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Community Assessment of Flood Risks and Early Warning System in Ratu Watershed, Koshi Basin, Nepal

Sagar Ratna Bajracharya [1,2], Narendra Raj Khanal [3], Pashupati Nepal [3], Sundar Kumar Rai [4], Pawan Kumar Ghimire [5] and Neera Shrestha Pradhan [1,*]

[1] International Centre for Integrated Mountain Development (ICIMOD), Lalitpur 44700, Nepal; sbajrach@myune.edu.au
[2] Riverine Landscapes Research Laboratory, Geography and Planning, University of New England, Armidale, NSW 2351, Australia
[3] Central Department of Geography, Tribhuvan University, Kirtipur 44618, Nepal; nrkhanal.geog@gmail.com (N.R.K.); nepalpashupati11@gmail.com (P.N.)
[4] Centennial College, Toronto, ON M1G3T8, Canada; sundar.rai@gmail.com
[5] Geographic Information System and Integrated Development Center (GISIDC), Lalitpur 44700, Nepal; pawan.ghimire@gmail.com
* Correspondence: neera.pradhan@icimod.org

Abstract: Nepal is highly vulnerable to flood-related disasters which cause considerable loss of lives and property. The vulnerability of communities to flood-related hazards can be reduced by proper planning, preparedness, and responses using various structural and nonstructural measures. The community-based flood early warning system is one such tool that enables local communities to enhance their resilience to flooding risks. This paper highlights the efficacy of the community assessment of flood risks and early warning systems. Using qualitative and quantitative methods, this paper evaluates the progress of a community-based flood early warning system implemented in the Ratu River—a small tributary of the Koshi River. The establishment of a community network in 2015 was instrumental in the dissemination of flood early warning information and in building local capacities to understand the risks and take timely action. The flood early warning resulted in awareness-raising, strengthened upstream–downstream linkages, and resulted in a greater willingness among communities to help each other prepare for flood disasters in the Ratu watershed.

Keywords: community risk perception; early warning system; flood disaster preparedness; Ratu watershed; upstream–downstream linkages

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1. Introduction

Nepal is highly vulnerable to different types of disaster due to its high relief, very high seismicity, fragile geology, steep mountain topography, deep and narrow river valleys with frequent mass wasting phenomena, highly concentrated precipitation occurring in four months (June–September) and accelerating rates of erosion [1]. In the two decades from 1988 to 2007, Nepal recorded over 7000 fatalities and ranked 23rd among countries concerning natural hazard-related deaths [2]. Nepal ranks seventh for deaths due to floods, landslides and avalanches, and eighth for flood-related deaths alone [3]. The frequency and magnitude of flash floods are likely to increase as rainfall patterns become erratic because of climate change. In Nepal, 246 people were killed and properties worth more than USD 8.2 million were damaged due to landslides and floods in 2016 [4].

The southern part of the country, known as the Terai, is highly prone to flash floods. Many of the rivers that drain the Terai originate from the southern slopes of the Siwalik range. These are seasonal rivers which swell during the summer months and dry up in winter. The Siwalik range is chiefly composed of sedimentary rocks, which are highly susceptible to soil erosion. The topography is highly rugged and its steep slopes also play a significant role in triggering flash floods, which occur during the monsoon and result in huge loss of life and property in the Terai. In August 2017, almost all districts in the Terai were affected by floods impacting a large number of households—134 people died, 43 were injured, and 30 were reported missing. A total of 186,293 houses were destroyed (https://reliefweb.int/report/nepal/unicef-nepal-humanitarian-situation-report-6-26-august-2017, accessed on 26 January 2021). The damage to crops was estimated at USD 84,490 (1 USD = NPR 117.34 on 2021/01/14); livestock losses were estimated at USD 9.8 million and damage to irrigation canals and embankments was pegged at USD 135 million. The estimated losses would be much higher if the damage to houses and other infrastructures such as roads, bridges, and culverts were included. The risk of flood and flash floods is likely to increase with climate change, particularly due to an increase in extreme events [5–8]. Furthermore, Rajbhandari et al. [9] have projected an increase in rainfall intensity, which is likely to exacerbate floods and flash flood hazards in future in the Koshi basin. A rapid increase in population and the encroachment of floodplains for development and settlements have exacerbated the risks associated with flood events. In this context, there is an urgent need for managing flood disaster risk in the country.

Flood early warning systems are one of the most effective ways to minimize the loss of life and property [10]. A reliable flood forecasting system is very important to enable the establishment of a reliable early warning system that is transmitted down to the community for minimizing the impacts of disasters [11]. Flood forecasting and early warning systems have been implemented around the world in a number of ways—some are very sophisticated (artificial neural networks, advanced flood modelling with satellite data, sophisticated statistical methods etc.) and some are very simple. For instance, the combination of ground-based meteorological data with satellite data, mobile networks and flood modelling in Africa [12]; drainage basin-scale geomorphological investigation combined with flood modeling in Italy [13]; ensemble numerical weather forecasting in combination with a rainfall radar in Belgium [14]; statistical conditional exceedance mode combined with observed gauge data [15], multivariate probability model together with risk probability in the coastal flood plain of the Sao Paulo North Coast, Brazil [16]; a two-dimensional hydraulic model, FLO-2D was used to assess the effects of flooding events associated with basin run-off and storm surge to evaluate flood risk in an ungagged coastal area in Italy [17]. Apollonio et al [18] also highlighted the benefits of the real-time management of flood risk by the identification of hazard areas by estimating the peak discharge and flood risk mapping.

In Nepal, like many other developing countries, the hydrometeorological station networks are sparse and rainfall data are available only after a significant delay owing to the limited spatial coverage of ground-based gauges, the unavailability of real-time rainfall data, and constraints in the technical and financial resources [11]. The simple, low cost, low tech, user friendly, easy to maintain and troubleshoot community-based flood early warning systems (CBFEWS) is useful and effective in remote rural flood-prone areas [19]. CBFEWS is an integrated system of tools and plans managed by and for communities, providing real-time flood warnings to reduce flood risks. CBFEWS is based on people-centered, timely, simple, and low-cost technology. It disseminates information to the vulnerable communities downstream through a network of communities and government bodies [20]. The beauty of CBFEWS is the active participation of the community from the beginning to end of the system—for instance, in the design, monitoring and management of the early warning system—and it is a bottom-up people-centered approach [19]. Cools et al. [14] highlighted that engaging local communities and authorities in the EWS design can improve the effectiveness of the whole early warning process and hence results in a higher response to an alert warning. CBFEWS have been implemented in a different parts of the world, for instance in Malawi, Indonesia, Cambodia, Niger, Pakistan, Afghanistan, India, Bangladesh, and Nepal, and have proved successful in saving lives and properties [14,19,21,22].

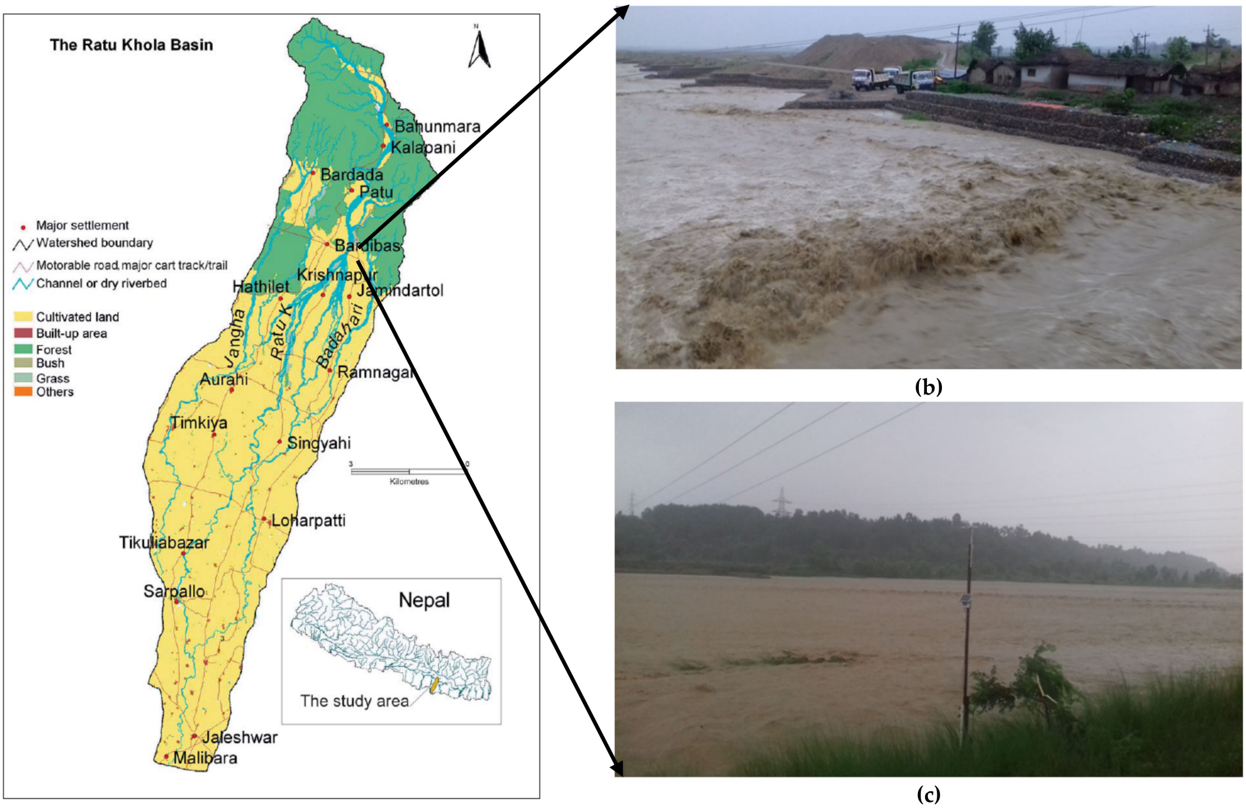
The Government of Nepal launched the Nepal Risk Reduction Consortium (NRRC), which identified five flagship priorities for disaster risk reduction in February 2011. Flagship 4 of the NRRC focuses on community-based disaster risk reduction as a priority and has created a consensus with stakeholders on the minimum characteristics of a disaster-resilient community. The characteristics include an inclusive community-based early warning system at village development committee (VDC)/ward, district, regional, and national levels, c.f. [23].

Disseminating early warning information about floods to vulnerable communities and decision-makers is very important for reducing the loss of life and damage to properties and infrastructure [24]. By establishing early warning systems, attempts have been made at global, regional and national levels to reduce such risks, for instance, flash flood warning systems for Africa [12], urban flood warning systems in Lanciano, Italy [13], the Global Flood Awareness System (GLoFAS) in Europe [25], but there is still exists a huge gap in getting such information to most vulnerable communities [26,27]. The need for flood early warning systems was highlighted in a Global Assessment of Risk, Nepal Country Report prepared in 2009 by the UN, Nepal [27]. A study by Khanal et al. [1] also recommended enhancing regional cooperation by exchanging flood information and developing flood early warning systems in rivers flowing from Nepal to India, like in the case of the Ratu river.

To address such gaps, a Community-Based Flood Early Warning System (CBFEWS), was piloted in the Ratu watershed, Nepal. The main objective of the study was to understand how the capacity of local people to deal with flood risk has been enhanced after the implementation of the CBFEWS. This paper highlights the community assessment of flood risks and early warning systems using qualitative and quantitative methods to establish a baseline and evaluate the progress of the community-based flood early warning system and also provides an opportunity to explore the application of operational CBFEWS in the flashy river. It also highlights the importance of the four key pillars of CBFEWS.

2. Study Area

The Ratu River originates in the Siwalik range at an altitude of 740 m above sea level (m.a. s.l.) and has a total length of 82 km. The channel slope at its headwaters is high and the slope decreases drastically when it enters the plains. The active river channel is as wide as 500 m in its middle reaches and is braided into several channels with two major tributaries. Located in the southern part of Nepal, the Ratu watershed covers a total area of 532 sq. km. (Figure 1). The watershed has a subtropical monsoon climate—summer temperatures exceed 30 °C—while the average winter monthly temperatures range between 15 and 20 °C. The average annual precipitation in the watershed ranges from 1035 to 1609 mm. More than 82% of the total annual precipitation occurs over four months (June–September) [1,28]. Ratu is a rainfed seasonal river, which dries up in the winter and becomes flashy in the summer (Figure 1). During the monsoon, heavy rains in the upstream trigger flash flooding downstream. A study by Khanal et al. [1] estimated peak discharge in the Bahunmara (the upper part of the Ratu river) at different time intervals and concluded that a ten-year return period flood might be more severe than a normal flood (less severe and which occurs every 2 or 3 years). The peak discharge increases as the river flows further south because other tributaries join the Ratu. Administratively, the watershed falls within two districts—Mahottari and Dhanusa—and includes 47 Village Development Committees. The study covers the whole watershed, but the interventions (components other than monitoring and early warning) are confined to the Sarpallo and Nainhi Village Development Committees (VDCs), the lowest political and administrative unit of Nepal with a total of 2134 households and a population of 18,279 [29].



(a) **(b)** **(c)**

Figure 1. Location map adopted from Khanal et al. [1] (**a**), Flood wave (**b**) and swelling of river at Lalgadh on 25 July 2016 (**c**). Lalgadh is one of three sites where early warning instruments have been installed along the Ratu River (Note: River is called Khola in Nepalese language).

3. Research Methodology

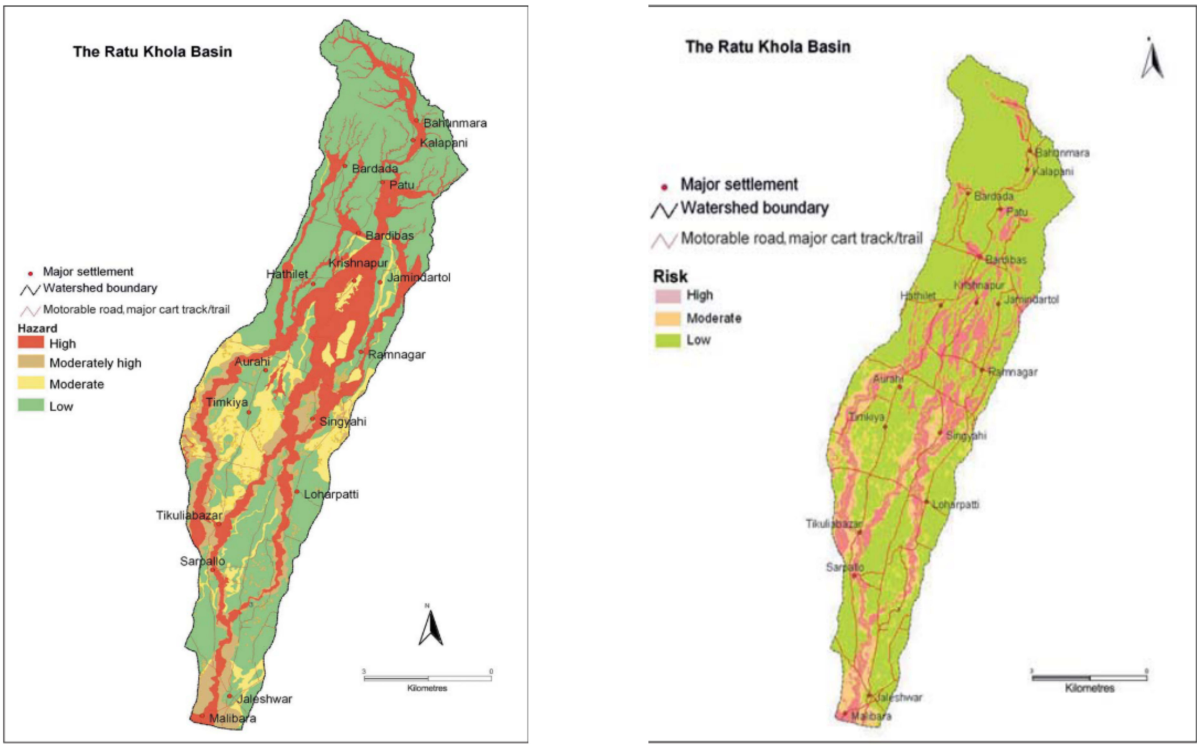
A commonly adopted method used in assessing the impact of an intervention is the use of time-series data taken pre- and post-intervention [30,31]. However, given that the interval of data collection between pre- and post-intervention was short, this study relies on panel data collected from the same sets of households at two points in time. The objective of the study was to assess the changes qualitatively rather than through a rigorous quantitative impact assessment. Field data were collected in 2015 for the baseline and in 2016 for the end line.

3.1. Literature Review

Secondary literature review was conducted to understand different modes of early warning system implemented by different organizations in Nepal. Information from scientific journals, news articles, project report, websites etc. were gathered to triangulate the information derived from primary sources.

3.2. Overview Methodology for Flood Hazard and Risk Mapping

Three different approaches were used to prepare inundation, hazard and risk map; of the basin. Those are: (i) geomorphological approach for hazard and risk mapping, (ii) numerical modelling using HEC-RAS with rainfall and runoff simulation for inundation mapping and (iii) social mapping involving local stakeholders for social flood hazard mapping. The detail of methodology used for preparing such inundation, hazard and risk maps is given in Khanal et al [1]. A composite flood hazard and risk map was prepared using the geomorphological approach (Figure 2). The inundation hazard map based on HEC-RAS was prepared for the 2 and 5 years return flow of both 50 and 100% discharge on the major channel of the Ratu River. Similarly, flood hazard maps drawn by the local stakeholders with the technical help from the research assistants during a group discussion in each VDCs in the Ratu watershed were also prepared, digitized and combined for the whole watershed. Comparative evaluation of the hazard maps prepared using three different approaches discussed above shows the area of different level of hazards were found more or less the same. Therefore, the map of hazard and risk was considered as the basis for the selection of the site for installation of CBFEWS and its impact study.



(a) **(b)**

Figure 2. Flood hazard and risk map in Ratu Watershed adopted from Khanal et al [1], Flood hazard zones (**a**), and Flood risk zones (**b**).

3.3. Primary Field Survey

Keeping in view spatial and temporal coverage of the intervention, a mixed-method using both the quantitative data and qualitative information was adopted for identification and quantification the impact. Data from the field were collected through a household survey, focus group discussion, key informant interviews, and case studies.

For a household survey, a stratified sampling method adopted in a previous study in the Ratu watershed was also adopted for this study [1]. The watershed was divided into six zones. Three zones were categorized as high, medium, and low, which were demarcated based on flood risk map prepared by Khanal et al. [1]. The remaining three zones—upper, middle, and lower—were classified based on the distance from the headwaters of the Ratu River to the downstream of the Nepal–India border. After dividing the VDCs, into 6 different zones, VDCs representing those 6 zones were selected randomly for a household survey. A quota sampling of at least 30 households was purposively determined. Though it is not a probabilistic sampling, statistical norms were followed while determining the sample size. According to the Central Limit Theorem, the results would be similar from a non-normally distributed population if the sample size is large. One rule of thumb states that the sample size should be 30 or more [32]. Considering this statistical norm, a total of 180 households, or 30 households from each zone, were surveyed. The households for the interview were selected randomly from the list of household heads obtained from the VDC offices. After selecting the names of household head randomly, the survey team went to the selected households and contacted each household head. He/she was briefed about the objectives of the survey by the enumerator and a good rapport was established so that the respondent felt confident and provided his/her responses well and accurately.

A semi-structured questionnaire was prepared for the household survey. Through the household survey, general perceptions regarding flood risk were obtained. In addition, information on the early warning system and its effectiveness, preparedness for flood risk reduction, and existing policy/institutions involved in reducing flood risk were also obtained through the household survey. The same households were surveyed before and after the intervention. To trace the location of the same households surveyed in the baseline study for the second-round survey, GPS coordinates were taken as a reference while carrying out the baseline survey and those locations were revisited, and the same households were interviewed in the second-round survey in 2016.

Focus Group Discussions (FGDs) were held with the communities to supplement the information obtained from the household survey. FGD guidelines were prepared to conduct the discussion consistently. During the group discussion, representation from different castes, ethnic groups, marginalized groups, Dalits (lower castes) and Muslims was ensured. Besides, discussions were held with both homogeneous (male only) and mixed groups (male and female). A total of 33 FGDs (baseline survey) and 36 FGDs (for end line study) were carried out in 40 communities and the group size ranged from 7–13 people (Figure 3).

Figure 3. A focus group discussion at Kalapani.

Key Informant Interviews (KIIs) were conducted with teachers, the elderly, administrators, and local leaders of political parties depending on the study area. While selecting informants, social distinctions were carefully considered. Altogether, 33 KIIs (baseline survey) and 39 KIIs (end line survey) were conducted. Individual accounts and perceptions were captured during interviews with key stakeholders. All the information collected from the field was thoroughly checked and analyzed using Microsoft Excel and relevant tables and figures were generated.

4. Community-Based Flood Early Warning System

The Yokohama Strategy [33], Hyogo Framework for Action 2005–2015 [34], and the current Sendai Framework for Action 2015–2030 [35] highlight the importance of CBFEWS in reducing disaster risk and enhancing the resilience of vulnerable communities. CBFEWS generates and disseminates meaningful and timely flood warnings to vulnerable communities threatened by flood, so they can prepare and act correctly in sufficient time to minimize the possibility of harm [36]. It comprises a set of tools and measures that help local communities use local resources and capacities to enhance their resilience to flooding risk. A common feature of community-based early warning systems is the involvement of existing organizational structures and mechanisms within communities. Other commonalities are participatory analyses such as hazard mapping, vulnerability and capacity assessments [37]. CBFEWS facilitates local communities to utilize local knowledge, resources and capacities to prepare and respond to hazards, which ultimately makes local communities capable of minimizing the exposure to flood risk [38]. The success of the CBFEWS depends largely upon the spatial prediction of the impacts and the involvement of local communities in both initial installation and warning [22]. In addition, the four elements of EWS, (i) risk knowledge and scoping, (ii) community-based monitoring and early warning, (iii) dissemination and communication, and (iv) response capability and resilience [36,39] (Figure 4), need to be interrelated. Failure in one element can result in the failure of the entire system [20,28,40]. One of the learnings from the ICIMOD's intervention on the field since 2010 is the need to maintain the sustainability of CBFEWS. To do so, in addition to the four elements identified above, the sustainability aspect needs to be integrated into the entire cycle. For a community-based system, this means that communities can continue and maintain the system independently [38], either by their own means or by other sources.

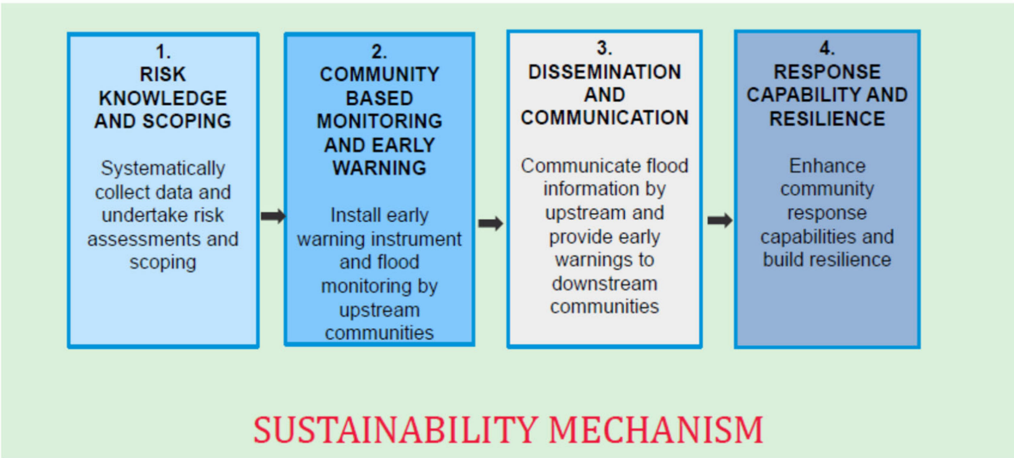
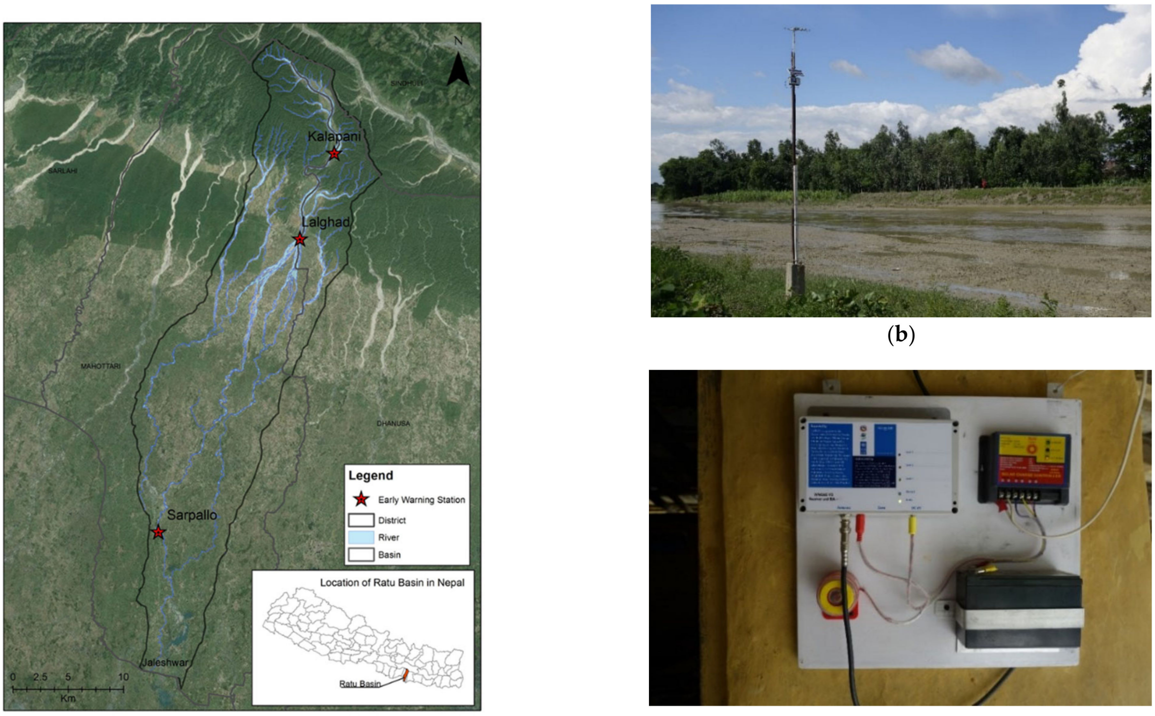


Figure 4. Elements of community-based flood early warning systems (CBFEWS). Source: Based on UNISDR, 2006, http://www.unisdr.org/2006/ppew/whats-ew/basics-ew.htm (accessed on 25 January 2021).

4.1. Intervention of CBFEWS in Ratu watershed

This was the first of its kind CBFEWS intervention in a flashy river in Nepal where the early warning instruments were installed along the Ratu River at three different sites—Kalapani, Lalgadh and Sarpallo—in 2015 to monitor the water level of the river (Figure 5a). These locations were selected in order to provide at least 2–3 h of lead time to the vulnerable communities for preparedness [22]. The instrument is simple and low-cost, consisting of two units—transmitter and receiver [21] (Figure 5b,c)— and was jointly developed by ICIMOD and Sustainable Eco Engineering (SEE). The transmitter unit is installed on the riverbank while the receiver unit is placed in caretaker's house. As the water level rises, the flood sensor attached to the transmitter unit detects it and sends the signals to the receiver unit via wireless technology. The real-time information was disseminated by the caretakers to the vulnerable communities, partners, and concerned government agencies using different modes like SMS, mobile phones etc. for flood preparedness [20].

The simple instrument works according to the principles of floating and conductivity. It is comprised of the Wireless Water Level Monitoring System, Version 3 (WWLMS V3) for water level sensing and signal transmitting. The instrument includes a modified sensor in which two types of sensors—a conductivity-based sensor and a floating based sensor—are used. The instrument has its own network ID. Radio Frequency Module (RFM) 12 with 433 MegaHertz (MHz) frequency is used to transmit a signal. The range of communication between transmitter and receiver units was more than 600 m [20].



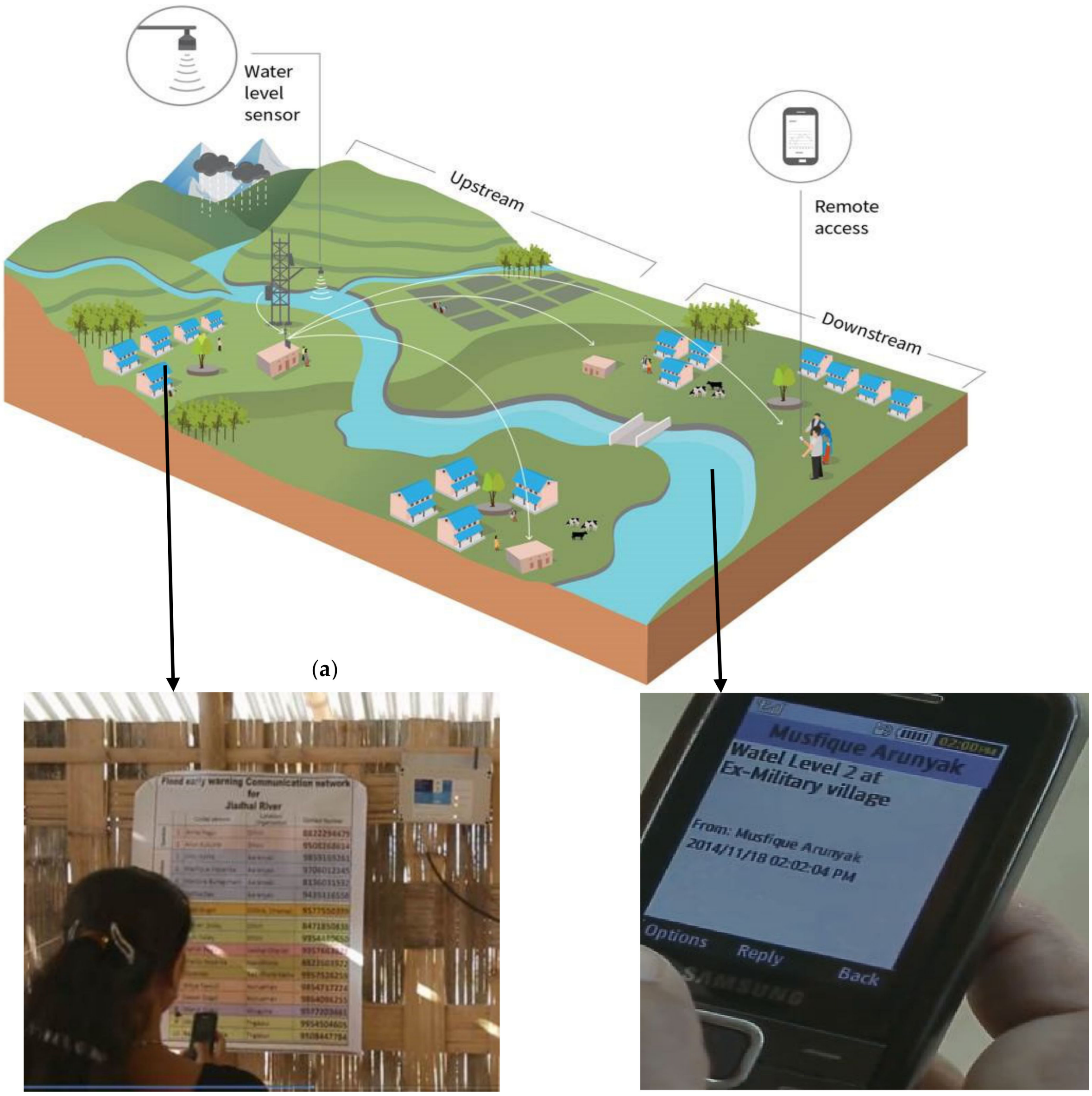
(**a**) (**b**) (**c**)

Figure 5. Ratu watershed with places of CBFEWS installed, indicated by a star (**a**); transmitter unit installed on the riverbank (**b**); and receiver unit at the caretaker's house (**c**).

Though CBFEWS is a low cost technology used to provide real-time information, it has increased the confidence level of the vulnerable segment of communities to deal with flood risks. Gita Devi, an FGD participant in Sarpallo, emphasized, "Before the installation of CBFEWS in our village, we had to stay awake all night and patrol during flood time. But after installation of CBFEWS we can sleep soundly. It has boosted our morale and confidence".

4.2. Mode of Operation

The flood early warning system developed in the Ratu watershed uses various modes of communication like sirens, SMS, and social networks. Once the water level rises upstream, the transmitter (attached to a sensor) on the river bank detects and transmits the signal to the receiver placed at the caretaker's house. The caretaker acts as both the receiver of the flood information and the disseminator of the early warning. Based on the signal level, the siren at the caretaker's house will blow and the caretaker disseminates the warning message to the vulnerable communities (Figure 6a–c). The messages are sent using numbers signify the water level and danger level: 1—the water level is normal: no action required; 2—water level is increasing: prepare for flood; and 3—water level has reached the danger level: run for your life. These thresholds for warning and danger levels of the river height were derived directly by working with communities to map historical flood events and to determine the relationship between observed river height at upstream location and expected inundation downstream based on past flood events [22,39]. Local knowledge was also used to categorize the intensity of the floods as well used to fine-tune the alert thresholds of the floods in different countries [14].



(**a**)

(**b**) (**c**)

Figure 6. Schematic diagram of CBFEWS (**a**); caretaker monitoring receiver and dissemination flood information (**b**); and vulnerable communities receive warning information (**c**).

5. Results and Discussion

5.1. Community Risk Knowledge

Risk knowledge is important for setting priorities for early warning systems, direct preparedness responses, and disaster prevention activities. It helps communities understand the risk situation, motivate people, prioritize needs for developing early warning systems and guide the preparation of disaster prevention and response measures. Risk knowledge covers the understanding of hazards and their nature, hazard management, the likelihood of hazard occurrence, risk reduction plans, and indigenous knowledge [38]. Greater awareness of flood risk would lead to mitigation and preparedness, which ultimately helps to reduce the risk of the flood [41]. The risk mapping in the Ratu watershed was done in 2007 [1].

Khanal et al. [1] reported 18% of the study area in the basin was at high flood risk, and especially the area included settlement zone, as well as the communities. The communities were some extent aware of the increasing flood risk in the watershed due to some previous flood risk studies. During the interview, one of the key informants mentioned the frequency and magnitude of the floods have been increasing, putting more people and properties at risk, combined with increased deforestation, the encroachment of the floodplain for settlements, and agriculture as well as soil erosion in the upstream area and the rise in the river bed as a result of siltation. Previous studies [42,43] have noted that deforestation, infrastructure development, floodplain development for agriculture and the encroachment of floodplains for settlement are major causes behind the increase in flood events and associated risks. Singh and Devkota [44] mention that intense rainfall was also found to be a major cause of the increasing risk of flood in the basin. Furthermore, around 90% of the total key informants (n = 39) reported that loss and damage to productive land and crops were the major impacts of flood events that occurred over the past ten years as well as flood adversely impacting livelihoods, infrastructure, and access to markets.

5.2. Community-Based Monitoring and Early Warning

The core of the flood early warning system is the monitoring and early warning service. This provides flood warnings to the vulnerable communities residing downstream, based on the real-time water level rise in the upper catchment of the basin. Regular monitoring of the state of the flood hazard is essential to produce an accurate, timely, and meaningful warning. It includes the observational stations (the sensor, the transmitter on the river, and the receiver in the caretaker's house), and user-friendly technologies as well as the upstream and downstream linkages. In CBFEWS, the communities are the main actors. The locally nominated caretakers were trained to operate and monitor early-warning instruments, and to disseminate early warnings to downstream communities when the river levels rose above the defined warning and danger threshold.

Earlier, the major sources of information on flood and flood risk were television, FM radio etc. (Table 1). During the field survey, the respondents in the study area mentioned that very few people listened to weather reports and forecasts from the radio/television because they were busy with household and other daily activities. In addition, many respondents relied on their local knowledge for forecasting floods and communicating flood risk. Local knowledge is an instrument for strengthening the understanding and awareness of flood risk and in communicating flood risk [14], for instance, predicting flood occurrence by looking at the position of clouds in the sky and estimating the amount of rainfall in the upper catchment. Sanjaya Paswan, a key informant, Hospital Tole, Mahottari explained, "Until now, we didn't have siren in our village to alert us from flood. So, we used to rely on nature to provide us early warning. The river water would start sounding strange and smell different, the ants would start to move their eggs and the crabs moved to higher ground. These were some of the signals that indicated that a flood might soon reach our village. Based on our experience, we just can say that it produced mix results i.e., sometimes it was true and sometimes false".

Furthermore, people in Aurahi village along the Ratu river used to get flood information and warnings from a milkman in the neighbouring town, who used to cross the river every morning to fetch milk [45] (source: http://lib.icimod.org/record/31841, accessed on 30 January 2021). There was a lack of a robust system for monitoring and early warning, but after the implementation of the CBFEWS, the flood information was disseminated through mobile phone from the caretaker (0% in 2015, 16.7% in 2016) and also through CBFEWS network members (0% in 2015, 37.8% in 2016), with a systematic channel. As a result, the percentage of households receiving prior information on flood increased from 5% to 54.44% within a year due to the installation of the CBFEWS (Table 2). However, the percentage of people receiving such information was still low due to the short duration between pre- and post-survey.

Table 1. Number of households using different sources of information about flood and its risk.

Source of Information	Before (2015)		After (2016)	
	No of Household	%	No of Household	%
Local government	12	6.7	12	6.7
National government	2	1.1	18	10.0
NGOs	9	5.0	2	1.1
Television/ FM radio	39	21.7	11	6.1
CBOs	10	5.6	11	6.1
Community workers	19	10.6	47	26.1
Village head	4	2.2	3	1.7
Newspaper	1	0.6	3	1.7
Caretaker (Mobile phone)	0	0.0	30	16.7
EW network	0	0.0	68	37.8

Source: Field Survey, 2015 and 2016. Note: It is a result of multiple-choice questions, so it does not add up to 100 percent.

Table 2. Number of households receiving prior information about flood.

Response	2015		2016	
	No of Household	%	No. of Household	%
Yes	9	5.0	98	54.44
No	171	95.0	82	45.56
Total	180	100.0	180	100.0

Source: Field survey, 2015 and 2016.

5.3. Dissemination and Communication

Once the water level in the river crosses the danger or warning level, the dissemination and communication components of a CBFEWS are critical [22]. Every warning related to flood hazard must reach to the most vulnerable segment of the community like women, children, the elderly, the disabled etc. To save lives and properties, the warning message should be clear and understandable and needs to be communicated through multiple channels to cover a large area of the affected community. Early warning is not only about technically accurate warnings but also an understanding of risk. It establishes a link between the producers and the consumers of the warning information aiming to prevent or mitigate a disaster [46,47]. The Community Disaster Management Committees (CDMC) and community task forces ensure that the warning messages reach all vulnerable segments through SMS, phones, hand sirens, and loudspeakers etc. [22](Box 1).

Box 1. The effectiveness of communication and dissemination of early warning information to the vulnerability community.

> During the flood of 2016, Ram Kripal Mahato, an early warning recipient in Pashupatinagar, Mahottari district (downstream of the Ratu River), received a warning call about an approaching flood from Lalgadh (upstream of the Ratu River) through the early warning network. He immediately disseminated the message to his neighbors and the community. Upon receiving the warning, a boy from the neighborhood ran to inform his father, who was working in the field. In a short span of time, they ran to a safer place leaving behind their bicycle. This way, they were able to save their lives but could not save their bicycle from the flood. This shows that people are well prepared for flood even when the lead time is very short.

Most of the interviewed participants reported that the siren installed on-site was effective in providing flood warnings to the community during floods (Table 3). Mira Karki from Lalgadh explained, “Getting flood information is critical. Now we do not need to go door to door to get flood information before moving to a safer place. The siren warns us and our confidence for avoiding the flood risk has increased”. One of the other important modes of communicating flood risks is mobile phones [40], which are ranked as the fourth in the study area.

Table 3. Number and percentage of households reporting the effectiveness of communicating early warning information available.

Method of Communication	Before (2015)		After (2016)	
	No of Household	%	No of Household	%
Telephone	9	5.0	1	0.6
Wireless radio	4	2.2	42	23.3
Siren	120	62.2	153	85.0
Megaphones	27	15.0	59	32.8
SMS	41	22.8	103	57.2
Radio FM	13	7.2	32	17.8
TV	0	0.0	1	0.6

Source: Field survey, 2015 and 2016 (Note: Since the survey contained multiple choice answers, the percentages do not add up to 100.).

5.4. Response Capabilities and Building Resilience

Response capabilities focus on building communities' capacities to respond appropriately to early flood warnings by putting into place well-defined response plans while building upon communities' capacities and knowledge [22] and communities must understand the risks and know how to respond. In the Ratu River, three taskforces—for first aid (FA), light, search and rescue (LSAR) and early warning system (EWS) were formed in the vulnerable communities. Furthermore, two committees— the Community Disaster Management Committee (CDMC) and the Village Disaster Risk Management Committee (VDRMC)—were formed during the intervention. A total of 192 people actively participated in the training and assembly of the necessary equipment for FA and LSAR. A total of eight training programs on the use of FA, the methods of community-based emergency response, the operation and maintenance of community-level flood risk management (FRM), design, implementation and management of the structural and nonstructural measures for flood risk management, and refresher training for FA, LSAR and mock drills were conducted for 1643 participants. This type of training on disaster management was very effective in building the competencies and improving the preparedness and response capacities of the local people before and after the flood disaster [48].

Awareness-raising programs like education, training, mock drills, and preparedness activities play a pivotal role in increasing the risk knowledge. This also includes raising awareness among local people, social bonding, skills, and the institutional set up within vulnerable communities. Though the study area covered the whole watershed, due to limited resources, the project intervention measures were confined to only two VDCs (Sarpallo and Nainhi) with a total of 2134 households and a population of 18,279 [29]. Furthermore, response capabilities and building resilience other than monitoring and early warning were also conducted within these two VDCs. These activities contributed to enhancing the level of awareness and confidence among the people, particularly among the women, who must deal with the flood risk since most of the men have migrated for work, and use the skills obtained through the training in flood risk management. Rinku Sing, Sarpallo explained, "Since many men migrate in search of employment, women have to deal with flood disaster management. Before implementation of CBFEWS, we used to run individually here and there to avoid the risk of flood. Now we have identified the safer place and we are prepared to go together with all the members of the family once we hear the siren".

The Ratu River has not experienced any severe flooding since the implementation of CBFEWS. However, the results showed that respondents were able to inform their communities about the flood and avoid human casualties due to the training provided to them. A focus group discussion with women participants in Sarpallo village revealed that they felt more secure from the flood after installing the CBFEWS in the Ratu River, as the system gives flood warnings in advance even at night. They said that the villagers do not need to go to the river each time to check the water level during flood season. According to them, this not only saves them time and effort but also lessens their dependence on the men, as it is usually the male family members who go out to check the water levels in the river. Now they get timely flood warning from upstream and disseminate it to the people who are at risk. They mentioned that CBFEWS can save the lives and properties of the poor people living in the flood prone areas.

In addition, the percentage of households who were not prepared for the flood incident decreased from 74% to 45% after the implementation of the CBFEWS. Furthermore, the percentage of households those evacuated to a safer place with their family members during floods increased to 56% from 42%. The percentage of households involved in flood risk management activities like draining flood water, repairing embankments, and planting vegetation increased considerably. However, due to the nonseverity of flood after the implementation of CBFEWS, no major change was reported, whereas awareness among people, such as participation in training, investing money for disaster risk management, emergency services as well as crop and livestock insurance showed increased levels compared to 2015.

6. Role of Institutions in Mitigating Flood Disaster

Good governance and institutional setup are vital to the success and sustainability of early warning systems. Mainly, the institutions formed at the local level could play a vital role in effective flood risk reduction [49] together with the collective efforts of local people in the aftermath of a flood. They are the cornerstone upon which the elements of the early warning are built, strengthened, and maintained [27].

The baseline survey showed that nearly 29% of households worked individually in dealing with the flood risk before the implementation of CBFEWS. It decreased to 16% after the implementation of CBFEWS and individuals started to work with communities by sharing flood information due to the awareness-raising and training activities provided by the project. People consulted neighbours, local groups, Community-Based Organizations (CBOs)/ International Nongovernmental Organizations (INGOs), the Red Cross Society, the Nepalese police, the Nepalese army, the armed police force, and the Early Warning Network for further help to deal with flood disasters.

The results showed an increase in the percentage of people aware of the activities of the different task force and the Early Warning Network formed by the Community-Based Flood and Glacial Lake Outburst Risk Reduction Project/ Department of Hydrology and Meteorology (CFGORRP/DHM) Nepal in 2015. Though the percentage of people reporting the role of CFGORRP/DHM was still low (i.e., 6%) in 2015, this number reached 12% after the implementation of the CBFEWS in 2016. Most households were aware that the government had played a key role in the construction of embankments and gabion walls, reforestation, the distribution of food, clothes, tents, and relief support to flood-affected people. However, the number of households with knowledge about the work of other institutions (NGO, private sectors) in reducing flood disaster risk was very low (less than 16%).

Nearly 14% of households reported the work of institutions was very effective, 63% reported moderate, and 23% reported not effective during flood disaster. However, the percentage of households reporting that the work was not effective during the baseline survey was 23%, but this percentage decreased to zero after the implementation of the CBFEWS. This might be due to the formation of task forces (FA, LSAR, and EWS) during the project intervention. Moreover, the response capacities of the local people to deal with flood disasters increased due to the formation of those task forces and their activities such as training and mock drills organized through wider public consultation (Figure 7). Previous studies in other places also reported that wider consultation with concerned institutions and governance was very effective in raising the response capacity of the local people [50,51].

(**a**) (**b**)

Figure 7. Mock drills on search and rescue (**a**) and EWS task force sharing flood information to villagers through megaphones (**b**).

7. Conclusions

Nepal is highly vulnerable to natural hazards, especially floods and flash floods, which are increasing in magnitude and frequency because of the country's fragile geological formation, its steep terrain, and its intense and highly variable precipitation. Furthermore, climate change is exacerbating the process, resulting in extreme events impacting vulnerable communities. A community's susceptibility to the impact of natural hazards and its vulnerability depend on the exposure of people and property to the hazard. Scientific assessments of the flood risks and forecasting remain few in practice, posing challenges to informed decision making. Timely risk information, awareness, and preparedness play a vital role in enhancing the resilience of vulnerable communities.

In this situation, a people-centered EWS can empower communities to make decisions to manage flood risk by receiving almost real-time flood information, leading to sufficient lead time for preparedness. This study explored communities' involvement in flood early warning, which was first piloted in a seasonal river in the Ratu watershed in Nepal in 2015. The progress of the CBFEWS was assessed considering the four major elements of an effective early warning system—community risk assessment, monitoring and early warning, dissemination and communication, and response capabilities, and building resilience.

The study indicated that after the implementation of CBFEWS in Ratu River, the communities' level of perceiving flood risks enhanced because they were involved in the conceptualization, the assessment of risks and vulnerabilities, and the generation of flood information upstream, as well as disseminating it to downstream vulnerable communities. The installation of the community-based water level monitoring instrument and dissemination of the information by using different modes of communication, such as sirens, telephones, SMS, and social networks, has reduced the uncertainty associated with traditional flood risk assessment and forecasting, as well increasing the coverage of the early warning information dissemination at the grassroots level. The capacities of the local people in understanding flood risk, as well as the knowledge and skill to respond to information increased because of participation in different flood hazard and risk assessment training sessions and mock drills. The establishment of institutional frameworks like task forces for first aid; light, search and rescue and early warning system; community disaster management committee; and village disaster risk management committee in two vulnerable communities enhanced their capacity and encouraged other communities to strengthen their institutional networks. The involvement of the households in preparing a community preparedness plan, which was undertaken by government institutions in the past, increased after the implementation of CBFEWS, leading to increased participation in and ownership of the activities.

In conclusion, CBFEWS was found to be one of the most effective examples of non-structural ways to address flood risk at the community level, minimizing loss of life and property. Given near real-time flood information and sufficient lead time for preparedness, it helped in enhancing the resilience of vulnerable sectors of the communities like women, children, the elderly, the disabled, etc. The active participation and involvement of local communities, government line agencies, and individuals in conceptualizing and operationalizing the early warning system has increased the level of confidence and ownership at the local level. Local institutions played a significant role in supporting vulnerable communities and enhancing their adaptive capacity and resilience to deal with flood risks. CBFEWS not only provided the early flood information but also helped them prepare to deal with the upcoming flood risk to save lives and livelihoods.

The study briefly touched on the sustainability aspect of CBFEWS; however, detailed research is required to understand and design the methodology for sustainable CBFEWS at the local level. The sustainability of CBFEWS needs to be integrated into all the four elements of EWS (Figure 4) considering its financial stability, institutional arrangements and establishment, technological enhancement and innovations, and social sustainability and inclusion. Community participation can be enhanced to design and implement actions for building resilience to flash floods, like risk assessment and hazard mapping, the use of low-cost information and communication technologies, and preparedness for upcoming flood risks. For future research, this study can be extended to other river tributaries where CBFEWS has been implemented, exploring the enhancement of community-led local low-cost early warning technologies, and conceptualizing a framework for the sustainability of the CBFEWS, considering the local context and the nature of the extreme events.

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Abbreviations

The following abbreviations are used in this manuscript:

CBFEWS	Community-Based Flood Early Warning System
CBOs	Community-Based Organizations
CDMC	Community Disaster Management Committees
CFGORRP	Community-Based Flood and Glacial Lake Outburst Risk Reduction Project
DHM	Department of Hydrology and Meteorology
FA	First Aid
FGD	Focus Group Discussions
FRM	Flood Risk Management
GLoFAS	Global Flood Awareness System
GPS	Global Positioning System
ICIMOD	International Centre for Integrated Mountain Development
INGOs	International Nongovernmental Organizations
KIIs	Key Informant Interviews
LSAR	Light, Search and Rescue
MHz	MegaHertz
NGO	Nongovernment Organization
NPR	Nepali Rupees
NRRC	Nepal Risk Reduction Consortium
RFM	Radio Frequency Module
SDIP	Sustainable Development Investment Portfolio
SEE	Sustainable Eco Engineering
USD	United States Dollar
VDC	Village Development Committee
VDRMC	Village Disaster Risk Management Committee
WWLMS V3	Wireless Water Level Monitoring System, Version 3

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