Missed Opportunities in Utilization of Weather Forecasts: An Analysis of October 2021 Disaster in Nepal.

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1. Context

This paper takes the unprecedented October 2021 rainfall over Nepal and uses it as a case study to discuss barriers to the effective use of early warning systems (EWS) in achieving disaster reduction objectives. The study focused on the dissemination of weather forecast information related to the October 2021 rainfall (the event) and the bottlenecks that prevented the EWS from being used to minimize damage. The paper examines the mechanisms and functionalities in Nepal's disaster risk reduction and management architecture. The recommendations present corrective measures to make the system more robust and to help in saving lives, property and livelihoods.

2. Weather Prediction

Since the 1970s, Nepal's Department of Hydrology and Meteorology (DHM) has been providing national weather information for aircraft operations and mountaineering expeditions. In 2005, the DHM began real-time river level observation in major rivers using remote observation technologies. Since 2007 it has been providing information of flood level at hydrology stations with the objective of minimizing disaster risks to the downstream communities. About a decade later in 2018, the DHM began using Numerical Weather Prediction (NWP) and weather alerts to support weather-induced disaster risk reduction. Generally, the duration of the NWPs is for three days and include temperature, precipitation and prediction of extreme weather events like heat and cold waves, storms, heavy rain etc. These predictions are also made for seven days if there is likelihood of severe weather event. The alerts provide additional lead time for disaster managers and at-risk communities to take precautionary actions to severe weather events and prevent damage from floods.

Currently, the DHM issues three-day weather forecasts every day and special weather bulletins if it sees the likelihood of severe weather event. It disseminates these via its web page and various media outlets. During the summer monsoon [South Asia Monsoon (SAM)], DHM issues flood alert and warnings according to the rivers and location of the communities along the riverbanks downstream of its gauging stations. The real-time water level of each river that is monitored is displayed in the Department's web page where it shows a warning of potential flood risk to the downstream region when water levels are high at the monitoring station[1].

Advancements in meteorology and hydrology sciences, as well as the development of satellite-based technology, including radars, have improved the accuracy of the assessment of occurrence of weather events. In recent times, the development and proliferation of communication technology such as mobile phones have helped in disseminating alert information to various users. This has led to proactive action and the saving of lives and, to a limited extent, salvable asset. In the 2014 and 2017 floods in Nepal, flood early warnings have reduced human deaths[2]. In coastal Bangladesh and the eastern coast of India, cyclone early warnings helped in saving thousands of lives[3] over the past two decades as compared to the fatalities in the similar cyclone events between 1970 and 1990[4]. A study in coastal communities in Bangladesh found that the local people

were willing to pay for improved early warning services for its usefulness to save lives, assets and livelihoods[5].

3. The 2021 October Rainfall

In Nepal, SAM generally starts on June 10 and ceases on September 23. In 2021, the DHM revised the arrival and withdrawal dates of SAM to June 13 and October 2 respectively[6]. When the SAM ends it is time to harvest the paddy that was planted in June, storing it for household use and/or selling. The end of the monsoon rain is also the start of the tourist season and of festival time. Weather in October and November is said to be pleasant, mild, and generally Nepal experiences lower pollution. However, there are anomalies. Rainfalls in October do not exactly obey the defined beginning and ending dates of monsoon. From 1951, for example, October has seen many high rainfall events (Table 1) across the country.

Table 1: Maximum 24-hour October rainfall above 140 mm in October (1951 to 2009)

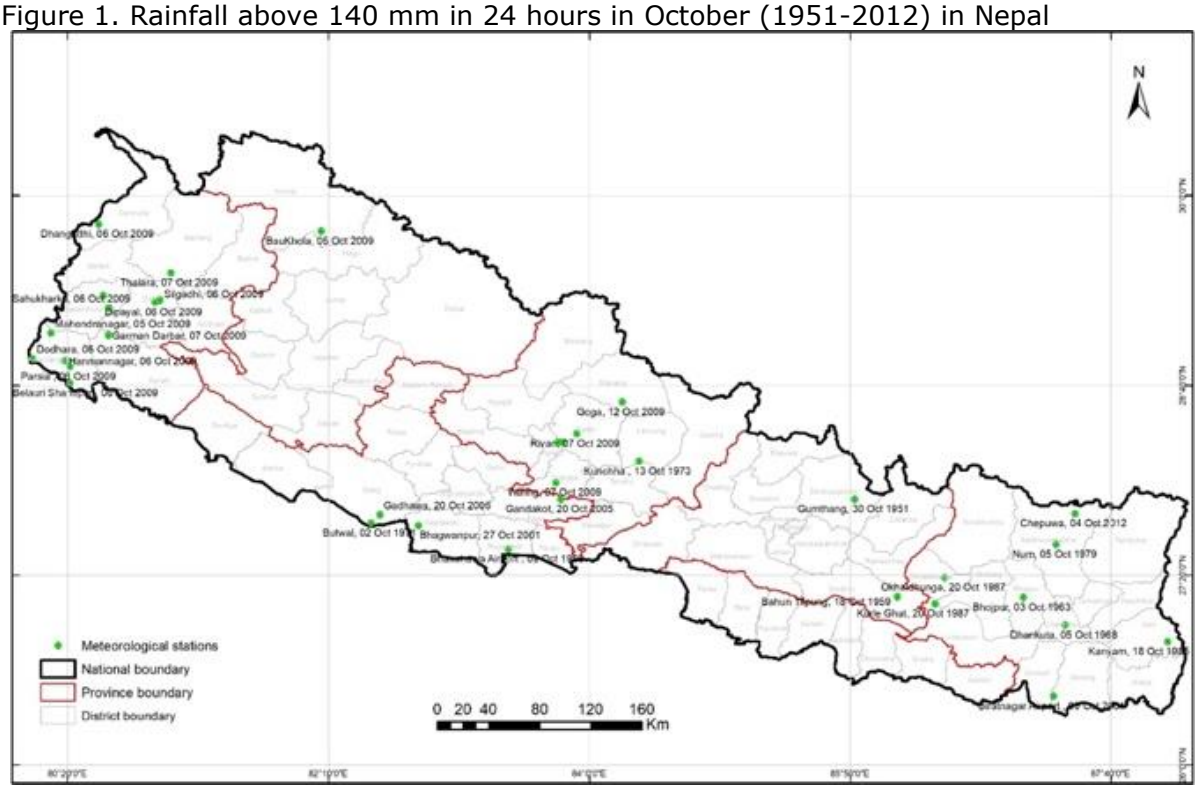
SN	Date	Station	District	Rainfall (mm)
1	30 October 1951	Gumthang	Sindhupalchok	229.1
2	18 October 1959	Bahun Tilpung	Sindhuli	246.9
3	03 October 1963	Bhojpur	Bhojpur	250.3
4	05 October 1968	Dhankuta	Dhankuta	165.6
5	02 October 1971	Butwal	Rupandehi	247.0
6	13 October 1973	Kunchha	Lamjung	259.0
7	05 October 1979	Num	Sankhuwasabha	350.0
8	18 October 1985	Kanyam	Ilam	352.0
9	20 October 1987	Kurle Ghat	Khotang	242.4
10	20 October 1987	Okhaldhunga	Okhaldhunga	140.3
11	09 October 1990	Bhairahawa Airport	Rupandehi	154.1
12	29 October 1998	Paundur	Kaski	315.9
13	06 October 2001	Biratnagar Airport	Morang	194.1
14	27 October 2001	Bhagwanpur	Kapilbastu	228.0
15	20 October 2005	Gadhawa	Dang	245.0
16	20 October 2005	Gandakot	Palpa	251.2
17	05 October 2009	Mahendranagar	Kanchanpur	309.5
18	05 October 2009	Bau Khola	Mugu	231.0
19	06 October 2009	Dodhara	Kanchanpur	326.4
20	06 October 2009	Hanmannagar	Kanchanpur	326.3
21	06 October 2009	Sahukharka	Dadeldhura	280.5
22	06 October 2009	Belauri Shantipur	Kanchanpur	264.3
23	06 October 2009	Parsia	Kanchanpur	258.8
24	06 October 2009	Dipayal	Doti	245.7
25	06 October 2009	Silgadhi	Doti	235.0
26	06 October 2009	Dadeldhura	Dadeldhura	210.0
27	06 October 2009	Dhangadi	Kailali	180.8
28	07 October 2009	Thalara	Bajhang	404.2
29	07 October 2009	Rivan	Kaski	380.6
30	07 October 2009	Garman Darbar	Kailali	361.3
31	07 October 2009	Bhadaure Deurali	Kaski	250.0
32	07 October 2009	Waling	Syanja	224.7
33	12 October 2009	Goga	Manang	301.0
34	04 October 2012	Chepuwa	Sankhuwasabha	336.0

Source: Gathered from various publications of DHM

On October 11, 2021, the DHM declared that the SAM had ended, about 18 days later than usual. Four days later, on October 15, the DHM reported that the weather system had

again become active in the country's west and issued alerts that heavy rains were likely in different parts of the country. Indeed, the forecast was true and heavy rains hit Uttarakhand in India and almost whole area of Nepal. The rains entered Nepal from west on October 17 and reached east Nepal and Sikkim two days later (Table 2 (a) and (b)). Unlike many years in the past, when the October rainfall seemed more localized, with the exception of 2009 (Table 1, Figure 1), the October 2021 rainfall and impacts were more widespread (table 2, Figure 2, 3, and 4).

Figure 1. Rainfall above 140 mm in 24 hours in October (1951-2012) in Nepal



Data Source: Table 1.

In west Nepal, heavy rainfall began on the evening of October 17th and continued until the 19th October. The country's 15 rainfall stations recorded over 200 mm rainfall in 48 hours (Table 2 (a)). By 10:30 a.m. of October 18th, about 12 hours after the event began, rainfall over the Chure hills of Nepal's western-most district of Dadeldhura had reached 164 mm. Southern Dadeldhura District received 502.2 mm rain, the highest 48-hour accumulated rainfall between 17th and 19th October (Table 2 (a) and Figure 2).

On the afternoon of October 19, the rain began to spread across the country and reached eastern Nepal. On the 19th and the 20th of the month, Ilam and Jhapa districts received highest rainfall (Table 2 (b) and Figure 3). During this 24-hour period, 12 rainfall monitoring stations across the country recorded over 200 mm of rainfall (Table 2 (b) and Figure 3). Across Nepal, the rains continued for following two days (October 20 and 21) but with a lower intensity than in previous days: in 24 hours only 50 mm rainfall was recorded (Figure 4). Rainfall stopped on October 22.

Table 2. Stations with over 200 mm of accumulated rainfall in 2021 October

(a) 48-hour rainfall (17 October 8:45 AM to 19 October 8:45 AM)				(b) 24-hour rainfall (19 October 8:45 AM to 20 October 8:45 AM)	
SN	**Rainfall Station**	**Rain (mm)**		**Rainfall Station**	**Rain (mm)**
1	Sahukharka, Dadeldhura	502.20		Tarahara, Sunsari	398.20
2	Gaira, Doti	367.00		Kanyam Tea Estate, Ilam	374.10
3	Jogbudha, Dadeldhura	367.80		Haraicha, Morang	367.00
4	Gaibande, Dadeldhura	357.80		Damak, Jhapa	302.00
5	Chaurbandale, Dadeldhura	349.00		Barmajhiya, Saptari	273.20
6	Dipayal, Doti	282.80		Letang, Morang	272.40
7	Sanphebagar, Achham	270.00		Dharan Bazar, Sunsari	269.90
8	Satbanjh, Baitadi	256.20		Ilam Tea Estate, Ilam	265.00
9	Mangalsen, Achham	232.00		Mai Pokhari, Ilam	250.60
10	Darchula New, Darchula	224.90		Anarmani Birta, Jhapa	241.40
11	Ghorepani, Myagdi	220.80		Mainachuli, Ilam	215.20
12	Darabang, Myagdi	220.60		Rajbiraj, Saptari	212.80
13	Khanchikot, Arghakhanchi	220.60		***Note:*** (a) Stations are in western Nepal west from Kali Gandaki River, (b) stations are in eastern Nepal in Koshi River Basin	
14	Attariya, Kailali	220.30			
15	Galkot, Baglung	211.40			

Source: DHM

Figure 2. 24-hour rainfall 18-19 October (Source: DHM)

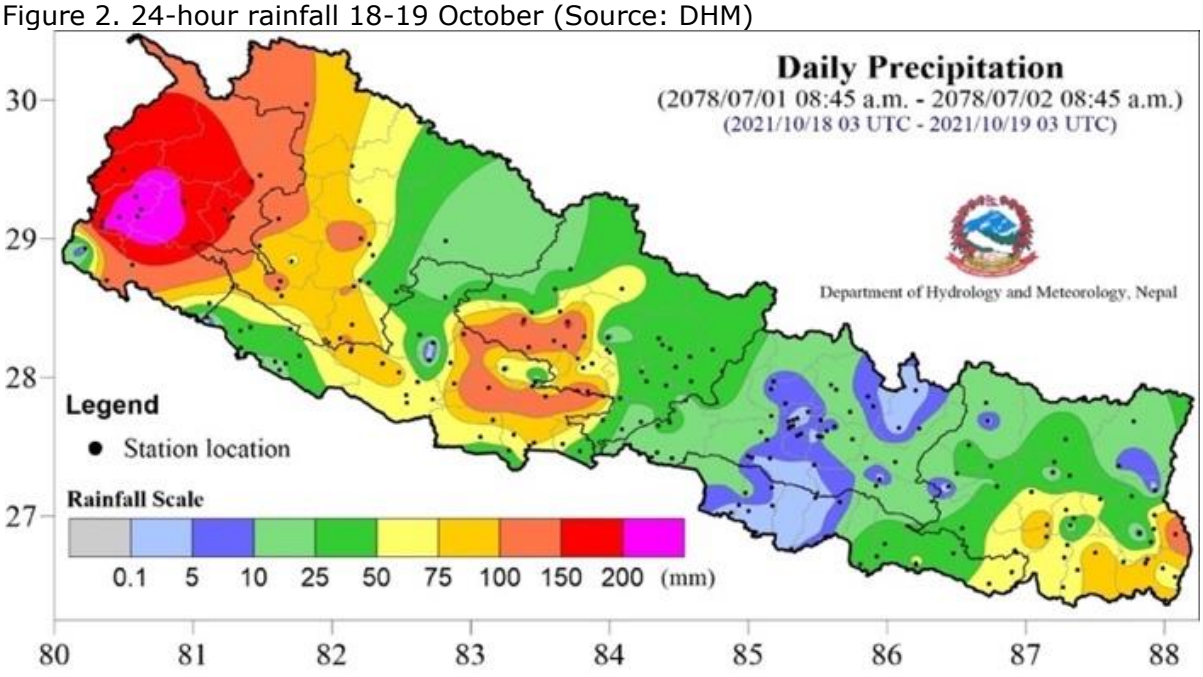


Figure 3. 24-hour rainfall October 19-20 (Source: DHM)

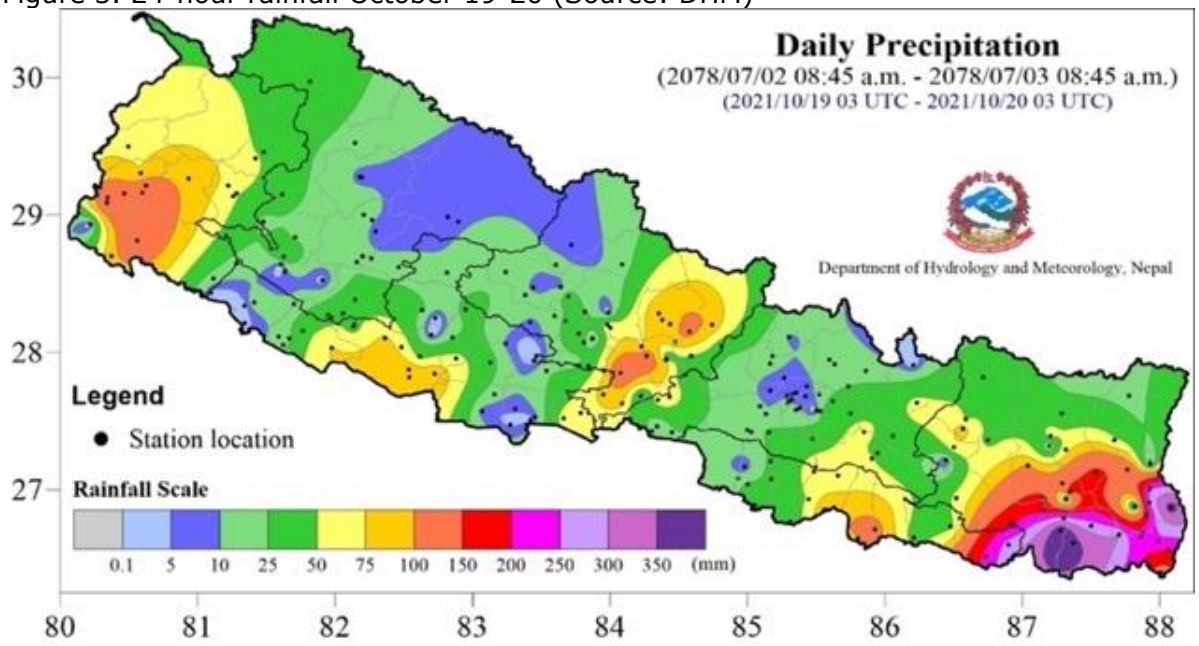
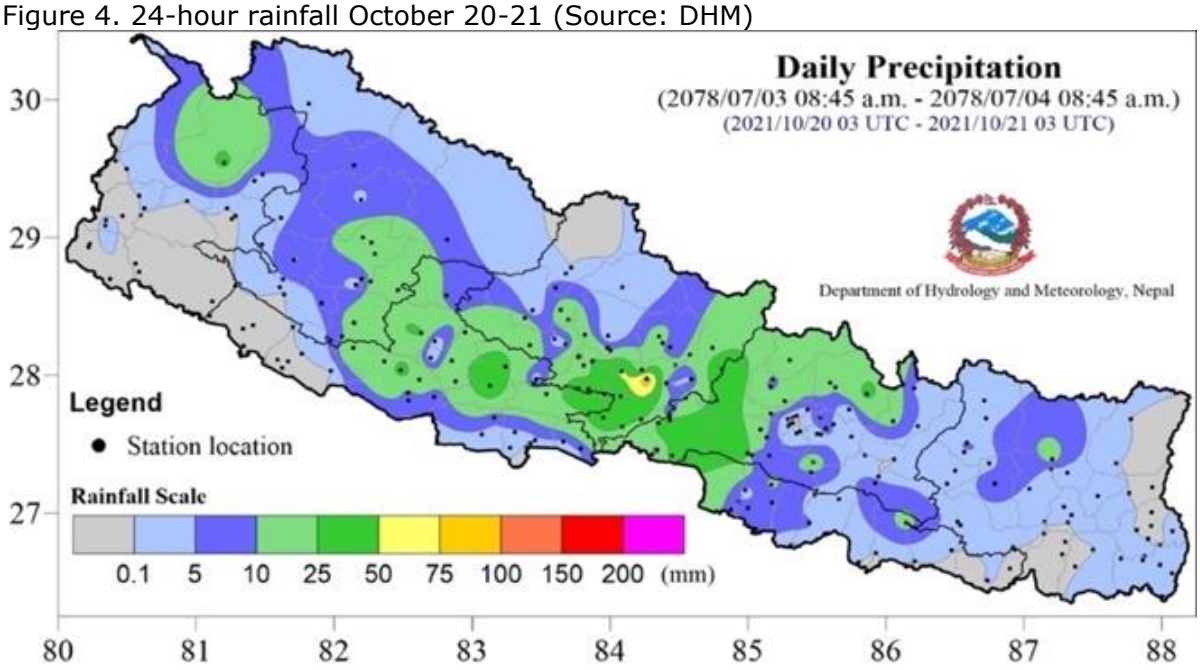


Figure 4. 24-hour rainfall October 20-21 (Source: DHM)



4. Impacts

The heavy rains, floods, inundation, and landslides resulted in human casualties, injuries, widespread damage to property, disruption of services, and negative effects on the livelihoods of people in Nepal. Roads, bridges, and electricity and telecommunication lines were damaged. The rainfall and flooding damaged the cut down and standing paddy across the country, with a higher negative impact in the west of Nepal. People travelling to and from their relatives after celebrating the annual Dashain festival were stuck on roads. In the following sections, we present a synopsis of the impacts of the heavy rainfall.

4.1 Deaths and Injuries

The heavy rain-induced landslides and floods claimed many lives in Nepal and India. Landslides and floods killed at least 55 people in Uttarakhand[7]. Nepal's Ministry of Home Affairs (MoHA) reported that the event killed 120 people, that 28 persons were missing, and that in addition 404 families were affected across the country[8].

4.2 Damage to Different Sectors

In Nepal, the damage to different assets and estimated economic losses in different sectors were reported as follows:

(a) Houses and settlements: According to Nepal's national disaster database[9], damage to houses and cattle sheds was spread across 17 districts while 10 districts were affected by landslides triggered by the rainfall. The hazards damaged about 179 houses (65 partially), and destroyed 20 cattle sheds.

(b) *Agriculture:* The largest damage was to paddy, the major crop ready for harvesting, cut for storage but left in farms[10]. In Nepal, paddy is grown in two seasons: March–June and June–October/November, known as *Chaite Dhan* and *Ashare Dhan* respectively.

In May of 2021, South Asian Climate Outlook Forum (SASCOF) had predicted above normal rainfall across Nepal. The Ministry of Agriculture and Livestock Development (MoALD) estimated that, in 2021, the main season paddy (known as *Ashare Dhan*) was planted in 13.57 million hectares (ha), 6,477 ha (0.48%) more than the area (13.50859 million ha) in 2020[11]. The Government of Nepal (GoN) officials and agricultural experts had estimated that, with more than higher monsoon rainfall, the increased area under cultivation, and the use of improved varieties of seeds, paddy production would be higher in 2021 than in the previous years[12].

The event damaged ready-to-harvest paddy and the production was less than expected. On January 31, 2021, the MoALD estimated a reduction of 9.92 percent in the production of the main season paddy against projected production for the year. The production was 8.74 percent lower than that in 2020 although the area under cultivation had increased. Productivity, which is measured in metric tonnes per hector, had decreased by 9.99 percent and, according to MoALD, this was the lowest productivity of *Ashare Dhan* in the last five years. The extreme rainfall led to 31.49 percent production reduction of paddy in the Sudur Pashchim Province's Kanchanpur and Kailali districts[13]. Similar scale of damage occurred in adjoining Bardia, Banke and Dang districts, which are among top rice producers in the country. Information on damage to other crops due to this rainfall is extremely limited.

(c) Livestock: The resulting landslides and floods killed 3 buffaloes, 6 oxen, 15 cows, 34 goats, 19 sheep, 32 pigs, and several poultry[14]. Economic valuation of the damages was not available.

(d) Roads: National media and the *National Disaster Update* bulletins, published by the National Disaster Risk Reduction and Management Authority (NDRRMA), reported that landslides and floods damaged many road sections and bridges. Media reports also mentioned complete cessation of daily transportation in all hill and high mountain districts of Mahakali and in the Karnali river basin areas[15]. Over 20 districts of central and eastern Nepal experienced the total cessation of vehicular movement for at least 3 days. It took many days to clear debris and reconstruct some of the damaged roads and restore crossings[16] and full mobility was restored by the end of October.

(e) Hydropower: The floods also affected several under-construction and operational hydropower plants. During monsoons, hydropower developers generally take construction

equipment away from flooded riverbeds and avoid harm. In October, however, they assumed that monsoon had ended, and returned to work with resulting damage. Consecutive hazards also damaged micro hydro plants across the affected regions, but the estimates available are sketchy[17].

(f) Others: The high rainfall and floods affected irrigation canals in many rural municipalities. In the Khalla Masti area of Kanchanpur District, a recent initiative on river rafting on the Mahakali River had to be stopped because the local roads that took tourists to the stations to board the rafts had been washed off[18]. The assessment of damage to natural ecosystems and the disruption of essential services are still not calculated due to a lack of methodology and assigned agencies to undertake this work.

4.3 Economic Impacts

The total cost of the damage in Nepal was estimated to be about 0.6% of the Gross Domestic Product (GDP)[19], including the major economic loss to the paddy crop[20]. It was reported that paddy worth NPR 11,875,161,000 (11.87 billion) was damaged[21]. Paddy contributes 5% to 6% of Nepal's GDP[22]. The Department of Roads (DoR) estimated that the total damage to roads and bridges in the 2021 monsoon season was NPR 2.35 billion, of which the damage due to the event amounted to NPR 1.05 billion, about 45 percent of the total damage[23]. According to the Independent Power Producers of Nepal (IPPAN), in 2021 monsoon, 16 under-construction projects and 10 completed projects experienced a cumulative damage totalling 85 million dollars[24]. The extent of damage to hydropower projects in the event is not available. Furthermore, indirect economic damage due to road blockade and cessation of transport, such as the loss to household income because of agricultural produce like milk, vegetables, etc not getting to the market has not been calculated.

5. Forecasts, Response and Post-event Actions

The following sections present the actions taken before, during and after the event to understand what could have been done differently to minimize the damage and losses. We build on the chronology of events from the day the DHM began forecasting heavy rainfall until the government took the decision to provide compensations and reconstruction support for the damage.

5.1 Pre-event Forecasts and Warnings

The DHM issues a 3-day (72 hour) weather forecast bulletin every day between 6:30 and 7:00 a.m. in the morning and by 6 p.m. in the evening all year round. This bulletin is disseminated through national radio stations, television channels, online news portals, and social media platforms. Since 2007, DHM has also been supporting dissemination of EWS messages to relevant district authorities and downstream communities. This practice builds on the learning of initiatives by non-government organizations on community-based flood EWS in Nepal dating from 2002. In 2018 DHM added weather forecasting to this information sharing platform providing alerts for multiple weather hazards. This provides more lead time to minimize potential flood risks.

In Nepal, currently, the flood EWS covers over a dozen rivers across the major basins in the Tarai region[25]. The DHM has institutionalized these EWSs and, with support from Nepal Telecom (NT) and Ncell, the two major telecom providers, sends alert and localized mass text messages via mobile phone networks to government authorities and communities living in flood-prone areas. Both NT and the Ncell have provided the services free of charge with dedicated staffs sending the text messages[26]. The messages are also disseminated through social media platforms like Facebook and Twitter.

(a) The messages: In Table 3, we reconstruct DHM's sequence of alert bulletins from October 11 to October 21, 2021.

Table 3. Timeline of DHM weather forecasts, alerts and warnings

Date	***Alerts***	***Images***
11th October 6 p.m.	Officially declares SAM's end[27]. The bulletin specifically mentions that monsoon will begin exiting from west Nepal on October 8 and completely on 11. DHM stops issuing flood alerts and warning service that was operationalized till October 9[28].	**Nepal Weather Forecast** @DHM_... · Oct 11, 2021 यस वर्षको मनसुन आज मिति २०७८/०६/२५ गते (११ अक्टोबर २०२१) बाट देशको समग्र भू-भाग वाट वाहिरिएको छ। mfd.gov.np/content/?id=34...
15th October	Issues a special weather forecast bulletin[29], recognizing the possibility of heavy rains and blizzards on 17th and afterwards, attributed to the combined effects of low pressure above Andhra Pradesh and Odisha coasts in India and westerly system. DHM indicates potential impacts of the weather event that the heavy rain may cause on agriculture and mobility and advises the authorities and public to take precautions in travel and agriculture activities.	**Nepal Weather Forecast** @DHM... · Oct 15, 2021 अबको केही दिन मौसम बदली हुँदै छ है, मौसम पूर्वानुमान हेरेर मात्र कृषि कार्य, यात्रा र अन्य कार्यहरु गर्नुहोला। विषेश मौसम बुलेटिन तलको लिंकमा राखिएको छ। mfd.gov.np/content/?id=34...
16th October 6 a.m.	DHM issues a usual 3-day weather/rainfall forecast via webpage[30], social media platforms and disseminated by radio stations, television channels, print and online media, reiterating the information of the previous day bulletin and the potential consequences of the events.	आगामी २४ घण्टाका लागि चेतावनी तथा परामर्श (Warning/Advisory for next 24 hours) प्रदेश १, प्रदेश नं २ र बागमती प्रदेशका थोरै स्थानहरूमा मेघगर्जन/चट्याङ सहित हल्का वर्षाको सम्भावना रहेकोले आवश्यक सतर्कता अपनाउनुहुन अनुरोध छ।
17th October	DHM issues a second special bulletin[31], warning of the possibility of heavy rain, accompanied by lightning and strong winds in many parts of the country from that night. Advises caution during travel and agriculture activities. Following the weather alert, on the same day, activates the flood and landslide updates again. Sends alert messages to people in western Nepal via mobile text. Both the weather forecast, and the flood forecasting are active in disseminating real-time updates via web page and other media.	**Nepal Weather Forecast** @DH... · Oct 17, 2021 विशेष मौसम बुलेटिन पोष्ट मनसुन – २ को लागिः mfd.gov.np/content/?id=34... **नेपाल बाढी सूचना-Nepal Flood Alert** Published by नेपाल बाढी सूचना · 5m #Special_Alert असोज ३१ रातीदेखि कार्तिक ३ सम्म महाकाली,सेती,भेरी नदी र सुदूरपश्चिम प्रदेशको मध्यपहाड,चुरे र तराई भई बहने स-साना नदीहरुमा बहाब उल्लेख्य बढ्ने र केहीमा सतर्कता तह आसपास पुग्न सक्ने; कर्णाली, नारायणी, कोशी, तिनाउ, कन्काई नदी तथा कर्णाली,लुम्बिनी,गण्डकी,बागमती प्रदेश,प्रदेश १ को मध्यपहाड, चुरे र तराई भई बहने स-साना नदीहरुमा बहाव बढ्ने र केहीमा आकस्मिक बहाब(Flash Flood) हुन सक्ने पूर्वानुमान रहेकाले उल्लेखित नदीहरुका तटीय क्षेत्रहरूमा उक्त अवधिभर विशेष सावधानी अपनाउनहुन अनुरोध छ। आगामी ३ दिनको मौसम सम्बन्धी जानकारीको लागि मौसम पूर्वानुमान महाशाखाद्वारा जारी गरिएको बिशेष बुलेटिन:
18th and 19th October	Along with real-time rainfall updates, DHM sends flood alerts and frequent updates to the communities along different riverbanks across the country. SMSs were sent via mobile phones. Weather Forecasting Division issues alerts of heavy rain via its 2 usual bulletins: first at 6 a.m.[32] and second at 6 p.m.[33] Flood Forecasting Division issues 4 real-time updates and flood alerts. Meteorological Forecasting Division (MFD) issues 1 real-time update on the day, as shown in the image. On 19th, DHM Flood Alert issues 9 alert messages for floods on different rivers across the country along with real-time rainfall updates in different stations.	**Nepal Weather Forecast** @ · Oct 18, 2021 हाल देशको अधिकांश भू-भागमा सामान्य बदली रहि सुदुर पश्चिम, लुम्बिनी र गण्डकी प्रदेशका केहि स्थानहरुमा र बाँकी प्रदेशको एक-दुइ स्थानमा मेघ गर्जन/चट्याङ्ग सहित हल्का देखि मध्यम वर्षा भईरहेको छ। आगामी ३ दिनको मौसम पर्वानुमानको लागीः mfd.gov.np @NDRRMA_Nepal **Nepal Flood Alert! ने...** · Oct 19, 2021 कार्तिक २, साँझ ५ बजे झापा, मोरङ, सुनसरी, सप्तरी लगायतका स्थानहरूमा पछिल्लो १२ घण्टामा अति भारी वर्षा भएको र थप वर्षा हुने पूर्वानुमान छ। तटीय क्षेत्र तथा डुबान भइरहने होचा भूभागमा रहनुहुनेहरूले भोलि सम्मै उच्च सतर्कता अपनाऔँ। #SMSAlert #boost
21st October	DHM issues a one-weekly agriculture-weather forecast for 21-28 October[34], predicting situation of rainfall/snowfall, maximum and minimum temperature changes and condition of sunshine, clouds lightning, fog, windstorms, and thunderstorms. It lacks location-specific information. The forecast shows improving weather over the week.	**Nepal Weather Forecast** @D... · Oct 22, 2021 साप्ताहिक कृषि-मौसम पूर्वानुमान वैद्यताको अवधी : २०७८ कार्तिक ०५ गते शुक्रबार देखि २०७८ कार्तिक ११ गते बिहीबार सम्म mfd.gov.np/content/?id=34...

Source: DHM

In addition to the MFD's forecasts and alerts, DHM's Flood Forecasting Division (FFD) provided a real-time status of rainfall in the automatic rainfall stations and flood every day between 17 and 21 October in its webpage[35]. It included warning messages to relevant authorities and communities where and when the rain crossed the rule of thumb threshold it has set[36].

(b) Message amplification: According to the NDRRMA's social media pages (Twitter, Facebook), it relayed the DHM's forecast messages, real-time updates and alerts about heavy rain, flood and related hazards.

5.2 Post-Event Actions

(a) Compensation of crop damage: The GoN's cabinet meeting on October 28, 2021 decided to provide compensation to the farmers who lost paddy crops[37] and formed a 5-member taskforce under the leadership of the Secretary of the Prime Minister's Office to draft a standard/procedure to evaluate damage and to provide compensation. The GoN approved the Standard to Provide Compensation of Paddy Crop Damage Due to Unseasonal Rainfall, 2078[38] on November 18, 2021. The document remains valid until Mid-July 2022 when Nepali fiscal year ends unless the GoN decides to extend its validity. It is expected that the compensation disbursement will be completed by mid-July 2022.

According to the Standard, the farmers who lost paddy crop will be compensated according to small, medium, and large size farms on which they grew the paddy. Small holder farmers will receive compensation up to 65 percent, medium land holder up to 30 percent and large land holder farmers up to 20 percent of the production cost. Respective local government and district authorities have been given the responsibility to implement and monitor a damage evaluation, to fix compensation as per the provisions of the Standard and to deposit the compensation amount in the bank accounts of the farmers.

(b) Damage reconstruction: The GoN, on December 6, 2021, declared 33 local government territories (rural and urban municipalities) in 10 districts as disaster affected[39]. The areas declared were identified on the basis of human casualties and damage to houses and settlements, including loss of livestock and damage to other property. On February 14, the GoN updated the declaration by adding another five local government areas to the list and by extending the effective period to May 14, 2022[40]. This declaration enables the GoN to implement recovery, reconstruction and resettlement programmes for the affected families.

6. Lessons

The weather system began after the SAM was officially declared withdrawn. The combination of the formation of low pressure above Bihar, Jharkhand, the inflow of moisture from the Indian Ocean and the Bay of Bengal, as well as westerly, higher velocity winds, brought significant rains within a week of SAM's end.

6.1 *Sources of Precipitation*

We identify the following two issues as key to furthering understanding of the sources of the precipitation:

(a) *Post-monsoon and winter precipitation*: The western disturbance that originated in the Mediterranean region is responsible for post-monsoon and winter rain in the northern Indian subcontinent. These rains support winter crops like mustard, potato, and wheat typically planted in a smaller area. The rains also add to soil moisture, aid in spring recharge, and minimize dry conditions. Changes in the character of these

rains, as well as a rise in average temperature by emission of greenhouse gases, will affect the winter crop production, will exacerbate droughts, and will result in higher risks of forest fires. This presents new institutional challenges, for example, the prevention and response to forest fires as well as in managing the impacts of droughts.

(b) *Climate trend:* An analysis of the climate of post-monsoon rains in Nepal from 1971 to 2014 shows a decreasing trend across the country, except in Humla and Mugu, the two western mountain districts, which show insignificant positive trends[41]. The trend of winter, pre-monsoon and monsoon rains varied across the country and showed difference even between two adjoining districts in the same climate zone, suggesting that future climate scenarios will remain uncertain. Nepal has two major constraints when seeking to analyse these trends. First, the existing meteorological stations are inadequate to cover the diverse microclimates in the country and, secondly, the country lacks long-term data. High mountain regions and remote areas have fewer stations than required for a meaningful climate trend analysis. The results of climate model thus have inherent uncertainty that must be recognised in climate forecasting endeavour and in devising adaptation strategies.

6.2 Weather Alert Messages

Despite the timely alerts about the event, there were human casualties, injuries, damage to assets and property, disruption of livelihoods, and damage to ready-to-harvest crops, especially paddy. This emphasises the extent of our negligence to disaster risk and the impact of extreme weather events which has already claimed our daily meals.

(a) Messaging: The DHM did communicate the forthcoming weather events in time with fair accuracy. Though the quality of forecast in term of certainty and lead time has increased in recent years, weather alerts still lack sufficient, spatial, temporal and sector specific impact details for the users to take informed decision. The question is whether the DHM should simply broadcast messages or whether it should work with the relevant sector authorities as shown in Figure 5 to develop site and sector-specific impact-based forecasts and advisories for timely action on the forecasts notices requires more discussion. It must be realised that the DHM cannot work in all components of the EWS.

(b) Uptake of alerts: Many actors did pick up on the alert by the DHM. The NDRRMA shared the real-time information between October 17 and October 21. The agency's' Facebook and Twitter platforms from October 15 to October 25 included daily situation reports of damage, losses and disruption of services like road closure due to the event. No record of actions by agencies like MoALD and Department of Agriculture (DoA) is available. The following issues emerge:

- Ministry of Home Affairs (MoHA) and the agencies under it such as the NDRRMA, who are primarily responsible for disaster management, seemed to focus more on post-event rescue and relief.
- The lack of mechanisms to support coordination and collaboration among the sectoral agencies holding clearly delineated roles and responsibilities to take appropriate actions was clear.
- Due to the Dashain festival and people returning from holidays to their work, many offices were still closed or had very limited staffs. For this reason, the uptake of the forecasts and the alert information by sector offices seemed to be low with very little or no action taken afterwards. Further study is necessary to confirm it and find institutional solutions to prevent the situation in future.
- The low uptake of the weather alerts could also be attributed to lack of location-specific impact-based rainfall forecasts, lack of human resources, poor coordination and the challenges of effectively communicating the risks.

(c) *Understanding extreme event trends*: Table 1 shows that, in the past, October did receive heavy rainfall and in 2009 was widespread across the country. An analysis of the extreme October rainfall data of 20 rainfall monitoring stations from across the country (DHM, nd[42]) shows heavy rainfall in 2014 as well. In both cases, the rainfall days do not tally with the withdrawal date of the SAM in Nepal. The argument that the frequency of extreme rainfall events in October, generally regarded as a post-monsoon month, has increased seems valid despite decreasing trend of total post-monsoon rainfall. For better results it is necessary to analyse the above-threshold rainfall (i.e., 140 mm in 24 hours) data from 1951 to 2021 across the country following the exit of the SAM.

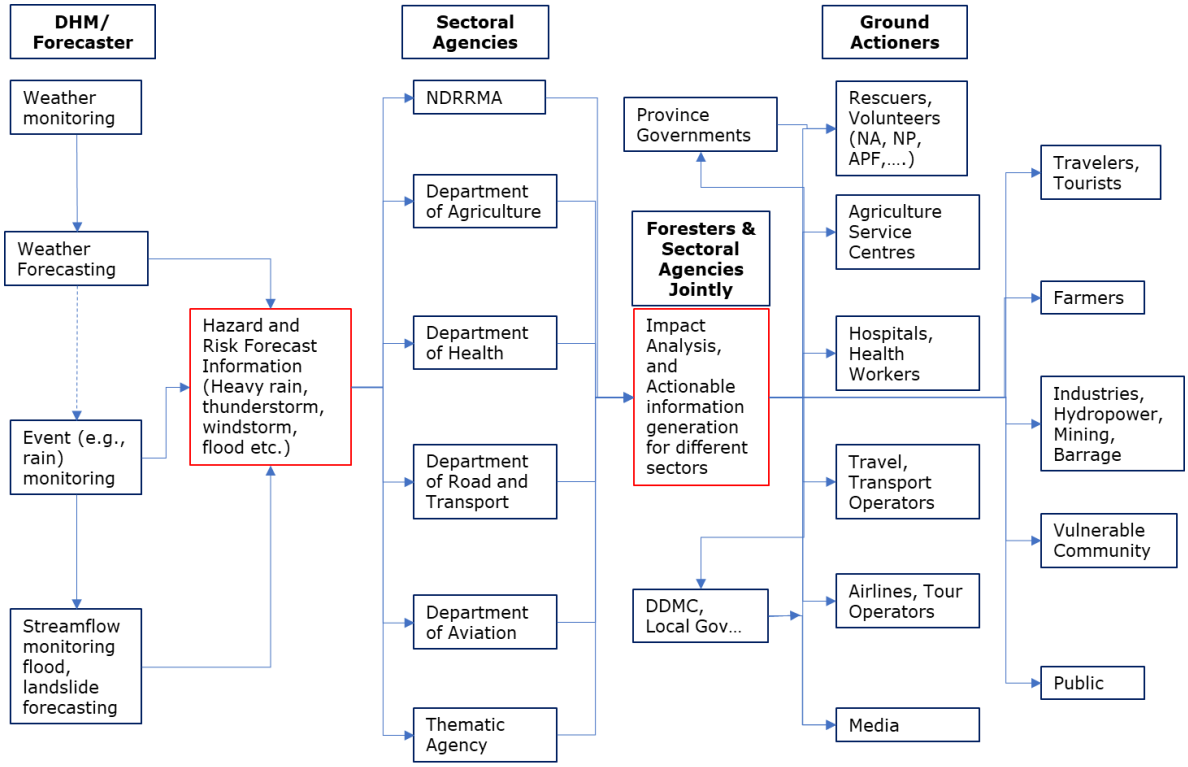
(d) *Preparedness:* In the past, the high rainfall on October 5–6, 2009, were concentrated in west Nepal (Figure 2). Then the EWS, unlike in 2021, was in its initial stages while disaster management focused on rescue and relief. The widespread unseasonal rainfall in 2021 seemed to catch everyone by surprise, and there was not even some semblance of preparedness while rescue and relief continue to be the dominant disaster management response.

6.3 Bottlenecks

The components of an EWS are interdependent and are tied into the process of information collection, analysis, sharing and actions by diverse actors at various decision-making levels and across geographies. An EWS is made of subsystems, with each component using different technologies, these need different approaches and the involvement of different agencies for mutually coordinated actions. For example, understanding the hazard risk requires the engagement of multiple sectoral agencies, working separately as well as collectively, to analyse the sector's exposure and vulnerability to hazards. Failure at any point can lead to the failure of the whole system outcome, i.e., to minimize damage and losses.

Figure 5 proposes a mechanism and process of early warning information generation, analysis, synthesis, and dissemination. Coordinated and timely decision-making actions are essential at each point. This is affected by the structures, mechanisms and functions within and between agencies to coordinate and communicate with each other, carry out agreed roles and take actions at appropriate levels.

Figure 5: Proposed Mechanism of Developing Actionable Early Warning and Dissemination in Nepal



The proposed mechanism could help examine the processing and sharing of forecasted information by disaster managers as well as by the first responders. It could also help identify bottlenecks where information analysis and sharing were not effective in the event. While detailed study is necessary to arrive at a conclusion, a lack of coordinated actions between the forecasters and the sectoral agencies was evident.

A major challenge in Nepal is to implement the common but differentiated roles and responsibilities by forecasters and sectoral agencies to (a) operationalize the EWS effectively and (b) take step-by-step timely actions (see Table 4 for details) to minimize impacts. The EWS builds on an intricate self-functioning mechanism consisting of (i) hazard (i.e. heavy rainfall) forecast, (ii) risk and impact analysis (see Figure 6), (iii) preparation of an impact table[43], and (iv) providing the ground level responders and concerned communities with clear instructions and advice (i.e. what to do, where to do, when to do, how to do, and what not to do etc), and (v) to mobilise rescuers and communities to take actions before and during the event hitting the area. The proposed impact table includes advisories that would be prepared jointly by the forecasters and the sectoral agencies based on the use of the risk and impact analysis matrix (Figure 6).

A preliminary examination shows that there was no further action taken following the forecast of the event on October 15 or subsequently (Table 3). DHM's weather forecast was relayed to the public but they did not make clear advisories either to the different sectoral agencies or to the communities likely to be affected such as farmers, aviation and mountaineering, agriculture, road, irrigation canal, barrage operators, hydropower, and sports. It is imperative that such early warning/advisory should reach the ground actors and the vulnerable communities providing clear instructions as soon as possible such that rescuers and communities can take early actions to avoid casualties and reduce damage to assets and disruption of public services.

6.4 Assessment of Damage and Economic Loss

The estimates of items that can be counted such as human deaths and injuries, livestock deaths, or collapsed buildings are fairly accurate. The assessment of damage of property and other indirect types of damage, though high, is rather sketchy. A lack of systematic approach to assessment is evident. The estimate of damage to paddy, for example, was made at a macro level while that of other agriculture products is not assessed. Similarly, the estimates of damage to hydropower plants is not systematic with data not available in one portal or organised according to specific events.

Different agencies use different methods to assess damage and there is variation in data available. Local government authorities with some input from the communities make guesses of the level of damage of assets. The tendency of the community is to generally exaggerate the damage with an expectation that the more the estimate, the more the governmental support. With climate change making extreme weather events more frequent, levels of damage increase, but assessment methods remain rudimentary.

6.5 Compensation

Though the GoN has planned to complete the compensation disbursement within this fiscal year (mid-July), the procedure of evaluating damage and losses for compensation is lengthy and bureaucratic. They also face technical and procedural challenges in evaluating damage and the scope of the compensation although the GoN has approved the procedure as mentioned above (section 5.1 (c)). While the District Administration Office (DAO) can immediately provide relief for victims who have lost their family members and relatives, their houses and other physical assets, the compensation for crops is a longer process. According to the 'Standard to Provide Compensation of Paddy Crop Damage Due to Unseasonal Rainfall 2078', the GoN has categorized farmers into three categories for providing compensation as follows:

(a) small holders (cultivating less than 10 *Kattha,* i.e. less than 1/3 of one ha),
(b) medium holders (cultivating from 10 *Kattha* to 3 *bigha*, i.e. 1/3 of 1 ha to 1.5 ha), and
(c) large holders (cultivating more than 3 *bigha*, i.e. 1.5 ha),

The GoN's plan is to compensate up to 65 percent, 30 percent, and 20 percent of production cost to small holders, medium holders and large holders respectively if paddy is damaged completely. For partial damage, 20 percent of the production cost of damaged crop is to be compensated irrespective of the category. An update on February 18, 2022 estimated the total amount for compensation to be NPR 5.52 billion[44]. However, authorities have verified the damage worth about NPR 850 million payable as compensation at the end of January 2022. Based on this estimate, the Ministry of Finance (MoF) has released NPR 1 billion to the MoHA in the second week of February 2022 as the compensation amount that will be distributed through DAOs.

7. Recommendations

We make the following recommendations:

7.1 Understanding Changing Regional Climate System

It is necessary to understand the changes in regional climate system such as the SAM and westerly rains. The following questions emerge:

- What impacts will higher average global temperature bring to the SAM and westerly winds and in regional moisture dynamics?

- How will rising temperature alter the trough dynamics, making moist winds cross over to the Himalayas in the north and affecting weather conditions in the northern Indian subcontinent?
- What is the likelihood of events like the October rain becoming frequent and more severe in the future?
- How different is the rainfall pattern (number of rainy days, depth, duration, spatial spread) from that 30 years ago?
- What are the capacities of regional, national, subnational and local-level agencies to understand the implications of climate uncertainties?
- What modifications would be needed within the government, private sector and community agencies to adapt to the emerging change in the SAM and westerly dynamics?
- How have the farmers adapted to the variation in onset and withdrawal dates every year?

7.2 Partnership and Cooperation

International and regional supports have enabled Nepal to access weather information, such as the forecasts for the 2021 monsoon, including the unprecedented October rainfall. Because of the emerging climate dynamics, international, regional and national agencies need to engage in deeper coordination to support enhanced understanding of the changing character of the SAM and westerlies. Nepal's many localised weather patterns must be better understood through enhanced monitoring and analysis. In addition, robust monitoring of regional weather circulations, supported by collaborative scientific examinations, is needed. International and regional efforts to monitor and forecast using weather observation and ground stations satellites, and cooperation across the board must continue.

7.3 Institutional Strengthening Early Warning System

In Nepal, in recent past, deaths were more due to landslides while flood EWSs have reduced human casualties by floods. However, in October 2021, the alert messages could not prevent damage to assets such as crops. We recommend a thorough review and reflection of the operational mechanism of the existing EWS in Nepal. Using a governance lens, the review should clarify the roles, responsibilities and accountability of the agencies from national to local level.

This event provides a clear lesson on the need of legally binding directives and standard operating procedures (SOPs) and information-sharing protocols (i.e., alert/warning protocols) to effectively operationalize the system. Both vertically and horizontally, it is necessary to maintain appropriate institutional mechanism and human resources to keep track of the forecast message for action. Since such unforeseen event might occur during and after major festive season, institutional framework, clear goals and priorities that define responsibility will be needed.

7.4 Generation, Sharing and Use of Information

The EWS must be made more robust to ensure more lead time while capacity to convert messages into action at the national, provincial, local governmental and community levels should be strengthened. It is essential to invest in technology and adequate capable staffing in the departments to improve forecasts and alerts with sufficient, spatial, temporal and sector specific impact details for the users to take informed decision. A resilient information management system is necessary with sufficient redundancies to ensure the flow of alerts, warnings and advisories is functional all the time.

Information management involves the following tasks: (a) bringing early warning weather messages to the communities for action (Figure 5); (b) providing information about

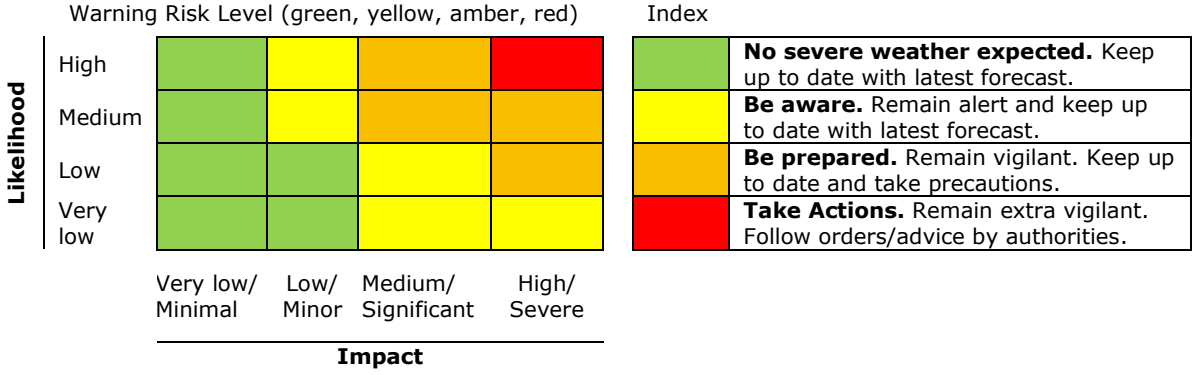
vulnerability and risk profile as well as build capacity of communities, forecasters, and disaster managers; (c) information sharing between and within sectors/authorities at national, subnational, and local levels including efficient mechanism for collecting feedback about the efficacy of the alerts and warnings; and (d) collection and management of data on damage and loss. The NDRRMA should begin preparing immediate, medium- and long-term strategies through multi-agency, stakeholder consultations and necessary legal instruments such as multi-hazard EWS directives, institutional arrangements, and an inter-agency common strategy/plan/protocol. This must be done as soon as possible.

7.5 Preparedness

It is likely that extreme weather events like that of October 2021 will be more frequent in the future. To minimize damage from such events, improved preparedness will be the key. Preparedness means more robust risk assessment methodologies and appropriate risk mitigation strategies. Governments at all levels must make forecast-based early actions, i.e., preventive measures following a forecast and before the actual event, a priority. DHM should further improve its forecasting capability. In an ideal situation, a multi-agency taskforce comprising forecasters, sectoral agencies/experts, and disaster managers must work together and take decision on steps to minimize impacts. Impact based forecasting is one instrument to achieve this objective. In this approach weather forecasting can be developed with a table that would list potential impacts on different properties and activities along with advisories for minimizing them.

Towards that end, the matrix (used globally) using a comparative scale (very low to high) of likelihood of the occurrence of an event (i.e., rainstorm) and its potential impact (very low to high/severe) will be helpful (Figure 6). It is imperative that the sectoral departments, along with the forecasters, immediately analyse the weather alerts and generate impact tables for respective sectors. The table should include possible impacts of the forecasted event on the people in their diversity, their assets, livelihoods and social activities (mobility, sports, meetings, agriculture work, etc.) in the area hit by the hazard (i.e., rainfall, storm, blizzard, inundation etc.) during the specific time/period.

Figure 6. Risk Analysis Matrix *(Source:* WMO and UK Met Office)



The next step would be providing actionable information for disaster responders and communities. For example, if the DHM forecasts heavy rainfall on specific date (in this case, October 15) potential impacts on ready-to-be harvested crop should be analysed and suggestions provided to farmers, agriculture service centres and local stakeholders. It should include a clear advisory on 'things to do' and 'things not to do' 'during' and 'after the event'. This did not happen in the October 2021 event.

7.6 Damage Assessment Method and Database

It is important for Nepal to develop robust methodology to assess both direct and indirect damage in production and service sectors from extreme events. It would reveal the scale

of economic damage and help policy makers as well as communities focus on taking preventive measures. It would also support estimation of the cost of inaction and of the benefits of preparedness in reducing damage. The October 2021 event showed that a single weather extreme event can eradicate development gains of several years. Local municipalities must be supported to systematically build this damage assessment capacity and the information included in the national database.

7.7 Institutional Reflection

Each agency must review its role on disaster risk reduction and management. Taking the event as a case, the agency needs to reflect on the shortcomings, lost opportunities and the challenges. Each agency should develop a strategy and a clear time-bound action plan for overcoming the challenges of coordination and revise policies to ensure synergy between the forecasters and the sectors of concern. Table 4 provides a matrix for self-assessment of actions, the opportunities missed, and timely and essential actions not taken. The matrix includes a checklist of timely and essential actions by the responsible authorities as well as the communities. It can help in reflecting on both horizontal (inter-agency) and vertical (from federal/national level, provincial to community level) coordination.

Table 4. EWS Analysis Matrix

Components of EWS	**Essential Actions**
Understanding Hazard and Risk	How well did forecasters understand multi-hazard risk from the heavy rain in mid-October?
	How well did farmers and local responders (DMCs, community taskforces, service providers, private sectors) understanding disaster risk from heavy rain in mid-October?
	How well did disaster managers at all levels understand the risk?
	How well did sectoral agencies at all levels understand risk?
	Did the sectoral agencies anticipate disaster risk of the rainfall in that time?
Hazard and Disaster Risk Monitoring	How effective and efficient was DHM's weather monitoring and forecasting?
	How effective and efficient was DHM's flood monitoring and forecasting?
	Did agriculture and other livelihood sectors monitor risk?
	Did road and transport sectors monitor risk?
	Did other development and service sectors monitor risk?
Risk Communication	How clearly was the message communicated by forecasters to other actors (i.e., MoHA, NDRRMA, DoA)?
	How timely and effective was communication within and between sectors?
	Did officials in the DoA meet after the forecast, analyse the potential impact on agriculture, and prepare messages about what, who and when to prevent damage to paddy?
	Did two-way communication take place between the forecasters and the DoA soon after the DHM made the forecast available?
	Did the forecasters and other agencies, including NDRRMA/MoHA communicate with each other after the forecast was available?
	Did authorities (i.e., DHM, DoA, NDRRMA) organise media briefing for clear messaging of impacts and advisories to various audiences?
	Did local authorities (including Chief District Officer (CDO), Local Governments) obtain actionable information?
	Did different communities and responders like DMCs, taskforces, security forces on the ground receive actionable information?
Risk Informed Early Action	Did farmers stop the cutting of paddy after receiving the forecast messages?
	Did farmers bring the harvested paddy to safety after receiving the forecast message?

Components of EWS	Essential Actions
	Did commuters change their travel plans after receiving the forecasts?
	Did the authorities' close risk prone travel routes?
	Did people move assets (grain, livestock, other movables) to safer locations?
	Did authorities take actions to minimize damage (e.g., irrigation channels)?
Effectiveness	Did the EWS ensure that the messages reach the last and most vulnerable members of the community?
	Did the early warning messages help reduce disaster risks?
	How beneficial were early warning messages for saving the human, physical and financial capital of the community?
	How well was the system managed and were the resources used in the most appropriate way?
Efficiency	How prompt and effective was decision-making to minimize damages?
	Did people understand the immediate danger from the hazard type?
	How early were EW messages issued?
	Did early warning facilities function appropriately and efficiently?
	Did those at risk take timely and right decisions?
Legitimacy	Did the community of end users accept early warning messages?
	How correct were early warning messages?
	How did the community respond to the early warnings?
	Does the early warning system accept local/traditional knowledge/practices?

Adapted from: Mercy Corps and Practical Action (2010). Establishing Community Based Early Warning System. Practitioner's Handbook.

The above matrix can also help analyse the functions and roles of the agencies shown in Figure 5 to investigate each point in the chain and fix the problems through detailed consultations and by reflecting on actions that could have been taken to minimise the impact of the disaster. The consultations should focus on the shared roles and responsibilities to analyse risk, and to prepare advisories and ways of communicating them effectively to officials of various sectoral agencies and people on the ground for timely actions.

7.8 Adaptation Challenges

It is important to strengthen the resilience capacity of the farmers to adapt to these changes, which are likely to become more frequent as a consequence of the warming of global atmosphere caused by continuing emission of greenhouse gases. If Farmers could have been provided with advice to transfer the cut-down paddy to safer places before the rain began, some of the paddy could have been saved. Similarly, commuters and those in long distance travels should be advised to postpone their travel plans temporarily. Advisories to hydropower developers, road and bridge construction sectors should suggest bringing equipment to safety from rivers likely to be flooded and face landslides. Achieving such shifts in behaviour needs strategic approaches. It is argued that the following three strategies would be appropriate: (a) adjusting rice cultivation practices to change in monsoon season dates, (b) making early warning effective, and (c) developing response mechanisms[45].

8. Conclusion

The 2021 October rainfall event caused widespread damage in the country and has major lessons for agriculture. Though the share of agriculture in the country's GDP in 2019 was 27 percent, over 66 percent of the economically active rural population still depend on agriculture and livestock-based vocations for livelihoods. Inadequate input, non-availability of fertilizers in time, poor links to market and unreliable irrigation bedevil the country's agriculture, and the results are low returns. Despite huge investments in the past, year-round irrigation is available to only 26.30 percent of the total 2.60 million ha land under cultivation[46].

The choices of crops, seeding and harvesting practices depend on the vagaries of monsoon and westerly rains. Amidst warming climate, weather extremes are increasing and are likely to continue to increase in the future with serious implications for Nepal's agriculture, economy, and sources of livelihood. Heavy and erratic rains, droughts, extreme heat, cold wave, windstorm, and hailstorms are threats to crops at all stages from seeding to harvest. Women, who constitute about 70 percent of the agriculture labour force, will be more vulnerable. This is also because the migration of young men has resulted women being more involved in agricultural activities, adding to their burden. Direct and indirect impacts on the agriculture sector of climate warming will be extensive and long-term, and every effort must be made to minimize the risks of erratic weather, likely to be made more erratic by climate change.

In October 2021, the DHM, thanks to past investment in weather forecasting and more than 15 years of learning from the use of community-based flood EWSs, did forecast the hazardous weather in time with fair degree of accuracy. The agency must continue to build this capacity and, in the future, increase the lead time from the present three days to a week. It is important to recognize that there are different types of users—men and women, rich and poor, educated and uneducated—who access and use information differently. Therefore, efforts must be made to tailor messages in a language that different users understand. While messages are foundational, without appropriate advisories to help users take preventive actions, they become meaningless. Farmers must also be provided with disaster risk financing support like social safety nets, risk transfer measures, i.e., insurance, bonds and timely compensation for the economic losses.

Conflict of Interest

This study has received no financial support and has no conflict of interest.

Acknowledgement

We extend our gratitude to anonymous reviewers for their inputs including copyedit. Various individuals and agencies provided data and information. We thank Regan Sapkota for his support in preparing Figure 1.

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60 mm in 1 hour,
80 mm in 3 hours,
100 mm in 6 hours,
120 mm in 12 hours and
140 mm in 24 hours.
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