad \text{Eq. 5}$$

Where LVI-$IPCC_a$ represents the LVI for sector *s* expressed based on the IPCC vulnerability framework, *E* represents the score obtained from the calculated exposure factor for area a, *AC* represents the calculated adaptive capacity score for area a and *S* represents the score obtained from the computed sensitivity contributing factor for area a. The scaling method used in this study for calculating both LVI and LVI-IPCC was adopted from studies conducted by (Hahn *et al.*, 2009; Hoq *et al.*, 2021). The LVI was scaled from 0 to 0.5, as the least and most vulnerable, respectively, and the LVI-IPCC was scaled from -1, as the least susceptible, to 1, as the most vulnerable.

RESULTS

Rainfall variability in the Gicumbi district

Rainfall is the main climate parameter contributing to flooding in Rwanda. Gicumbi experiences variations in

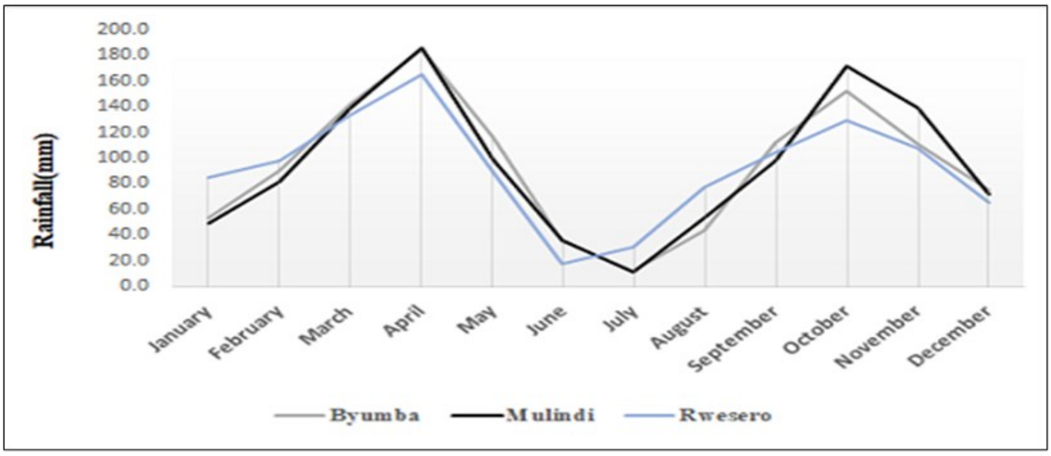

Fig. 3. *Mean monthly rainfall in the three stations located in the Gicumbi district (2011-2021)*

annual rainfall between 1200 and 1500 mm (WFP, 2018). The study analysed the variability of monthly rainfall and trends in annual rainfall over the study period (2011-2021). The mean monthly rainfall at the three stations for the 11 years (2011-2021) is shown in Fig. 3.

The variations in the mean monthly rainfall, coefficient of variation (CV), and standard deviation (SD) are presented in Table 2. The study showed that the Byumba, Mulindi, and Rwesero stations recorded rainfall peaks of 184.5 mm, 185.6 mm, and 165.5 mm in April, respectively. The rainfall at the Byumba and Rwesero stations varied considerably each month, while the rainfall at the Mulindi station varied moderately, except in September.

The results obtained from the Mann-Kendall trend test **(**Table 3**)** indicate a very high variability in annual rainfall at Mulindi (CV=32.5), Rwesero (CV=29.2 %) stations and a moderate variability in Byumba (CV= 26.7 %) stations. A statistically insignificant trend in annual rainfall was recorded at all study stations (Byumba, Mulindi, and Rwesero). While decreasing rainfall was reported in the Byumba and Rwesero (negative slopes) stations, increasing rainfall was recorded in the Mulindi (positive slope) stations. The annual rainfall trends and variability at the three stations are shown in Fig. 4 and Table 3**,** respectively.

Households' perception of changes in rainfall pattern

Variations in households' perceptions of rainfall changes were also examined. The study employed Chi-square tests to test the households' perception of rainfall changes by study areas, and occupation status. The majority of respondents in the six areas (Miyove= 95.4 %, Ruvune= 94.1 %, Kageyo= 92.5 %, Byumba=90.8 %, Nyankenke=72.4 %, Rukomo= 64.1 %) experienced an increase in the duration of rainfall. The statistical analysis revealed significant variation in households' perceptions of rainfall changes across the study areas (p= 0.001). The variation in the perception of rainfall across areas reflects the number of complex topographic features and circulation patterns in a particular area. A statistically significant variation (p= 0.004) in households' perceptions of rainfall was recorded for different occupation statuses. The variation in households' perception of rainfall concerning their occupation status can be attributed to the activities that households are engaged in and the effect of rainfall on their well-being. Given that some households relied on

Table 2. Variation of monthly rainfall in the three stations in the Gicumbi district (2011-2021)

Months	Byumba			Mulindi			Rwesero		
	Mean	**SD**	**CV (%)**	**Mean**	**SD**	**CV (%)**	**Mean**	**SD**	**CV (%)**
January	52.9	48.4	91.5	48.9	50.4	103.2	84.4	54.0	64.1
February	90.5	42.7	47.2	81.3	31.6	38.9	98.3	58.9	60.0
March	142.9	78.4	54.9	138.8	64.2	46.3	134.0	68.1	50.8
April	184.5	77.7	42.2	185.6	70.0	37.7	165.5	65.2	39.4
May	115.9	68.9	59.5	99.4	58.3	58.8	89.1	77.0	86.5
June	34.8	33.1	95.1	35.5	51.8	146.3	17.0	37.3	219.5
July	12.4	11.7	94.9	10.9	8.6	79.3	30.5	60.0	196.7
August	43.1	34.3	79.6	53.7	38.0	70.8	76.9	55.9	72.7
September	112.0	69.0	61.6	97.5	21.6	22.2	104.3	56.3	54.1
October	152.1	62.5	41.1	171.5	73.9	43.2	129.4	66.8	51.7
November	110.5	42.6	38.6	139.3	147.0	105.6	107.9	38.2	35.5
December	74.7	41.8	56.0	71.7	39.3	54.9	65.5	30.7	47.0

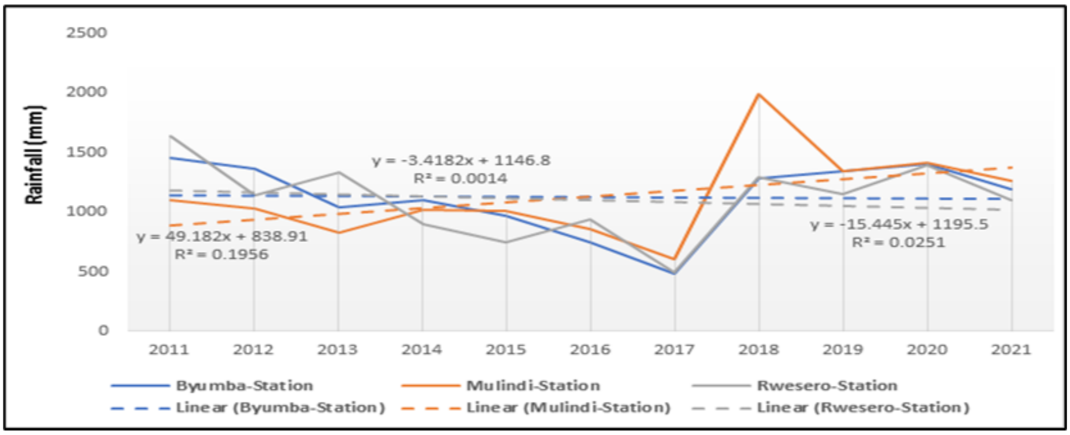

Fig. 4. *Annual rainfall trends in the three weather stations in the Gicumbi district (2011-2021)*

Table 3. Annual Rainfall variability at the three weather stations in the Gicumbi district (2011-2021)

Station	Min.	Max.	Mean	SD	CV	Trend mm/year	Kendall's tau	p-value
Byumba	488.0	1457.0	1126.2	300.8	0.27	-14.000	-0.091	0.755
Mulindi	607.0	1991.0	1134.0	368.8	0.33	34.286	0.164	0.533
Rwesero	490.0	1641.0	1102.8	323.1	0.29	-22.500	-0.091	0.755

rain-fed agriculture, livelihood and food security were affected in every case of rainfall variability.

Flooding in the Gicumbi district

Gicumbi district is located in the northern province of Rwanda. The province is well known for its frequent flooding, which can result in infrastructure, property, and occasionally even fatalities. Over the last five years, the province has seen at least 1,500 natural disasters, including landslides and floods, which have caused over 5,000 damaged dwellings and over 200 fatalities (Nkurunziza, 2023). The historical flood events that occurred annually in respective districts in the northern province are shown in Fig. 5. Data on flood events for 2002-2023 was obtained from the EM-DAT database (EM-DAT, 2023). Fig. 5 shows that Gicumbi district has experienced several more flood events (2002, 2003, 2017, 2020 and 2023) than other districts. Except for the Burera district (p= 0.033), statistical results revealed an insignificant increasing trend in annual flood occurrences in other districts that experienced flood events, including Gicumbi, Gakenke, Musanze, and Rulindo.

Exposure of households to flooding

The exposure of households to flooding in each of the six areas was examined by considering climate parameters (rainfall) and households' perceptions and experiences of climate variability and natural hazards (flooding). Relevant indicators for each major component presented in Table 4, were selected and used to measure the extent to which households in each area were exposed to flooding. Considering natural hazards (flooding), the results showed that households in Miyove were highly exposed to flooding, with an impact index of 0.635, followed by Kageyo, Nyankenke, Ruvune, Rukomo, and Byumba. Regarding natural hazard indicators, households in all study areas were exposed to high-risk zones. However, Byumba was the area from which most households (98.9 %) lived at high risk, while 72.4 % had inadequate access to early warning systems, with an impact index of zones 0.989 and 0.724, respectively. Concernig climate variability, households in the six study areas were more vulnerable, with those in Miyove and Kageyo experiencing the most increase in climate variability.

In terms of indicators, 98.7 % of households in Miyove experienced heavy rainfall (impact index: 0.987), with Ruvune having the majority of households (95.4 %) experiencing an increased duration of rainfall (impact index: 0.954), while Rukomo had the majority of households that experienced an increase in floodwater (impact index: 1). Most households in Byumba reported the occurrence of hailstorms (impact index: 0.979). Despite most rural households relying on crop farming as their primary source of income, over 50 % of households in all study areas reported that floods affected their farming activities. Table 4 shows the normalized indices of the selected indicators for each major component of the exposure.

Sensitivity of households to flooding

The sensitivity of households to flooding in the six study areas was examined by accounting indicators of the sensitivity of major components, including health, food, water, and housing, which were considered because of their essential role in households facing natural hazards (floods). Based on the index computed for food security, households with high sensitivity to food security were recorded in the six areas. Byumba had more

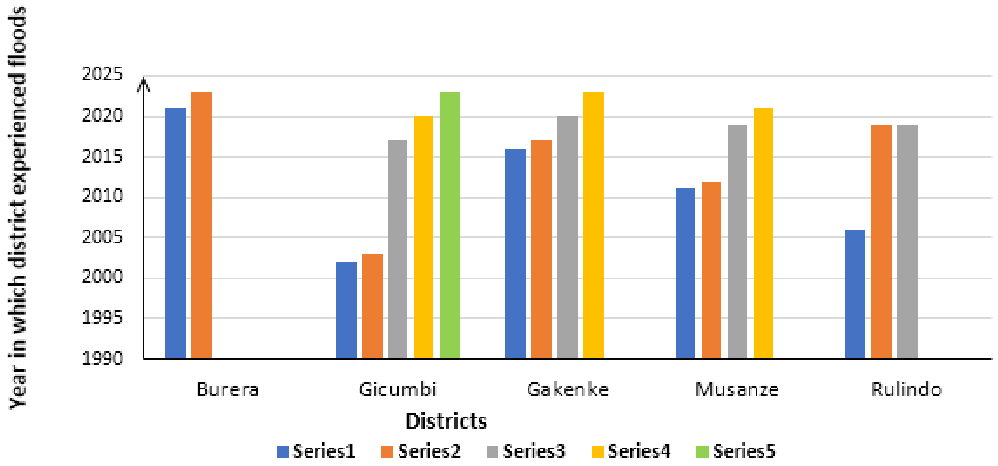

Fig. 5. *Flood events in Northern Province of Rwanda*

sensitive households, with an impact index of 0.581. Over 50 % of households in Kageyo, Ruvune, Miyove, and Nyankenke solely relied on their farms to obtain daily food, with impact indices of 0.678, 0.646,0.595 and 0.585, respectively. More than 50 % of households in each of the six selected areas indicated that they could not save crops harvested to eat for the next time and seeds for the following year's crop growth. Except in Miyove, households in other areas were found to be highly sensitive to water security, with an impact index of 0.557 for Kageyo, 0.535 for Miyove, 0.521 for Byumba, 0.494 for Nyankenke, and 0.428 for Ruvune.

High sensitivity to inadequate water security in terms of availability and accessibility was recorded for households in five areas (Kageyo (0.557), Miyove (0.535), Byumba (0.521), Nyankenke (0.494), and Ruvune (0.428)). At the same time, Rukomo (0.352) was found to be less sensitive. Households in Byumba and Kageyo reported spending an average of over 50 min to get to a safe drinking water source. More than 50 % of households in Byumba, Kageyo, Miyove, and Nyankenke reported the problem of water conflict and inadequate access to safe water for drinking and domestic use as a result of insufficient quantity of water. In terms of poor health conditions and inadequate access to health facilities, households in Miyove, Ruvune, and Byumba were highly sensitive (impact index: Miyove (0.501); Ruvune (0.447); Byumba (0.432)), whereas Rukomo and Nyankenke were less sensitive. Households indicated physical conditions and chronic diseases such as diabetes and asthma as one of the factors causing significant negative effects on their ability to achieve a sustainable livelihood. Miyove (63.6 %) had most households that lived with chronic illness. The inadequate sanitary latrines were recorded for the majority of households in Ruvune (84.3 %), Miyove (68.1 %), Byumba (60.2 %), and Rukomo (59.7 %). The study found that households in Byumba, Kageyo, Miyove, Rukomo, and Ruvune took an average of over 50 mins to reach the nearest health facility. It also revealed that households in these areas were highly sensitive to inadequate housing, with 92.8 % of households in Byumba being the most sensitive. More than 50 % of households across the six areas lived in poor housing conditions and were affected by floods. The normalized indices for the major sensitivity components are shown in Table 5.

Adaptive capacity of households

The adaptive capacity of the households was examined in consideration of various indicators of adaptive capacity's significant components, including socio-demographic status, livelihood strategies, and social networks. In terms of socio-demographic status, high adaptive capacity was recorded for households in Byumba (0.532), followed by households in Nyankenke (0.307), Kageyo (0.274), Miyove (0.270), Rukomo (0.217), and Ruvune (0.206). Households with the highest dependency ratios were Byumba and Nyankenke. Households (46.5 %) in Nyankenke had the highest illiteracy rate, while Kageyo was reported as the area with households (40.7 %) headed by females. The study reported low literacy and inadequate skills as key factors prohibiting rural households from asserting their basic rights or participating in additional activities that could generate income or accumulate assets. Low adaptive capacity in terms of poor livelihood strategies was reported for households in Miyove compared to those in Ruvune, Nyankenke, Kageyo, Byumba, and Rukomo. The majority of households in Nyankenke (62 %), Miyove (59 %), Kageyo (41.9 %), and Ruvune (35.2 %) were engaged in crop farming. In comparison, those in Rukomo (47.7 %) and Byumba (46.9 %) were involved in daily wage labor such as agricultural wages, transportation services, and self-employment. Households engaged in crop farming struggled to cope with floods as their main livelihood activities were impacted .

The rate of households involved in government jobs was low, averaging 1.8 % across the six areas. Households engaged in daily wage labor, the self-employed, and government workers also reported floods disrupting their daily livelihood. Sometimes, they were obliged to miss work due to floodwater that affected their property and other utilities.

Over 50 % of households in Miyove depended on more than one source of income, while those in Byumba (80.6), Kageyo (72.8 %), Nyankenke (55.1 %), Rukomo (80.6 %), and Ruvune (52.9 %) depended on a single source. The study identified the opportunity for rural households to work in other communities was still challenging. The study reported that more than 50 % of households in all study areas had poor knowledge and skills in adapting to floods. In terms of social networks, households in the six areas had poor social networks, with an impact index of 0.935 in Byumba and 0. 920 for Kageyo 0. 919 for Rukomo, 0.898 for Miyove, 0.831 for Miyove, and 0.819 for Nyankenke. Over 50 % of households in the six areas had limited access to support from local governments and (NGOs), and were not involved in community or social groups. Many were also unwilling to seek credit due to a lack of regular income or collateral. Table 6 presents the normalized indices for the indicators of the major adaptive capacity components.

Overall vulnerability of households in Gicumbi district to flooding

The vulnerability index for each major component was computed to determine its influence on household vulnerability. Despite the differences in the index values of some major components, households in each of the study areas were more vulnerable to poor social networks in terms of adaptive capacity, inadequate food security and poor housing in terms of sensitivity, and increased climate variability in terms of exposure to floods. The impact index values for each major component are shown in Fig. 6.

Using the LVI-IPCC approach, the LVI was computed considering the composite indicators of adaptive capacity, exposure, and sensitivity. The scale for the IPCC vulnerability index ranges from -1 to +1, indicating the least and most vulnerable households in a given area. Regarding vulnerability contributing factors, households in Ruvune and Miyove were the most exposed and sensitive to floods, respectively, whereas those in Byumba reported

high adaptive capacity. Considering the overall computed vulnerability, households in Miyove were more vulnerable to flooding, with an aggregated vulnerability index of 0.123. The scores for the contributing factors are also presented in Fig. 7 (vulnerability triangle), and scores from 0 to 0.7 show low and high contributing

Table 4. Normalised indices for indicators of exposure major components

Major components	Indicators	Study areas in the Gicumbi district					
		Byumba	Kageyo	Miyove	Nyankenke	Rukomo	Ruvune
Natural Hazard (Flooding)	Average number of flood events experienced by HHs	0.333	0.350	0.266	0.283	0.350	0.300
	HHs who did not receive early warning prior to flood occurrence	0.724	0.543	0.363	0.569	0.477	0.647
	HHs whose member got injured due to floods	0.040	0.16	0.181	0.034	0.059	0.098
	HHs whose fam activities have been affected by floods	0.836	0.679	0.795	0.913	0.850	0.960
	HHs who live in the high-risks zones (proximity of slopes or low-laying areas)	0.989	0.716	0.931	0.844	0.641	0.843
Climate Variability	HHs with experience of heavy rainfall	0.989	0.987	1.000	0.948	0.925	0.980
	HHs who faced increased duration of rainfall	0.908	0.925	0.954	0.724	0.641	0.960
	HHs with experience of the occurrence of hailstorms	0.979	0.901	0.954	0.965	0.910	1.000
	HHs who experienced the rise in floodwater	0.979	0.950	0.971	0.931	1.000	0.980
	Mean SD of monthly rainfall (2011-2021)	0.546	0.546	0.546	0.546	0.546	0.546
LVI for exposure component	Natural Hazard (Flooding)	0.521	0.442	0.435	0.432	0.381	0.472
	Climate Variability	0.880	0. 861	0.885	0.822	0.804	0.893

HHs= Households, LVI= Livelihood Vulnerability Index

Table 5. Normalised indices for indicators of sensitivity major components

Major components	Indicators	Study areas in the Gicumbi district					
		Byumba	Kageyo	Miyove	Nyankenke	Rukomo	Ruvune
Health	Average time HHs use to get to the nearest health facility	0.385	0.327	0.302	0.171	0.237	0.261
	HHs with a member living with a disability	0.336	0.308	0.386	0.275	0.343	0.254
	HHs with a member having a chronic illness	0.408	0.321	0.636	0.379	0.343	0.431
	HHs without sanitary latrine	0.602	0.246	0.681	0.362	0.597	0.843
Food	HHs who depend on their farm for food	0.316	0.678	0.590	0.585	0.417	0.646
	Average time HHs suffer to get food in the year (Range: 0-12)	0.550	0.341	0.216	0.408	0.491	0.416
	HHs that do not save the crop harvested to eat for different time during a year	0.959	0.703	0.500	0.620	0.820	0.529
	HHs that do not save the seed for the following year's crop growing	0.959	0.777	0.772	1.000	0.865	0.843
	Average crop diversity Index (Range: 0-1)	0.269	0.202	0.170	0.254	0.228	0.181
Water	HHs who get water from natural source or unsafe drinking water sources	0.561	0.654	0.545	0.982	0.671	0.843
	Average time HHs use to get to safe drinking water sources	0.392	0.379	0.232	0.134	0.231	0.147
	Water conflict in the HHs' community	0.602	0.679	0.863	0.517	0.328	0.705
	HHs with no consistent access to water	0.530	0.518	0.500	0.344	0.179	0.019
Housing Means	HHs whose houses are not in a good condition	0.938	0.740	0.840	0.741	0.686	0.686
	HHs whose houses were affected by floods	0.918	0.567	0.840	0.775	0.597	0.843
LVI for sensitivity components	Health	0.432	0.300	0.501	0.296	0.380	0.447
	Food	0.610	0.540	0.449	0.573	0.564	0.523
	Water	0.521	0.557	0.535	0.494	0.352	0.428
	Housing Means	0.928	0.653	0.840	0.758	0.641	0.764

HHs= Households, LVI= Livelihood Vulnerability Index

Table 6. Normalised indices for indicators of adaptive capacity major components

Major components	Indicators	Study areas in the Gicumbi district					
		Byumba	Kageyo	Miyove	Nyankenke	Rukomo	Ruvune
Socio demographic status	Dependency ratio	1.333	0.083	0.100	0.183	0.133	0.133
	Average number of members in the household	0.276	0.276	0.346	0.323	0.276	0.261
	HHs headed by a female	0.244	0.407	0.318	0.258	0.194	0.196
	HHs whose head is illiterate (didn't attend school)	0.275	0.333	0.318	0.465	0.268	0.235
Livelihoods strategies	HHs whose primary source of income is from crop farming	0.336	0.419	0.590	0.620	0.388	0.352
	HHs who depend on crop farming and livestock	0.030	0.209	0.295	0.000	0.059	0.392
	HHs who depend on daily wage	0.469	0.246	0.068	0.344	0.477	0.176
	HHs whose source of income is a monthly salary	0.040	0.049	0.000	0.000	0.000	0.019
	HHs whose source of income from small business	0.000	0.000	0.022	0.000	0.000	0.019
	HHs who depend on a single source of income	0.806	0.728	0.454	0.551	0.806	0.529
	HHs whose fam activities have been affected by floods	0.836	0.679	0.795	0.913	0.850	0.960
	HHs whose non-farm activities have been affected by floods	0.244	0.345	0.657	0.137	0.014	0.215
	HHs whose head or any other family member didn't receive training to cope with floods	0.918	0.975	0.750	0.948	0.835	0.941
	HHs where a family member is employed in another community	0.051	0.234	0.272	0.189	0.074	0.078
	Average agricultural Livelihood Diversification Index	0.274	0.233	0.152	0.133	0.176	0.127
Social Networks	HHs who didn't receive support from local government authorities	0.938	0.950	0.954	0.758	0.895	0.902
	HHs who didn't receive support from NGOs	0.959	0.987	0.977	0.913	0.955	0.946
	HHs who were not members of social/community organisation	0.938	0.987	0.909	0.927	0.912	0.941
	HHs who were not member of farm cooperatives or association	0.957	0.814	0.840	0.982	0.910	0.980
	HHs who didn't receive support from relatives or friends	0.887	0.864	0.477	0.517	0.925	0.725
LVI for adaptive capacity components	Socio-demographic Status	0.532	0.274	0.270	0.307	0.217	0.206
	Livelihoods Strategies	0.287	0.287	0.323	0.267	0.273	0.265
	Social Networks	0.935	0.920	0.831	0.819	0.919	0.898

HHs= Households, LVI= Livelihood Vulnerability Index

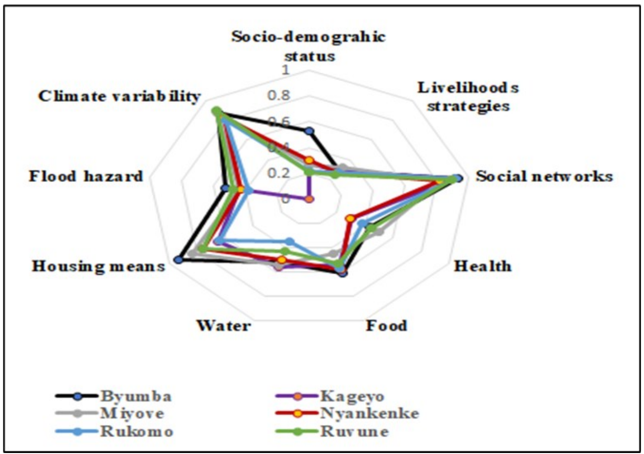

Fig. 6. *Spider diagram for the vulnerability index of major components*

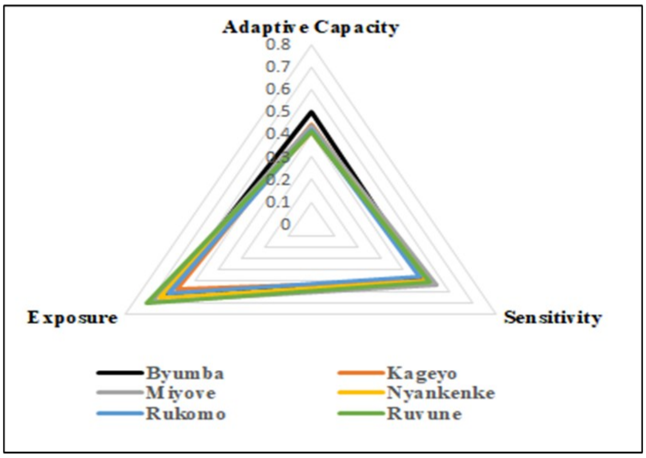

Fig. 7. *Triangle diagram for the vulnerability contributing factors*

Table 7. Livelihood Vulnerability Index based on vulnerability contributing factors

	Study areas in the Gicumbi district					
	Byumba	**Kageyo**	**Miyove**	**Nyankenke**	**Rukomo**	**Ruvune**
Adaptive capacity	0.498	0.442	0.439	0.413	0.423	0.411
Sensitivity	0.481	0.495	0.537	0.502	0.468	0.509
Exposure	0.620	0.576	0.685	0.648	0.614	0.705
LVI-IPCC	**0.058**	**0.066**	**0.123**	**0.117**	**0.089**	**0.120**

factors, respectively. Table 7 presents the overall computed vulnerability for households in the six areas.

DISCUSSION

The present study assesses the vulnerability of households to flooding in six areas in Gicumbi district in Rwanda: Nyankenke, Rukomo, Byumba, Kageyo, Miyove, and Ruvune. A deeper understanding of the vulnerability of households across study areas will contribute to future research, development, and implementation of effective strategies to improve community livelihoods and increase community awareness about flood risks for resilience and vulnerability reduction, particularly in the prone areas in the Gicumbi district. The vulnerability of households to flooding was assessed using key components like socioeconomic status, livelihood strategies, social networks, housing means, water, food, health, natural hazards (floods), and climate variability.

The study examined climate variability in terms of heavy rainfall, increased rainfall duration, occurrence of hailstorms, and increased floodwater experienced by households as a result of household exposure to flooding. The variability of changes in rainfall was recorded at the study stations, whereas trends in annual rainfall were insignificant. However, the study identified a significant variation in households' perceptions of rainfall changes across the study areas and household occupation status. Nahayo *et al.* (2019) noted that rainfall variations are the primary factor affecting the livelihood of the local community in the Gicumbi district. This study demonstrated that a high mean monthly rainfall (2013-2017) contributed to weather-related events, such as landslides, floods, windstorms, lightning, rainstorms, and hailstorms. According to Okeleye *et al.* (2016), areas routinely receiving excessive rainfall and flooding are more vulnerable. In their findings, Chavez Michaelsen *et al.* (2020) indicated that various local livelihood activities are affected by climate variability, making rural communities more vulnerable. Hailstorms were found to occur more often and sometimes caused damage to households' belongings, such as accumulation, resulting in power outages, downed trees, flash floods, and mudslides on steep terrains. Floods affect people, particularly those impoverished and residing in flood-prone rural areas (Parvin *et al.*, 2016). Over 50 % of the respondents in each study area lived in high-risk zones like slopes and low-lying areas. According to Dube *et al.* (2018) and Haenfling *et al.* (2019), residents of flood-risk locations without suitable housing are more susceptible to the detrimental consequences of flooding.

More than 60 respondents in each area lived in poor housing conditions, while floods damaged more than 50 % of respondents due to inadequate building materials. Constructing or restoring houses resistant to severe weather events is one of the most economical ways to adjust to climate change.The respondents claimed to be aware of using sturdy building materials like cement blocks. However, they pointed out that a common barrier preventing individuals from building strong hurricane-resistant homes is a lack of financial resources. This is consistent with the findings of Almeida and Wei (2017), who found that a house's quality, location, and construction matter as much as its affordability. Disasters that are persistent and becoming more common cause enormous losses in direct economic costs, slower economic progress, and poverty. Households in all study areas reported experiencing a similar average number of flood events (between 2.6 and 3.1). Parvin *et al.* (2016) noted that people's lives and livelihoods are in danger of frequent and severe flooding. Frequent disasters prevent impacted households from rebuilding and recovering their livelihoods, exacerbating the negative effects of these losses while threatening access to food and ruining livelihoods at the household level (FAO, 2013). The development of efficient early warning systems may help promote livelihood resilience by strengthening adaptive capacities and coping strategies (Baudoin *et al.*, 2014). Except for Miyove, the lack of access to early warnings was found to be a major problem in other areas and claimed to contribute to inadequate awareness of flood risks. The outcomes of the study align with the arguments of Mondal *et al.* (2020), who argued that the range of flood adaptation strategies that households can employ to prevent damage from flooding is influenced by the availability of early warnings.

Households with chronic illnesses are more vulnerable to health-related climate change impacts, as their risk of disease and death can increase when exposed to climate change-related effects, including weather events, poor air quality, and water-related illnesses (US EPA, 2022). Miyove, Ruvune, and Byumba had many households with chronic diseases and no sanitary latrines. The respondents revealed that latrines collapsed during heavy rains due to inadequate construction, predisposing households to infectious diarrheal diseases. According to Akter *et al.* (2022), contaminated water, inadequate sanitation, and poor hygiene increase the risk of developing infectious diseases, further supporting this finding. Water is crucial in maintaining a fair, sustainable and productive rural economy. Despite being an essential element for human health, nutrition, and agricultural production, water also opens up employment opportunities in many key sectors of the rural economy (International Labour Organization (ILO), 2019). Water scarcity endangers productivist livelihood pursuits while impeding post-productivity rural livelihood growth (Tabane, 2014). Households in all study areas did not have sufficient safe drinking water and were highly dependent on water obtained from natural sources. Despite efforts to improve water accessibility and availability, households indicated water conflicts and a lack of safe water as major challenges. They added that the situation worsened during heavy rains, as the water sources from which they obtained water were affected by floodwater. Adaptive capacity is key to developing societal resilience and assisting in disaster risk reduction (Didham & Ofei-Manu, 2020). The potential capacity of an individual, community, or adaptation system determines how well it can respond to the effects or repercussions of climate change (Dinda, 2015). Poor socio-demographic characteristics, such as a low literacy rate, high dependency ratio, and inadequate housing structure, reduce the adaptive capacity of rural households (Sam *et al.*, 2017). The respondents in the Byumba indicated that high household dependency led to a high demand for labour because a small number of people must work to generate and supply the requirements of a large number. In a study by Umaru and Adedokun (2020), a high dependency ratio and illiteracy rate of households were among the factors that increased flood vulnerability. Adelekan and Fregene (2015) noted that an inadequate capacity for adaptation is further exacerbated by low educational attainment, which restricts communities' opportunities to seek new careers, acquire new skills, and have a voice. Erima *et al.* (2023) and Okeleye *et al.* (2016) provided additional support for this, arguing that low levels of education and formal education can have a detrimental effect on people's knowledge and awareness of disaster risk management, making it more difficult for them to make logical decisions during floods. Most respondents were engaged in crop farming, with an average of 44.5 % of households in all areas. An average of 64.5 % of households in five areas relied on a single source of income, except for households (55.1 %) in Miyove, who depended on more than one source of income. This was in contrast with the studies conducted by Hoq *et al.* (2021) and Marcela Beltrá n-Tolosa *et al.* (2022), who found that households engaged in multiple sources of income are comparatively less vulnerable to floods.

The respondents indicated that their engagement in more than one source of income did not serve the purpose, as both their farm and non-farm activities were extremely affected by floods. Apart from being crucial for ensuring a sustainable means of subsistence, livelihood strategies can provide vital guidance for addressing problems resulting from natural catastrophes (Ao *et al.*, 2022; Haeffner *et al.*, 2018). Floods can directly and indirectly affect households' livelihoods by reducing food availability and income. The fact that an average of 53.8 % of households in all areas relied on their farms to obtain daily food made them more vulnerable to food insecurity, as over 50 % of them in each area were unable to store food to eat and seed for the next year crop growing owing to insufficient crop yield caused by floods. As crop farming constituted the primary source of income for most respondents, they believed that floods exacerbated their precarious living conditions. Achoja (2019) suggested that the availability and consumption of food by vulnerable rural households declined due to flood hazards. This finding indicates that Indigenous agricultural households face challenges related to food security and severe floods. Social networks are acknowledged as essential tools for enhancing resilience to environmental and socioeconomic shocks by strengthening adaptive capacities (Wang *et al.*, 2021). The ability to engage with social networks and institutions is crucial to increasing the number of low-income rural households (Sam *et al.*, 2017). However, low participation of households in social networks within the six areas was evident in the Gicumbi district. The study by John (2020) showed the potential for robust social networks, unified communities, and different local organisations willing to assist households in responding to floods. Dapilah *et al.* (2020) noted that households engaged in multiple group activities and social networks exhibited a greater diversity of livelihood strategies and demonstrated greater resilience to perceived climate change due to their networks' ability to provide them with the material and non-material resources necessary for diversification.

Considering the overall computed vulnerability index, households in Miyove were the most vulnerable to flooding, followed by those in Ruvune and Nyankenke. Despite the recorded differences in the level of vulnerability, households in six areas were sensitive and exposed to flood hazards. However, Miyove households were found to be the most exposed, while those in Ruvune were the most sensitive to flood hazards. Households in Byumba were the least vulnerable and had the highest adaptive capacity. Using the LVI and LVI-IPCC approaches, this study assessed the strength of existing livelihood strategies and the potential for communities to adapt in response to exposure and sensitivity to flooding. Notwithstanding the valuable insights gained, certain issues need to be addressed. The primary focus of this study is on households' vulnerability to flooding in the affected areas of the Gicumbi district.

Conclusion

In Gicumbi district, floods have become an annual event (EM-DAT, 2023), severely impairing every facet of the community's livelihood. Using LVI and LVI-IPCC approaches improved the present understanding concerning various factors influencing households' vulnerability to flooding. Climate variability (rainfall) and household experience concerning flood hazards increase households' exposure to flooding. High variations were recorded in rainfall changes and statistical tests concerning households' perceptions indicated that variability in rainfall differed across the study areas. Broadly, a lack of clean water, inadequate water supply, insufficient food, poor house quality, and poor health conditions influenced the sensitivity of households. Poor social networks adversely affected the adaptive capacity of households in all study areas. Rural households were particularly vulnerable to flood risks. They had poor resilience to loss because of their limited ability to absorb and recover from losses in farming income and other means of subsistence. Policymakers and relevant stakeholders should enhance their efforts to develop strategies that strengthen the resilience of rural households to reduce their vulnerability to flooding. These include establishing local awareness programs to educate people about current and potential flood risks, diversification of rural livelihoods for increased household income, educating the public about the possible dangers of construction in high-risk locations, and accelerating progress toward increased access to safe water and proper sanitation. The study's conclusions might have been constrained by its focus on particular areas and development sectors in Gicumbi district. Further research is required to determine whether the findings hold for other places in Gicumbi district. Furthermore, comparative analyses of variations in households' vulnerability to flooding in different districts across Rwanda are necessary.

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Data availability
Data are available upon request.

Conflict of interest
The authors declare that they have no conflict of interest.

REFERENCES

1. Achoja, F. O. (2019). Causal Linkages between Flood Hazards and Food Insecurity: Evidence from Nigeria. *Cukurova University, Agriculture Faculty*, *2*(34), 91–99. https://doi.org/10.36846/cjafs.2019.1
2. Adu, D. T., Kuwornu, J. K. M., Anim-Somuah, H., & Sasaki, N. (2018). Application of livelihood vulnerability index in assessing smallholder maize farming households' vulnerability to climate change in Brong-Ahafo region of Ghana. *Kasetsart Journal of Social Sciences*, *39*(1), 22–32. https://doi.org/10.1016/j.kjss.2017.06.009
3. Ahmadi, S., Movahed, R. G., Gholamrezaie, S., & Rahim-

ian, M. (2022b). Assessing the Vulnerability of Rural Households to Floods at Pol-e Dokhtar Region in Iran. *Sustainability 2022, Vol. 14, Page 762*, *14*(2), 762. https://doi.org/10.3390/SU14020762
4. Akter, J., Islam, M. R., Akter, S., Rahman, M. M., Hossain, F., Anam, M. R., Alam, M. A., Sultana, P., & Rashid, S. (2022). Equity in access to safely managed sanitation and prevalence of diarrheal diseases in Bangladesh: a national and sub-national analysis. *BMC Infectious Diseases*, *22* (1), 1–8. https://doi.org/10.1186/S12879-022-07884-4/TABLES/4
5. Alam, G. M. M. (2017). Livelihood Cycle and Vulnerability of Rural Households to Climate Change and Hazards in Bangladesh. *Environmental Management*, *59*(5), 777–791. https://doi.org/10.1007/S00267-017-0826-3/METRICS
6. Almeida, S. J., & Wei, H. S. (2017). *Affordable Housing : Challenges and the Way Forward* (Issue 2011).
7. Amuzu, J., Kabo- Bah, A. T., Jallow, B. P., & Yaffa, S. (2018). Households' Livelihood Vulnerability to Climate Change and Climate Variability: A Case Study of the Coastal Zone, The Gambia. *Journal of Environment and Earth Science*, *8*(1), 35–46. http://hdl.handle.net/10419/174883
8. Dazé, A. (2011). Understanding Vulnerability to Climate Change: Insights from Application of CARE's Climate Vulnerability and Capacity Analysis (CVCA) Methodology. *CARE Poverty, Environment and Climate Change Network (PECCN)*, 31. http://www.careclimatechange.org/files/adaptation/CARE_Understanding_Vulnerability.pdf
9. Ao, Y., Tan, L., Feng, Q., Tan, L., Li, H., Wang, Y., Wang, T., & Chen, Y. (2022). Livelihood Capital Effects on Famers' Strategy Choices in Flood-Prone Areas—A Study in Rural China. *International Journal of Environmental Research and Public Health*, *19*(12). https://doi.org/10.3390/ijerph19127535
10. Basiru, A. O., Oladoye, A. O., Adekoya, O. O., Akomolede, L. A., Oeba, V. O., Awodutire, O. O., Charity, F., & Abodunrin, E. K. (2022). Livelihood Vulnerability Index: Gender Dimension to Climate Change and Variability in REDD + Piloted Sites, Cross River State, Nigeria. *Land 2022, Vol. 11, Page 1240*, *11*(8), 1240. https://doi.org/10.3390/LAND11081240
11. Baudoin, M.-A., Henly-Shepard, S., Fernando, N., Sitati, A., & Zommers, Z. (2014). Early warning systems and livelihood resilience: Exploring opportunities for community participation. *UNU-EHS Institute for Environment and Human Security*, *December*. http://www.munichre-foundation.org/dms/MRS/Documents/Resilience-Academy/2014_resilience_academy_wp1.pdf
12. CTCN. (2018). *Climate Change Vulnerability Assessments | Climate Change Resource Center*. https://www.fs.usda.gov/ccrc/topics/assessments/vulnerability-assessments
13. Dapilah, F., Nielsen, J. Ø., & Friis, C. (2020). The role of social networks in building adaptive capacity and resilience to climate change: a case study from northern Ghana. *Climate and Development*, *12*(1), 42–56. https://doi.org/10.1080/17565529.2019.1596063
14. Didham, R. J., & Ofei-Manu, P. (2020). Adaptive capacity as an educational goal to advance policy for integrating DRR into quality education for sustainable development. *International Journal of Disaster Risk Reduction*, *47*, 101631. https://doi.org/10.1016/J.IJDRR.2020.101631
15. Dinda, S. (2015). Adaptation to Climate Change for Sustainable Development. *Https://Services.Igi-Global.Com/Resolvedoi/Resolve.Aspx?Doi=10.4018/978-1-4666-8814-8.Ch018*, 363–391. https://doi.org/10.4018/978-1-4666-8814-8.ch018
16. District, G. (2018). *Gicumbi District Development Strategy (DDS)*.
17. District, G. (2022). *Resettlement Action Plan for the Rehabilitation, Upgrading and Maintenance Works of Additional Works of Byumba Urban Roads in Gicumbi District 15 . 53Km* (Issue October).
18. District, G. (2023). *Updated Environmental and Social Management Plan (ESMP) for Second Additional Financing for the Rwanda Quality Basic Education for Human Capital Development Project in Gicumbi District*.
19. Dube, E., Mtapuri, O., & Matunhu, J. (2018). Flooding and poverty: Two interrelated social problems impacting rural development in Tsholotsho district of Matabeleland North province in Zimbabwe. *Jàmbá : Journal of Disaster Risk Studies*, *10*(1). https://doi.org/10.4102/JAMBA.V10I1.455
20. Dubey, P., & Chaturvedi, S. S. (2022). Assessment of Livelihood Vulnerability to Climate Change: A Study from Northeast, India. *J. Himalayan Ecol. Sustain. Dev*, *17*.
21. EM-DAT. (2023). *The International Disaster Database by Centre for Research on the Epidemiology of Disaster (CRED).* https://doi.org/(assessed 23/08/024)
22. Erima, G., Egeru, A., Gidudu, A., Bamutaze, Y., Kabenge, I., & Asiimwe, R. (2023). Determinants of households' flood risk coping strategies in a high exposure system of the Manafwa catchment and Lake Kyoga Basin. *Water Policy*, *25*(5), 468–491. https://doi.org/10.2166/WP.2023.231
23. Etongo, D., & Arrisol, L. (2021). Vulnerability of fishery-based livelihoods to climate variability and change in a tropical island: insights from small-scale fishers in Seychelles. *Discover Sustainability*, *2*(1). https://doi.org/10.1007/s43621-021-00057-4
24. FAO. (2013). Resilient Livelihoods-disaster risk reduction for food and nutrition security Framework Programme. In *The Framework for Teacing Evaluation Instrument* (Issue 1100).
25. GCA. (2021). Water Resources Management, Floods, and Disaster Risk Management. *Global Center on Adaptation*, 388–415. https://gca.org/wp-content/uploads/2022/07/06_WTW_14855_GCA_2021_Sect2_WATER_v5.pdf
26. Gerlitz, J. Y., Macchi, M., Brooks, N., Pandey, R., Banerjee, S., & Jha, S. K. (2017). The Multidimensional Livelihood Vulnerability Index–an instrument to measure livelihood vulnerability to change in the Hindu Kush Himalayas. *Climate and Development*, *9*(2), 124–140. https://doi.org/10.1080/17565529.2016.1145099
27. Haeffner, M., Baggio, J. A., & Galvin, K. (2018). Investigating environmental migration and other rural drought adaptation strategies in Baja California Sur, Mexico. *Regional Environmental Change*, *18*(5), 1495–1507. https://doi.org/10.1007/S10113-018-1281-2/METRICS
28. Haenfling, C., Schori, A., Marsters, H., Borman, B., & Our, D. R. (2019). Social vulnerability indicators for flooding in

Aotearoa New Zealand : Research report. In *Wellington:Environmental Health Indicators Programme, Massey University*.

29. Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change*, *19*(1), 74–88. https://doi.org/10.1016/J.GLOENVCHA.2008.11.002
30. Hoq, M. S., Raha, S. K., & Hossain, M. I. (2021). Livelihood Vulnerability to Flood Hazard: Understanding from the Flood-prone Haor Ecosystem of Bangladesh. *Environmental Management*, *67*(3), 532–552. https://doi.org/10.1007/S00267-021-01441-6
31. Huong, N. T. L., Yao, S., & Fahad, S. (2019). Assessing household livelihood vulnerability to climate change: The case of Northwest Vietnam. *Human and Ecological Risk Assessment: An International Journal*, *25*(5), 1157–1175. https://doi.org/10.1080/10807039.2018.1460801
32. Iliyyan, D. U., Boer, R., & Hidayati, R. (2022). Community Livelihood Vulnerability of Tanah Merah and Lobuk in Sumenep Regency to Climate Change. *Agromet*, *36*(2), 88–100. https://doi.org/10.29244/j.agromet.36.2.88-100
33. International Labour Organization (ILO). (2019). Water for Improved Rural Livelihoods. *International Labour Organization (ILO)*, 1–12. https://www.ilo.org/global/topics/economic-and-social-development/rural-development/WCMS_729058/lang--en/index.htm
34. IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press*. https://researchspace.csir.co.za/dspace/handle/10204/12710
35. Kamal, N., & Pachauri, S. (2018). *Mann-Kendall Test - A Novel Approach for Statistical Trend Analysis*. *63*(1), 18–21.
36. Khan, M. A., Hasan, K., & Kabir, K. H. (2022). Determinants of households' livelihood vulnerability due to climate induced disaster in southwest coastal region of Bangladesh. *Progress in Disaster Science*, *15*, 100243. https://doi.org/10.1016/J.PDISAS.2022.100243
37. Koirala, S. (2015). Livelihood Vulnerability Assessment to the Impacts of Socio-Environmental Stressors in Raksirang VDC of Makwanpur District Nepal. *The Department of International Environment and Development Studies, Noragric*. https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/283371
38. Madhuri, Tewari, H. R., & Bhowmick, P. K. (2015). Livelihood vulnerability index analysis: An approach to study vulnerability in the context of Bihar. *Jamba: Journal of Disaster Risk Studies*, *6*(1). https://doi.org/10.4102/JAMBA.V6I1.127
39. Mag, T. F. (2023). *Key achievements of Green Gicumbi project in three years - The Forefront Mag*. https://theforefrontmagazine.com/key-achievements-of-green-gicumbi-project-in-three-years/
40. Mai, N. N. (2022). *Literature Review on Assessment of Livelihood Vulnerability to Climate Change and Recommendation of the Assessment Method for the North Central Coast | FFTC Agricultural Policy Platform (FFTC-AP)*. Food and Fertilizer Technology Center for the Asian and Pacific Region. https://ap.fftc.org.tw/article/3117
41. Malakar, K., Mishra, T., & Patwardhan, A. (2018). Perceptions of multi-stresses impacting livelihoods of marine fishermen. *Marine Policy*, *97*, 18–26. https://doi.org/10.1016/J.MARPOL.2018.08.029
42. Marcela Beltrá n-Tolosa, L. I., Cruz-Garcia ID, G. S., Ocampo, J., PradhanID, P., & QuinteroID, M. (2022). Rural livelihood diversification is associated with lower vulnerability to climate change in the Andean-Amazon foothills. *PLOS Climate*, *1*(11), e0000051. https://doi.org/10.1371/JOURNAL.PCLM.0000051
43. Mekonen, A. A., & Berlie, A. B. (2021). Rural households' livelihood vulnerability to climate variability and extremes: a livelihood zone-based approach in the Northeastern Highlands of Ethiopia. *Ecological Processes*, *10*(1), 1–23. https://doi.org/10.1186/S13717-021-00313-5/FIG.S/11
44. MIDIMAR. (2017). *The Monthly and Annual Data on Disasters Countrywide. The Ministry of Disaster Management and Refugee Affairs (MIDIMAR).*
45. Mondal, M. S. H., Murayama, T., & Nishikizawa, S. (2020). Determinants of Household-Level Coping Strategies and Recoveries from Riverine Flood Disasters: Empirical Evidence from the Right Bank of Teesta River, Bangladesh. *Climate 2021, Vol. 9, Page 4*, *9*(1), 4. https://doi.org/10.3390/CLI9010004
46. Nahayo, L., Nsengiyumva, J. B., Mupenzi, C., Mindje, R., & Nyesheja, E. M. (2019). Climate Change Vulnerability in Rwanda, East Africa. *International Journal of Geography and Geology*, *8*(1), 1–9. https://doi.org/10.18488/journal.10.2019.81.1.9
47. NISR. (2012). Fourth Rwanda Population and Housing Census. In *Fourth Rwanda Population and Housing Census.*
48. NISR. (2023). The Fifth Rwanda Population and Housing Census, Main Indicators Report, February 2023. In *Ministry of Finance and Economic Planning National Institute of Statistics of Rwanda* (Vol. 5, Issue 1).
49. Nkurunziza, B. M. (2023). *Rwanda: Northern Province Hit By 1,500 Disaster Cases Over Past Five Years.* https://allafrica.com/stories/202304170334.html
50. Okaka, F. O., & Odhiambo, B. D. O. (2019). Health vulnerability to flood-induced risks of households in flood-prone informal settlements in the Coastal City of Mombasa, Kenya. *Natural Hazards*, *99*(2), 1007–1029. https://doi.org/10.1007/s11069-019-03792-0
51. Okeleye, S. O., Olorunfemi, F. B., Sogbedji, J. M., & Aziadekey, M. (2016). Impact Assessment of flood disaster on livelihoods of farmers in selected farming communities in Oke-Ogun region of Oyo State, Nigeria. *International Journal of Scientific & Engineering Research*, *7*(8), 2067–2083.
52. Panthi, J., Aryal, S., Dahal, P., Bhandari, P., Krakauer, N. Y., & Vishnu Prasad, P. (2015). Livelihood vulnerability approach to assessing climate change impacts on mixed agro-livestock smallholders around the Gandaki River Basin in Nepal. *Regional Environmental Change*, *16* (2016), 1121–1132. https://doi.org/https://doi.org/10.1007/s10113-015-0833-y
53. Parvin, G. A., Shimi, A. C., Shaw, R., & Biswas, C. (2016). Flood in a changing climate: The impact on livelihood and how the rural poor cope in Bangladesh. *Climate*, *4*(4). https://doi.org/10.3390/cli4040060
54. Peng, L., Xu, D., & Wang, X. (2018). Vulnerability of rural

household livelihood to climate variability and adaptive strategies in landslide-threatened western mountainous regions of the Three Gorges Reservoir Area, China. *Https://Doi.Org/10.1080/17565529.2018.1445613*, *11*(6), 469–484. https://doi.org/10.1080/17565529.2018.1445613

55. Piya, L., Joshi, N. P., & Maharjan, K. L. (2015). Vulnerability of Chepang households to climate change and extremes in the Mid-Hills of Nepal. *Climate Change*, *135* (2016), 521–537. https://doi.org/https://doi.org/10.1007/s10584-015-1572-2
56. Pörtner, H.-O., Roberts, D. C., Melinda M. B., T., Elvir, P., Katja, M., Andrés, A., Marlies, C., Stefanie, L., Sina, L., Vincent, M., Andrew, O., & Bardhyl, R. (2022). Climate Change 2022_ Impacts, Adaptation and Vulnerability_ *Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, *August*, 37. https://doi.org/10.1017/9781009325844.Front
57. Poudel, S., Funakawa, S., Shinjo, H., & Mishra, B. (2020). Understanding households' livelihood vulnerability to climate change in the Lamjung district of Nepal. *Environment, Development and Sustainability*, *22*(8), 8159–8182. https://doi.org/10.1007/s10668-019-00566-3
58. Red, B., Flanders, C., Red, J., & Societies, C. (2022). *Final Report of the EPoA Rwanda : Floods and Windstorm* (Issue June).
59. REMA. (2019). *"Assessment of climate change vulnerability in Rwanda - 2018", Rwanda Environment Management Authority, Kigali,2019*.
60. Rentschler, J., & Salhab, M. (2020). People in Harm's Way : Flood Exposure and Poverty in 189 Countries. *Policy Research Working*, *October*, Policy Working Paper 9447. https://openknowledge.worldbank.org/handle/10986/34655
61. Sam, A. S., Kumar, R., Kächele, H., & Müller, K. (2017). Vulnerabilities to flood hazards among rural households in India. *Natural Hazards*, *88*(2), 1133–1153. https://doi.org/10.1007/s11069-017-2911-6