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RESEARCH ARTICLE

Characterizing rural households' livelihood vulnerability to climate change and extremes in Migori River Watershed, Kenya

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ABSTRACT

Sub-Saharan Africa, of which Kenya is part, is considered the most vulnerable region to climate change impacts due to its dependence on rain-fed agriculture and natural resources. Since the rural livelihood systems in Kenya are expected to bear some of the worst effects of climate change, it is imperative to assess rural households' vulnerability to climate change impacts to facilitate the development of adaptation strategies. Therefore, this paper determines the level and sources of households' livelihood vulnerability to climate variability in the Migori River watershed, Kenya. The Livelihood Vulnerability Index (LVI) framed within the Intergovernmental Panel on Climate Change (IPCC) vulnerability framework (LVI-IPCC) was applied. A cross-sectional household survey conducted on 318 randomly selected households was used to assess how vulnerability differs across three watershed zones, upstream, midstream, and downstream. The LVI-IPCC scores were −0.047, −0.003, and 0.008 for the upstream, midstream, and downstream zones, respectively, with significant differences noted in the scores (ANOVA, $p < 0.05$). Findings indicate that while the livelihoods in all three zones showed moderate vulnerability to environmental and socio-economic stressors, there are notable variations between them. The downstream households exhibit the highest vulnerability, attributed to their lower adaptive capacity, increased exposure, and heightened sensitivity. Conversely, the upstream households demonstrate the least vulnerability compared to the other zones, owing to their lower sensitivity and exposure, as well as better adaptive capacity. Policy recommendations for reducing households' exposure to climate risks and for strengthening their adaptive capacity are discussed.

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Climate change; rural household livelihoods; livelihood vulnerability index; LVI-IPCC; watershed development

1. Introduction

1.1. Background

Climate change is a major environmental challenge that poses a threat to the world population (Dhungana et al., 2018; IPCC, 2019). The Intergovernmental Panel on Climate Change (IPCC) report indicates that between 2011 and 2020 the global mean temperature was 1.1°C warmer than at any time in the last 100,000 years and global mean precipitation rose by 2% since the 1950s (IPCC, 2021). Further, IPCC predicts a temperature rise of up to 1.5°C in the next 20 years (2021–2040) and 0.3–4.8°C by the end of this century depending on emission scenarios (IPCC, 2022). These climatic changes have been manifested through an increase in the frequency of hot days and cold nights, erratic precipitation patterns, an increase in the occurrence of natural hazards like floods, droughts, and landslides, as well as an increase in the prevalence of various crop and livestock pests and diseases (Asrat & Simane, 2017; Chepkoech et al., 2018; Das & Ansari, 2021). These events influence the biological, geophysical processes, and socio-economic systems, which adversely affect the ecosystems (Sintayehu, 2018), agricultural production (FAO, 2018), public health (Butler, 2018), water resources (Das & Ansari, 2021), economics (Hallegatte et al., 2018) and social justice (Fadda, 2020). These impacts threaten the lives and livelihoods of communities in both the developed and developing world, making climate change a global phenomenon (Burgess et al., 2020; IPCC 2021).

Of the developing world, Africa is among the most vulnerable continents to climate change impacts because of its dependence on rain-fed agriculture, a climate-sensitive sector, and poor adaptive capacity resulting from high poverty levels (Chepkoech et al., 2018; IPCC, 2019). Moreover, Sub-Saharan Africa is said to be a more vulnerable region with projections indicating that by the year 2050, the crop yields may decrease by 10–15% (IPCC, 2022) and by 2100 the crop revenues could decline by 90% (Islam & Karim, 2019; Wudil et al., 2022). This is because the region has already faced and will continue to face high temperatures, periodic floods and droughts, aridity, and erratic precipitation patterns (IPCC, 2019; Serdeczny et al., 2017). Kenya is characterized by a third of the total population (about 16 million) living on less than 1 USD a day (KNBS, 2019), agriculture employs 40% of the total population and 70% of rural population, agriculture contributes 33% to the countries' national GDP, and agricultural sector is considered the most vulnerable to climate-related hazard and risks (FAO, 2022; Nyika, 2022; USAID, 2020). Stockholm Environment Institute study notes that unless actions to improve climate change adaptation are effective, Kenya may lose up to 3% of its GDP each year by 2030 (Buhr et al., 2018); due to climate change impacts which are expected to cause serious socio-ecological and economic implications on

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livelihoods that are reliant on natural resources like agriculture and ecotourism (Elema, 2018). All of these point to the necessity for urgent actions in the country to develop and apply climate change adaptation measures. The first step in designing adaptation strategies is to assess the factors that contribute to vulnerability in order to inform policies and programmes to minimize risks associated with climate change (Huong et al., 2019; Huynh & Stringer, 2018; Orsetti et al., 2022).

Limited research has been conducted on households' vulnerability to climate change impacts in Kenya's fragile watershed agro-ecologies, despite the country's reliance on agriculture as a major contributor to GDP and rural livelihoods (FAO, 2022). While the projected implications of climate change on these livelihoods are recognized (Nyika, 2022; USAID, 2020), there is a significant research gap in understanding the specific vulnerabilities experienced by households in these areas. Existing studies have primarily focused on broader aspects of climate change impacts particularly in rangelands and arid areas (Opiyo et al., 2014; Quandt, 2018, 2020; Quandt et al., 2017), neglecting the unique challenges faced by households in watershed agro-ecologies. Closing this research gap is crucial for developing targeted adaptation strategies and informing policy interventions that address the specific vulnerabilities of households in these contexts. Therefore, as an attempt to bridge this knowledge gap, this paper assesses the livelihood vulnerability of households in the three zones of the Migori River watershed using the LVI-IPCC approach. The Migori River watershed, situated in the Lake Victoria basin, has been previously affected by warming temperatures and changing rainfall patterns, which are likely to have implications for the local livelihoods (Lejju, 2012; Sewagudde, 2009). By applying the LVI-IPCC approach, this study will provide valuable insights into the vulnerability of watershed households to climate change and how this vulnerability varies across different zones. These findings will provide a deeper understanding of the complexities and potential opportunities for enhancing climate resilience in watershed agro-ecologies. Additionally, as the first application of the LVI-IPCC approach in Kenya, this study pioneers the use of a standardized and internationally recognized methodology to evaluate the vulnerability of households in Kenya's context. By doing so, it establishes a benchmark and reference point for future studies on vulnerability assessment in the country, ensuring consistency and comparability in research findings. Furthermore, this study acknowledges the importance of understanding vulnerability within the local context, emphasizing the need to tailor adaptation and mitigation strategies accordingly. This recognition of context-specific vulnerability can guide policymakers and development practitioners in designing targeted interventions to effectively address the unique challenges faced by households in Kenya in the face of climate change.

The general aim of this study, therefore, is to determine the level and sources of rural households' livelihood vulnerability to climate change and extremes in the Migori River watershed, Kenya, using the LVI-IPCC approach. The specific objectives of this research are to: (i) adapt the existing Livelihood Vulnerability Index (LVI-IPCC) developed by Hahn et al. (2009) to be relevant to the Migori River watershed in order to create a local livelihood vulnerability index, (ii) apply the LVI-IPCC to assess and compare the household livelihood vulnerability to climate change of three zones of the Migori River watershed, and (iii) identify key factors or sub-indicators of the LVI-IPCC which significantly contributes to the household livelihood vulnerability of the watershed zones, in order to suggest the suitable alternatives for adaptation of policies to climate change.

1.2. Literature review: theoretical framework of livelihood vulnerability assessment

Vulnerability is an ambiguous concept with varying definitions across fields (Gallopín, 2006), but in climate change studies, the IPCC definition is generally accepted by scholars as all-encompassing (Burgess et al., 2020). The IPCC (2022) defines vulnerability in climate change as the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. Climate change vulnerability is dynamic, varying temporally and spatially, depending on both ecological and socio-economic processes (Huong et al., 2019). Climate change vulnerability assessment has been demonstrated to be an effective approach for identifying vulnerable systems and developing suitable climate change adaptation strategies (Orsetti et al., 2022). Vulnerability assessment encompasses a broad range of methodologies for systematically integrating and evaluating interactions between human beings and their physical, social, political, and economic surroundings (Hahn et al., 2009; IPCC, 2019). However, vulnerability assessments have also been highly critiqued. One major criticism is that they often involve aggregating multiple indicators into a single metric, which can oversimplify complex social, economic, and environmental dynamics (Jones & Tanner, 2017). This reductionist approach may overlook the nuances and complexities of vulnerability, leading to a loss of valuable information. In literature, there is no unified agreement on how to estimate vulnerability, although most evaluation methodologies comprise one or more of the following factors: risk exposure, vulnerability to damages, and resilience (Laurien et al., 2022). Although there are several approaches to livelihood vulnerability analysis, a more practical approach is investigating how vulnerable a community is in comparison to others and which component contributes to the community's vulnerability level (Huong et al., 2019).

Most scholars rely on the vulnerability framework based on the IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity (Huynh & Stringer, 2018; IPCC, 2022). This vulnerability framework proposed by the IPCC is regarded as a powerful analytical tool for assessments (Araro et al., 2020; Legese et al., 2016). Within this broader framework, Hahn et al. (2009) developed an indicator-based vulnerability assessment, the Livelihood Vulnerability Index, which has been utilized by numerous scholars and scientists in various regions (Al Mamun et al., 2023; Alam et al., 2017; Mukherjee & Siddique, 2020; Panthi et al., 2016; Siraw et al., 2018; Tewari & Bhowmick, 2014). The Livelihood Vulnerability Index (LVI-IPCC) is a composite index of all major components mapped onto the three IPCC contributing factors to vulnerability, exposure, sensitivity and adaptive capacity (Hahn et al., 2009). Exposure relates to climate-induced stressors which affect a livelihood system, sensitivity reflects the extent to which a livelihood system is impacted by or responsive to climate-induced stressors whereas adaptive capacity describes the ability of a livelihood system to adjust to climate change (Huong et al., 2019; IPCC, 2021). The LVI-IPCC approach 'uses multiple indicators to assess exposure to natural disasters and climate variability; social and economic characteristics of households that affect their adaptive capacity; and health status, food and water resource characteristics that determine their sensitivity to climate change impacts' (Al Mamun et al., 2023; wPanda & Amaratunga, 2016). One of the major critiques of this indicator-based approach is related to the selection and weighting of indicators. The choice of indicators and their relative importance in the index can be subjective and may not fully reflect the priorities and experiences of the local communities (Tran et al., 2021). The weighting of indicators may also be influenced by the preferences and biases of the assessors, potentially leading to a distorted representation of vulnerability (Tran et al., 2021). Moreover, the LVI-IPCC, as a static index, may not fully capture the temporal dynamics of vulnerability. Vulnerability is often dynamic, influenced by factors such as seasonal variations, shocks, and long-term trends. The index may not adequately capture these temporal dynamics, limiting its ability to provide a nuanced understanding of vulnerability over time.

The LVI-IPCC is designed to provide local policy-makers and development organizations with a pragmatic tool for understanding and assessing vulnerabilities at various levels to facilitate the effective formulation of targeted climate change adaptation programmes and policies (Huong et al., 2019). In the first application of LVI-IPCC, Hahn et al. (2009) used the LVI-IPCC approach for the first time in two villages in Mozambique with varying ecological and socio-economic conditions where they established that the livelihood of one village was more confined by a physical limitation (water resources) whereas the other had extreme vulnerabilities in its socio-demography. Since then, the LVI-IPCC approach has been used to evaluate the livelihood vulnerability of communities and regions in other developing countries. Although Africa is considered the most vulnerable region to climate change impacts, the LVI-IPCC approach has, however, only been applied to study communities in Ethiopia (Asrat & Simane, 2017; Siraw et al., 2018), Ghana (Amoatey & Sulaiman, 2020) and Kenya (Koech et al., 2020) besides the initial use in Mozambique.

Besides the African continent, various studies from various zones of the globe threatened by climate change and extremes have utilized the LVI-IPCC index to determine the level of vulnerability of farmers/rural households to climate extremes using the 'vulnerability as expected poverty' approach. For instance, a study by Adhikari et al. (2020) examined the vulnerability of households in the watershed in western Nepal, one of the 10 most climate-vulnerable countries among the developing countries (IPCC, 2019), and found climate-induced hazards like drought, landslide, and thunderstorm as major contributors to the high vulnerability of the households' livelihood strategies. Huong et al. (2019) study which assessed the vulnerability to climate change of three agriculture-dependent communes in northwest Vietnam, a country whose coastal region is becoming more vulnerable to climate-induced risks including sea level rise, coastal flooding, salinity intrusion, and coastal erosion, established that higher vulnerability in the communes is primarily a result of higher vulnerability on physical, financial, and social capitals. In the Grande Riviere community in Trinidad, an island nation of the Caribbean region threatened by heavy rainfall events, sea level rises and socio-economic stresses, Ganase and Teelucksingh (2011) study concluded that low adaptive capacity and resilience levels are the causes of high vulnerability levels of Small Island Developing States like Trinidad. A vulnerability assessment of nine communities in Bangladesh's coastal region constantly threatened by natural disasters like cyclones, river bank erosion, salinity intrusion, water stagnation, and heavy rainfalls found high water resource vulnerability as the major factor in perpetuating coastal households' poverty (Hosen, 2016). Another study examining agricultural livelihood vulnerability to climate change in Bluefields in Jamaica, an island nation experiencing increased rainfall variability and changing seasonal precipitation patterns, showed farmers in Bluefields have the greatest amount of vulnerability in the area of social networks and water issues (Fath, 2014).

2. Methods

2.1. Description of the study area (Migori River watershed)

This study focuses on the Migori River watershed (Figure 1), a catchment for the Migori River covering about 2597 km^2 of the land area of Migori County in western Kenya with a total population of about 733,111 (KNBS, 2019). Situated at 1500 m a.s.l. altitude, this catchment stretches from the Chepalungu Forest in Emuria-Dikiri Sub-county of Narok County to the shores of Lake Victoria. The entire watershed experiences an inland equatorial climate characterized by 13–24°C average temperatures and 700–1800 mm mean annual precipitation. Due to its closeness to Lake Victoria, the region experiences two wet seasons and two dry seasons annually. Due to these climatic conditions, the major crops cultivated in the region include maize, beans, vegetables, tobacco, coffee, sugarcane, and ground nuts. Agricultural production is limited by the occasional drought and flood conditions (Magige, 2018). In some areas, the waters of Migori River are harvested for irrigation purposes to support crop production during droughts.

The watershed is divided into three main regions/zones (Opiyo et al., 2023): the upstream area, primarily encompassing Kuria West and East Sub-counties; the midstream area, primarily covering Suna East and West Sub-counties; and the downstream area, primarily spanning Nyatike Sub-county. This classification, originally conducted by JICA (2014), is based on geographical characteristics that result in distinct differences in channel geometry, microfacies, grain size, and geological processes among the three segments. The channel geometry transitions from high sinuosity in the upstream region to moderate-low sinuosity in the midstream region and eventually to slight sinuosity or even partially straight in

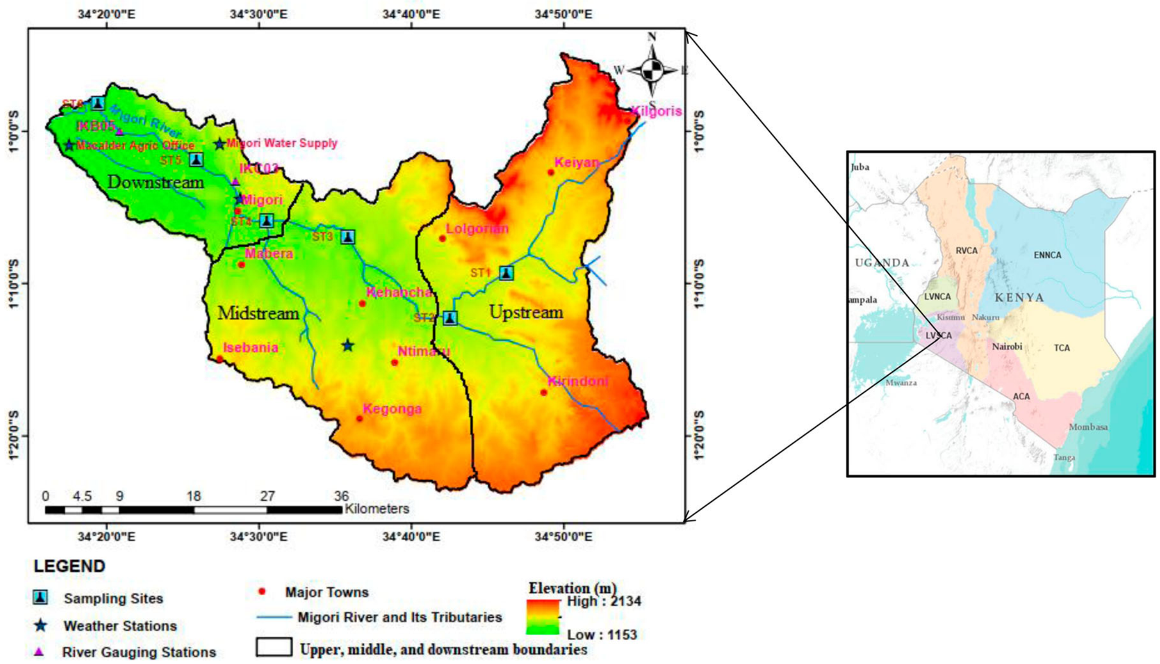

Figure 1. Map showing the three zones of Migori River watershed (Opiyo et al., 2023).

the downstream region (JICA, 2014). The upstream, midstream, and downstream zones cover land areas of 1061.78, 914.36, and 622.23 km^2, respectively.

The upstream zone of the Migori River watershed is mainly made up of highlands, hills and protected forest blocks; the midstream zone is generally gently sloping compared to the upstream region; and the downstream zone is a semi-arid region characterized by relatively slow water flow velocity and a lot of lateral erosion (Odumo et al., 2011). In terms of land use/land cover, the upstream is dominated by extensive agricultural and deforestation practices, the midstream zone is mainly dominated by urbanization and agricultural practices, while the downstream region is dominated by mining and urban development activities (Opiyo et al., 2022). Three primary ethnic groups are present along the length of the Migori River in the following manner: the Maasai community (engaged in agro-pastoralism) resides in the upstream region, the Kuria community (involved in farming and mining) inhabits the midstream area, and lastly, the Luo community (engaged in farming, mining, and fishing) is situated downstream.

2.2. Data collection process and analysis

A descriptive cross-sectional survey was conducted in the Migori River watershed between January and February 2022, covering households in the three watershed zones: upstream, midstream, and downstream. The total sample size for the study was determined based on Fisher's formula:

$$n = \frac{NZ^2P(1-P)}{d^2\,(N-1) + Z^2\,P(1-P)}$$

where n is the required sample size, Z is the 95% confidence interval under the normal curve that is 1.96, $p = 0.5$ (proportion of the population to be included in the sample that is 50%), N is the size of population (153,954 households), d is the margin of error or degree of accuracy (0.05). From this equation, a total sample size of 384 households was determined for the survey, which when split equally among the three zones would result in a sample size of 128 households per zone. The actual sample size per zone was, however, reduced to 106 households in consideration of the financial constraints, available time resources, unexpected weather events occurring during the planned sampling period, and inaccessibility of certain households in mountainous regions. The study employed equal sample sizes for the three watershed zones rather than unequal sample sizes (proportionally-distributed sample sizes) to avoid the two practical issues/problems that often occur when performing one-way ANOVA with unequal sample sizes: reduced statistical power, and reduced robustness to unequal variance (Parra-Frutos, 2013). The statistical power of a test that compares groups, that is the probability that a test will detect some effect when there actually is one, is highest when each group has an equal sample size (Parra-Frutos, 2013). Literature has shown that the greater the differences in sample sizes, the lower the statistical power of one-way ANOVA, which is why researchers typically want equal sample sizes so that they maximize statistical power and thus a greater probability of detecting true differences (Glen, 2022; Parra-Frutos, 2013; Shingala & Rajyaguru, 2015). Concerning robustness to unequal variance, studies show that unequal sample sizes can lead to unequal variances between samples, which affect the assumption of equal variances in tests like ANOVA (Grace-Martin, 2021; Rusticus & Lovato, 2014). Thus, having both unequal sample sizes and variances dramatically affects statistical power and type I error rates, therefore, making the results of one-way ANOVA hard to trust (Rusticus & Lovato, 2014).

The selection of the 106 respondent households per each watershed zone was obtained through multi-stage sampling. In the first stage, administrative units called divisions within the various sub-counties located in the respective zones formed the clusters. In the second stage, sampled villages were purposively drawn from the randomly-selected clusters based on their proximity to the river, whereby those with households within 2–5 km from the river were chosen as they are the ones whose livelihoods are closely linked to the ecosystem functioning of the river system. In the third stage, a simple random sampling technique was used to select respondent households from within the chosen villages. Prior to the beginning of household survey activities, village elders and local administrative officials were consulted to explain the purpose of the study, understand the local livelihood realities (which helped in developing indicators and questionnaire items), and obtain permission to visit the selected households.

Household survey data was collected by nine trained enumerators, three in each watershed zone, using pre-tested, interviewer-administered semi-structured questionnaires. The household questionnaires consisted of sections intended to get information on indicators outlined in Table 1. During the exercise, the household questionnaires were administered to household heads (or other senior members of the selected households) by trained enumerators at the respondents' houses and farms, upon obtaining verbal consent. Cultural norms dictated that the male be interviewed as the head of the household unless stated otherwise or unless absent then the spouse or the next responsible adult (over 18 years of age) family member who understands the family and area well. In practice, it was customary to consider the male as the household head when both the husband and wife were present during the research, aligning with the cultural norms of the tribal ethnic communities residing in this watershed. Interviews were primarily conducted with the male unless otherwise specified by the husband, indicating that the wife should be interviewed as the household head. This approach was crucial for ensuring the smooth and successful execution of the research, as the Maasai and Kuria ethnic tribes in this watershed adhere to strict traditional cultural norms. These norms for instance dictate that when visiting their homes, one is required to greet the husband first before the wife. Failure to do so may result in aggressive hostilities, including being chased away from the homestead. Recognizing and addressing these realities and challenges during research planning is imperative for a conscientious researcher to ensure successful implementation. Each interview lasted about 35 min on average. The collected datasets were cleaned, edited, coded, and organized in MS Excel, and data analysis was performed using SPSS version 24.0. The outputs are presented in tables and figures.

2.3. Livelihood Vulnerability Index (LVI-IPCC) calculation

The Livelihood Vulnerability Index integrated with the IPCC's vulnerability framework (LVI-IPCC) as developed by Hahn et al. (2009) was adopted in assessing the vulnerability of households in the three zones of the watershed. This framework has been applied by several previous studies (Minh et al., 2019; Panthi et al., 2016; Shah et al., 2013; Tewari & Bhowmick, 2014; Tjoe, 2016; Zhang & Fang, 2020). The LVI-IPCC comprises eight major components (i.e. socio-demographic profile, livelihood strategies, social networks, health, food, water, natural disasters, and climate variability) distributed across the three dimensions of vulnerability (i.e. exposure, adaptive capacity, and sensitivity). Each of the eight major components of the LVI-IPCC is comprised of numerous sub-components or indicators, totalling 47 (Table 1). These indicators were developed based on the researcher's knowledge of the area, and literature review, and included some of the initial 29 indicators developed by Hahn et al. (2009), which were adjusted and customized to reflect the local realities of the watershed. The indicators considered under each major component, the source of information, their measurement scale, and their functional relationship with vulnerability are shown in Table 1.

The LVI-IPCC calculation is based on a balanced weighted-average approach, where each indicator contributes equally to the overall index (Hahn et al., 2009; Pandey & Jha, 2011; Simane et al., 2016; Sullivan, 2002). To analyse the LVI-IPCC for the three watershed zones, five major steps were followed. Firstly, the raw data of the indicators were transformed into appropriate numeric units of measurement such as count, ratios, indices and percentages. Secondly, since each indicator is measured on a different scale, the data of all the indicators were standardized to a scale between 0 and 1 using either Equation (1) or (2) (Hahn et al., 2009; Panthi et al., 2016). Equation (1) was used where the indicator has a positive relationship with vulnerability i.e. vulnerability increases with the increase in the value of indicators while Equation (2) was applied where the indicator has a negative relationship with vulnerability i.e. vulnerability will decrease with an increase in the values of indicators.

$$IndexS_z = \left\{ \frac{S_z - S_{min}}{S_{max} - S_{min}} \right\} \quad (1)$$

$$IndexS_z = \left\{ \frac{S_{max} - S_z}{S_{max} - S_{min}} \right\} \quad (2)$$

where $IndexS_z$ is the standardized value of the indicator for households in watershed zone z; S_z is the actual value of the same indicator; and S_{min} and S_{max} are the minimum and maximum values, respectively, of the same indicator.

Thirdly, after the standardization of all indicators, the indicators were averaged using Equation (3) to obtain the index of each major component for the respective watershed zones.

$$M_c = \left\{ \frac{\sum_{i=1}^{n} IndexS_{zi}}{n} \right\} \quad (3)$$

where M_c is one of the eight major components for each watershed zone; $IndexS_{zi}$ represents the indicators indexed by i that make up each major component; and n is the number of indicators in each major component. The weights of each major component are determined by the number of indicators that

Table 1. Vulnerability dimensions, major components, indicators and hypothesized relationships.

IPCC Vulnerability Dimensions	Major Components	Indicators	Functional Relationship to vulnerability	Source
Adaptive Capacity	Socio-demographic Profile (SDP)	% of female-headed HHs	Positive (high percentage increases vulnerability)	DHS (2006); Hahn et al. (2009)
		Dependency ratio of HHs	Positive (high ratio increases vulnerability)	DHS (2006); Hahn et al. (2009)
		The average age of household heads	Positive (old ages increases vulnerability)	Toufique and Yunus (2013)
		% of HHs who have not gone beyond primary education	Positive (higher education level of households head decrease vulnerability)	DHS (2006); Hahn et al. (2009)
		% of HHs with more than four members	Positive (higher numbers of family members increases vulnerability)	Campbell (2013)
		% of HHs with orphans	Positive (higher numbers of orphans increases vulnerability)	Adu et al. (2018)
		% of HHs where members had any informal skill	Negative (higher numbers of skilled family members reduces vulnerability)	Cutter et al. (2008)
		% of HHs with members needing dependent care	Positive (high % leads to high vulnerability)	Adu et al. (2018)
	Livelihood strategies	% of HHs with family members working in a different community/county	Negative (the high % lowers vulnerability)	World Bank (1998)
		% of HHs solely dependent on agriculture and livestock as their only source of income	Positive (higher the numbers, higher is the vulnerability)	Hahn et al. (2009)
		Average agricultural livelihood diversification index	Negative (more agricultural livelihoods reduce vulnerability)	DHS (2006); Hahn et al. (2009)
		% of HHs who took a loan in the past 5 years	Negative (higher %, lower the vulnerability)	Corbett (1988); Hahn et al. (2009)
		Income diversification index	Negative (more income sources reduce vulnerability)	Hahn et al. (2009)
		Natural resource and livestock index	Negative (more natural resources and livestock livelihoods reduce vulnerability)	Toufique and Yunus (2013)
	Social networks	Average Receive: Give ratio	Negative (lower ratio leads to higher vulnerability)	DHS (2006); Hahn et al. (2009)
		Average Borrow: Lend Money ratio	Negative (more sources of lending money reduce vulnerability)	World Bank (1998); DHS (2006); Hahn et al. (2009)
		% of HHs that have not asked their local government for any assistance in the past12 months	Negative (more assistance reduces vulnerability)	WHO/RBM (2003); Hahn et al. (2009)
		Availability of amenities (average no. of types of amenities)	Negative (high availability reduces vulnerability)	Toufique and Yunus (2013)
		% of HHs with membership in social groups	Negative (higher % reduce vulnerability)	Panthi et al. (2016)
		% of HHs that have received or attended training	Negative (more training reduce vulnerability)	Piya et al. (2012)
		% of HHs owning communication device	Negative (higher % reduce vulnerability)	Panthi et al. (2016)
Sensitivity	Health	Average time to reach the nearest health facility (on foot)	Positive (longer distance increases vulnerability)	Hahn et al. (2009)
		% of HHs with a family member with chronic illness	Positive (high % leads to high is the vulnerability)	Hahn et al. (2009)
		% of HHs where a family member had to miss work or school in the past 6 months due to illness	Positive (high % leads to high is the vulnerability)	World Health Organization/ Rollback Malaria (2003); Hahn et al. (2009)
		% of HHs without sanitary toilet	Positive (high % leads to high vulnerability)	Madhav (2010); Toufique and Yunus (2013)
	Food	% of HHs dependent on the family farms for food	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		Average crop diversity index	Positive (high index leads to high vulnerability)	Campbell (2013)
		On average number of months, households struggle to find/ % of HHs who report at least one month of food insecurity per year	Positive (the higher the number of months, the higher the vulnerability)	Hahn et al. (2009)
		% of HHs that do not save crops	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs that do not save seeds	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
	Water	% of HHs using unprotected water source	Positive (the higher the % using unsafe drinking water, the higher the vulnerability)	DHS (2006); Hahn et al. (2009)
		Time to travel to the source of natural water	Positive (longer distance leads to higher vulnerability)	Toufique and Yunus (2013)

(*Continued*)

Table 1. Continued.

IPCC Vulnerability Dimensions	Major Components	Indicators	Functional Relationship to vulnerability	Source
		% of HHs that have to go far to fetch water (above 5 km)	Positive (longer distance leads to higher vulnerability)	IIPS and ORC Macro (2007)
		% of HHs that do not have a consistent water supply	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs reporting water conflicts in the previous years	Positive (high % leads to high vulnerability)	Azene et al. (2018)
		The inverse of the average number of litres of water stored per household	Negative (higher litres stored lowers vulnerability)	Hahn et al. (2009)
Exposure	Natural disasters	Average frequencies of flood events in the past 10 years	More reflects high exposure	Williamsburg Emergency Mgmt. (2004)
		Average frequencies of drought events in the past 10 years	More reflects high exposure	Williamsburg Emergency Mgmt. (2004)
		Average frequencies of land degradation events in the past 10 years	More reflects high exposure	Williamsburg Emergency Mgmt. (2004)
		% of HHs with an injury or death as a result of natural disasters in the last 10 years	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs that do not receive a warning about the pending natural hazard	Positive (high % leads to high vulnerability)	Hahn et al. (2009)
		% of HHs with an injury or death to their livestock as a result of natural disasters in the last 10 years	Positive (high % leads to high vulnerability)	Adu et al. (2018)
		% of HHs with losses to physical assets (homestead/agricultural. equipment/ machinery) due to natural disasters	Positive (high % leads to high vulnerability)	Adu et al. (2018)
		% of HHs with crop failure as a result of natural disasters in the last 10 years	More reflects high exposure	Campbell (2013)
	Climate variability	% of HHs that perceived rising trend in daily temperature for the last 10 years	More reflects high exposure	Hahn et al. (2009)
		% of HHs that perceived annual temperature changes for the last 10 years	More reflects high exposure	Hahn et al. (2009)
		% of HHs who have experienced annual rainfall changes for the last 10 years	More reflects high exposure	Hahn et al. (2009)

make up each major component and are incorporated to make sure that all indicators contribute equally to the final LVI-IPCC (Hahn et al., 2009). Fourthly, once the values of each major component for each watershed zone were obtained and their weights determined, the major components were combined under their respective vulnerability categorization, exposure (natural disasters and climate variability), sensitivity (health, food, and water), and adaptive capacity (socio-demographic profile, livelihood strategies, and social networks). The values for each vulnerability categorization for each watershed zone were then calculated based on weighted averages of their respective major components using Equation (4a)–(4c):

$$Exposure_z = \left\{ \frac{W_{nd}ND + W_{cv}CV}{W_{nd} + W_{cv}} \right\} \tag{4a}$$

where W_{nd} and W_{cv} are the weights for natural disasters and climate variability, respectively; and Exposure$_z$ (exposure score for the studied watershed zone).

$$Sensitivity_z = \left\{ \frac{W_hH + W_fF + W_wW}{W_h + W_f + W_w} \right\} \tag{4b}$$

where W_h, $W_{f,}$ and W_w are the weights for health, food, and water, respectively; and $Sensitivity_z$ (sensitivity score for the studied watershed zone).

$$Adaptive\ Capacity_z = \left\{ \frac{W_{sdp}SDP + W_{ls}LS + W_{sn}SN}{W_{sdp} + W_{ls} + W_{sn}} \right\} \tag{4c}$$

where W_{sdp}, W_{ls}, and W_{sn} are the weights for socio-demographic profile, livelihood strategies, and social networks, respectively; and $Adaptive\ Capacity_z$ (adaptive capacity score for the studied watershed zone).

Finally, the three vulnerability contributing factors were combined using Equation (5) to calculate the LVI-IPCC for each watershed zone.

$$LVI - IPCC_z = (\text{Exposurez- Adaptive Capacity}_z)* \text{Sensitivity}_z \tag{5}$$

where $LVI\text{-}IPCC_z$ is the LVI for the studied watershed zone, $Exposure_z$ (weighted average of natural disasters and climate variability), $Sensitivity_z$ (weighted average of the health, food, and water), and $Adaptive\ Capacity_z$ (weighted average of the socio-demographic, livelihood strategies, and social networks). Upon obtaining the value for LVI-IPCC, the rating system shown in Table 2 was used in classifying the livelihood vulnerability of the three watershed zones. This rating system has a scale ranging from 1 (indicating most vulnerability) to −1 (indicating least vulnerability) based on IPCC (2014).

3. Results and discussion

3.1. Exposure

Exposure is a major contributing factor to the vulnerability of rural households, and it describes the nature and extent to which agro-based livelihood systems are vulnerable to significant variation in climate (IPCC, 2014). Exposure analysis generally reveals that the downstream (0.486) was the most exposed to climate-change-related shocks followed by the

Table 2. Vulnerability Classification scheme for LVI-IPCC.

Vulnerability Classification	Overall LVI-IPCC Values
Very high	0.61–1
High	0.21–0.60
Moderate	0.20–(−0.19)
Less	(−0.20)–(−0.60)
Very less	(−0.61)–(−1)

midstream (0.468) and the upstream (0.345) (Table 3). Exposure vulnerability dimension at each watershed zone was captured through analysis of its two major components – natural disasters and climate variability – whose results are shown in Table 3.

3.1.1. Natural disasters

Natural disasters component consisted of eight indexed-indicators (Tables 1 and 3). When these eight were aggregated, the downstream (0.309) was found to be the most vulnerable based on natural disaster vulnerability index followed by the midstream (0.285) and the upstream (0.107) (Table 3), with ANOVA (at $p < 0.05$) indicating that statistically significant differences exist in these vulnerability index values between the zones ($F = 5.196$, $p = 0.002$). The average number of floods, drought, and landslides incidences in the past 10 years was highest at the downstream (6.25, 3.3, and 2.7, respectively), followed by the midstream (3.7, 2.4, and 1.8, respectively), and lowest in the upstream (2, 0.5, and 1.1, respectively). This implies that the downstream has greater vulnerability to natural disasters than did the midstream and the upstream sections. Over the years, the downstream zone has experienced frequent occurrences of drought, floods, and landslides (Magige, 2018). Regions that experience frequent floods or droughts incidences are known to be more exposed and thus more vulnerable (Feyissa et al., 2018). About 11% of upstream, 6.25% of midstream and 3.08% of downstream households did not receive a warning about an impending natural disaster – floods, droughts, or landslides – translating to indices of 0.110, 0.063, and 0.31, respectively. As a result, 51.9% of downstream, 45.1% of midstream and 15.8% of upstream households reported a natural-disaster-related injury or death to a household member(s) in the last 6 years. Households in the watershed zones, midstream downstream and upstream reported a natural-disaster-related injury or death to their livestock in the last 6 years by 82%, 74% and 43%, respectively. About 48.1% of downstream households, 27.9% of midstream and 8.55% of upstream have experienced crop failure in the past 6 years. However, there was a minimal loss to physical assets such as homestead structures or farming equipment as a result of natural disasters since 7%, 5.8% and 3.2% of downstream, midstream and upstream households, respectively, reported experiencing such losses for the past 6 years.

3.1.2. Climate variability

Climate variability component consisted of three indexed-indicators (Tables 1 and 3). When the three indicators were aggregated, the upstream (0.979) was found to be the most vulnerable on the climate variability component followed by the downstream (0.959) and midstream (0.953) (Table 3). However, ANOVA (at $p < 0.05$) showed that no statistically significant differences exist in these vulnerability values between the zones ($F = 0.859$, $p = 0.456$). The proportion of households that have experienced daily temperature changes for the last 10 years was 98.1%, 95.3%, and 94.3% for the upstream, midstream and downstream, respectively, while the proportion of households that have experienced annual temperature changes for the last 10 years was 100% for upstream, 95.3% for midstream and 93.4% for downstream. Temperature fluctuations have significant implications for agricultural livelihoods' vulnerability, as rising temperatures have been known to have major impacts on crop growth and hence yields (Hussain & Hanif, 2013). With respect to precipitation, 100% of downstream, 95.7% of upstream and 95.3% of midstream households have experienced annual rainfall changes for the last 10 years. This indicates that there's not much difference in climate variability across the three watershed zones, which could be attributed to their similar agro-ecological settings. It has been previously established that erratic precipitation patterns contribute to low agricultural production leading to food

Table 3. Indexed scores of exposure analysis across the zones of Migori River watershed.

Indicators	Index Scores			Major Components	Index Scores		
	Upstream	Midstream	Downstream		Upstream	Midstream	Downstream
Average frequency of floods in the past 10 years	0.000	0.350	0.179	Natural Disasters	0.107	0.285	0.309
Average frequency of droughts in the past 10 years	0.000	0.100	0.217				
Average frequency of landslides in the past 10 years	0.050	0.167	0.237				
% of HHs with an injury or death as a result of natural disasters in the last 6 years	0.157	0.451	0.519				
% of HHs that do not receive a warning about the pending natural hazard	0.110	0.063	0.031				
% of HHs with an injury or death to their livestock as a result of natural disasters in the last 6 years	0.425	0.816	0.740				
% of HHs with losses to physical assets due to natural disasters	0.032	0.058	0.070				
% of HHs with crop failure as a result of natural disasters in the last 6 years	0.085	0.279	0.481				
% of HHs that perceived a rising trend in daily temperature	0.981	0.953	0.943	Climate variability	0.979	0.953	0.959
% of HHs that perceived annual temperature changes	1.000	0.953	0.934				
% of HHs who have experienced annual rainfall changes	0.957	0.953	1.000				
Exposure LVI					0.345	0.468	0.486

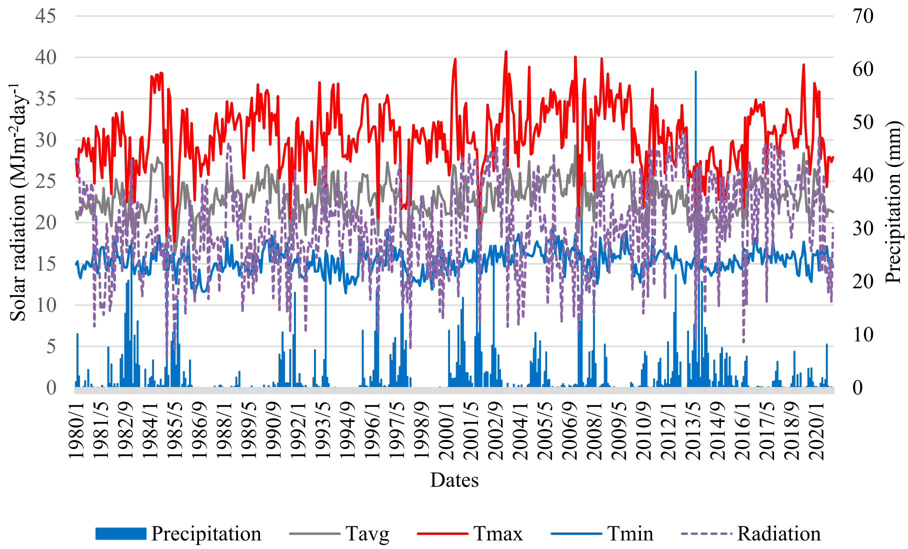

Figure 2. Daily weather profile for Migori River watershed showing trends of precipitation, average (T_{avg}), minimum (T_{min}) and maximum (T_{max}) temperature, and radiation.

shortages which exposes households in the East African countries to vulnerability (Araya et al., 2015).

To develop a more comprehensive and accurate understanding of climate variability in the area, the study triangulated the watershed people's perceptions of climate variability with meteorological data by extracting long-term monthly and annual temperature (average, min and max °C), rainfall (mm) and solar radiation (W/m^2) data for the period between 1980 and 2020 from the local meteorological stations, and computing their means (± standard deviation) (Figures 2 and 3). The mean (± standard deviation) value for annual precipitation of the Migori River watershed during the last 40 years (1980–2020) was 3.41 ± *1.69* mm. On the other hand, the mean (± standard deviation) value of average monthly temperature was *22.30* ± *0.73°C*, where the mean minimum, and mean maximum values ranged from *14.78°C to 16.08°C* (*15.48* ± *0.29°C*), and *26.47°C to 32.84°C* (*30.42* ± *1.33°C*), respectively. The linear regression model revealed that the average minimum and maximum temperatures had risen by *0.006*°C and −*0.016*°C per year over the last 40 years, respectively (Figure 3). This finding is consistent with the research by Kenya Meteorological Department (KMD) that indicated a 0.21°C rise in mean annual temperature per decade (IPS, 2019). Generally, it was found that both the household survey reports and meteorological records concur on temperature and rainfall variations in the watershed. Climate change has lately occurred in the Migori region, resulting in irregular precipitation patterns, increasing temperatures and rainfall volumes, frequent and lengthy dry seasons, and spells of water shortages (Ayugi et al., 2016; Relief-Web Kenya, 2021). This situation constrains the ability of Migori River watershed to produce ecological services, putting further strain on accessibility to and utilization of livelihood resources.

3.2. Sensitivity

Sensitivity, as a major contributing factor to the vulnerability of rural households, describes the extent to which an agro-based livelihood system is impacted, either negatively or positively, by climate-related events/elements (IPCC, 2014). Sensitivity major components are health, food and water, whose

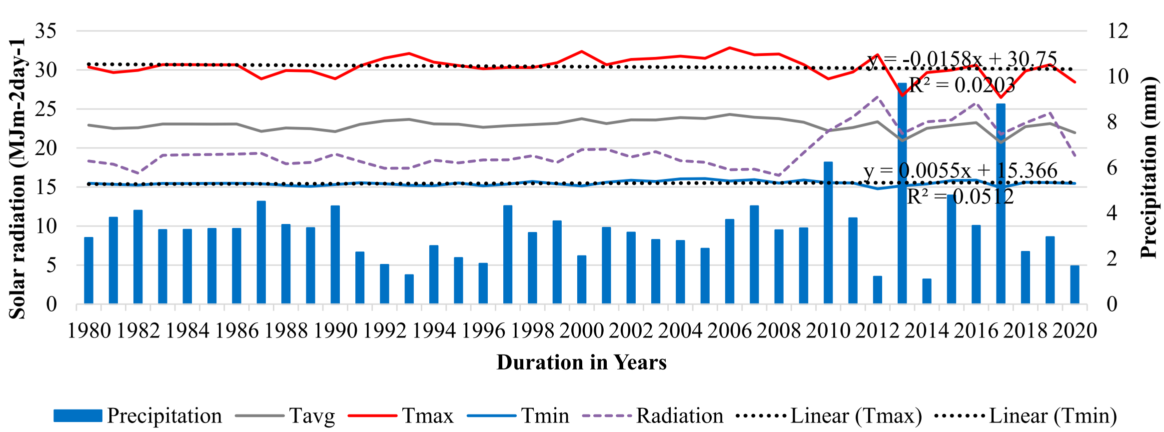

Figure 3. Mean annual rainfall (mm), mean annual radiation, mean maximum (T_{max}), mean minimum (T_{min}), and average (T_{avg}) monthly temperature (°C) of the Migori River watershed during the last 40 years (from 1980 to 2020).

Table 4. Indexed scores of sensitivity analysis across the zones of Migori River watershed.

Indicators	Index Scores Upstream	Midstream	Downstream	Major Components	Index Scores Upstream	Midstream	Downstream
Average time to nearest health facility (on foot)	0.418	0.330	0.299	Health	0.418	0.493	0.435
% of HHs with a family member with chronic illness	0.330	0.679	0.528				
% of HHs where a family member had to miss work or school in the past 6 months due to illness	0.887	0.915	0.821				
% of HHs without sanitary toilet	0.038	0.047	0.094				
% of HHs dependent on family farm for food	0.792	0.613	0.679	Food	0.232	0.205	0.365
Average crop diversity index	0.367	0.113	0.600				
Average number of months, households struggle to find food	0.000	0.300	0.500				
% of HHs that do not save crops	0.000	0.000	0.024				
% of HHs that do not save seeds	0.000	0.000	0.024				
% of HHs use natural untreated water (river, pond)	0.821	0.557	0.943	Water	0.440	0.372	0.434
Time to travel the source of natural water/	0.398	0.303	0.288				
% of HHs that have to go far to fetch water	0.689	0.491	0.585				
% of HHs that do not have a consistent water supply	0.000	0.283	0.085				
% of HHs reporting water conflicts	0.142	0.189	0.057				
The inverse of the average number of litres of water stored per household (range: >0–1)	0.588	0.412	0.647				
Sensitivity LVI					0.365	0.349	0.412

results are shown in Table 4. Sensitivity analysis shows that the downstream (0.412) has the highest sensitivity in ecological stability followed by the upstream (0.365), then midstream (0.349) (Table 4).

3.2.1. Health

This component consisted of four indexed-indicators (Tables 1 and 4). When these four indicators were aggregated, the resulting overall health vulnerability index showed that the midstream (0.493) was the most vulnerable on the health component followed by downstream (0.435) and upstream (0.418). Based on ANOVA at $p < 0.05$, the health vulnerability index values showed no statistically significant difference between the zones ($F = 0.074$, $p = 0.974$). The midstream households reportedly travel an average of 30.4 min to reach the nearest health facility on foot while the upstream households travel an average of 21.4 min and downstream an average of 11.7 min. This implies that the midstream households are more vulnerable than the downstream and upstream with regards to the average time a household takes to reach the nearest health facility on foot. Poor access to health care tends to deteriorate the health condition of rural households, making them more vulnerable to adverse climatic circumstances (Adu et al., 2018; World Bank, 2010). Chronic illnesses were reported by two-thirds (67.9%) of households in the midstream compared to 52.8% in the downstream and 33% in the upstream; an indication that the downstream and the upstream are less vulnerable to chronic illnesses compared to the midstream due to better access to private and government health facilities. Physical wellness is critical since it allows people to efficiently engage in various agricultural and non-agricultural activities and attain their livelihood goals. Poor access to health care services may put a strain on households' adaptive capacity, increasing their sensitivity to climatic variability and other extreme climate events (Asrat & Simane, 2017).

Further, the proportion of households where a family member had to miss work or school in the past 6 months due to illness was highest in midstream (91.5%) than the upstream (88.7%) and downstream (82.1%). This could be attributed to the documented high malaria prevalence in the midstream area (Solís et al., 2018) and the lack of sanitary latrine/toilets. Evidently, about 40% of households in the downstream, 24.7% in the midstream, and 23.8% in the upstream reportedly lack sanitary latrines. Lack of sanitary latrines makes households vulnerable to contracting illnesses including cholera and typhoid.

3.2.2. Food

This component consisted of five indexed-indicators (Tables 1 and 4). When these five indicators were aggregated, the resulting overall food vulnerability index showed that the downstream (0.365) was the most vulnerable on the food security aspect followed by upstream (0.232) and then midstream (0.205) (Table 4). These differences in the food vulnerability index between the zones were found by ANOVA (at $p < 0.05$) to be statistically significant ($F = 2.749$, $p = 0.047$). The average number of months that households struggle to find adequate food was zero months per year for the upstream while the downstream and midstream is two months per year. This implies that the upstream has greater food security compared to other areas of the watershed. Food security enhances a household's resilience to external stressors such as catastrophic weather occurrences (World Bank, 2010). This is because when households and communities get access to larger amounts of high-quality food; real prices decline, leading to a rise in real income, which may encourage them to adjust their climate change plan (World Bank, 2010). Approximately 80% of upstream households are solely dependent on their family farm for food compared to the 67.9% of downstream and 61.3% of midstream households. Studies show that households that obtain their main food source from their family farms are more vulnerable to the effects of climate change (Minh et al., 2019; Shah et al., 2013; Zhang & Fang, 2020). Based on the average crop diversity index, the midstream (0.29) and the upstream (0.31) were less vulnerable compared to the downstream (0.40). On average, the downstream households grow 1.65 types of crops, the upstream households grow 2.32 types of crops, and the midstream households grow 2.64 types of crops. The less vulnerability of the upstream and midstream zones in terms of crop diversity may be due to the fact that households in these zones have access to land through various arrangements, family-inherited land, rented, and leased land, which promotes the cultivation of various crops and hence lessens household sensitivity to climate-change-related stressors. All households in the upstream and midstream reportedly store crops and save seeds while 2.38% of downstream households don't store crops and do not save seeds.

3.2.3. Water

This component consisted of six indexed-indicators (Tables 1 and 4). When these six indicators were aggregated, the resulting overall water vulnerability index showed that the upstream (0.440) was the most vulnerable on the water security aspect followed by the downstream (0.434) and finally the midstream (0.372) (Table 4). These differences in the water vulnerability index between the zones were found by ANOVA (at $p < 0.05$) to be statistically significant ($F = 4.172$, $p = 0.039$). About 94% of households in the downstream, 82% of households in the upstream, and 56% of households in the midstream reportedly use natural water sources such as rivers and streams for their domestic water needs. Using a natural water source has a greater likelihood of increasing a household's exposure to waterborne infections and water shortages during drought periods (Etwire et al., 2013). On average, the midstream households store 492L of water compared to 127L in upstream households and 87L in downstream households. Consequently, 100% of upstream, 91.5% of downstream and 71.7% of midstream households have a consistent water supply. This is attributable to the existence of the Migori River and its tributaries (streams) which supplies adequate water to the households within the three watershed zones, even during dry seasons. With about a third (28.3%) of midstream households reportedly not having water available at their source every day, the midstream households seem extremely vulnerable in terms of water insecurity compared to other watershed sections. This explains why they reportedly store higher volumes of water compared to the households from other sections that have a consistent water supply. The findings established that about 68% of upstream, 60% of downstream and 49% of midstream households have to go far to fetch drinking water i.e. beyond the 1 km distance recommended by the WHO (Huong et al., 2019). Upstream households reportedly walk 44.0 min of a round-trip on average to get water compared to 33.8 min in the midstream and 25.2 min in the downstream of a round-trip to get water. Since the SDGs recommends that access to basic drinking water should take 30 min or less for a round-trip (Water Supply Sanitation and Collaborative Council, 2015), it's evident that both the upstream and the midstream have greater vulnerability compared to the downstream in terms of the average time for water access. Water conflicts are minimal in the watershed as only 18.9% of midstream, 14.2% of upstream and 5.5% of downstream households experience water conflicts in the previous years.

3.3. Adaptive capacity

Adaptive capacity is one of the contributing factors to the vulnerability of rural households and it is based on three indicators (Tables 1 and 5). It is the ability of an agro-based livelihood system to adjust to climate change in order to lessen probable losses, capitalize on opportunities, or cope with the repercussions (IPCC, 2014). Findings show that upstream (0.487) has a higher adaptive capacity than the midstream (0.477) and the downstream (0.475) (Table 5). High adaptive capacity is critical in reducing the vulnerability of households to multiple climate-induced stressors.

3.3.1. Socio-demographic profile (SDP)

The socio-demographic profile component consisted of eight indexed-indicators (Tables 1 and 5). When these eight indicators were aggregated, the upstream (0.479) was found to be the most vulnerable on the socio-demographic profile followed by the downstream (0.433) and the midstream (0.429) (Table 5). Through ANOVA (at $p < 0.05$), statistically significant differences were observed in the SDP values between the zones ($F = 9.721$, $p = 0.000$).

The proportion of female-headed households was highest in the downstream (34.9%) of the watershed and lowest in the upstream (26.4%) and midstream (26.4%). This could be due to migration from rural areas of male household members to urban places to earn a living or the death of male household heads. Studies have shown that female-headed households are less adaptive and hence more vulnerable compared to male-headed ones (Daudu et al., 2021; Opiyo et al., 2014). The upstream showed more vulnerability (1.42) on the dependency ratio index than the downstream (1.09) and midstream (0.95). This is an indication that the proportion of dependent household members (<18 years and >65 years) is higher in the upstream zone than in the other watershed zones. The average age of household heads was 44.6 years in the upstream, 47.2 years in the downstream, and 48.7 years in the midstream. With respect to education, over half of the household heads in the downstream (56.6%), and nearly a half of household heads in the midstream (49.1%) and upstream (47.2%) have not gone beyond primary-level education. This level of limited schooling makes households more vulnerable to climate-induced stressors, due to reduced adaptive capacity (Deressa et al., 2008). Such households are unable to undergo meaningful training, have minimal diversification experience, and rely mainly on climate-sensitive activities such as rain-fed cultivation and livestock breeding (Dumenu & Obeng, 2016). Furthermore, in watershed sections where the majority of household heads had not gone beyond primary education, informally or formally acquired vocational skill level was high: downstream (0.123), midstream (0.292), and upstream (0.613).

Formal education enhances a household's adaptive capacity as it improves the household's capacity to better recognize challenges affecting them and, as a result, look for feasible solutions in the proper places (Etwire et al., 2013). The results

Table 5. Indexed scores of adaptive capacity analysis across the zones of Migori River watershed.

Indicators	Index Scores			Major Components	Index Scores		
	Upstream	Midstream	Downstream		Upstream	Midstream	Downstream
% of female-headed HHs	0.264	0.264	0.349	Socio-demographic Profile	0.479	0.429	0.433
Dependency ratio/level of HHs	0.273	0.158	0.156				
The average age of household heads	0.488	0.471	0.365				
% HH who have not gone beyond primary education	0.472	0.491	0.566				
% of HHs with more than four members	0.784	0.838	0.914				
% of HHs with orphans	0.745	0.642	0.877				
% of HHs where members had any informal skill	0.613	0.292	0.123				
% of HHs with members needing dependent care	0.191	0.274	0.117				
% of HHs with members working in a different county	0.009	0.368	0.217	Livelihood Strategies	0.605	0.506	0.596
% of HHs solely dependent on agriculture	0.878	0.736	0.783				
Average agricultural livelihood diversification	0.788	0.333	0.879				
% of HHs who took a loan in the past 5 years	0.632	0.479	0.406				
Income diversification index	0.700	0.500	0.633				
Natural resource and Livestock index	0.625	0.620	0.660				
Average Receive: Give ratio	0.646	0.717	0.804	Social Networks	0.376	0.507	0.418
Average Borrow: Lend Money ratio	0.892	0.940	0.887				
% of HHs that have not asked their local government for any assistance in the past 12 months	0.000	0.519	0.094				
Availability of amenities	0.875	0.833	0.848				
% of HHs with membership in social groups	0.000	0.047	0.085				
% of HHs that have received or attended training	0.132	0.368	0.094				
% of HHs owning communication device	0.085	0.123	0.113				
Adaptive Capacity LVI					0.481	0.477	0.475

indicated that 91.4% of downstream households, 83.8% of midstream households, and 78.4% of upstream households have a household size beyond the 4-members national average. Large family sizes that exceed the national average are said to be more vulnerable to environmental stressors since they are more likely to have a large proportion of dependent household members (<18 years and >65 years) (Nkondze et al., 2013). On the other hand, other studies concur that large family sizes with working-age members possess an increased supply of human capital that would contribute to the strengthening of livelihood resilience through labor-force participation, remittance flows, and risk management (Weldegebriel & Amphune, 2017). Based on the proportion of households with orphans, the downstream (0.877) was found to be more vulnerable than both the midstream (0.642) and the upstream (0.745). The study revealed that 87.7% of downstream households, more than three-quarters of upstream households (75.4%), and about two-thirds of midstream households (64.2%) have at least one orphan.

3.3.2. Livelihood strategies

A livelihood strategy is a survival or wealth accumulation plan for households/communities, intended to mitigate risk and also reduce poverty (Gautam & Andersen, 2016). This component consisted of six indexed-indicators (Tables 1 and 5). When these six indicators were aggregated, the upstream (0.605) was found to be the most vulnerable on the livelihood strategies vulnerability index followed by the downstream (0.596) and then the midstream (0.506) (Table 5). Based on ANOVA at $p < 0.05$, the livelihood strategies vulnerability index values showed no statistically significant difference between the zones ($F = 1.559$, $p = 0.182$). This study established that the livelihood strategies of households in the Migori River Watershed are diversified and include crop production, livestock keeping, and access to other natural resources, off-farm activities, and household members working outside the locality of Migori County. In terms of the proportion of households with family members working in a different county, the upstream showed less vulnerability (0.99) than did downstream (0.78) and midstream (0.63). Results showed that 99.1% of upstream households, 78% of downstream households, and 63% of midstream households had at least one working in a different county. A high proportion of households in the upstream (87.8%), downstream (78.3%), and midstream (73.6%) are solely dependent on agriculture as the only source of income; which makes them highly vulnerable since agriculture is a climate-sensitive sector (Tewari & Bhowmick, 2014). In this case, the upstream was found to be more vulnerable (0.87) in terms of dependency on agriculture compared to the other watershed sections, since it is believed that households that depend exclusively on agriculture are more vulnerable to climate change than those that don't depend exclusively on agriculture (Hahn et al., 2009). Based on these figures, there is a high sole dependency on agriculture as an income source by households in the watershed, and Žurovec (2018) believes that such a situation is driven by the deficiency of alternative sources of income in the region.

Based on the average agricultural livelihood diversification index, the midstream was less vulnerable (0.39) compared to the upstream (0.24) and the downstream (0.21); this means that the households in the midstream engaged in more diverse agricultural practices (crop production, livestock rearing, aquaculture, and agroforestry) than those in the upstream and the downstream. This phenomenon was also reflected in the income diversification index where the midstream (0.35) showed less vulnerability compared to downstream (0.31) and upstream (0.29). This is because diversifying agricultural practices and income sources serve as insurance against the impacts of climate-related shocks and allows the household to shift to a better income level, which facilitates the development of a suitable climate change response hence greater adaptive capacity (Eakin & Bojórquez-Tapia, 2008). On the natural resource and livestock index, however, the upstream (0.50) was less vulnerable compared to the midstream (0.380) and the downstream (0.34).

The three livelihood strategies, on-farm, off-farm, and non-farm, as defined by Barrett et al. (2001) were pursued by the households in the Migori River watershed with varying degrees of engagement. Even though on-farm livelihood strategy (crop production, livestock rearing) generally accounts for the vast majority of income sources, with over three-quarters of households in each watershed zone reportedly relying solely on it as their everyday income source, some households in the watershed pursued off-farm (processing, packaging, transport or sale of farm produce) and non-farm livelihood strategies (small-scale trade, remittance, forestry, rental income, and employment in healthcare, education, mining, tourism or governance sectors) with varying degrees of involvement to augment their earnings from on-farm livelihood activities. Alongside on-farm activities, 32.1% of upstream households, 39.6% of midstream households, and 64.2% of downstream households engaged in off-farm activities while 55.7% of upstream households, 67.9% of midstream households, and 76.4% of downstream households engaged in non-farm activities. The proportion of households that took a loan in the past 5 years was 59.4%, 52.1%, and 36.8% in the downstream, midstream, and upstream, respectively, indicating that there's lower intake/access to loans for households in the upstream compared to the other watershed sections. In conclusion, most households in the three watershed zones had less diverse livelihood strategies, a situation which could be attributed to their understanding and experience of exposure to environmental stressors including disasters.

3.3.3. Social networks

Social networks have a significant role in managing risks (Zhao, 2013). This component consisted of seven indexed indexed-indicators (Tables 1 and 5). When these seven indicators were aggregated, the midstream (0.507) was found to be the most vulnerable on the social network vulnerability index followed by the downstream (0.418) and the upstream (0.376) (Table 5). However, ANOVA (at $p < 0.05$) showed that no statistically significant differences exist in these vulnerability values between the zones ($F = 2.056$, $p = 0.094$). The average receive-give ratio was higher among households in the midstream (1.49) compared to households in the upstream (1.37) and downstream (1.18); implying that households in the midstream were reportedly receiving more in-kind help from others than they were offering it to others compared with the upstream and downstream. The study also established that 100% of upstream households, 90.6% of downstream households, and 48.1% of midstream households have not asked their local government for any assistance in the past 12 months. This is an indication that although households in the three watershed sections received assistance, they preferred to request aid from friends and family relations rather than their local government officials.

The results on the average borrow-lend money ratio indicate that households within the entire watershed borrow more money than they lend, and are therefore financially vulnerable. However, midstream households reported that they borrowed money more frequently than the downstream and upstream households; the borrow-lend money ratio was 1.49 for the midstream, 1.47 for the downstream, and 1.01 for the upstream. The study established that the midstream households are borrowing more money than they are lending it, and thus are financially more vulnerable compared to the other zones. Hahn et al. (2009) observe that households are more vulnerable when they often borrow money more than they lend money. Borrowing and lending money represents the monetary and in-kind financial support that households obtain from their social network (Hahn et al., 2009). Therefore, the high financial exchange between the watershed households indicates that the social network is stronger. Regarding membership in social organizations, 100% of upstream households, 95.3% of midstream households, and 91.5% of downstream households reportedly have some household members with membership in social organizations such as sports, religious, or conservation groups. This high participation in social organizations increases the adaptive capacity of the watershed households to multiple stressors. According to Armah et al. (2010), community-level associations are formed through friendship, monetary exchange, kinship, or similar cultural and religious beliefs. Such networking helps sustain livelihoods and manage environmental resources and disasters, especially those caused by climate change (Bernier & Meinzen-Dick, 2014; Etwire et al., 2013).

The proportion of households in the downstream, upstream, and midstream that received some training from either government or non-governmental organization was 90.6%, 86.8%, and 63.2%, respectively. The majority of households own some type of communication device as reported by the 91.5% of upstream households, 88.7% of downstream households, and 87.7% of midstream households. Access to communication devices like phones, radios, and TVs promotes exposure to climate-related information which enhances the household's adaptation to climate-induced stressors including disasters like floods (Gbetibouo, 2009). Regarding, the average number of amenities, the downstream section was reported to have more amenities (0.22) compared to upstream (0.18) and midstream (0.20). The downstream households are therefore less vulnerable in terms of institutional access compared to the other two watershed zones because households with greater institutional access are better positioned to cope with various climate-induced risks (Agrawal, 2010).

In general, the vulnerability scores of all the eight major components of each watershed zone were summarized in a vulnerability spider diagram (Figure 4), with a scale ranging between 0 (least/less vulnerable) and 1.0 (most vulnerable). Accordingly, the upstream is more vulnerable in terms of climate variability (0.98), livelihood strategies (0.61), and the socio-demographic profile (0.48) while the midstream is more vulnerable in terms of climate variability (0.95), livelihood strategies (0.51) and social networks (0.51). The downstream was found to be the most highly exposed to climate variability (0.96) and natural disasters (0.31) and less adaptive in terms of livelihood strategies (0.60).

Of the entire set of major components of LVI-IPCC, climate variability seems to be the major factor that contributed considerably to the high levels of vulnerability of the watershed

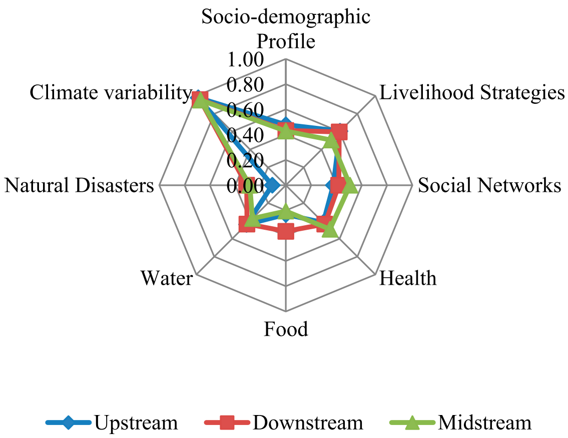

Figure 4. Vulnerability spider diagram of the major components of LVI-IPCC.

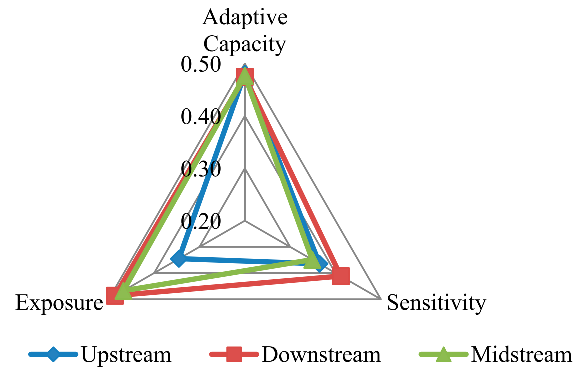

Figure 5. Vulnerability triangle diagram of LVI-IPCC vulnerability dimensions for watershed zones.

zones whereas socio-demographic profile and food were the two major contributors to less levels of vulnerability.

3.4. Livelihood Vulnerability Index assessment and policy-programme implications

Based on the IPCC approach, overall vulnerability is assessed based on the individual indices for the contributing factors of exposure, sensitivity, and adaptive capacity. The distribution of the indexed major components for the three vulnerability contributing factors and the overall LVI-IPCC across watershed zones is presented in Table 6 and Figure 5. The LVI-IPCC estimates for the upstream, midstream, and downstream were −0.047, −0.003, and 0.008, respectively (Table 6), with One-way ANOVA (at $p < 0.05$) indicating that statistically significant differences exist in the computed LVI-IPCC scores between the three watershed zones ($F = 2.498$, $p = 0.019$). These estimates compared to the rating scale (Table 2) indicate that the livelihoods of all the three watershed zones are moderately vulnerable to environmental and socio-economic stressors, probably due to similar agro-ecological settings. Although the three watershed zones are moderately vulnerable to environmental and socio-economic stressors, the total LVI-IPCC score was highest in the downstream zone and lowest in the upstream zone; an indication that the livelihoods of downstream households are the most vulnerable to multiple stressors followed by the midstream households and then the upstream households. The livelihoods of the downstream zone are most vulnerable because they have the least adaptive capacity (0.47), highest exposure (0.49), and highest sensitivity (0.41) whereas the upstream households are relatively least vulnerable than the other zones due to less sensitivity (0.36), less exposure (0.35) and better adaptive capacity (0.48). Previous studies show that communities with high exposure to climate variability and extreme climate-induced events but low adaptive capacity experience high livelihood vulnerability (Deressa et al., 2008; Feyissa et al., 2018).

The LVI-IPCC values computed for the three watershed zones in this paper are generally lower than the 0.348 index value computed for coastal communities in Bangladesh by Toufique and Yunus (2013); −0.03 and 0.02 calculated for Nariva (Trinidad) and Caroni (Tobago) communities by Shah et al. (2013), and index values computed for Naugachia (−0.07), Kharik (0.06), Bihpur (0.06), Ismailpur (0.06), Narayanpur (0.07), Rangra Chowk (0.08), Gopalpur (0.012) communities in India by Tewari and Bhowmick (2014). The index values for the watershed are however within the values of −0.074 and +0.005 calculated for Moma and Mabote districts of Mozambique by Hahn et al. (2009) who developed and first applied the LVI-IPCC tool. Although these values were obtained using varying sets of indicators, they show the global replicability or applicability of this tool in various agro-ecological settings.

Generally, the livelihoods of all the three watershed zones of the Migori River socio-ecological system are moderately vulnerable under environmental and socio-economic stressors, mostly due to the less adaptive capacity and greater sensitivity. Based on the findings, the low adaptive capacity of the households in the watershed is mainly contributed to by large family sizes, which are beyond the national average; heavy dependence on agriculture and natural resources which are

Table 6. Summary of the Livelihood Vulnerability Index results for the three watershed zones.

	Index Scores				Index Scores		
Major Components (No. of indicators)	Upstream	Midstream	Downstream	LVI-IPCC Vulnerability Dimensions	Upstream	Midstream	Downstream
Socio-demographic profile (8)	0.48	0.43	0.43				
Livelihood Strategies (6)	0.61	0.51	0.60	Adaptive Capacity	0.48	0.48	0.47
Social Networks (7)	0.38	0.51	0.42				
Health (4)	0.42	0.49	0.44				
Food (5)	0.23	0.21	0.37	Sensitivity	0.36	0.35	0.41
Water (6)	0.44	0.37	0.43				
Natural Disasters (8)	0.11	0.29	0.31	Exposure	0.35	0.47	0.49
Climate variability (3)	0.98	0.95	0.96				
LVI-IPCC Index = (Exposure-Adaptive capacity) × Sensitivity					−0.047	−0.003	0.008

climate-sensitive livelihood sources; comparatively high dependency ratios due to less number of members employed adults; and low literacy levels of household heads. These factors make households less able to cope with diverse stressors, and therefore policies focusing on enhancing incentives for households to engage in off-farm enterprises and non-farm employment, as well the provision of adult literacy and skills training to household heads on alternative livelihood options to enhance human capital in both short and long terms should be considered by policymakers. A high level of sensitivity of health of households to climate-induced risks is mainly contributed to by limited access to health care services characterized by widespread lack of sanitary latrines, majority of households having at least one member suffering chronic illness and having a family member who missed work or school in the past 6 months due to illness; these contribute to the exposure of the households to vulnerabilities and so targeted installation of latrines, regular and free household-level health checkups, and construction of more health facilities can help increase the health index of the people living in the watershed. On the other hand, high level of sensitivity of water to climate variability is majorly contributed to by majority of households using unsafe drinking water from natural water sources which could be contaminated with heavy metals and disease-causing pathogens, households having to travel beyond 1 km distance to fetch water and occasionally experience water conflicts with other communities. To mitigate this situation, policymakers should prioritize initiatives focusing on improving access to clean piped water supply or implementing household-level water treatment solutions like chlorination. Additionally, efforts should be made to minimize the distance households need to travel for water collection by establishing closer water points and implementing efficient water supply schemes. Addressing water conflicts with neighbouring communities necessitates the involvement of Water Resource User Associations (WRUAs) to facilitate community dialogues and employ conflict resolution mechanisms to resolve water access issues. To ensure the ongoing safety of drinking water sources, public health interventions such as regular monitoring and testing for heavy metals and pathogens should be incorporated.

The results of this study provide valuable insights into the research questions posed. This study generally aimed to determine the level and sources of rural households' livelihood vulnerability to climate change and extremes in the Migori River watershed, Kenya, using the LVI-IPCC approach. To achieve this, the study had specific objectives that have been addressed and answered by the study results. Firstly, the existing Livelihood Vulnerability Index (LVI-IPCC) was adapted to be relevant to the Migori River watershed, creating a local livelihood vulnerability index. The results of this adaptation provided a comprehensive assessment framework specific to the local context, allowing for a more accurate analysis of household vulnerability. Secondly, the LVI-IPCC was applied to assess and compare the household livelihood vulnerability to climate change across three zones of the Migori River watershed. The findings revealed that all three zones exhibited moderate vulnerability, but significant variations existed between the zones. The downstream households were identified as the most vulnerable due to their lower adaptive capacity and higher exposure and sensitivity to climate risks, while the upstream households showed the least vulnerability with better adaptive capacity and lower sensitivity and exposure. Lastly, the study aimed to identify key factors or sub-indicators of the LVI-IPCC that significantly contribute to household livelihood vulnerability in the watershed zones, with the goal of suggesting suitable alternatives for policy adaptation to climate change. The results highlighted several contributing factors, including large family sizes, heavy dependence on agriculture and natural resources, high dependency ratios, and low literacy levels of household heads. These factors were identified as limiting households' adaptive capacity and ability to cope with diverse stressors.

Overall, the results of this study make several significant contributions to the broader literature on household vulnerability to climate change. Firstly, by adapting the existing Livelihood Vulnerability Index (LVI-IPCC) to the specific context of the Migori River watershed using 47 indicators, the largest number ever used in similar studies, this study provides a localized and comprehensive assessment framework that can be applied to similar regions. This contributes to the methodological advancements in vulnerability assessment, particularly in the context of rural households. Furthermore, the findings shed light on the specific factors and sub-indicators that significantly contribute to household vulnerability in the watershed zones, offering insights into the key drivers of vulnerability and potential areas for targeted interventions.

For policy-programme implications, LVI-IPCC approach could be used to forecast future vulnerability, such as under basic future climate scenarios or even evaluating the effect of a particular policy or programme by adjusting the value of the indicator that is anticipated to change and re-computing the overall vulnerability index. For instance, if a programme or project is intended to promote the uptake of smart-agriculture technologies, like adoption of bio-fertilizers, improved seeds, irrigation practices and rainwater collection, to a particular extent in a given area, the decision-makers may adjust these LVI values to represent this shift. The expanded adoption and utilization of smart-agriculture technologies would result in a lower overall LVI-IPCC score and based on this change in LVI-IPCC score, the decision-makers would therefore be capable of predicting how their intervention will potentially affect the vulnerability of the households in the area of interest.

4. Conclusions and recommendations

The paper shows that the rural livelihoods of Migori River watershed communities are moderately vulnerable to environmental and socio-economic stressors, which is to be expected of livelihoods that are dependent on natural resources especially rain-fed agriculture as in this case. The high level of exposure of the watershed to drought, floods, and landslides shows that natural disasters play prominent roles in influencing exposure to climate risks, the high level of sensitivity of health and water to climate variability shows that the absence of a sustainable land use system increases households' sensitivity to climate-induced stressors, whereas the limited adaptive capacity shows that access to basic infrastructure, and education and training impacts households' adaptive capability. Although the three watershed zones studied are moderately vulnerable, the livelihoods of the downstream zone are most vulnerable because they have the least adaptive capacity, highest exposure, and highest sensitivity whereas the upstream households are relatively least vulnerable than the other zones due to less sensitivity, less exposure, and better adaptive capacity. Therefore, it can be deduced that when the exposure level is higher than the adaptive capacity, the vulnerability level becomes high and when the adaptive capacity is higher than exposure, there is low vulnerability.

The study puts forward a set of recommendations to enhance the resilience and adaptive capacity of watershed households to climate change impacts. Firstly, it emphasizes the need to enhance climate information provision and disaster warning preparedness to reduce downstream households' exposure to climate risks such as droughts, floods, and landslides. In addition, the study highlights the importance of improving agricultural outputs through the adoption of climate-smart agriculture technologies, particularly bio-fertilizers, improved seeds, and irrigation practices. To reduce heavy dependence of livelihoods on the climate-sensitive agricultural and natural resources sector, the study suggests promoting non-farm and off-farm income-generating activities by providing incentives and support. It also recommends supporting skills development and vocational training programmes to create employment opportunities for household members, which would help decrease dependency ratios and enhance economic resilience. Furthermore, the study emphasizes the need to enhance adult literacy and educational opportunities for household heads to improve their access to information, enable them to make informed decisions, and engage in adaptive practices effectively.

As demonstrated by this study, the Livelihood Vulnerability Index (LVI-IPCC) is a simple and practical tool that can be rapidly applied by governments, policymakers, and development organizations to identify vulnerable communities, pinpoint factors contributing to households' vulnerability at the community or sub-county level, and prioritize potential intervention areas. In assessing the vulnerability of households in this watershed to climate change and variability in western Kenya using the LVI-IPCC tool, this paper used more indicators compared to the previous studies, which not only shows the dynamism of the tool but also demonstrates the global applicability of this tool in understanding the local communities' vulnerability to environmental and climate change regardless of the number of indicators selected.

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