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International Journal of Disaster Risk Management • Vol. 8. No. 2 • https://doi.org/10.66050/y4bdrt95

Publisher: Scientific-Professional Society for Disaster Risk Management

International Journal of Disaster Risk Management

Article

Indigenous Flood Early Warning Systems for Hydropower-Dam-Induced Flood Risk: A Case Study of the Dassenech Community in the Lower Omo Valley, Ethiopia

Seid Ahmed[1*]

[1] Department of Sociology, College of Social Sciences and Humanities, Hawassa University, P.O. Box 05, Hawassa, Sidama Region, Ethiopia.

* Correspondence: seidahmedSOSW@gmail.com; tel.: +251-910068380/984-658-086

Received: 9 February 2026; Revised: 18 July 2026; Accepted: 20 August 2026; Published: 21 August 2026.

ABSTRACT

The effort to mitigate the impacts of hydropower-induced flood disasters in the lower Omo Valley often focuses on conventional flood early warning systems, which are primarily based on scientific data and models for information dissemination. These solutions can save lives when flood disasters strike vulnerable pastoral and agro-pastoral communities of the Dassenech. However, this needs to be complemented by action to address the underlying components of vulnerability and their interrelated human, socioeconomic, livelihood, and cultural factors of the pastoral and agro-pastoral communities of the lower Omo Valley. These influence the risks of hydropower-induced flood disasters. An important component addressing these factors is the local communities' traditional indigenous early-warning system for floods. To explore and analyze the study, the researcher employed interpretativist epistemological paradigm along with a qualitative research method to understand from the study participants' or actors' own perspective, and to examine the world they experienced via key informant interviews, in-depth interviews, focus group discussions, and a case study with nearly 68 participants. This Indigenous flood early warning system is especially important where conventional flood early warning information is inaccessible. Therefore, this article describes and analyses the Dassenech Indigenous flood early warning system in the face of hydropower-induced flood disasters, and the extent to which local communities use it. However, the study findings indicate that local community acceptance and responsiveness to flood early warning are essential to effective end-to-end early warning systems, as the pastoral and agro-pastoral villagers of the Dassenech indigenous knowledge system are a key element of flood early warning systems. They also form the foundation of their generation-old, community-based flood warning and preparedness strategies. Therefore, to respond to and cope with flooding disasters and other associated events such as drought, food insecurity, and disease outbreaks, incorporating and integrating local communities' indigenous knowledge systems and practices with national disaster risk reduction policies and strategies will bring long-lasting solutions to the lower Omo Valley pastoral and agro-pastoral communities' well-being.

Academic Editor:
Prof. Dr. Vladimir M. Cvetković

e-ISSN2620-2786

Ahmed, S. (2026). Indigenous Flood Early Warning Systems for Hydropower-Dam-Induced Flood Risk: A Case Study of the Dassenech Community in the Lower Omo Valley, Ethiopia. *International Journal of Disaster Risk Management*, 8(2), 111-140.

KEYWORDS

indigenous knowledge; flood disaster; Dassenech people; early warning system; hydropower; agro-pastoral communities.

1. Introduction

The consequences of climate change pose significant threats to human welfare, ecological equilibrium, and livelihood resilience (Salah et al., 2024). Sub-Saharan Africa is widely acknowledged as exceptionally vulnerable to climate change impacts compared with other regions of the continent. Pastoralist communities worldwide, including those in Sub-Saharan Africa, have long faced a range of social, economic, and climate-related impacts. In Ethiopia, pastoralist and agro-pastoralist communities are threatened by climate change, which directly affects natural resource availability and livestock yields. Despite increasing vulnerability factors and the resulting pressures on pastoralist and agro-pastoralist livelihoods, the potential impact of climate change remains high, threatening their ability to maintain livelihoods and improve resilience to climate change-induced disasters such as drought and flooding.

In recent years, climate change has altered flooding disasters around the globe (Cvetković, 2026). As a result, an increasing number of studies are modeling the impact of global climate change on floods, with a main focus on changes in the magnitude and frequency of flood events. Floods have become among the most frequent and deadly phenomena, affecting an average of 520 million people a year (World Meteorological Organization [WMO], 2013). Even though efforts to mitigate the impacts of flood disasters often focus on infrastructural development, such as high-tech solutions like sophisticated early warning systems based on scientific data and models (Sithole et al., 2015). These solutions can save lives and livelihoods when disasters affect communities; however, they need to be complemented by actions to address the underlying components of vulnerability – the interrelated human, social, economic, and cultural factors that influence risk and contribute to turning a hazard into a disaster. According to Sithole et al. (2015), local traditional knowledge is an important component that addresses these factors and can increase community resilience.

Contemporary research emphasizes further exploring the interrelationships between EWS sub-systems, despite the need for renewed attention to overcoming the barriers that constantly restrain the combined operations of different sub-systems in critical situations (Sukhwani et al., 2019). Despite their impact, flood disaster early warning systems have been understudied or downplayed by social researchers and by government and non-governmental entities, particularly in the lower Omo Valley downstream pastoral and agro-pastoral communities. Little research has examined flooding disasters. Among these is Eyasu et al. (2015) in their article "Potential Assessment of flood-based farming on lower Omo Ghibe basin". The central focus of their study emphasizes the impacts of upstream government intervention on the Omo River on downstream flood-based farming practices rather than the multifaceted effects of flood disasters; additionally, it mainly focuses on the livelihood dimension of flooding and lacks social and environmental perspectives for the study area. Another researcher who studied flood modeling and mapping of the Lower Omo Gibe River Basin is Eshetu (2018). His study focuses exclusively on a hydrological modeling system from an engineering perspective. It does not include the perspective of local communities, particularly downstream villagers in the Lower Omo Valley. In addition, Asmelash (2020), in his article "The Impact of Omo Kuraz Sugar Project on Dassenech people," tried to assess the livelihood trends of the Dassenech people before the implementation of the Omo sugar project. However, the study focuses solely on the impact of the Lower Omo Valley government development project. It does not include upstream government interventions or the livelihood influences of local communities' indigenous flood early warning systems.

Each rural community has unique disaster early warning indicators and well-developed structures that apply local wisdom to respond more quickly and efficiently to varied disasters (UNEP, 2014). This wisdom is referred to as Indigenous knowledge, peasant knowledge, traditional environmental

knowledge, traditional ecological knowledge, Indigenous technical knowledge, endogenous knowledge, or folk knowledge (Sillitoe, 2000). Indigenous knowledge is a body of knowledge acquired by local people over time through experiences, society-nature relationships, and community practices. It is passed down through community-based institutions across generations (Sillitoe, 2000). Such Indigenous knowledge refers to the methods and practices developed by a group of people through an advanced understanding of their local environment and agro-ecology, formed over numerous generations of habitation in a certain geographical location. This knowledge differs from other types of knowledge as it originates within the community and is transferred through informal means. It is collectively owned, developed over generations, adaptable, and embedded in a community's way of life as a means of survival and well-being.

Local and traditional knowledge of natural phenomena remains crucial for many communities in this era of technological advancement. Indigenous knowledge has long developed as part of communities' relationship with their environment, offering the potential to enrich environmental research, policy, and disaster risk reduction efforts. This allows at-risk communities to mitigate, prepare for, respond to, and recover from disasters well before the establishment of high-tech early warning systems. An effective flood early warning system is a prerequisite for timely response to avert and mitigate the impact of hydropower-induced disasters affecting pastoralist and agro-pastoralist communities in the lower Omo Valley. While early warning systems exist across the country, concerns remain about whether the flood early warning information is timely, accurate, accessible, and prompts early action. These concerns highlight inefficiencies in conventional flood early warning systems in the lower Omo Valley of Southern Ethiopia and underscore the importance of indigenous systems used by the Dassenech pastoral and agro-pastoral communities. Indigenous flood early warning systems are particularly important where conventional systems are inaccessible, coarse, or unsuitable for location-specific decisions in rural communities.

The lower Omo Valley in Southern Ethiopia is an arid area occupied mainly by pastoral and agro-pastoral communities. Like other cross-border pastoral and agro-pastoral lowland regions, the Dassenech possess Indigenous knowledge and practices, but specific studies on their flood early warning system remain limited. It remains unclear how Indigenous and conventional early warning systems can be integrated to address hydropower-induced disasters in the Dassenech communities. Therefore, this paper explores and describes the Dassenech's Indigenous flood early warning knowledge in detail, how local communities use it, and the extent to which villagers use it to mitigate the effects of hydropower-induced flood disasters. The study also explores the perceived credibility and usefulness of Indigenous flood early warning systems for hydropower-induced flood disasters caused by upstream hydroelectric dam-controlled emergency water and reservoir releases during the heavy rainy season. It offers recommendations for integrating Indigenous and conventional systems. The study aims to raise awareness among decision-makers and policymakers, encourage further research, and provide a foundation for integrating Indigenous and conventional flood early warning systems into the disaster policymaking process to enhance their effectiveness in mitigating hydropower-induced flood disasters in the Lower Omo Valley.

Overall, the study findings contribute to a greater understanding of flood early warning systems, including the mechanisms and strategies at play in the context of changing social, economic, and environmental realities in the Lower Omo Valley downstream pastoral and agro-pastoral communities of the Dassench people. It also contributes to methodological approaches and theoretical and conceptual knowledge in assessing the use of tools from the systematic review tradition. It suggests approaches that help future reviewers conduct a successful review focused on a particular study context. It maps out existing knowledge gaps in a way that enables more informed research and points to new directions for future research that may help shed light on new phenomena.

2. Methods

2.1. Description of Study Area

South Omo pastoral and agro-pastoral people are found in the Southern region of Ethiopia, bordered to the south by Kenya, southwest by South Sudan, west by Bench Maji, northwest by Kefa, to the north by Konta, Gamo, Gofa, and Basketo, northeast by Dirashe and Konso, and to the east by the Oromia Region.

The area is named for the Omo River, which flows south into Lake Turkana on the western side. Mago National Park and Tama Wildlife Reserve are located on the eastern bank of the Omo River. Lake Chew Bahir, surrounded by Stephanie Wildlife Sanctuary, lies at the eastern border of this area. Notable high points include Mount Smith (2560 meters) and Mount Mago (2538 meters). West of the Omo is the most sparsely populated part of Ethiopia, inhabited by Pastoralist and agro-pastoralist ethnic groups. The infrastructure of the area is "weak and for the most part non-existent; this is a disadvantage inherited from historical neglect of a typical marginal region (ibid)." It is also observed that the South Omo people are "one of Ethiopia's socially most diverse areas. It contains a minimum of 8 different ethnic groups, and possibly as many. Social diversity therefore compounds the existing problems of isolation and acute shortage of basic infrastructure, despite recent years' professional and technical manpower increasing significantly."

South Omo has 8906 kilometers of all-weather roads and 412 kilometers of dry-weather roads, for an average road density of 37 kilometers per 1000 square kilometers. In 2024, population growth is projected to be approximately 419,793 to over 800,000, depending on recent regional re-demarcation (i.e., separation of Ari Zone from the original South Omo Zone boundary. With an area of 21,055.92 square kilometers, South Omo has a population density of 27.23. While 43,203, or 7.53%, are urban inhabitants, a further 25,518, or 4.45%, are pastoralists. A total of 125,388 households were counted, resulting in an average of 4.57 persons per household and 121,309 housing units.

According to a World Bank (2024) report inhabitants of South Omo have limited access to electricity, this zone has a road density of 22.7 kilometers per 1000 square kilometers (compared to the national average of 30 kilometers), the average rural household has 0.4 hectare of land (compared to the national average of 1.01 hectare of land and an average of 0.89 for the former Southern region) the equivalent of 1.5 heads of livestock. 11.5% of the population is in non-farm-related jobs, compared to the national average of 25% and a regional average of 32%. 37% of all eligible children are enrolled in primary school, and 7% in secondary schools. 77% of the zone is exposed to malaria, and 61% to Tsetse fly. The memorandum gave this zone a drought risk rating of 348. The Ministry of Agriculture and Rural Development selected this zone as one of several areas for voluntary resettlement of farmers from overpopulated areas; the program did not identify specific zones or woredas. However, the lower Omo Valley downstream pastoral and agro-pastoral communities include Dassenech, Hamer, Nyangatom, Bena-tesmay, and Selamago Woredas; this study was undertaken in Dassenech Woreda, which has been vulnerable to the Omo River flooding disaster and its multifaceted effects for a decade.

2.1.1. Lower Omo River Valley

The Lower Omo River Valley in southwestern Ethiopia is a semi-arid region with extraordinary biodiversity, and many distinct indigenous pastoral, agro-pastoral, and fishing communities reside there (Avery, 2013). However, over the last two decades, the lower Omo River valley has experienced expansion of large-scale commercial agriculture, infrastructure such as the Gibe dam, and human settlement (Carr, 2011). While protected areas in the lower Omo Valley increasingly face challenges associated with land-cover change, this endangers the future of these unique landscapes. Chiefly, agricultural expansion, livestock grazing, human settlement, and infrastructure development have become problematic, often resulting in the loss of natural habitat critical for ecosystem services that support pastoral and agro-pastoral livelihoods and the food security on which they rely.

Pastoralism and agro-pastoralism in the lower Omo River valley usually implies that an interdependent relationship exists between local ecology, livestock, and people (and their social institutions) in a resource-scarce, dry climate, and highly variable conditions (Behnke et al., 1993; Nori et al., 2008; Reid et al., 2008). This interdependency represents a complex form of natural resource utilization and management involving dynamic but continuous ecological balance between pastures, livestock, and people (Nori et al., 2008; IFAD, 2009). To sustain their livelihoods and food security, pastoralist and agro-pastoralist villagers have traditionally demonstrated pragmatic adaptive responses to climate and environmental changes (Grain, 2017; Nori et al., 2008). This livelihood option in the lower Omo Valley is considered economically, culturally, and socially viable for maintaining community and environmental well-being because it can simultaneously provide secure livelihoods, conserve ecosystem services, and honor cultural values and traditions (PFE et al., 2010; Lind et al., 2020). At the same time, the future agronomic potential and economic viability of this system will depend directly on the sustainable management of the natural resource base that underpins it, which is under constant pressure from the expansion of state activities, including Omo River hydropower upstream damming and related large-scale sugar plantations. This particularly affected the important flood-retreat crop cultivation activities of pastoral and agro-pastoral villagers of the Dassenech.

These changes in the socio-environmental system are further expected to increase food insecurity and shocks for Dassenech people due to climate change, including frequent drought, malnutrition, disease outbreaks, and more. Thus, communities in the lower Omo Valley have faced land tenure changes ranging from occupation to dispossession due to upstream damming and associated large-scale sugar plantations along flood retreat and grazing lands. These changes, combined with political-economic marginalization, have made it increasingly difficult for villagers to sustain their flood retreat-based livelihood system and have fundamentally challenged their adaptive capacity to climate change and food insecurity.

Dassenech Woreda is located in the South Omo Zone of the Southern Regional State in Southwest Ethiopia. It is 860 km away from Addis Ababa and 205 km from Jinka. The woreda is bounded by Hamer woreda to the North and east, Kenya to the south, and Nyangatom woreda to the west and Northwest. The woreda covers a total area of 234,274 ha, with elevation ranging from 275 meters to 400 meters above sea level, and is found at a latitude and longitude of 4°48′N 35°58′ECoordinates: 4°48′N 35°58′E. It has only one Agroecological zone: Kolla (100%). The Woreda's mean annual rainfall is about 350 mm. The annual mean temperature ranges from 30 °C to 40 °C (Dassenech Woreda Pastoral Development Office, 2024).

The Dassanech speak an East Cushitic language and live on the Ethiopia-Kenya border on the northern shore of Lake Turkana and further north along the Omo River. The population is estimated at 48,067 (CSA, 2007), and the Woreda Health Center currently estimates the Dassanech population at 80,000. According to unpublished data from the South Omo Zone Administration, Dassenech covers 2,575 sq km. Until 2006, the area was part of the administrative unit of Kuraz woreda. Following the 2006 administrative restructuring, Dassenech was elevated to a District (Woreda) level, with its capital at Omorate, about 852 km south of Addis Ababa. The Dassanech Woreda is divided into 40 units called kebele. The study area is shown in Figure 1.

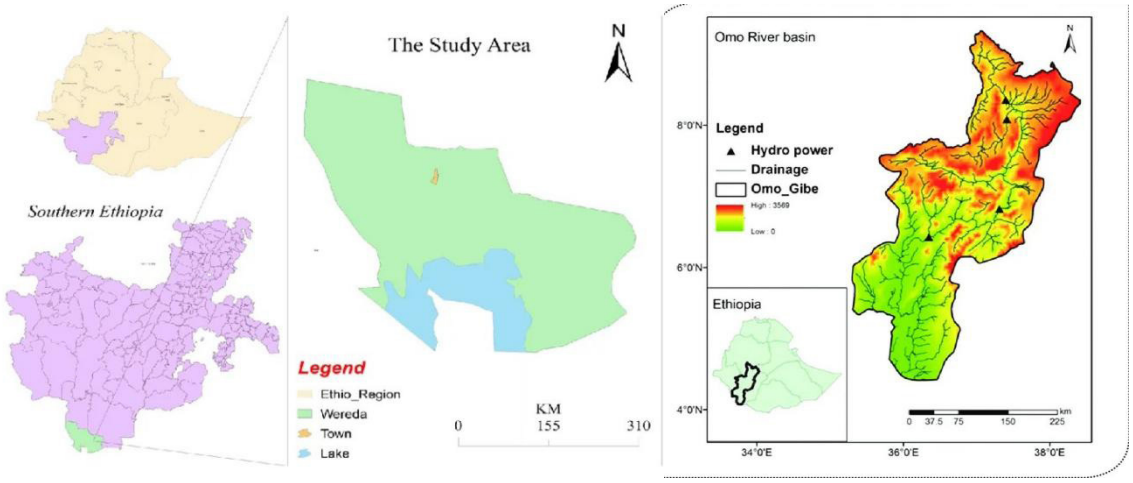

Figure 1. Dassenech Woreda map and Omo River Basin.

2.2. Methodological Paradigm

In social science research, three major theoretical paradigms exist: positivism, phenomenology or interpretivism, and pragmatism. Among these, phenomenologists or interpretivists have a long history in philosophy and sociology (Berger & Luckmann, 1967). As Douglas (1970) wrote, "The 'forces' that move human beings, as human beings rather than simply as human bodies . . . are 'meaningful stuff.' They are internal ideas, feelings, and motives." That important reality is what people perceive it to be. The interpretivist seeks to understand this through qualitative methods, such as participant observation, in-depth interviewing, and others, that yield descriptive data (VanderStoep & Johnston, 2009). Therefore, to explore and analyze local communities' indigenous early warning systems from the study participants' or actors' perspectives and points of view, and to examine the flooding disaster they experienced, the researcher employs a phenomenological or interpretative epistemological paradigm to understand the phenomenon from the participants' perspectives.

2.2.1. Study Approach and Design

Given the exploratory nature of this study, the researcher used a qualitative research design, along with participatory rural appraisal tools and techniques, to address the gaps in each approach. This enabled the researcher to derive concepts on flooding disasters and early warning systems, discussion themes, insights, and an understanding of Dassenech pastoral and agro-pastoral communities' disaster resilience strategies. However, qualitative research design also has its own limitations. The major drawback of qualitative analysis is that it is time-consuming, and researchers' interpretations are limited, as well as the influence of researchers' personal experiences and knowledge on the observations and conclusions related to this study. Although investigating causality between different disastrous events in the study area is difficult, the complexity of explaining differences in information obtained from study respondents may lead to data inconsistency when concluding (Chetty, 2016). However, through an inductive thematic analysis approach focused on analyzing and theorizing themes rather than testing preconceived models or hypotheses, and with the assumption that knowledge is constructed, it is possible to build evidence-based discussion themes. Therefore, this study explored and described the phenomena under investigation through narrative analysis of major themes. The researcher focused on the perspectives, interpretations, and experiences of the Dassenech people regarding the impact of the Gibe III hydrodam, flooding disasters, early warning systems, and their impact on the pastoralist and agro-pastoralist livelihoods and survival strategies.

2.2.2. Sampling Procedure and Sample Size

Qualitative researchers often question the generalizability of findings to larger populations, as such conclusions extrapolate sampling unit characteristics beyond their contextual meaning (VanderStoep & Johnston, 2009). Researchers may employ several sampling design methods when sampling the study area and target populations in Dassenech. The study employed a non-probability purposive sampling strategy to align with the study's objectives and themes. To gather in-depth data, the researcher intentionally selected participants based on their characteristics, attributes, knowledge, and experiences related to flooding disasters. This approach enabled the researcher to gain an in-depth understanding of the study area. It ensured adequate representation of the study population, based on the representative attributes of the participants studied throughout the analysis. The sample size is typically determined by the level and type of analysis planned. It is essential to include a sufficient number of rare groups to obtain meaningful responses. Aim for a sample size that yields meaningful results for the study. To avoid potential biases throughout sample selection, the researcher undertook necessary steps to minimize associated risk, including defining the purposes of the study, identifying the sample of individuals or units, and obtaining informed consent from study participants.

However, for this study, we used maximum variation and typical case purposive sampling methods. This enabled the study to capture the widest possible range of variation in participants' characteristics and attributes, allowing us to understand the most diverse flooding disaster experiences and viewpoints of the Dassenech people. In addition, to understand the most common and average experiences and characteristics within the pastoral and agro-pastoral communities studied, a cluster-based typical case sampling method was used to select representative flooding disaster-exposed villages and the characteristics of the cluster population's Indigenous early warning system. To address limitations of this sampling method, including generalizability to the larger population, subjective biases from preconceived notions that can affect the study's validity, sampling error, and ethical considerations, the researcher took steps to avoid and mitigate these risks. The sample size was determined based on the major themes under exploration. This enabled the researcher to ensure equal representation among respondents, including Dassenech community leaders, elders, and development agents. Government representatives from pastoralist development affairs offices, Agriculture and natural resource development offices, PSNP, DRMM sectors, and woreda offices, as well as non-governmental organization representatives currently active in the study area, and Ghibe-III Dam representatives, were also included. The sampling was based on the data collection tools described under each data collection instrument. The study included 68 participants: 16 key informants, 12 in-depth interviewees, 32 focus group participants, and 8 case study participants.

2.2.3. Source of Data

The researcher used primary and secondary data sources for the study. Primary data were collected through key informant interviews, in-depth interviews, Focus group discussions, and case studies. Published and unpublished research papers related to pastoralist and agro-pastoralist issues, especially those on the study area and topic; reports; journal articles; literature on historical, socio-economic, cultural, political, and ecological data; and GOs' and NGOs' project intervention reports were used as secondary data sources. Reports related to Lower Omo Valley communities, particularly the Dassenech, by individual researchers and institutions were critically reviewed. The data from both sources were then used as background information and as a building block to strengthen the presentation of the study findings and analysis.

2.2.4. Method of Data Collection

The backbone of every research is the collection of data that a researcher has identified as worthy of analysis (Papachroni & Lochrie, 2015). Interviews, survey questionnaires, publicly available information, and audio-visual material are all potential data sources for a researcher. However, collect-

ing data can be challenging, either due to insufficient data or overwhelming datasets (Papachroni & Lochrie, 2015). Evaluating data sources is therefore helpful, saving valuable time and resources and leading to better analysis and more robust results. Good data collection practices depend on the research tradition. This study employed qualitative data collection tools, including key informant interviews, in-depth interviews, focus group discussions, and case studies.

2.2.4.1 Key Informant Interview

Key informant interviews are qualitative interviews with people who have knowledge and understanding of the specific topics of the study or problem being addressed in the community. According to Mikkelsen (2005), key informants may include ordinary people with field experience, not necessarily specialists, but often more knowledgeable about local issues than officials. A key informant from the community under study is a privileged witness because, because of their position, activities, or role and responsibility, they have a good understanding of the problem under exploration. To collect detailed data on Omo River flooding impacts, community vulnerabilities, resilience, coping mechanisms, and the early warning system, the researcher selected four clusters most affected by flooding (Rate – Borkonoch, Kelem Cluster, Libemuket, and Delegnmur cluster) and collected data between March 2024 and April 2024. The researcher conducted key informant interviews with 16 people in these purposively selected kebeles: community leaders, elders, social institution representatives, and development agents.

2.2.4.2 In-depth Interview

An in-depth interview is a useful qualitative data collection tool used for a variety of purposes, including needs assessment, program refinement, issue identification, and strategic planning. According to Guion et al. (2011), qualitative in-depth interviews are most appropriate when the researcher wants to ask open-ended questions that elicit in-depth information from relatively few people (as opposed to surveys, which tend to be more quantitative and are conducted with large numbers of people).

Qualitative in-depth interviews were used to explore major themes, including Omo River flooding patterns, community livelihoods, vulnerability to the effects of disastrous events, and adaptation strategies. The researcher purposively selected twelve (12) respondents using purposive sampling. These included selected government entity representatives, such as pastoralist development affairs offices, Agriculture and natural resource development offices, the pastoral productive safety net program (PSNP), Disaster response and resilience management (DRMM) sectors, Woredas Administrative Offices, Woreda health Offices, and livestock and fishery resource development offices. The data collection process through this method was carried out between May 2024 and June 2024, and included four (4) non-governmental organization representatives currently active and operating in the study area. Planned in-depth interviews with Ghibe-III dam representatives or concerned representatives were not carried out due to time and cost limitations. To address this gap, the researcher conducted in-depth interviews with identified representatives from the water, mining, energy, and irrigation development offices. Although data were collected through qualitative in-depth interviews, the tools helped the researcher address issues not covered in the FGDs, as well as provide detailed elaborations through a key informant interview questionnaire. Throughout the process, the researcher developed qualitative in-depth interview data-collection guidelines and theme-based questionnaires to ensure the quality of the data-collection process.

2.2.4.3 Focus Group Discussion

Focus groups provided an alternative to multiple individual interviews, facilitating collective insights, which is used to generate qualitative insights or produce direct quotes that can represent the view of the group under study, as well as to fill the gaps in other qualitative data collection tools, which have been used for this study, while accessing the views of those who would not be willing or able to speak up at larger group meetings. This is possible because FGD groups can be comprised entirely of people from specific disadvantaged groups who would not find it easy to discuss their particular opinions in a mixed setting. Therefore, for this study, the researcher brings together a group of eight (8) community members. The sampling of these selected group members for a focus group was random; however, intentional decisions were made to achieve the best group composition in light of the study themes and probing questions. Under the guidance of a trained moderator, the researcher conducted group discussions to gather insights. As a result, nearly four (4) focus group discussions were conducted in June 2024. Each group consisted of eight (8) participants, and a total of 32 people were selected from communities living downstream of the Omo River in the Dassenech communities (i.e., Rate, Kelem, Arikol, and Seremret kebeles). Indeed, focus group discussions with these kebeles provided immense qualitative data and information about the trends and patterns of Omo River flooding, communities' indigenous early warning systems, villagers' adaptation and coping strategies, as well as the effects of hazardous events (drought, flooding, disease outbreaks, i.e human and livestock, conflict, etc), which have been the major themes of the discussion.

2.2.4.4 Case Study

There are several types of case studies. A researcher may choose to conduct a single case study or a collective case study. According to VanderStoep and Johnston (2009), a collective case study compares several related cases. A case study can also focus on one person and be called a biographical case study, or on one event and be called a critical incident study. For this study, a collective approach was used, enabling the researcher to explore and describe the nature of the Omo River flooding indigenous early warning system and the strategies of the Dassenech people to cope with its impact.

During the data collection process, carried out in July 2024, the researcher purposively selected four (4) villages. This was based on their vulnerability and exposure to flood disasters, and the effectiveness of early warning systems in mitigating flooding disasters. Villagers were then asked about the impact of flooding disasters, community early warning systems, and their livelihood activities, resources they depend on, and livelihood outcomes. Details of the subjective aspect, such as feelings, beliefs, impressions, or interpretations, enabled an in-depth understanding of villagers' flooding disaster experience. Throughout this data collection, semi-structured interviews were administered to collect detailed data from selected villagers. The major themes explored in this case study were livelihood types, vulnerability context, coping strategies related to flooding disasters, and trends in access to and use of early warning systems. To collect the required data, two separate case studies were conducted at each selected village, Delegnmur, Seremirt, Koro, and Selegn clusters, with a minimum of two participants. Table 1 summarizes the participant categories.

Table 1. Summary of study participant categories by data collection method and location.

Employed data collection methods	Target location/cluster/ kebele	Participant category	Sample size
Key informant interview	(Rate – Borkonoch, Kelem Cluster, Libemuket, and Delegnmur cluster	Community leaders, elders, social institutions representatives, and development agents	16
In-depth interview	Omorate Cluster	Pastoralist development affairs offices, Agriculture and natural resource development offices, pastoral productive safety net program (PSNP), Disaster response and resilience management (DRMM) sectors, Woredas Administrative Offices, Woreda health Offices, and livestock and fishery resource development offices	12
Focus group discussion	Rate, Kelem, Arikol, and Seremret kebeles	Women, youth, disadvantaged social groups, and social institution leaders	4FGD/32 Participants
Case study	Delegnmur, Seremirt, Koro, and Selegn cluster	Based on their vulnerability and exposure to the effects of flood disasters	8

2.3. Data Analysis and Interpretation

Data collected through qualitative tools were organized based on the study objectives using qualitative analytical procedures. The data were logically categorized based on identified patterns within and across key concepts. Therefore, the research used content analysis, guided by the grounded theory approach, to construct a theory from the study's analysis. The transcribed data were categorized according to the themes guiding the study's discussions. The qualitative data were then analyzed using thematic analysis. To identify and present recurring patterns of themes, the researcher used inductive thematic analysis, which allows themes to emerge directly from the collected data. This enabled the researcher to explore, investigate, and understand the perceptions, experiences, broader ideas, and opinions of the study population towards the Omo River flooding disaster and local communities' Indigenous early warning system. In order to do so, the researcher followed manual-based steps, including familiarization with collected data to examine the data for broader themes, coding patterns (including sub-themes), generating and reviewing themes, and finalizing themes - defining and naming major themes of the study analysis to ensure they match the research questions and objectives. Connections between theory and practice were then examined using the early warning system conceptual Framework, which informed the study's conclusions and recommendations.

2.4. Research Ethics

Before conducting this research, the proposal and data collection tools were reviewed by the Institutional Review Boards (IRBs) of academic institutions. These committees oversaw the research proposal with due respect for participants' ethical considerations and confidentiality. After approval, the required data were collected from study participants from January 2024 to May 2025. In addition, the authors and sources of secondary data were clearly presented throughout this paper in several ways, such as in-text citations and the article's reference list. To safeguard participants' confidentiality and protect their interests in the study, informed consent was obtained throughout the data collection process.

2.5. Limitation of the Study

Due to the broad nature of the themes under study, the researcher may face difficulty collecting all required data within the study schedule, including researcher subjectivity, political sensitivity, and verifying local communities' predictive accuracy of indigenous early warning indicators. To address these concerns, the researcher employed purposive sampling, triangulated collected data, and worked closely with relevant local government, non-governmental entities, and community representatives, enabling the researcher to address these concerns throughout the study process.

3. Results

This section presents the study's results and discussion. The collected data were analyzed through content analysis guided by a grounded theory approach. The transcribed data were then categorized according to the major themes identified through thematic analysis. The thematic analysis included Indigenous flood early warning systems, Trends and Patterns of Omo River Flooding, Local Community Risk Knowledge, Traditional and indigenous early warning systems of the Dassenech, Early Warning and Preparedness Systems, Community-Based Early Warning Systems, and Gibe III dam risk to the Lower Omo Valley Downstream Community. Table 2 and Figure 2 summarize respondent demographics.

3.1. Demographic Characteristics of Respondents

Table 2. Demographic attributes of respondents.

SN	Key Informant Interview		In-depth Interview		Focus Group Discussion		Case Study	
	Male	Female	Male	Female	Male	Female	Male	Female
1	11	5	11	1	14	18	8	0
Total	16		12		32		8	

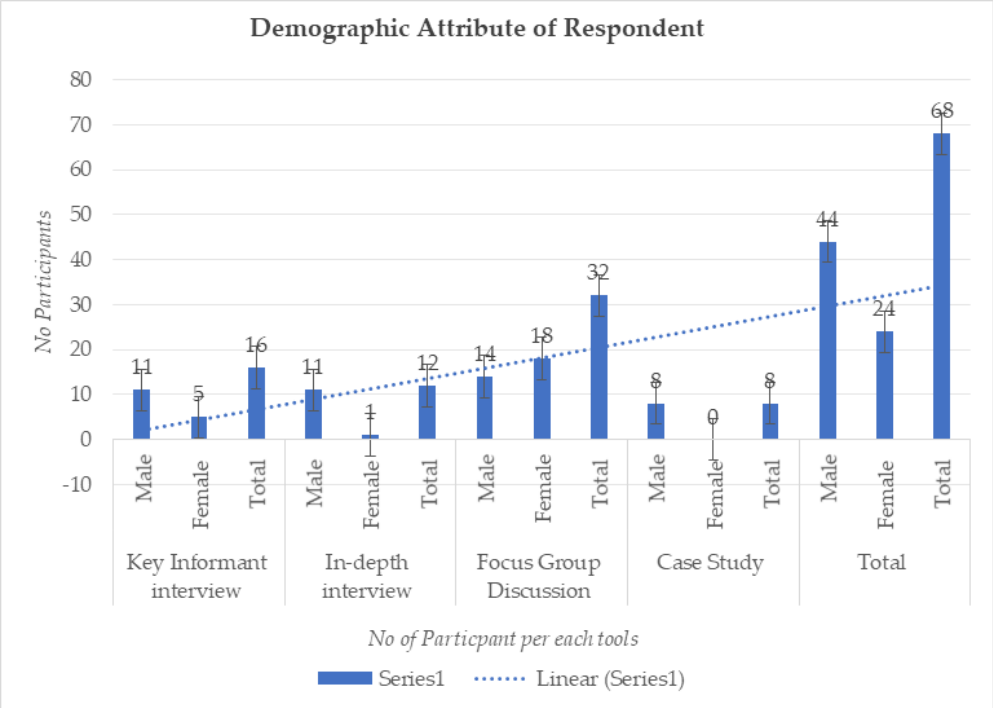

Figure 2. Demographic attributes of respondents, disaggregated by gender.

3.2. Indigenous Flood Early Warning System

Rural communities in the lower Omo Valley, particularly the Dassseneh, are highly exposed to both natural and man-made hazards. They are also vulnerable to environmental and climate change impacts. Before the advent of advanced early warning systems, these communities developed traditional methods to forecast hazards, disseminate warnings, and respond to emergencies. Such knowledge is passed on from one generation to the next, including observation of animals, celestial bodies, and other environmental features, as well as the use of local technologies and materials for hazard prevention and mitigation, for example, through observing cloud rise and fall and the Omo River's natural flow patterns. When threatened by a hazard, Indigenous communities of the Dassenech respond by using this knowledge and practices, which have evolved over generations and will continue to adapt to future changes, due to their strong attachment to the social, economic, and cultural practices of Dassenech villagers. These traditional, often faith-based beliefs and practices, embedded in their day-to-day lives, are key to their resilience in the face of flood hazards. However, communities are concerned that this knowledge might be lost as the elderly die without transferring it to younger members of the communities. Still, neither government nor non-governmental entities have undertaken any effort or program to preserve this knowledge. Rapid environmental change also challenges the community's capacity to use and adapt to the effects of hydropower-induced flood disasters in the area, including recurrent drought, food insecurity, and disease outbreaks.

Indigenous and traditional flood early warning knowledge is a valuable national and local resource for cost-effective, participatory, and sustainable disaster management. To better leverage it, it is necessary to understand, acknowledge, and respect it as valuable existing practice, validate it to establish its scientific basis, and promote and integrate it into education, policies, programs, and projects for disaster risk reduction (DRR) and climate change adaptation (CCA) actions. More often, efforts to mitigate the impacts of flood hazards and climate change focus on high-tech solutions such as sophisticated early warning systems based on scientific data and models. These solutions can save lives when hazards affect communities; however, they must be complemented by actions that address the underlying components of vulnerability—the interrelated human, social, and cultural factors that influence flood risk and contribute to turning a hazardous event into a disaster. An important component that addresses such factors and that can increase the resilience of local pastoral and agro-pastoral communities is their local knowledge. Such local Indigenous community knowledge is often disregarded or denied by modern flood disaster management efforts, and more generally by recent development policies.

However, it has proved to be a useful resource for communities to manage crises of all kinds and, in conjunction with other sources of knowledge, can better prevent, respond to, and recover from flood shocks. Various studies have shown that local community knowledge and practices can significantly reduce disaster risk, as shown since the early 1970s. Therefore, acknowledging traditional and indigenous knowledge and cultural heritages is fundamental to building a culture of safety and resilience at all levels. Indeed, leveraging existing local Indigenous flood early warning knowledge systems for disaster risk reduction actions is essential not only for immediate success, but also for long-term sustainability. Participation and integration of local communities' traditional wisdom in all flood disaster risk reduction (DRR) processes are necessary to pursue the objectives of the Sendai Framework for DRR, and promote sustainable development for better disaster risk reduction policies, strategies, and programs in practice.

3.3. Trends and Patterns of Omo River Flooding

Globally, wetlands support pastoralist and agropastoralist communities because of their high productivity, but they face increasing anthropogenic pressures (Mitchell, 2013). This applies particularly to sub-Saharan African countries, where many people directly depend on wetlands for their subsistence livelihoods, such as agriculture (livestock production, flood recession agriculture, and fishing (Adams, 1993; Mitchell, 2013). The Omo River deltas in the lower Omo Valley provide vital

resources for local communities but are often degraded and losing their significance (Syvitski et al., 2009; Tessler et al., 2015). One of the most important drivers of this degradation is reduced river dynamics and sedimentation resulting from upstream Omo River modifications, such as dams. This has significant implications for the ecology and livelihoods of villagers who depend on the Omo River's ecosystem goods and services. Major debates over Omo River upstream hydropower dam projects and the associated water-energy-food security nexus have become an ongoing global issue (Müller-Mahn et al., 2022). Still, the Dassenech pastoral and agro-pastoral people are severely vulnerable to the negative effects of the Gibe III hydropower dam project-induced flood disaster. Field evidence is illustrated in Figure 3.

Figure 3. Omo River flooding affecting the Delegnmur and Koro clusters.

According to the Dassenech Woreda Disaster Risk Reduction and Food Security Development Office Assessment Report (2024), a decade ago, the pastoral and agro-pastoral communities of the Dassenech people had a better life and livelihood system than they do now. After the construction of the Gibe III hydro-power dam upstream of the Omo River basin, the flood-recession-based livelihood of the Dassenech was significantly affected. Overflow of the Omo River, or Omo River flooding, brings both opportunities and risks to the lower Omo Valley pastoral and agro-pastoral communities, specifically the Dassenech people. Following Omo River flooding, the village engaged in flood-recession agriculture to adapt and improve their livelihood system.

In recent years, changes in the intensity and magnitude of Omo River flooding have significantly impacted the lives and livelihoods of the Dassenech pastoral and agro-pastoral communities. As a result, most Omo River-surrounding villagers, i.e., nearly twenty-eight kebeles, have been affected and lost most of their livestock assets, grazing and farmlands, social service-providing institutions including schools, health posts, and centers, and human settlements were also destroyed.

The flooding exposed nearly 15,888 children and 3,960 pregnant and lactating women to risks such as drought, malnutrition, food and water shortages, social displacement, and disease outbreaks. As a result of recurrent Omo River flooding, more than 10 health posts and two health centers were damaged and became dysfunctional, and others remain at serious risk. This intensifies villagers' vulnerability to multifaceted disease outbreaks and hampers the provision of health services to last-mile pastoral and agro-pastoral communities in the lower Omo Valley. In addition, the flooding disaster severely damaged local communities' livelihoods, including the loss of 65,750 livestock assets (61,170 cattle and 4,580 goats and sheep). The situation worsened further, exposing nearly 1,354,000 livestock assets to livestock disease epidemics and feed shortages. Table 3 and Figure 4 summarize these impacts.

Table 3. Impact of flooding on people, infrastructure, and livestock.

Human		Infrastructure		Lost Livestock	
Women	Children	Schools	Health facilities	Cattle	Small Ruminant
3,960	15,888	71	12	61,170	4, 580

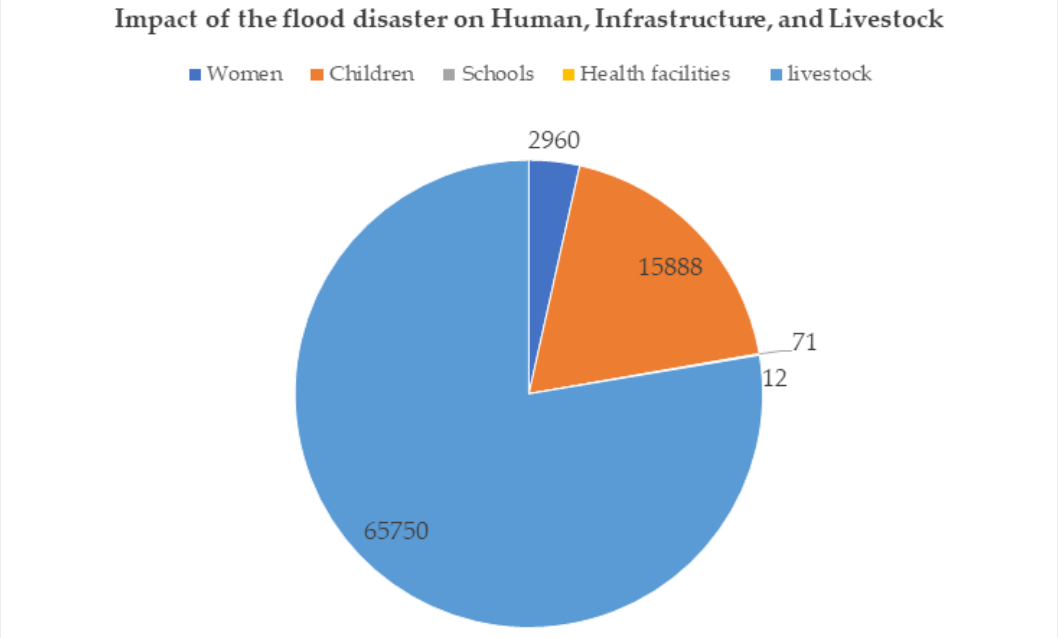

Figure 4. Impact of flooding on people, infrastructure, and livestock.

Since 2015, Omo River flooding has also caused significant damage to government institutions, including human and animal health posts, health centers, schools, etc. Following human displacement in 2012 and 2013, almost all primary school students were out of school. The property of more than fifteen (15) kebeles or villages was damaged, i.e Toltale, Sermerate, Gibte, Gnimorulung, Loyre, Buzuno, Gnzefet, Gneteberuk, Elkolete, Bandra, Libemuket, Nebremus, Lomosiya, Mokonte, and Agolchiyes. However, in 2023 - 2024, the situation worsened and affected other Omo River-surrounding kebeles (Chetekogn, Shera, Loyere, and Kapusia). As a result, 71 school classes and administrative rooms were destroyed, including scholastic materials and equipment, and 4,303 primary school students were out of school.

Despite this, the hydropower-induced flooding disaster also caused serious damage to irrigation water pumps and farm fields, and to human and livestock water points in nearly 28 Omo River-surrounding kebeles. Between 2008 and 2014, villagers in the Omo River area lost 66 irrigation water pumps, 19 farm fields, 10 water storage facilities, 6 hand-dug wells, and shallow wells. This increases their vulnerability to drought, disease outbreaks, food and clean water shortages, etc. Despite this, in 2016 (2023 – 24), artificial flooding from the Gibe III hydropower dam changed the dynamics of Omo River flooding, making villagers' vulnerability more severe and affecting almost all Omo River-surrounding kebeles in the district. This is primarily due to inadequate consultation by Gibe III hydropower dam authorities with Lower Omo Valley communities and the ineffectiveness of the conventional Omo River flood early warning system. Figure 5 illustrates the associated risks.

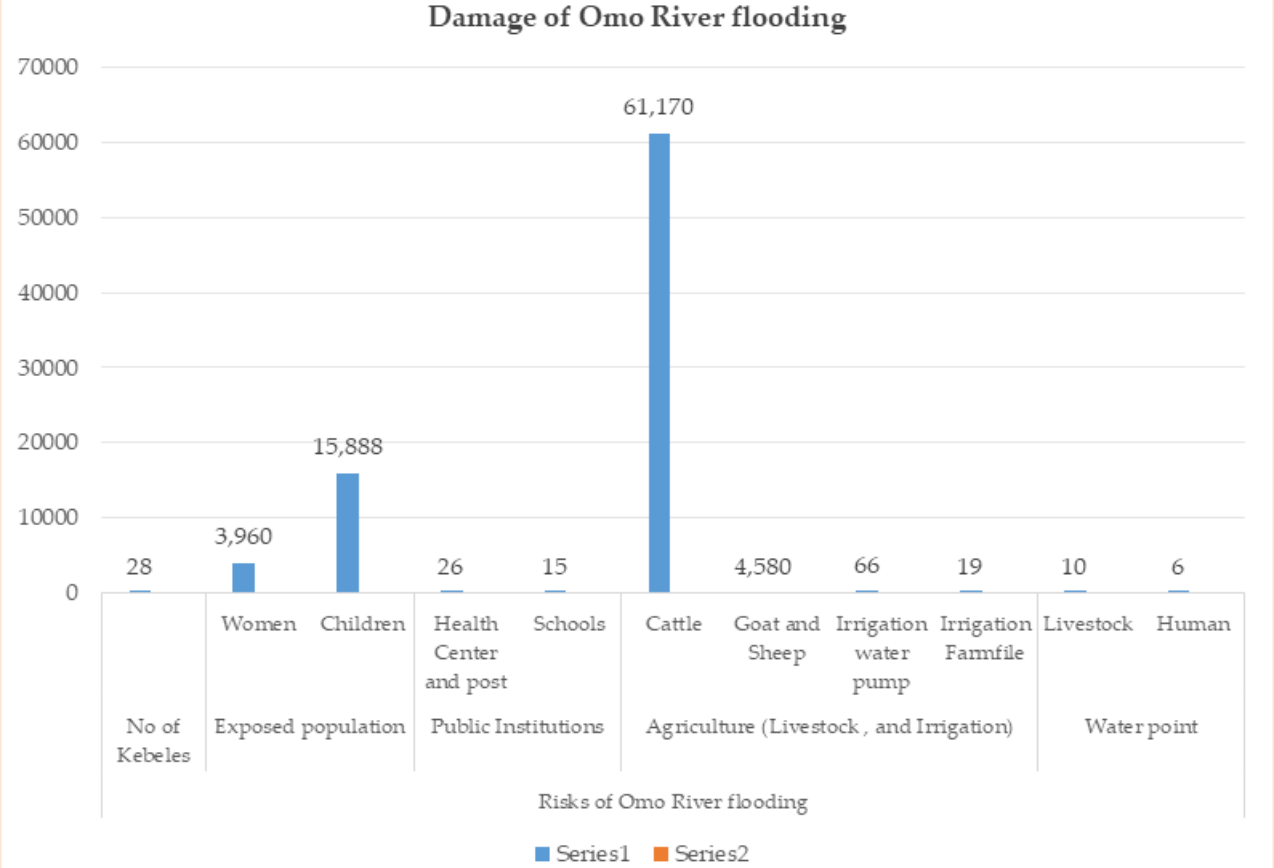

Figure 5. Risks associated with Omo River flooding (2024–2025).

"The flooding occurred at night, and we were unable to evacuate from the place where we reside – from our village. Now I do not have either cattle or goats; the flood already took them to Turkana Lake. Now I do not have any means to support and feed my family (milk, butter, etc), which is one of the devastating events I have never seen before." (KI - 1 women representatives)

3.4. Traditional and Indigenous Early Warning System of the Dassenech

Traditionally, the Dassenech are divided into eight territorial sections or clans (emeto). These include the Shirr, Inkoria, Narich, Elele, Riele, Oro, Randal, and Kuoro. Despite the recent re-organization of the Dassenech society into 'modern' administrative units by the government, which affected clan-based settlement patterns, and the functions of traditional social and cultural institutions, which are the backbone of their survival and resilience, the emeto structure remains strong and functional throughout the Dassenech territory. Territorial sections serve as identity markers for residents and autonomously manage internal affairs, including resource use and generational power transfer. They also oversee religious rituals, conflict resolution, and early warning for hazards like drought and flooding. Furthermore, the Dassenech are divided into eight exogamous, non-territorial clans (turo): Turinyerim, Fargar, Galbur, Turat, Ili, Mur, Edze, and Tiyeme. The clans reside in all territorial sections, although each section may not have all eight clans (Gebre, 2012). Apart from their

division into territorial sections and clans, the Dassenech people have an Indigenous age system that divides people into generation sets and groups. According to Gebre (2012), a particular generation is in power, led by the council of Arra that consists of Challaba (the ultimate decision-makers). Certain clans are also believed to have power over natural phenomena such as drought, Omo River flooding, and livestock disease outbreaks, as well as social events such as war and cattle raids. For example, Challaba and Nane handle communities' early warning system related to drought and flooding; the Galbur are believed to handle water and crocodiles; the Turat to heal fire burns; and likewise, the Turinyerim are believed to cure snake bites and make rain at the time of drought and pasture shortage, and the Fargar to heal animal diseases and avoid flies. Moreover, the Turinyerim and the Fargar are believed to have divine power to ensure victory over enemies during war and cattle raids.

The study reveals that at-risk communities in the lower Omo Valley have a long history of environmental observation and accumulated knowledge related to these changes. Their knowledge system includes elements of flood disaster prevention, risk awareness, and preparedness. Before an Omo River flood, each village in Challaba usually observes changes from the usual in livestock, such as sickness and disease infestation, declines in grazing pasture, and Omo River flow patterns. Then Challaba sends a message through young-generation social groups called kabana to each village leader, elders, and clan leaders to gather for the Nab meeting. After the Nab discussion, decisions are passed, and kabana disseminate the information to the whole village to prepare for the upcoming event. Vulnerable villagers also employ complex strategies to respond to, cope with, and recover from the impact of flood hazards. These traditions and practices have influenced how local pastoral and agro-pastoral communities anticipate and adapt to extreme Omo River floods, weather events, and other hazards. The pastoral and agro-pastoral communities of the Dassenech have a wealth of indigenous knowledge related to flood disaster risk reduction (DRR) and flood early warning systems in the four clusters where the field study has been conducted. The practices range from observing animals, celestial bodies, and other environmental features to forecast Omo River hazards, mostly handled by Challaba and Nane, to using specific local resources to build flood hazard–resistant structures and cope with scarcity during flood disasters. Reliance on traditional and faith-based practices to manage flood events highlights an Indigenous knowledge system that may not be explained through scientific or empirical methods. Figure 6 and Table 4 summarize the community structure and observation-response process.

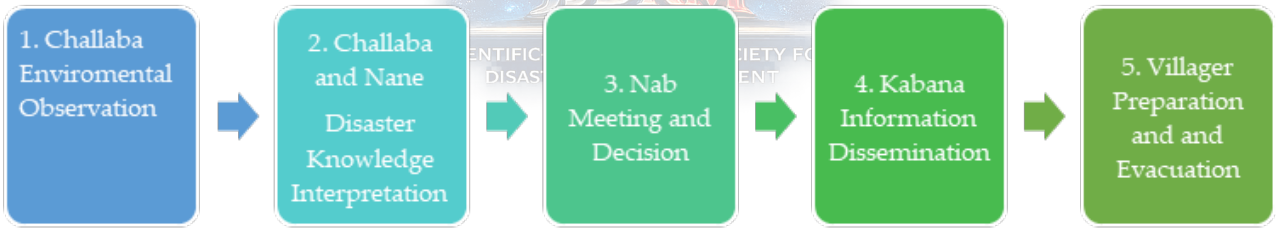

Figure 6. Dassenech community structure for indigenous early warning.

Table 4. Indigenous early warning observations, interpretations, indicators, communication channels, and response actions.

Environmental Observation	Disaster Risk Knowledge Interpretation	Indicators	Communication channel	Response action
Challaba usually observe changes from the usual in livestock, such as sickness and disease infestation, declines in grazing pasture, and Omo River flow patterns.	Observation of animals, celestial bodies, and other environmental features for forecasting Omo River hazards, which are mostly handled by Challaba and Nane	Change in environmental features, desertification, change in rainfall pattern and Omo River overflow, decline of livestock pasture, traditional signs on celestial bodies of small ruminants	Kabana Information Dissemination: After the end of the Nab meeting, the decision will be passed, and the Kabana will disseminate the information to all villagers to prepare themselves for the upcoming event	Following the early warning message passed from Challaba and Nane through Kabana, the village prepares itself to cope and evacuate from its usual residential location.

3.4.1. Local Community Risk Knowledge

Many communities, including the Dassenech, can forecast disasters. Elders, especially the Challaba and Nane, predict events by observing the sky, river flow patterns, and signs of disease outbreaks. Thus, elders believe they receive signs and knowledge regarding upcoming flood-hazardous events. When elders are sure about an event, they disseminate alerts and warnings through the youth and adult generations. This body of measures and strategies helps villagers anticipate and reduce the impact of disasters, especially Omo River flooding. However, key informants noted that traditional Indigenous flood early warning knowledge and practices among the Dassenech are diminishing. Study participants noted that modern early warning systems, knowledge, and new belief systems and religions are gradually challenging the authority of elders' traditional Indigenous flood early warning systems, accumulated through generations through local pastoral and agro-pastoral legends.

3.4.2. Local Communities' Risk Monitoring, Forecasting, and Warning System

Fieldwork revealed that pastoral and agro-pastoral elders monitor local environmental changes, such as river flow, animal behavior, pasture conditions, and celestial bodies, to predict Omo River flood hazards. These elders' observations of environmental features in their villages allow communities to predict upcoming heavy rainfall, Omo River flooding, drought, and human and animal disease outbreaks, and to prepare for such hazards and mitigate their impacts. While key warning indicators vary according to the types of hazardous events, for Dassenech communities, the occurrence of flooding disasters associated with elders, especially the Challaba and Nane, is predicted by observing the sky, river flow patterns, and signs of disease outbreaks. For drought and livestock disease outbreaks, Turinyerim predict the upcoming drought season, which is based on changes in rainfall patterns and the decline of livestock pasture, along with high pest infestation in the flood-retreat cereal crop - sorghum production area. At the same time, the clan called Fargar is considered a divine power in predicting expected conflict with neighboring ethnic groups, particularly with Nuangatom, Hamer, Toposa, and Turkan pastoralists of Kenya.

"During the "Nab-meeting," our village elders, including Challba and Nane, told us about the impending Omo River flooding disaster and warned us to evacuate early from the government villagization resettlement residential place to move up to the Kibsh mountainous area. Due to our livelihood system already established in the place where we reside, we are unable to take appropriate measures; as a result, we lost all of our property, including agricultural farmland and small ruminants." (KI - 2)

3.4.3. Local Community Disaster Prevention, Mitigation, and Preparedness

Community acceptance and responsiveness to flood early warnings are essential for effective end-to-end early warning systems among pastoral and agro-pastoral villagers in Dassenech. This requires building local and national capacities through systematic training and education, implementing disaster preparedness plans, and community awareness programs led by disaster management authorities (UNDRR, 2021). Villagers in the lower Omo Valley are constantly on alert for upcoming hazardous events (Omo River flooding). Oral traditions passed down through generations in the form of legends, visions, and stories are plentiful, and people rely on them for guidance as to what to do in the face of Omo River flood hazards. Various dissemination methods have been used within the Dassenech indigenous communities to warn people and villagers about impending flood disasters. Pastoral and agro-pastoral communities of the Dassenech people have Indigenous traditional customary practices which play a key role in reducing the risks of hazardous events. Beliefs and customary rules related to environmental conservation and natural resource management (e.g., grazing land) are instrumental in preventing and mitigating the effects of Omo River flood hazard events by reinforcing respect for the environment. Knowledge of natural resources supports resilience by enabling livestock diversification and grazing land management. Mobility also underpins coping strategies during Omo River flooding disasters. Local communities' Dassenech indigenous early warning system is highly effective at building local trust, providing rapid hyperlocal cues, and prompting immediate community action. But their knowledge system faces limitations under rapid climate change and extreme, unprecedented-scale disasters. Yet overall success depends on how well traditional environmental observation blends with modern conventional early warning systems.

3.4.4. Early Warning and Preparedness System

Active involvement of local communities is a key element of flood early warning systems and forms the foundation of community-based flood warning and preparedness systems. The key informant interviewed villagers from the Dassenech pastoral and agro-pastoral communities, who depend on the environment and natural resources for their livelihood; they have developed extensive knowledge of potential flood hazards and show a high level of risk awareness. They have devised a variety of ways to disseminate warnings and react swiftly when hazards are approaching.

Risk-sensitive Housing Construction: Local knowledge accumulated through generations forms the foundation of traditional housing design. Traditional designs adapt to local hazard patterns and help minimize their impact on households and communities. The Dassenech pastoral and agro-pastoral communities build their house from "alang branches" using iron sheets, leather, and grass as cover. This traditional housing construction significantly minimizes the loss of their properties during hazardous events (e.g., flooding).

3.4.5. Limitations of Local Communities' Early Warning System

The advancement of early warning systems is hindered by a complex array of challenges that undermine inclusivity, efficacy, and responsiveness. Lack of knowledge on how to coordinate across different timescales and on relevant formal and informal datasets for EWS impedes its effectiveness. Local communities' indigenous knowledge plays a crucial role in predicting hazardous events, particularly in places where conventional early warning systems do not reach villagers. Historically, their knowledge of hazard occurrence is stored within these communities and, combined with their ability to observe environmental indicators, enhances their preparedness for, response to, and recovery from disasters. The Dassenech pastoral and agro-pastoral communities rely on various environmental signs, including changes in vegetation, lunar cycles, cloud formation, livestock behavior, wind speed and direction, to predict and anticipate flooding disaster events. These traditional knowledge system and practices, refined over generations, provides localized, trusted, and contextually relevant early warning systems. However, in the contemporary world, climate and environmental change introduce complex factors that alter seasonal Omo River flow patterns. Subjective interpretation and a lack of institutional integration reduce the accuracy and wide-scale reliability of key warning indicators as environmental conditions shift rapidly. This is mainly due to disruptions in historical ecological knowledge and cues, which make indicators less accurate.

Following the Gibe III hydropower dam construction, these generations-old early warning indicators of the Dassenech people, which rely solely on their traditional flooding disaster early warning system, are declining in intergenerational effectiveness due to the younger generation increasingly relying on modern technological or conventional systems while weakening the oral transfer of traditional knowledge from elders. Further, formal disaster management policies and strategies often view their indigenous indicators as unscientific, creating parallel systems that ignore local communities' generations-old wisdom. This is mainly due to limited commitment among concerned entities to integrate indigenous knowledge systems into disaster management policy frameworks alongside conventional early warning systems.

4. Discussion

4.1. Community-Based Early Warning System

Over the past several years, human societies worldwide have used a variety of structural and non-structural measures to counter the growing frequency and intensity of disasters (Sukhwani et al., 2019). Among these, Early Warning Systems have globally been acknowledged as one of the key non-structural measures for disaster mitigation and preparedness due to the multifaceted benefits

they provide to the community. Despite their effectiveness, operations during rapid-onset disasters like flooding are often disrupted for a range of reasons, creating a critical barrier to the smooth functioning of EWSs (Sukhwani et al., 2019). Yet, with a changing climate, more severe and frequent flooding events are expected across different parts of the world, and while vulnerability levels differ, most low-income developing countries are much more prone to its negative impacts than people living in high-income and developed countries. Even though countries with limited resources are highly constrained, non-structural measures of EWSs shall play a critical role in flood preparedness. Therefore, a comprehensive understanding of flood early warning systems and their major limitation is very significant to improve their function (Sukhwani et al., 2019). However, in the Lower Omo Valley, local government flood early warning systems certainly focus on saving lives, unless combined with a people-centered network that considers villagers' perspectives on disaster management. Often, local government lacks a critical understanding of villagers' traditional flood early warning systems and is less sensitive to and concerned about the needs and interests of the pastoral and agro-pastoral flood early warning perspective and experiences. This tends to ignore local communities' traditional and indigenous flood early warning systems, and the local government needs to identify and understand the relationship pastoralists and agro-pastoralists have with their agro-ecology or environment.

"Local government reached us after the flood damage caused to our village just to provide us some recovery support (i.e food items). Despite prior to or before the occurrence of Omo River flooding, elders understood and forecasted upcoming disaster and their effect on the lives and livelihood of our communities through our traditional early warning practices". (KI - 3)

Therefore, to be effective, local government flood early warning systems must be understandable, trusted, and relevant to the pastoral and agro-pastoral communities they serve. Warnings will have little value unless they reach people most at risk, who need training to respond appropriately to approaching flood hazards. Social identity and locally grounded relationships can also shape community disaster resilience (Cvetković, 2023).

4.1.1. Pastoral (Agro-) Community Early Warning System

A community-based early warning system is an integral step in community-managed disaster risk reduction (CMDRR). It is a means for local communities to collectively address common disaster risks and pursue shared disaster risk reduction measures. They are developed, managed, maintained, and owned by the community, and in the process, they empower the local community. They build on what communities already know about the risks they face, their knowledge of anticipating the effects of hazards, and they explore the coping strategies they already use. The impacts of hydropower-induced flooding disasters can be mitigated with pastoral and agro-pastoral local communities' traditional knowledge by creating an enabling environment for effective planning, physical and environmental protection measures, and response and preparedness. This can be achieved through relevant, participatory risk reduction, preparedness, and response measures that consider the social, economic (livelihood), cultural, political, and historical constraints of lower Omo Valley pastoral and agro-pastoral villagers.

4.2. Integrating Formal (Conventional) and Indigenous Early Warning Systems

Despite strong performance in human development and social infrastructure, the government's failure to ensure adequate preparedness and mitigation pushed back the state's development by decades (Goyal, 2019). Integrating indigenous and formal early warning systems seems a logical option, since pastoral and agro-pastoral lives and livelihood systems rely on indigenous technical knowledge, practices, and beliefs (ecological, cultural, and spiritual) to guide decisions on resource use and management, as well as responses to shocks. Indigenous and conventional early warning systems have both unique characteristics and shared features. Some unique characteristics of IEWS include the use of multi-hazard indicators (Meteorological, biological, astrological, and animistic indicators); continuous, localized, area-time monitoring of weather and climate prediction; and tacit knowledge and inherited skills. The conventional early warning system, on the other hand, mainly uses meteorological data that are gathered both locally and remotely; relies on modeling of historical data for verification and forecasting; produces forecasts at specified times; has longer lead time; uses technical skills learned through formal learning; and is divorced from an epistemic framework in the search for universal validity. The two systems, however, share common features, including the use of meteorological indicators; the combination of current and historical information in forecasting; and a shared aim to inform critical decisions on resource use and management, and on strategies to evade or mitigate the impact of shocks. Community resilience assessment also benefits from clearly defined, context-sensitive indicators that connect social, institutional, and infrastructural capacities (Milenković, Cvetković, & Renner, 2024).

"Integrating indigenous knowledge into modern science can improve livelihoods (Brokensha et al., 1980; Sillitoe, 2000). The community feels valued and therefore confident in participating in risk-reduction initiatives. This, by extension, ensures they can respond immediately to potential risks and consequently strengthens resilience and self-confidence. This suggests that a demand-driven approach, as opposed to the predominant supply-driven or top-down approach of most EWS, may be more effective.

4.3. Gibe III Dam Risk to the Lower Omo Valley Downstream Community

Pastoral and agro-pastoral communities of the Dassenech people have historically faced social, economic, and political marginalization. The great majority of the people are dependent upon access to natural resources. This isolated resource economy is, in turn, highly dependent on the Omo River seasonal flood cycle. The impact has been rippling across the area, touching all those engaged in the local economy. The Gibe III hydropower brought two types of change to the pastoral and agro-pastoral communities of the Dassenech people. Gibe III hydropower has significantly eroded traditional livelihoods based on flood-recession cultivation. It has also caused severe damage to lives and livelihoods through artificial flooding from the dam reservoir.

Even though, as per the informant of this study, the change in the natural patterns of Omo River flooding caused by the Gibe III hydropower dam negatively affects the lower Omo Valley downstream pastoral and agro-pastoral Dassenech Communities. As a result, they lost their traditional flood recession crop cultivation system, seasonal grazing land, and disrupted and the socio-economic well-being of the rural villagers. Further, more recently, Omo River flooding caused incompensable damage to the lives and properties of nearly 28 kebeles of the district (District Early Warning Department, 2024). The observed effects are illustrated in Figure 7.

Figure 7. Effects of Omo River flooding in the Libemuket cluster (2024).

4.3.1. The Crisis of the Gibe III Dam in the Human Rights Context

Indeed, hundreds of thousands of indigenous pastoralists and agro-pastoralists of multiple ethnicities in the lower Omo Valley, specifically the Dassenech people, have been so severely disenfranchised over decades that they have had no recourse but to move to land along the Omo River (Carr, 2017). There, they depend on the Omo River for varying combinations of livestock rearing, flood recession agriculture, fishing, and other livelihood activities, as well as for potable water supply for household consumption. Even though the government underestimates the size of the vulnerable population and the real threat that government development intervention poses to their continued existence, added to this impending destruction is the plausible threat of Gibe III hydropower dam-related effects and artificial flooding, which caused unprecedented human and environmental decimation in the Omo basin (e.g., food insecurity and drought). Therefore, the government has not adequately considered either the rights of these indigenous pastoral and agro-pastoral communities or the risk that the Gibe III hydropower poses to them. As a result, it continued the violation of human rights outlined in the Ethiopian Constitution and the UN Declaration on the Rights of Indigenous Peoples, either eliminating the natural seasonal Omo River flooding or causing unintended effects and damage caused by the Gibe III hydropower dam's artificial flooding. It entirely disrupts the subsistence economy of the lower Omo Valley downstream pastoral and agro-pastoral communities – the Dassenech people. Despite that, mitigation and compensation measures taken by the government are inadequate and undermine the existing subsistence economy and impoverish socio-economically and politically marginalized communities of the Dassenech. Figure 8 illustrates children's vulnerability.

Figure 8. Children vulnerable to the effects of Omo River flooding.

4.4. Early Warning Systems and Policy Framework

Several studies show that, for early warning systems to be effective, they must be integrated into disaster mitigation policies. Good governance priorities include protecting the public from disasters

through the implementation of disaster risk reduction policies (UNEP, 2012). Natural phenomena cannot be prevented, but their human, socio-economic, and environmental impacts can and should be minimized through appropriate measures, including risk and appropriate action plans. More often, these problems are given attention during or immediately after a disaster. Disaster risk reduction measures require a long-term plan, and early warning should be seen as a strategy to effectively reduce the growing vulnerability of communities and their assets. Indeed, the information provided by early warning systems enables authorities and institutions of various levels to immediately and effectively respond to a disaster. Government, local institutions, and communities must be involved in the entire policy-making process, so they are fully aware and prepared to respond with short- and long-term action plans. The policy process is summarized in Figure 9.

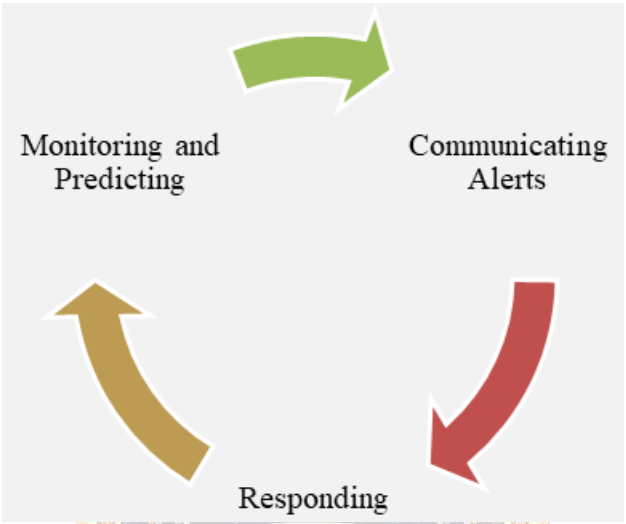

Figure 9. Early warning system policy-level process and operational aspects (based on UNEP, 2012).

Prediction of Risk is Insufficient for Effective Decision Making: For effective decision making within the early warning process, Prediction efforts by the scientific community alone are insufficient for decision makers. The scientific community and decision makers should outline the strategy for effective and timely decision making by indicating what information is needed by decision makers, how predictions will be used, how reliable the prediction must be to produce an effective response, and how to communicate this information and the tolerable prediction uncertainty so that the information can be received and understood by authorities and the public (UNEP, 2012). A miscommunicated or misused prediction can result in costs to society. Prediction, communication, and the use of information are necessary factors in effective decision-making within the early warning process. Innovative flood risk management therefore requires technological tools to be linked with locally appropriate preparedness and communication arrangements (Cvetković & Martinović, 2020).

Developing Effective Communication Strategies: According to UNEP (2012), local and national governments have sometimes kept the pubic in the dark when receiving technical information regarding imminent threats. The lack of clear and easy-to-use information can sometimes confuse people and undermine their confidence in public officials. Conversely, there are quite a few cases where the public may have refused to respond to early warnings from authorities and have therefore exposed themselves to danger or forced governments to impose removal measures. In any case, clear and balanced information is critical, even when some level of uncertainty remains. For this reason, the information's uncertainty level must be communicated to users together with the early warning (UNEP, 2012). This will be more effective when integrated with the Dassenech pastoralist and agro-pastoralist indigenous wisdom of early warning strategies.

Establish Proper Priorities: Resources need to be allocated wisely, and priorities should be set based on risk assessment on the ground, for long- and short-term decision-making, such as investing in local, traditional, and indigenous early warning systems, education, or enhancing monitoring and observation systems (UNEP, 2012). In addition, decision-makers need to be able to set priorities for

timely and effective response to a disaster when it occurs based on the information received from the early warning system. As well, decision makers should receive necessary training on how to use the information received when an alert is issued and what the information means.

Clarify Responsibilities: Institutional networks among different entities need to be developed with clear responsibilities. Complex problems such as disaster mitigation and response require multi-disciplinary research, multi-sector policy and planning, multi-stakeholder participation, and networking involving all the participants of the process. United Nations Environment Program (UNEP, 2012) describes how decentralization in the decision-making process will lead to an optimal solution in the early warning system by clarifying national and local government and at-risk communities' responsibilities. Then, collaboration will improve efficiency, credibility, accountability, trust, and cost-effectiveness. This collaboration consists of sharing information and participatory strategic planning and programming.

Establish and Strengthen Legal Framework: Several studies reveal that there are numerous actors involved in early warning response plans (government authorities, non-government entities, and local communities); the decision-making and legal framework of responsibilities should be set up in advance to be prepared when a disaster occurs.

4.5. Localization and Contextualization of an Early Warning System

According to UNDRR (2017), the effectiveness of an early warning system in collecting and disseminating information is essential. However, not all early warning information is useful to all stakeholders, and in the case of community- and household-level stakeholders, the predominant highly technical information collected may not be the actual information needed to inform and enable early action. Thus, while standardization of EWSs at the global and national level is increasing, effective PC-EWS incorporate local traditional knowledge and expertise as well as the locally contextualized concerns of daily life to render information meaningful to hazard-affected people and useful for early action. Apart from the need for more granular and locally specific forecasts, the ways in which information is presented must be distilled to the most basic, locally relevant, and actionable points. A people-centered model is shown in Figure 10.

Figure 10. People-centred early warning system.

5. Conclusions

The Dassenech pastoral and agro-pastoral communities of the Lower Omo Valley have a long trend of survival strategies for managing Omo River flooding disasters, developed well before the advent of advanced flood early warning systems. These strategies include flood hazard monitoring, forecasting, and response to both natural and man-made flood hazards, as well as climate change impacts. These communities have developed traditional methods of flood disaster forecasting and early warning systems that effectively reduce the risk of hydropower-induced flood disasters. These systems also enable responses to other hazards such as drought, food insecurity, and disease outbreaks, especially when integrated with the conventional flood early warning system and national disaster risk reduction policies and programs.

The study highlights the need for integrating both conventional and Indigenous early warning systems to improve flooding disaster mitigation and prevention in the lower Omo valley. Identifying accurate and compatible integration indicators will help create a policy environment conducive to sustainable, livelihood-based, pastoral and agro-pastoral early warning systems. Therefore, through acknowledging such pastoral and agro-pastoral livelihood-based traditional and indigenous hazard monitoring and survival system as fundamental resources to build an advanced flood early warning system will enhance the effectiveness of local government early warning mechanisms and strategies to reduce the risk and damage of Omo River seasonal flooding on villagers' lives and livelihood system. Hence, advocating and promoting the inclusion of livelihood impacts of flood early warning systems under the national disaster risk reduction and social protection policies, strategies, and practices will create a culture of social resilience at the last-mile villagers of the lower Omo Valley downstream pastoral and agro-pastoral communities. Based on the study findings, the following key recommendations are provided for policymakers, local and nation government, non-governmental entities, local communities, and future researchers. More broadly, disaster resilience is multidimensional and depends on coordinated action among communities, institutions, and other key actors (Milenković & Cvetković, 2025).

In order to make the key recommendation of the study find more actionable cooperate disaster management partnership plate-form need to be established to integrate indigenous and conventional early warning system between local communities, national and regional disaster risk management concerned government entities, civil society organization, policy makers, and academic research institutions.

5.1. National Government

- Strengthen the capacity of local and regional concerned government entities, and existing local knowledge and structure of pastoral and agro-pastoral communities livelihood based early warning system based on what villagers already know about the trend and patterns Omo River flood risk they face and their knowledge of anticipating the effects of Omo River flooding disaster coping strategies they already use.
- Address concern related to Gibe III hydro-power dam artificial flooding, and its effect on the live and livelihood system on lower Omo valley downstream pastoralist and agro-pastoralist communities.
- Address and respond the limitation and critiques of currently operating technocratic approach of an early warning system through integrating both the conventional and traditional or indigenous early warning system of the villager to pastoral and agro-pastoral communities development program, policies, and strategies.
- Adapt bottom-up approach and strategies to ensure the involvement of local communities to enable community based early warning system developed, managed, maintained and owned by local at-risk communities through creating enabling environment for pastoral and agro-pastoral villagers to deal with their situation.

- Create enabling environment for local institutions and communities to be involved in the entire pastoral and agro-pastoral disaster risk reduction policy making process to improve their preparedness to respond Omo River flooding disasters with short and long-term action plan.
- Contextualize people-center early warning system approach, driven by pastoral and agro-pastoral at risk-communities, enabled through multi-stakeholders' collaboration (i.e government and non-governmental entities).

5.2. *Civil Society*

- Strengthen the ability of pastoral and agro-pastoral communities to respond to disasters through enhanced skills and knowledge of hazard risks, community participation, disaster preparedness, and set-up of early action systems.
- Enhance the capacity of pastoral and agro-pastoral villagers of the lower Omo valley local entities on preparedness, DRR, resilience, and adaption to support anticipatory action intervention.
- Enable decentralized, inclusive, and participatory planning and decision-making process for anticipatory action.
- Capacitate at-risk pastoral and agro-pastoral people of the lower Omo valley – to self-determine needs and define acceptable level risk and triggers for early action.

5.3. *Policy Makers*

- Promote and support preparedness and early action of local actors and pastoral and agro-pastoral communities of the lower Omo valley in the design and implementation of disaster risk reduction policies and strategies; -
- Prioritize partnership and strategies which seek to build national, regional, and local level Omo river flood forecasting capacities and better connect risk information services to local actors and at-risk pastoral and agro-pastoral communities.
- Strengthen the enabling environment for collaboration and connection between local communities and national and local forecast in the flood early warning system.
- Provide political commitment or financial and human resources to communicate and contextualize Omo River flood risk information to make it accessible to vulnerable at-risk pastoral and agro-pastoral communities.

5.4. *Local Community and Community Institutions*

- Ensure Pastoral and agro-pastoral communities' active participation in the early warning system
- Contribute knowledge on local context, traditional and indigenous forecasting and information from community-based risk assessment.
- Contribute to observation, data and local forecasting knowledge, strengthen relationship with providers, help identify practical multi-hazard impact-based forecasts and warning with and for different EWS end-user of pastoral and agro-pastoral communities, and share feedback to inform continual improvement of the system.
- Participate in risk assessment and contribute knowledge and capacity on risk, and how they are perceived and the driver and barriers to early action.
- Communicate needs and feedback on current and desire access to use and impacts of EWSs and action.

- Disseminate warning, increase reach and access and inform choices of format, language, and channel of communication.
- Building trust and understanding in warning received, ensure planned actions are relevant and feasible for all vulnerable pastoral and agro-pastoral communities these most at risk.
- Develop, share, and implement early action protocol, take early and timely action, mobilize and organize other villagers' action, and overcome resistance or delay in acting, and help to sustain the system at village level.

Author Contributions: Seid Ahmed designed the study, developed the protocol, prepared the initial manuscript, conducted the literature search and analysis, and reviewed and edited the article.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Institutional Review Board Statement:

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: All data associated with this study are presented in the article.

Acknowledgments: The author thanks the instructors of the Department of Sociology at Hawassa University for their technical support and advice, and Research Advisor Fekadu Israel (Assistant Professor) for consistent professional mentorship, advice, and technical support.

Conflicts of Interest: The author declares no conflict of interest.

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