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Cost-benefit analysis of flood early warning system in the Karnali River Basin of Nepal

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ABSTRACT

Nepal is severely flood-prone and ranks 20th worldwide in terms of flood-affected population. Although it is widely acknowledged that both national and community-based early warning systems (EWS) can reduce the impact of floods, studies quantifying the cost-benefits remain scarce. This study analyzes the costs and benefits of the EWS in the Lower Karnali River Basin in Nepal through 453 household surveys, 30 focus group discussions and 40 key informant interviews. The results show that households found the EWS to be beneficial and reliable, allowing them to save movable property, livestock and vehicles and health costs equivalent to NPR 117,027 (USD 1083) per household during the flood. The benefit-cost ratio is between 24 and 73 depending on different scenarios. 98% of the respondents would be willing to pay an annual fee of NPR 79 (USD 0.70) for five years if the existing flood EWS was to be managed by the community disaster committees. This can generate NPR 694,426 (USD 6430) annually, which would cover the annual maintenance and operating cost of the system. EWS gradually changes behaviors of communities over time as they start to trust the system and lead times are increased, resulting in more social capital and a wider range of early actions that reduce avoidable loss and damage. Improving the forecast lead time by 1 h can increase the current savings by 1.83 times. The results of the cost-benefit analysis can inform the policy-making of state and non-state actors and contribute to securing further funding.

1. Introduction

The frequency and intensity of natural hazards are increasing. Increasing risks and impacts of natural hazards threaten human-welfare and economic growth, claim lives and damage physical and social infrastructure. Globally, the estimated direct economic damages from around 7000 natural hazard events, between 1980 and 2004, were about one trillion USD and two million people were reported killed [1]. Recurring and extreme events increase people's vulnerability, particularly of the poorest communities, since these often have the weakest infrastructure, are dependent on farm-based livelihoods, and generally lack the capacity to cope and adapt. Also, it can lead to changes in individual preferences such as an increase in risk aversion, prosocial behaviour and impatience [2], which can positively or negatively influence the level of vulnerability.

Flooding affects more than one-third of the world's land and about 82% of the world's population [3]. Nepal is considered one of the most disaster-prone countries and is exposed to multiple hazards including earthquakes, floods and landslides [4,5]. Globally, it is ranked 20th in terms of the flood-affected population [6], and 47th in terms of vulnerability to climate change [7]. According to the Post Flood Recovery Report of 2017, the Nepal flood of 2017 affected 1.7 million people living in 35 districts. It destroyed 41,626 houses and partially destroyed 150,000 houses. The estimated value of the damage is NPR[1] 60.71 billion, which is equivalent to three percent of the total gross domestic product of Nepal [8]. The government of Nepal has prioritized the improvement of flood resilience of communities and infrastructure [9]. In several countries across the world, flood early warning systems (EWS) are increasingly applied as a preparedness measure throughout the world since timely information about the flood can help people living in downstream areas to reduce human casualties and save movable assets [10]. EWS includes understanding and mapping the

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[1] NPR is Nepalese Rupees. 1 USD ~ NPR 108 per August 2019.

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hazard; monitoring and forecasting impending events; processing and disseminating understandable warnings to political authorities and the local population; and undertaking appropriate actions in response to the warning in time [11].

It is widely acknowledged that effective EWS presents an inherent component of good-practice Disaster Risk Reduction (DRR) and their importance has been emphasized in global policies [12]. Many global and regional studies have highlighted empirical evidence that shows the effectiveness of EWS in terms of reducing human casualties and saving property [13,14]. Quantifying benefits of EWS is considered a difficult task [15]; hence, despite the high priority of a flood warning system little is understood about its costs and benefits [16], and previous studies on the topic scarce. There is literature on costs and benefits of disaster risk management [13,14,17]. In the UK, HM Treasury has made the use of Social Cost-Benefit Analysis (CBA) mandatory for the appraisal of public projects, where the expected economic benefits attributable to the project must exceed the total economic cost of the resources used in the course of the project. Practical Action used this approach to evaluate their livelihood-centered DRR project in Nepal [17]. While estimating the monetary benefits of flood EWS in Europe, Pappenberger et al. [15] found that benefits are of the order of 400 Euros for every 1 Euro invested. Hallegatte [18] estimated that upgrading hydro-meteorological information and EWS in the developing world to the standard of these services in the developed world would lead to between 300 million and 2 billion USD avoided asset losses annually, an average of 23,000 saved lives per year, and between 3 and 30 billion USD of additional economic benefits annually. Very often, cost-benefit analyses of EWS are based on theoretical scenarios and focused on EWS in developed countries [14,18–23]. There is an apparent need to generate more robust knowledge by focusing on case studies in developing countries, where, on the one hand, the impacts of floods have more severe consequences and capacities are lower, and on the other hand, extensive efforts are or should be taken by the state, and especially non-state actors to install new EWS [24]. Strong evidence and stock-taking of implemented EWS are also essential to create adequate policies and corresponding funding. Therefore, this study performs a CBA of the EWS in a flood-prone area in Nepal and aims to fill this gap in the literature.

The results of this study show that EWS contributes to saving movable property of the households and also reduces human casualties in downstream communities. The estimated value of the benefits generated from the EWS installation is equivalent to NPR 117,027 (USD 1083) per household during the flood. The benefit-cost ratio is between 24 and 73 depending on the scenario employed. Households are willing to pay an annual fee of NPR 79 (USD 0.70) for five years to maintain the EWS. The results also suggest that an improved forecast lead time increases the benefits of EWS. For instance, an hour forecast lead time can increase the current savings by 1.83 times. Our results indicate that the benefits of an EWS outweigh the costs, all while providing additional non-monetary benefits (e.g. increased social capital).

The rest of this paper is structured as follows. The next section describes the study area and the EWS in place. The methodology section justifies our mixed-methods approach: a case study with desk research, focus group discussions as well as a representative field survey of the households in the Karnali River Basin. The results are split into four parts. First, the socio-economic status of the households surveyed is described. Second, the flood occurrence and impact as experienced by the households are represented via their rating of the different effects. Third, the performance of the EWS, the early actions taken and the improvements possible are given. Fourth, the CBA using the costs of operating the EWS (desk research) and benefits experienced (from the field survey) was conducted. The discussion section puts the result into a wider perspective, such as results from other literature as well as the legal framework in terms of disaster risk management in Nepal. Finally, the main conclusions are identified as well as recommendations for further research such as the inclusion of also the non-economic loss and damage in the CBA.

2. Materials and methods

2.1. Case study

The research used the case study research approach [25], appropriate for understanding a problem under consideration in a real-life setting [26], and often applied in researching early warning systems [14]. Case study research is criticized for providing findings that are difficult to generalize [27]; however, it is important to point out that the case study approach, in its conceptual foundations, aims to bring new insights that will contribute to the expansion of the existing theories rather than generalisability of findings[26]. Through exploring a case study in Nepal, this research aims to bring empirical evidence for strengthening the case for increased investment in disaster preparedness and risk reduction.

Nepal has three large river systems (the Kosi, Narayani, and Karnali) with multiple tributaries where flood frequencies are high and impact on the communities living along the river banks are considerable. The Karnali/Ghaghara is one of these three river systems that drain western Nepal with an upper and lower part. The Lower Karnali River Basin is *trans*-boundary in nature, passing from Nepal to India, and has an average annual precipitation of 1479 mm, of which 77% occurs during the monsoon season [28]. The Karnali originates in the Tibetan plateau and high mountains with an altitude between 5500 and 7726 m above sea level and joins the Sharda River in India. The basin is 45,269 km^2 and extends from the Dhaulagiri Mountain in the east to the Nanda Devi Mountain in the west [28] The length of upper Karnali, upstream of the village of Chisapani Nepal, is 230 km [29]. The basin is mainly snow-fed with 1361 glaciers over 1740 km^2 [30]. The Karnali basin has six major watersheds including West Seti, Kawadi, Humla Karnali, Mugu Karnali, Tila, and Bheri. The upper Karnali basin is dominated by rugged terrain and has the lowest human development index compared to the other regions of Nepal. Indigenous communities including Tharu and Sonar live in the area and depend on a farm-based economy. The Karnali contributes to local as well as national economy through fishing, irrigation, and hydropower.

Communities in the Lower Karnali River Basin, below Chisapani (Kailili and Bardiya districts) experience flooding regularly. The available data [31,32] for the 2008–2019 period indicate the occurrence of floods on an almost yearly basis (e.g. 2008, 2009, 2010, 2011, 2012, 2013, 2017), with severe flooding experienced in 2014. The estimated value of the damages caused by Karnali floods, between 2000 and 2016, is NPR 102.49 million (USD 879,000) at five percent interest rate [29]. During this period, 1519 houses were destroyed; 2247 families were evacuated and 23,130 people of 4270 families were affected. In the 2014 Karnali flood, 38 people were killed; 17 were injured; 3137 households were fully damaged and 4823 households were displaced in the Kailali and Bardia districts [33]. It is important to emphasize that creating a coherent overview of loss and damage (e.g. the number of deaths, houses destroyed and economic loss) versus the hazard event characteristics is a challenging task in the context of the developing world. Data sets differ in spatial and temporal resolution, due to for example, differences in data collection and reporting procedures [34]. Also, there can be barriers to data sharing, especially in rather immature data ecosystems [35].

The Lower Karnali River Basin has been chosen as a case study due to the existence of the EWS. Practical Action, in partnership with the Department of Hydrology and Meteorology (DHM), has been working on low-tech, community-based flood EWS (CBEWS) in Nepal since 2008. Unlike national and global EWS, a CBEWS is based on community involvement and a participatory process where vulnerable communities drive information collection and analysis, resulting in early warning messages that enable communities to take action and reduce losses and damages[36]. In 2010, Practical Action and DHM incorporated the flood gauge station in the Chisapani gorge (Fig. 1) -that was established in 1962- into an EWS. From that moment onwards the water levels from the gauge were used in flood warnings for communities [33]. This system has been improved over time through the development and use of simple technology (such as telemetry) to monitor and record in real-time the water level in the river.

Based on the monsoon levels, over several years, three thresholds - alert level, warning level, and danger level have been agreed upon between the key stakeholders involved (i.e. local communities, DHM and municipal officials). The gauge reader informs community people, police, and the army through phone calls and SMS when the river reaches a predetermined threshold (the alert level). Then, EWS task forces inform the community disaster management committees as well as every community member. There are three different task forces: (i) the safety and rescue team rescues the injured people; (ii) the first aid team provides first aid treatment and transports the injured to the hospital and (iii) the EWS team does internal and external coordination. The committee does the overall coordination including shelter management and relief. EWS task forces use hand sirens, flags and megaphones for mass communication to reach local people. When the river reaches the second threshold (warning level), the EWS task force receives a second phone call and SMS from the gauge station and they request people to evacuate to safer places. They help highly vulnerable people including people with disabilities, elderly people, pregnant women, and children to reach a safer place. Finally, if the river level exceeds the highest threshold (the danger level) the final message is communicated to everyone to evacuate and prepare for a destructive flood event. Fig. 2 shows the communication and dissemination mechanism of the early warning messages.

The initial EWS provides warning information two to 3 h before the flood (the forecast lead time), which is related to the time required for accessing upstream information on time. The False Alarm Rate (FAR) of the initial EWS is, given the very short lead time, zero. During the forecast lead time, early actions can be taken that reduce losses and damages caused by the floods, particularly human casualties, movable assets, and livestock. During the floods of 2013, the EWS proved to be effective in saving communities' life and property due to the early warning information, although farmlands still got damaged [37]. However, the forecast lead time only allows for a very short preparedness or implementation time, i.e. the time required to implement and complete early actions. This short preparedness time can be enough for active and healthy people to, for example, evacuate, but not for disabled people, pregnant women, elderly people, and children, putting their lives at risk. It is also important to emphasize that the preparedness time will not be the same for everyone as the preparedness time is dependent on where someone is (at the market, in the forest, at home) and through which channel they receive the forecast. Increasing the lead time will provide more opportunities for vulnerable communities to reduce human casualties and damage to property and livestock.

In the fiscal year 2015/16, hydrological forecasts from rainfall-runoff modeling were integrated into the EWS monitoring and warning component resulting in a probabilistic forecast with an increase of 5 h in the forecast lead time. Downstream households can now receive flood warning information seven to 8 h before the flood [5]. There is a chance of false alarms, for example when a water gauge gets obstructed with debris. To avoid this, the government releases alerts only after manual verification to avoid false warnings to the communities [38]. The FAR for the forecast of seven to 8 h will not be zero as for shorter lead times, but most likely still very close to zero. As part of the flood EWS, mock drills are carried out annually before the rainy season. This activity strengthens the awareness of risk preparedness and enables a prompt response when a real flood occurs. It is estimated that the flood EWS serves 52,782 people of 8796 households of five municipalities of the Kailali and Bardia districts. These municipalities include Geruwa Rural Municipality, Janaki Rural Municipality, Madhuban Municipality, Rajapur Municipality, and Tikapur Municipality.

2.2. Economic valuation

Different methodologies for economic valuation are available. For example, the World Bank [39] compared a resilience package -consisting of e.g. providing universal access to early warning, reducing exposure and asset vulnerability of poor people-with an asset loss package -consisting of e.g. reducing exposure and asset vulnerability of non-poor people and providing universal access to finance, by calculating at the national level. The avoided well-being and asset losses. In contrast to this approach at the national level, a CBA is usually the most appropriate for interventions at the community level. Taking into account that an EWS already exists in the lower Karnali River, this study calculates the present value of the costs and benefits as compared to a "no-EWS" baseline [17], discounting backward to the start date of the EWS. The CBA does not only take into account the benefits as derived from both quantitative (i.e. household survey) and qualitative data sources (i.e. stakeholder consultation) on the period shortly after the start of the EWS until the date of the survey, but also future benefits beyond the survey date. Similarly, the costs are based on costs already made and future costs to be made.

As explained, this study relies on collecting primary data on the benefits of an EWS during historical flood events. DHM provided the costs of installing and maintaining the EWS. The benefits in terms of avoided loss and damage as obtained from the primary data can in principle be validated or matched with flood loss and damage as reported in secondary data sources. However, this is a challenging task since detailed data on flood damage is often confidential and not released by authorities [40]. Also, sufficiently detailed data often simply does not exist, especially in the context of developing countries. This is particularly the case for poor and vulnerable communities, as they often take part in the informal economy, inadequately captured in most databases. Moreover, the asset loss in a country will be higher in absolute terms in the richer and more wealthy areas than in the poorer areas [39], if these are equally exposed, making it more difficult to filter out the required data from aggregated data sets. An additional challenge is to link the flood damage data to hazard-specific event data (such as the flood return period). The World Meteorological Organisation (WMO) has started a pilot project to systematically catalog hazard information of hydro-meteorological (weather-related) events allowing for a unique matching with other losses and damages databases [41].

2.3. Data collection

Focus Group Discussions (FGDs) were conducted to develop categories of the goods and assets that households can save due to early warning information. The FGDs focused on identifying and discussing changes in flooding over time, the infrastructure constructed to reduce the damage in the villages and the sustainability of the EWS (i.e. how to define sustainability). Following the FGDs, social mobilizers (i.e. staff of the project) working to support the EWS program and national experts working in disaster risk reduction were interviewed to understand the operation, effectiveness, and sustainability of the EWS. Based on the results of the FGDs and the interviews, questions for the household survey were developed. The survey included questions on the socio-economic background of participants, flood frequency and impacts, flood EWS and its sustainability aspects (see the supplementary material). The social mobilizers were oriented as the enumerators. The sample size (n) was estimated using Slovin's formula [42]:

$$\mathrm{n} = \frac{N}{(1 + Ne^2)} \mathrm{n} = \frac{N}{(1 + Ne^2)} \tag{1}$$

where N is the total population and e is the margin of error. Here, the total beneficiary households from the EWS (N) is 8796 households with a 5% margin of error. Based on this formula, a total of 453 households (n) were selected for the survey. Thereafter, households were stratified

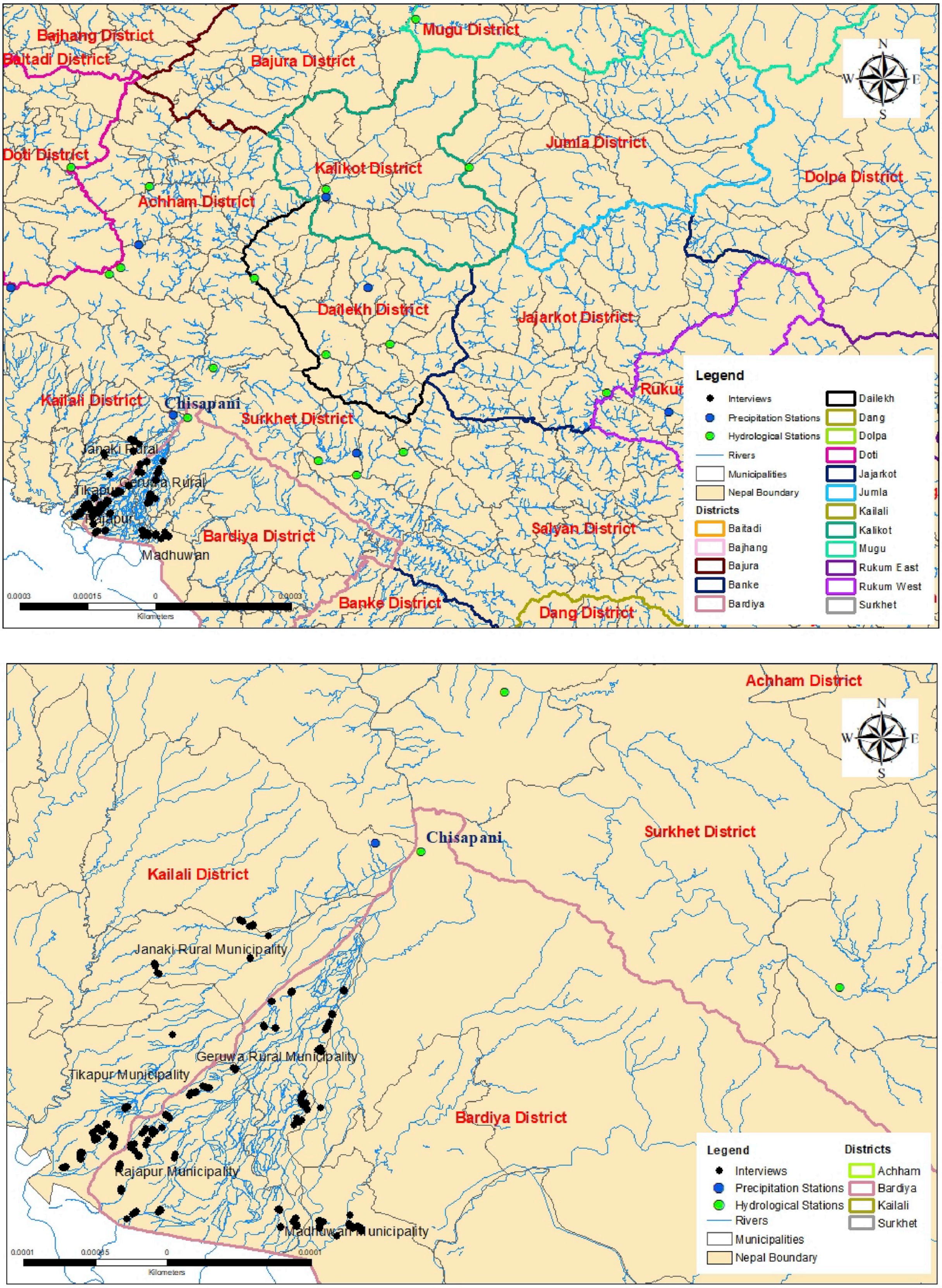

Fig. 1. Maps of the Lower Karnali River Basin showing the hydrological and precipitation stations, the municipality and district boundaries and the places where the interviews were taken.

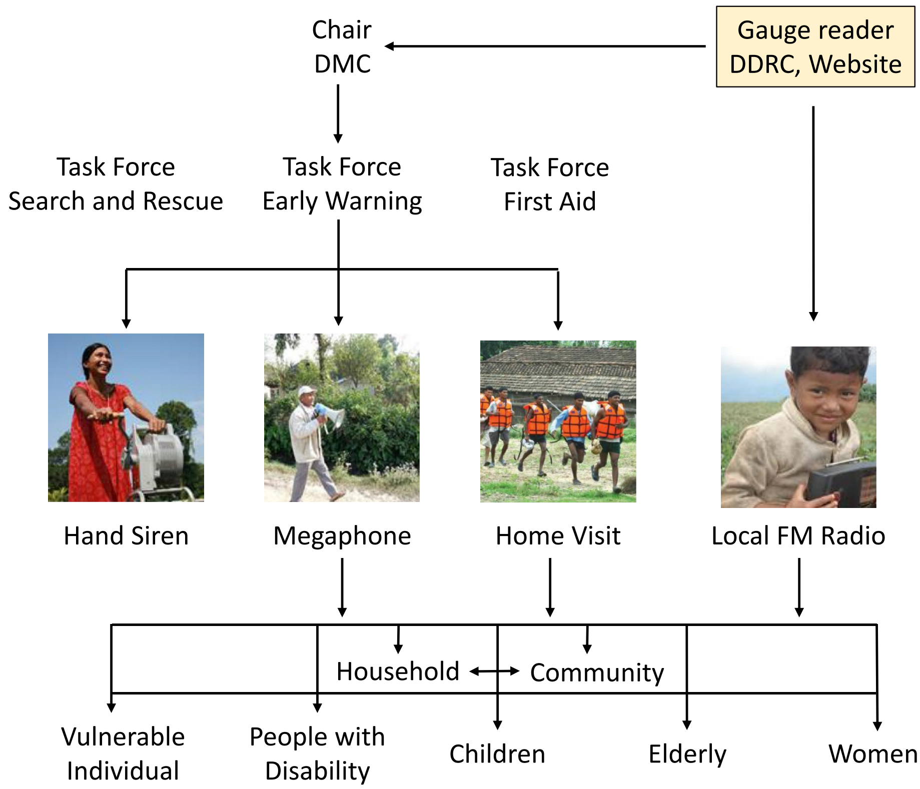

Fig. 2. Communication and dissemination mechanism of the early warning messages [38]. Disaster management committee (DMC); District Disaster Relief Committee (DDRC).

according to the working cluster (i.e. villages) where Practical Action was implementing programs. Households in each cluster were distributed equally. Then, a random systematic sampling approach was employed to identify individual households to interview. This means that the first household was identified randomly and then every 10th household was selected within the cluster. The head of the household of either gender was interviewed.

2.4. Data analysis

The overall cost of the EWS is taken as the total cost for all four components, where the monitoring and warning component (installation of the EWS and its regular maintenance and monitoring) constitutes the largest cost item. The benefits are the accumulated household-level benefits (i.e. the avoided loss and damage as identified through the household survey). Indirect benefits were estimated using the contingent valuation method determining the willingness-to-pay (WTP) of the respondents for improved scenarios. Contingent valuation determines how much the costs would be to restore, replace or repair loss and damage to the previous level [36]. A sensitivity analysis was carried out under different scenarios. The scenarios were developed based on the report from the technical team that assessed the effectiveness of the EWS. These scenarios inform the benefit-cost ratios of EWS under different uncertainties. The included scenarios are about the income resiliency of households, availability of financial institutions, their adaptation behaviour in terms of storing cereals and an increase in cost.

Table 1
Descriptive statistics of the sample. SD (standard deviation).

Variable	Mean	SD
Age (years)	38.08	10.96
Education (years)	3.97	4.18
Family size (number)	6.48	2.97
Land area (Katha)	13.71	16.06
Distance to Karnali river (minute walk)	11.96	10.47

Paying costs and receiving benefits do not occur only once, but continuously. They result in both cash in- and outflows throughout the lifecycle of the EWS [43]. It is, therefore, required to have a fixed timeframe for the CBA. The cash flow for the given period is discounted to reflect present values (PVs). The PV of costs and benefits of EWS is estimated using the following formula;

$$PV = \frac{FV}{(1+r)^t} \tag{2}$$

where t is the life cycle period of the EWS or the number of years of the cash flow, r is the discount rate, and FV is the net cash flow (either benefits or costs). As per discussion with the Department of Hydrology and Meteorology of Nepal, the life span of the system cannot be predicted as it is working well since its establishment in 2008. Therefore, this study used 20 years, as common for continental studies [40], and a 5% discount rate to estimate the PV of economic costs and benefits of EWS. One of the questions in the household survey asks if a household could save due to flood early information in the last flood they experienced and if yes the estimated value. These estimated values are used as the typical benefit the households achieved in the flood events they reported on before the last flood (and from 2010 to 2017) as well as for events in the future period of 2017–2029. The benefits are weighed with the percentage of households that reported benefits. For the future period, flood events are assumed to happen in 2022, 2023 and 2027, 2028, leading to a total of eight flood events in the 20 year study period.

3. Results

3.1. Socio-economic status

Table 1 describes the sample. Of the total respondents, 279 (62%) are female. The average family size in the study area is 6.48 people while the average education of respondents is still the primary level. The average landholding size is 13.71 Katha (1 Katha = 338.63 m^2). The settlement distance from the river ranges from as close as one to as far as 45 min (measured by the time needed to walk the distance). Tharu, an indigenous community, is the major ethnic group (68%) in the area, agriculture is the main occupation of respondents (62%), followed by waged labor (23%). Hence, agriculture is the main source of household income (65%) followed by daily wage[2] (26%) and jobs in India (4%). The households also have substantial livestock including cattle, buffalos, goats, pigs, chicken, and ducks. The average number of four-footed livestock is 6.20 animals per household. The gross national income per capita based on purchasing power parity is USD 942 for the Kailali district and USD 1086 for Bardia [44].

3.2. Flood occurrence and impact as experienced by households

The household survey, executed in April and May 2018, indicates that 36% of households were affected by the annual flooding of the Karnali during the rainy season (June to September). In the 2014 flood, about 90% (404) households reported being affected by the flood. During the flooding period, they moved to a safer place, which is on an average of a 19-min walk. More than two-thirds (68%) of households stated that they lost property during the last experienced floods, in addition to crop loss and house repair costs. The value of the damage is NPR 63,876 (USD 591) per household. Over the last ten years, the 2014 flood was found to be the most devastating as it affected 90% of the households in the study area. Among them, 196 (43.27%) households received relief materials from various humanitarian organizations, such as Nepal Red Cross Society, and voluntarily active local groups, which are worth around NPR 10,000 per family. Table 2 gives the rating by the community of the effects of the flooding.

3.3. Flood early warning system performance and early actions taken

Households stated that they received flood early warnings for -on average-the last 4.18 years. The variation could be due to migration as the flood-affected area is attractive to migrants from the hills. The average lead time at which households received an early warning before the flood arrives is 2.75 h and ranged from 30 min to 6 h. Households received information through five different means (Fig. 3). Of the total respondents, 70% had participated in disaster-related training and all had participated in a flood mock drill. On average, every household had participated in one mock drill per year and participants spent 3 h in the mock drill which ranged from 1 to 8 h.

All households stated that they were fully prepared to respond to a flood. This was mainly due to the annual mock drill and the capacity development program. Respondents took three major actions (i) run away with family members (42%), (ii) inform neighbors (36%), and (iii) save property (22%) immediately after receiving the flood early warning (Fig. 4).

67% of participants had suggestions to improve the flood EWS by shifting gauges upstream to increase the lead time (80%), offering warning in the local dialect (84%), hiring gauge readers as permanent staff (68%) and conducting training on preparedness (60%). Respondents were inconclusive about who is managing the flood EWS in their area. Almost two-thirds (65%) considered that an international or national NGO was doing this versus 20% the community, 10% the local government and 5% the government. In contrast, 46% suggested that the EWS should be managed by local government, 26% voted for community-based management, and 20% stated that the central government should lead, while only 8% of respondents were in favour of NGO management.

The study also asked respondents about the sustainability of the flood EWS. They were asked whether they would pay an annual fee for five years if the existing EWS was managed by community disaster management committees. Of the total respondents, 98% were ready to contribute and the average annual WTP was NPR 79 per household. The annual total WTP of the entire beneficiary households for the community-based EWS management was NPR 694,426 (USD 6430).

3.4. Costs of flood EWS installation

Based on the information available, the following assumptions were made:

(i) Climate and hydrological stations, and sensors for water level measurement were established in 2010;
(ii) Climate change information and rainfall display boards were installed in 2016;
(iii) Staff salary (gauge monitor and reader) is the only annual cost between 2010 and 2015 and remains constant throughout the period.

Details of the cost to establish and operate a flood EWS are reported in Table 3. The cost data were taken from the Department of Hydrology and Meteorology and Practical Action. The past expenditure was adjusted using a discounted rate of 5%. The estimated present value of the cost over 20 year period at the 5% discount rate is NPR 21,679,491 (USD 200,736).

3.5. Benefits of flood EWS

Both the FGDs and the survey showed that there is a consensus that the flood EWS is beneficial to the community. Households reported benefits due to EWS in terms of saving assets, cereal grains, livestock and forage during the flood. The second type of benefit is around reducing health issues such as avoiding stress increase, family disruption, and human loss. Of the total respondents, 96% indicated that they were able to save property due to flood EWS in the last flood they faced. Also, they indicated that the EWS has reduced casualties in their area. The reported value of saving during the flood was NPR 117,027 (USD 1083) per household. The maximum amount of savings is related to cash and jewelry (NPR 31,847), transportation including motorcycle, tractor and cart (NPR 16,356), livestock (NPR 24,944) and cereals (NPR 27,685). 97% of the households who saved property indicated that they could save more if the lead time increased by an hour. The expected saving of 1 h additional lead time is 1.83 times the current saving. Similarly, they expected that if the lead time can be increased by 2 h, then they could save 2.56 times of the current saving.

84% of survey participants reported that they would not be able to save anything without early warning, as opposed to 16% that could save without flood EWS. Of the total respondents, 93% have stated their preference for human casualty reduction. The estimated annual WTP for human casualty reduction is NPR 123.70 (USD 1.14) per household. The estimated total annual WTP for human casualty reduction is NPR 1,088,038 (USD 10,074). The following assumptions were made to estimate benefits;

(i) Of total households, only 84% could save due to flood EWS,
(ii) In recent years, flood frequency is increasing as major floods occurred in 2008, 2009, 2013, 2014 and 2017 (based on DHM dataset from Chisapani station),
(iii) Major floods like 2014 may have been one-in-1000 year event [45].
(iv) Households' resilience is very high, meaning that they can recover within one week given high savings. This means that they will have an equal amount of property available in the following rainy season.

[2] Daily wage income is the earning based on the actual working days. During the study period the daily wage rate was NPR 350/Day (USD 3.25/day).

Table 2
Rating by the community of the severity of the effects of the floods.

Variables	Percentage with a rating score of					Mean	Median
	1	2–3	4–7	8–9	10		
	No effect	Low effect	Medium effect	Serious effect	Extremely serious effect		
Back house life normal	10	43	41	5	1	3.77	3
Tension from flood	7	17	55	21	0	5.40	6
Leave dwelling house	12	30	47	10	1	4.35	4
Flood fear	10	9	48	32	1	5.77	6
Repairable loss	18	32	43	6	1	3.73	3
Loss to house building	20	28	46	5	1	3.82	4
Unrepairable loss	21	42	34	3	0	3.23	3
Loss of livestock	27	31	38	4	0	3.41	3
House price devaluation	24	32	40	4	0	3.41	3
Health effect of flood	16	30	50	4	0	3.89	4

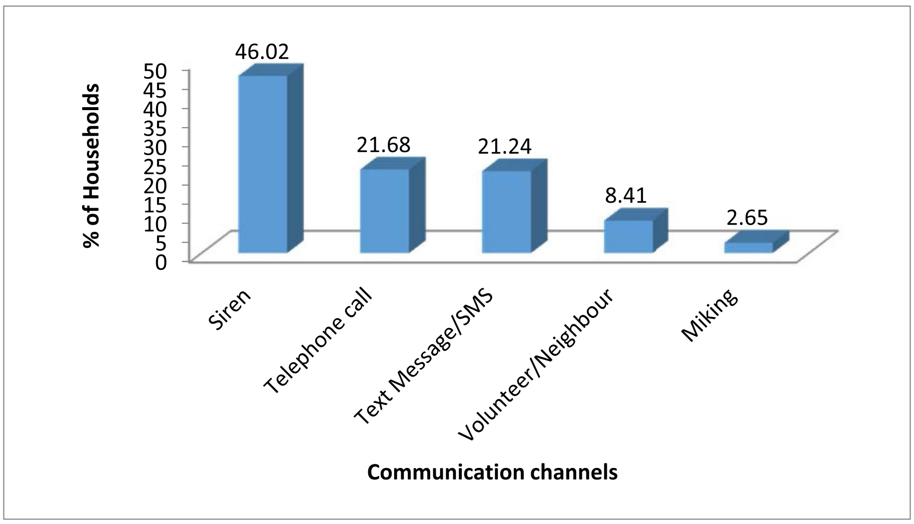

Fig. 3. Communication channels through which households received the early warning information (%).

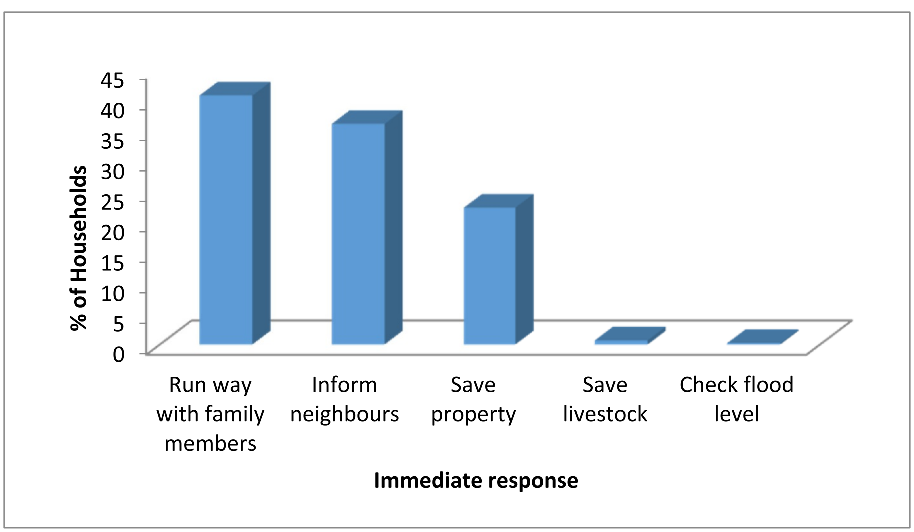

Fig. 4. Immediate response of households after flood early warning (%).

The present value (PV) of the benefits is estimated to be NPR 1.80 billion (USD 16.70 million) for the given period.

The benefit-cost ratio of the flood EWS for the given period is 83, which seems extremely high. The internal rate of return of the flood EWS is 409%. A sensitivity analysis was carried out to understand how uncertainty can influence the BCR of the flood EWS. The following scenarios were used:

- Scenario I – farmers cannot recover all costs within a year. They require a two-year interval to recover livestock and vehicles.

Table 3
Description of costs.

Scenario	Particular	Unit	Quantity	Rate (NPR)
1	Climate stations	Number	7	2,500,000
2	Hydrological stations (precipitation)	Number	20	750,000
3	Cable way	Number	1	3,500,000
4	Sensor for water level measurement	Number	1	15,000
5	Install meteorological station data in computer model (12 stations)	Lump sum		3,532,620
6	Install the climate change information	Lump sum		6,555,089
7	Rainfall display board in public areas	Lump sum		1,707,430
8	Training to community and authorities	Lump sum		606,630
9	Annual maintenance cost	Lump sum		100,000
10	System recharge annual cost	Lump sum		10,000
11	Annual staff cost (3 person)	Month	36	15,000

- Scenario II – all households transact through financial institutions in the community, therefore the risk of losing cash is reduced by 75%, and they have the same capacity as Scenario I
- Scenario III – in addition to Scenario II, the households have a safer place for cereal grain stock, therefore, no risk of damage
- Scenario IV- benefits remain the same but the annual maintenance and staffing costs increased by 8% per year
- Scenario V: a combination of scenarios III and IV

The sensitivity analysis reported in Table 4 indicates that flood EWS generates high returns of investment. In all cases, it has a high BCR and Internal Rate of Return, which indicates its usefulness.

4. Discussion and analysis

The CBA shows that an EWS is beneficial for flood-affected downstream communities as it helps them to reduce property damage and avoid casualties. It also increases their capacity to tackle floods; EWS gradually change behaviors of communities over time as they start to trust the systems and lead times are increased, resulting in a wider range of early actions that reduce avoidable loss and damage. Our study used estimates of the benefits, as expressed by the households interviewed, based on a range of historical flood events, including extreme events. It is not clear how households have “averaged” for these different types of events to come at a typical number. The sensitivity analysis of various assumptions indicates how an EWS reduces loss and damages from floods under different assumptions. These estimations are in line with an existing study that shows that the BCR of a flood EWS could be up to 400 [15]. The BCR can be even further improved as respondents indicated that improved lead time may increase the value of avoided damage by 1.83–2.56 times of their current savings.

However, households are still losing NPR 63,876 (USD 591) in the case affected by a flood. This figure is around half of the value of the saved property. This finding is in line with the findings from the existing studies showing that flood EWS could save between 25% and 60% [40,46]. A limitation of our study is that not all of the flood effects listed in Table 2 are monetized. The table also includes non-economic loss and damage at the individual household level, such as impacts concerning displacement (time away from home, loss of security) or impact on health (diseases, stress, and fear), that we have not yet included in the CBA. The flood fear and flood-related stress observed are in line with the existing literature that showed that there is a fourfold higher risk of psychological distress in a flooded group [47]. Also, 36% of the households in the Karnali River Basin reported that they are affected by floods every year. This could be a reason behind having a WTP for improved flood EWS that could make them stress-free, which is NPR 1,088,038 (USD 10,074). A reduction of stress can lead to financial benefits, such as reduced health costs or other ones that are not yet taken into account in this study, such as having less optimal coping capacity.

Table 4
Present value of costs and benefits, benefit-cost ratio and Internal Rate of Return for five scenarios (in NPR).

Scenarios	PV of costs	PV of benefits	BCR	IRR (%)
Scenario I	22,968,277	1,455,766,295	63.38	372.64
Scenario II	22,968,277	1,060,185,977	46.15	335
Scenario III	22,968,277	601,675,364	26.15	278.13
Scenario IV	24,712,039	1,804,114,832	73.00	365.85
Scenario V	24,712,039	601,675,364	24.34	278.13

Fankhauser and Dietz give an overview of ways to value non-economic loss and damage, coming from a climate change perspective [48]. Paudel [49] has put forward a way to value non-economic loss and damage specifically for Nepal. The contingent valuation method [50,51] is one such approach. Translated to the (negative) health benefits, this could mean asking respondents how much they are WTP for the given period to reduce health-related risks that could have occurred due to a flood in the absence of prior information. Also, local health centers could give valuable inputs on this. Apart from non-economic loss and damage, there are also economic non-material effects that were not included in the CBA that did most likely occur, such as lost income. In terms of costs, we included the costs for the monitoring and warning component of an EWS but no or only very little costs for the other components. For example, for the communication and dissemination component only the installation of the climate change information was included, but not the costs for other communication channels. The government of Nepal co-operates since 2016 with the two major mobile service providers to broadcast bulk SMS messages with flood early warning information to communities and the costs involved are not known nor included in the CBA.

Nevertheless, it is important to note that including the non-economic loss and damage in the CBA would make the BCR higher and it is expected that this increase will be more important than the decrease due to the inclusion of more costs. This notion is supported by the fact that the downstream communities are willing to pay for sustaining the EWS. The estimated total WTP for managing EWS is NPR 694,426 (USD 6430) or -equivalently- an annual fee per household of NPR 79 (USD 0.70), which is 29% higher than the annual maintenance and operating costs NPR 540,000 (USD 5000). This indicates that flood EWS can be made financially sustainable, whereby an option would be to handover management responsibilities to communities It is widely accepted that local communities can manage resources wisely compared to the government and a private company [52]. However, an EWS should not be the sole and complete responsibility of the community it serves.

National Meteorological and Hydrological Services (NHMSs) are considered an essential component of the national taxpayer-funded government infrastructure [53]. Hydrological and meteorological services are publicly mandated to provide early warning and, often, especially in developing countries, focus on the meteorological and hydrological forecasting, given limited resources. For Nepal, the Disaster Risk Reduction Management Act [54] includes the obligations in terms of providing EWS. User-specific and value-adding services can in principle be developed on top of these forecasts but are rarely provided. The business model for the private sector is considered too weak, especially when it comes to developing this service for the poor. To localize and improve a flood EWS requires -amongst others-improving the observational network (not only the main rivers but also the tributaries). This comes at a high cost. An analysis for Bangladesh of an improved system showed that the installation of gauges and the payment of wages to gauge readers make up the largest part of the start-up and observations and measurement costs, respectively 40% and 67%. The overall costs for an improved system in all flood-prone unions in Bangladesh are estimated at USD 2,5 million for the initial start-up phase and USD 2 million for operation and maintenance each year [55]. The Nepal National Early Warning Strategic Action Plan (NEWSAP) states that 0.01% of the total GDP or Rs 150 million (USD 1.3 million) has to be invested in EWS for 2013. This estimate is based on a guideline of spending 7% of total losses on preparedness and 10% of preparedness on EWS. These amounts pose real challenges to national governments in developing countries. They try to complement their national budgets -that are often fully needed for keeping installed capacity with designated authorities up and running-with additional income streams or by shifting the funding gap to the local level. The funding of the Department of Hydrology and Meteorology in Nepal is an example of these additional funding streams. The Department of Hydrology and Meteorology is not only funded by the national government treasury (annual and programmatic budgets), but also through bilateral relations (US, India, China), International Organizations (WMO, World Bank, ICIMOD), United Nations agencies and international non-governmental organizations. For example, the World Bank-funded as part of the Pilot Programme for Climate Resilience project the upgrading of 80 meteorology (rainfall and weather) stations with real-time telemetry technologies [56]. Practical Action supported upgrading several meteorology and hydrology stations and the Government of India did so in the neighboring catchment areas. For communication and dissemination, the Department of Hydrology and Meteorology was funded by UNDP and Practical Action to cover telecom expenses as well as to invest in display boards, radio handsets, and computers in national and district emergency operation centers.

The EWS has also developed the response capacity of downstream communities. Annual mock drills and different committees to coordinate during flooding time is crucial to its success. This increases social cohesion and improves social capital in the flood-affected area [57]. A significant number of households (36%) inform their neighbors immediately after receiving the flood warning, which is an indication of improved social capital. More than eight percent of the households have indicated that their neighbors are the primary source of early warning.

5. Conclusions

This financial assessment of the flood EWS indicates that EWS is successful to avoid damages, particularly of movable properties. The flood EWS has high returns on investment as the estimated value of benefits is higher than the estimated value of costs of installation and operation in different scenarios. However, there are still damages that households are facing as EWS cannot save 100% private or public property. The results of this study strongly indicate that improving a flood EWS by increasing lead time helps to minimize the avoidable loss and damage from floods. The results also allow identification of new early actions that can be implemented in the additional time window presented by increased lead time. Our results can also be placed in the wider context of impact-based forecasting [58] where NMHS are increasingly focusing on not only predicting the weather but also the impact, this allows humanitarian organizations to make early actions more adequate in terms of preventing the potential impact. The results could be used by the government of Nepal to inform policy-making and secure funding to improve the accuracy and coverage of the current national EWS by e.g. setting up more automatic river level sensors and weather stations in different parts of the country. Similarly, it can be used by NGOs to further develop and strengthen community-based EWS. Apart from the monitoring and warning component, also the other components should be strengthened. Households have suggested to supply flood warning in local dialects and to provide regular training on preparedness to improve the early actions taken.

Besides reducing damages due to floods, the EWS is successful in improving social capital in the downstream communities as a substantial number of households inform their neighbors immediately after receiving flood warnings and this is the primary source of many households. Households have expressed their WTP to manage flood EWS by themselves. Therefore, community-based EWS could be one of the appropriate strategies to make flood EWS sustainable. The study also suggests that mental stress is one of the major effects faced by households due to the flood. They have shown their WTP if the flood EWS can increase the lead time. An increased lead time gives them additional time to act early, thereby reducing the mental stress.

Future research will include also the non-economic loss and damage in the CBA and intends to use also (open) secondary data on historical flood events, such as on the experienced loss and damages, to contrast the estimated benefits as came out of the field surveys. Also, comparing the experienced loss and damage in a period before and after the EWS was installed in the Karnali Basin (2008) would be an alternative approach to do a cost-benefit analysis. In that case, it will also be important to take into account how the EWS evolved and how climate change affected the severity and occurrence of floods over these periods.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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