Government of Nepal

Ministry of Energy, Water Resources and Irrigation

Department of Hydrology and Meteorology

STANDARD OPERATING PROCEDURE (SOP) FOR FLOOD EARLY WARNING SYSTEM IN NEPAL

Standard Operating Procedure for
Flood Early Warning System in Nepal

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Disclaimer

This document is made possible by the support of the Z Zurich Foundation. The contents are the responsibility of Department of Hydrology and Meteorology (DHM) and Lutheran World Relief. This do not necessarily reflect the view of the Z Zurich Foundation.

Preface

One of the mandates of the Department of Hydrology and Meteorology (DHM) is to provide flood early warnings to vulnerable communities and to major stakeholders. We are happy to share our achievements in flood early warning system (EWS), which has significantly reduced the loss of lives and properties. So far, we have been able to establish flood EWSs in major rivers, in a few flashy rivers and in areas downstream of two glacial lakes that are considered potentially dangerous. Our aim is to continuously extend the services throughout the country covering all types of hazards induced by weather, climate and water. To achieve the targets, we are now at a stage of accessing an automated real time data acquisition system. This publication, ***Standard Operating Procedure for Flood Early Warning System (SOP-FEWS)*** intends to provide consistent and standard procedures at the critical time of flooding events so that the communities can act effectively during the worst period of flood hazards.

We appreciate the role of different international and national organizations for their support in the DHM's endeavor to serve communities through awareness creation, logistic support, information dissemination and local level coordination. Using this SOP, communities can use the information and warnings in an optimal manner for their safety and for managing their valuables during flooding.

The SOP is the first attempt of DHM for effective flow of flood-related information among the major stakeholders and the vulnerable communities. The document will be reviewed regularly based on practicality and feedbacks obtained from different stakeholders. We also highly appreciate comments and feedbacks from the stakeholders and communities for improving and updating the document.

We would like to thank the Lutheran World Relief (LWR) for their contribution in bringing out this publication. We express our sincere gratitude to the Ministry of Home Affairs (MoHA), Internal Affairs and Law Ministry of the Province Number Five, Susta Rural Municipality, District Administration Office (DAO) Nawalparasi, and District Coordination Committee (DCC) Nawalparasi for their active involvement while developing this SOP-FEWS.

I also thank Mr. Ram Gopal Kharbuja, Deputy Director General, Mr. Rajendra Sharma In-Charge, Flood Forecasting Section, Mr. Binod Parajuli, and Mr. Sunil Pokhrel Hydrologists of DHM for providing overall supervision and necessary guidance during the preparatory phase of this SOP. Special thank goes to Dr. Keshav Prasad Sharma, an expert and consultant, who worked hard to bring the document in this shape. Last but not least, we express our thanks to Mr. Santosh Dahal and Mr. Narayan Gyawali from LWR for their untiring effort in preparing this valuable document and for all sort of coordination.

Dr. Rishi Ram Sharma
Director General

June, 2018

Abbreviations

APFM	Associated Program on Flood Management
BRCH	Building Resilience to Climate Related Hazards
CAP	Common Alert Protocol
CDMA	Code-Division Multiple Access
CDMC	Community Disaster Management Committee
CFGORRP	Community Based Flood and Glacial Lake Outburst Risk Reduction Project
CRED	Center for Research on the Epidemiology of Disasters
CREWS	Climate Risk and Early Warning System
DAO	District Administration Office
DCC	District Coordination Committee
DDG	Deputy Director General
DDRP	District Disaster Preparedness Plan
DEM	Digital Elevation Model
DEOC	District Emergency Operation Center
DHM	Department of Hydrology and Meteorology
DMC	Disaster Management Committee
DRRMA	Disaster Risk Reduction and Management Act
DSS	Decision Support System
DWIDM	Department of Water-Induced Disaster Management
EM-DAT	Emergency Events Database maintained by CRED
EOC	Emergency Operation Center
EWS	Early Warning System
FEWS	Flood Early Warning System
GFDS	Global Flood Detection System
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
GSM	Global System for Mobile
HEC	Hydrologic Engineering Center
HKH	Hindu Kush-Himalaya
HMS	Hydrologic Modelling System
HYCOS	Hydrological Cycle Observation System
INGO	International Non-Governmental Organization
ICHARM	International Center for Water Hazard and Risk Management
ICIMOD	International Center for Integrated Mountain Development
IFM	Integrated Flood Management
IFRC	International Federation of Red Cross and Red Crescent Societies
IT	Information Technology
ITU	International Telecommunication Union
LEOC	Local Emergency Operation Center
LWR	Lutheran World Relief
MoFAGA	Ministry of Federal Affairs and General Administration
MoFALD	Ministry of Federal Affairs and Local Development

MoHA	Ministry of Home Affairs
MoU	Memorandum of Understanding
MoEWI	Ministry of Energy, Water Resources and Irrigation
MS/OR	Management Science/Operations Research
Ncell	Ncell Axiata Company (mobile service provider)
ND	No Date
NDMA	National Disaster Management Authority
NDMC	National Disaster Management Council
NEOC	National Emergency Operation Center
NGO	Non-Governmental Organization
NTC	Nepal Telecom
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service, NOAA
OCHA	Office for the Coordination of Humanitarian Affairs of the UN Secretariat
OUP	Oxford University Press
PEOC	Provincial Emergency Operation Center
QGIS	Quantum GIS
QPF	Quantitative Precipitation Forecast
RAS	River Analysis System
RIMES	Regional Integrated Multi-hazard Early Warning System
SAARC	South Asian Association for Regional Cooperation
SCADA	Supervisory Control and Data Acquisition
SDMC	SAARC Disaster Management Center
SMS	Short Message Service (text messaging service on mobile phone)
SOP	Standard Operation Procedure
SSB	Single Side Band wireless transmission
TRMM	Tropical Rainfall Measuring System
UNDP	United Nations Development Program
UNDRO	United Nations Disaster Relief Office
UNOSAT	United Nations Operational Satellite Applications Program
UNISDR	United Nations International Decade for Natural Disaster Reduction
UNU-EHS	UN University institute for Environment and Human Security
WECS	Water and Energy Commission Secretariat
WHYCOS	World Hydrological Cycle Observation System
WMO	World Meteorological Organization
WRI	World Resource Institute

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Executive Summary

Floods and landslides make up almost three quarters of all natural disasters occurring in Nepal. In terms of the number of people affected by floods each year, Nepal ranks twentieth in the world. Changing demographics in the country's vulnerable floodplains and impacts of climate change are the two central factors affecting Nepal's flood-related damages and loss of life. Flood Early Warning System (FEWS) is one of the approaches applied to mitigate the risks posed by floods. FEWS is a widely accepted non-structural measure with huge potential to save lives and protect properties.

Floods and landslides occupy almost three-fourth of the disasters occurring in Nepal. Nepal has been ranked at twentieth position among the countries in the world in terms of people affected by floods every year.

Since most of the rivers in Nepal are relatively small, access to real-time data is the key prerequisite for creating a reliable flood warning system. Recent innovations in computer software and advancements in data transmission through mobile technologies have made it possible to implement and manage a flood forecasting system even with relatively limited resources. Furthermore, improved hydro-meteorological networks and more accurate digital elevation models (DEMs) have created ample opportunities for improvement of the hydrological and hydraulic models' capabilities to predict flood impacts.

The main objective of the Standard Operating Procedure (SOP) for FEWS is to develop simplified sustainable instructions that define the roles and responsibilities of major stakeholders as well as community members. Since bottom-up approaches are limited due to Nepal's existing infrastructural arrangements, the SOP aims to ensure the involvement of local communities in all phases of FEWS development and implementation. Community members play a particularly important role during the delineation of vulnerable zones. Community-based disaster management units are particularly helpful in identifying vulnerable areas and evacuation routes, overseeing the operations of field stations and disseminating flood forecasts and warnings. Regular interactions among communities and major stakeholders is an integral part of the SOP.

Precipitation in Nepal is dominated by summer monsoons that last for about four

Besides government agencies,several NGOs are also contributing in different aspects of disaster mitigation.

months starting in June. Almost 80 percent of annual precipitation occurs during this period. Therefore, floods are generally observed in July and August when the Southwest monsoon is at its peak. In addition, heavy precipitation during such a short time period causes land surfaces to quickly reach their capacity to absorb rainwater, and the rain that is not absorbed accumulates and contributes to flooding. Flash floods are usually observed during pre-monsoon season when localized high-intensity rainstorms are a frequent phenomenon. The proposed SOP covers the warning processes for floods as well as flash floods.

Nepal's Ministry of Home Affairs (MoHA) has been designated by the Natural Calamity (Relief) Act of 1982 to serve as the lead agency responsible for disaster-related activities. In collaboration with the Department of Hydrology and Meteorology (DHM), MoHA has already established a web-based National Emergency Operation Centers (NEOC) in Kathmandu and District Emergency Operation Centers (DEOCs) in most districts in Nepal. NEOC and DEOCs are open 24 hours a day throughout the year. Similarly, DHM is a designated government entity for predicting and disseminating weather forecasts and warnings. DHM has been maintaining a network of 28 hydrological stations and 88 meteorological stations equipped with telemetry systems. DHM is in the process of upgrading several of its hydrometric stations with telemetry.

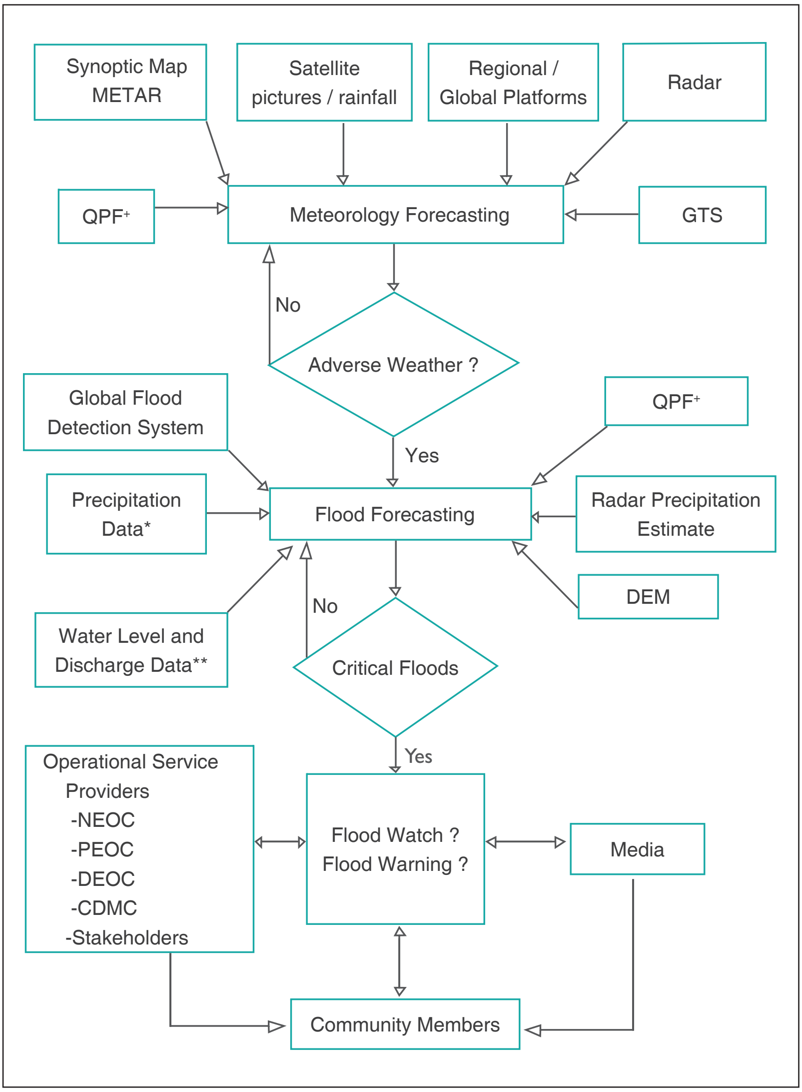
In collaboration with the government agencies, several Non-Governmental Organizations (NGOs) are also contributing to disaster risk mitigation in Nepal. The capacity of NGOs in social mobilization is recognized and respected, which creates potential for collaborative initiatives. DHM has been working with a number of NGOs on the development of a Memorandum of Understanding (MoU) in the field of information dissemination to affected communities.

The roles of government agencies and NGOs engaged in disaster mitigation efforts are defined in the table below. The table is divided by four major components of FEWS: monitoring, risk assessment, forecast dissemination and capacity building.

Component	Task	Responsibility
Monitoring	Manuals, guidelines, trainings and quality management	Flood Forecasting Center, DHM
	Operation, maintenance and upgrading of stations; maintenance of hydrological and meteorological equipment	District DHM offices
	Operation of telecommunication systems and software management	Outsourced with supervision by DHM
	Maintenance and operation of manual observation systems at monitoring sites	Community
	Processing data received from a telemetry/manual observation with necessary validation	Flood Forecasting Center, DHM
	Development of high-resolution spatial data	DHM
Risk Assessment	Hydrological and hydraulic modeling	Flood Forecasting Center, DHM
	Floodplain mapping and risk identification with field verification	Flood Forecasting Center, DHM
	Obtaining additional support from Common Alerting Protocol (CAP) such as Google Public Alerts and Global Flood Detection System (GFDS)	DHM
Forecast dissemination	Disseminate flash flood watches, warnings and severe flood warn-ings to communities and relevant agencies	DHM, NEOC, DEOC/PEOC
	Feedback through self-assessment and feedback from communities	Flood Forecasting Centre, DHM
Capacity Building	Training	Training Section, DHM
	Awareness Programs: piloting, preparation of awareness materi-als, seminars, workshops and interactive programs, mock-drill exercises, etc.	All key stakeholders and NGOs
	Aid provision to handicapped mem-bers of local communities	Local government agencies and NGOs
	International collaboration and manage-ment of information - Decision Support System (DSS), Global Flood Detection System (GFDS), Quantitative Precipitation Forecast (QPF) from Regional Integrated Multi-Hazard Early Warning System-RIMES, National Oceanic and Atmospheric Administration -NOAA, Tropical Rainfall Measuring System (TRMM) etc.	DHM

Floods are predicted at the flood forecast and flood warning centers managed by DHM. Flood warnings are disseminated via Internet, display boards and SMS texts when the water level crosses a specified flood watch mark. Flash flood warnings are disseminated when three-hour precipitation exceeds a threshold value specified for a given precipitation station or using a black-box approach such as an application programming interface (API) model. A summary of the procedures is illustrated in the figure below.

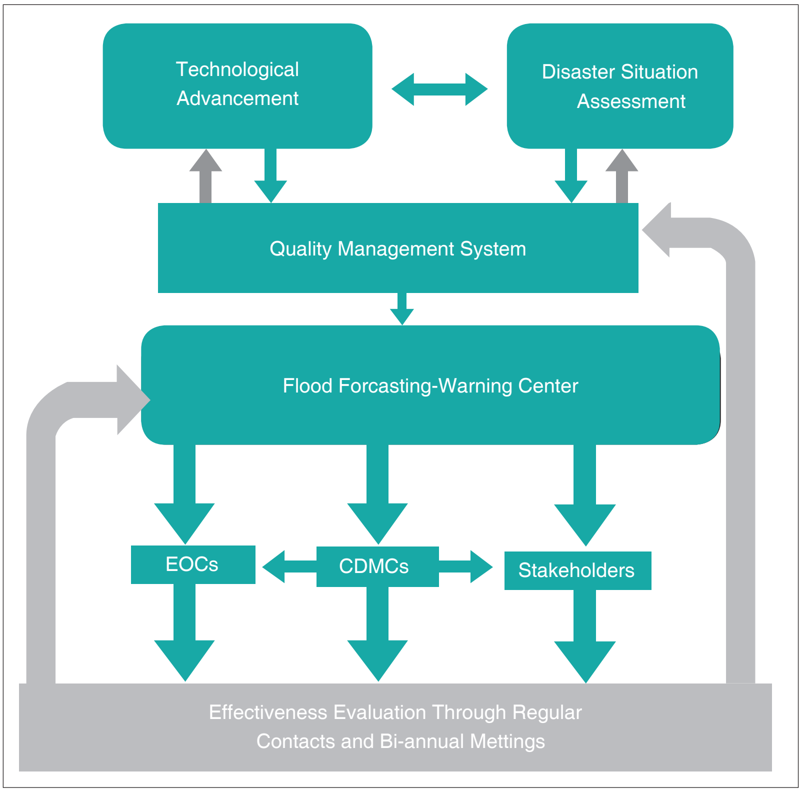
Flood information dissemination has three major stages: flood watch,flood warning and severe flood flood warning. First stage is the flood advisory for preparedness whereas the other stages are the situations to act.



Flood information dissemination has three major stages: flood watch, flood warning and severe flood warning. The flood watch stage is the flood advisory to ensure preparedness whereas the other two stages signal the need to act.

Quality management through feedback includes self-assessment as well as responses from stakeholders and community members. Feedback helps to review FEWS and reassess its reliability, accuracy and usefulness. Benefits of an early warning system depend on the response programs. If warnings are either neglected by the beneficiary community and relevant agencies or fail to reach the affected individuals and entities, then such FEWS is not worth investing in. The following figure illustrates a quality management system proposed within FEWS. Feedback from the users of the services constitute an essential element that can contribute towards the enhancement of FEWS.

Quality management system through feedback mechanism includes self-assessment as well as responses from stakeholders and communities.



Continued research, trainings and awareness programs are important for developing and updating FEWS. Research and development in this sector is also important in the context of rapidly changing technologies and advancements in software development. A special Research and Investigation Section already exists under MoHA's Disaster Management Division. DHM can collaborate with the section involving in-house as well as external experts. NGOs can play an important role in supporting such research activities by bridging gaps between institutions or assisting in piloting basin-scale investigations.

SOP must be revisited and reviewed on a regular basis based on stakeholder feedback. Reviews are also required with changing organizational strengths and advancements in available hardware and software.

Definitions

Disaster (Natural):
Disaster (Natural): Sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, economic and environmental losses that exceed the community's or society's ability to cope using its own resources [IFRC].

Early Warning System (EWS):
An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events [UNISDR].

Flash flood:
A flood caused by heavy or excessive rainfall in a short period of time, generally less than six hours. Flash floods are usually characterized by raging torrents after heavy rains that rip through river beds, urban streets or mountain canyons sweeping everything before them. They can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed, or after a sudden release of water by a debris or ice jam [NWS].

Flood:
An overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway such as a river, stream or drainage ditch. Ponding of water at or near the point where the rain fell [NWS].

Flooding:
Overflowing by water of the normal confines of a stream or other body of water, or accumulation of water by drainage over areas that are not normally submerged [WMO].

Floodplain:
A floodplain is the normally dry land adjoining rivers, streams, lakes, bays, or oceans that is inundated during flood events (Chow, Maidment, & Mays, 1988).

Glacial Lake Outburst Flood (GLOF):
Sudden release of a significant amount of water retained in a glacial lake, irrespective of the cause [OUP].

Hazard (Natural):
Natural hazards are severe and extreme weather and climate events [WMO].

Inundation:
Large amounts of water covering an area that is usually dry [OUP].

Lead Time (Flood Forecast):
Amount of time between a flood forecast and the onset of flood [OUP].

Lead Time (Flood Warning):
Amount of time between a warning being received and the onset of flood [OUP].

Introduction

With an average of 156,573 people worldwide affected by floods every year, the 2014 World Resource Institute (WRI) report puts Nepal in twentieth place among 163 nations based on the number of people impacted by floods (Winsemius & Ward, 2018). The recent publication by the Center for Research on the Epidemiology of Disasters (CRED) also listed Nepal as one of the top 10 countries in the world in terms of disaster-related mortality (Guha-Sapir, Hoyois, Wallemacq, & Below, 2017). Overall, floods and landslides make up almost 75 percent of disasters in Nepal (Sharma, 2014). Figure 1 presents the comparison between the average annual flood impacts globally (IFRC, 2016) and the average annual flood impacts in Nepal (DesInventar, 2018).

An example of a recent flood in the Terai region of Nepal shows that a total of 1.7 million people were affected with damages reaching 61 billion Nepalese Rupees (three percent of GDP) as a result of a flood that lasted for less than a week (19 - 24 August 2017). That flood claimed 143 lives, leaving 80 percent of the Terai completely inundated. General patterns of floodplains in Nepal are illustrated in Figure 27 and Figure 28. An effective and sustainable Flood Early Warning System (FEWS) has significant potential to reduce flood-related fatalities and property damage. Studies show that an effective FEWS is able to significantly reduce loss of life and save properties (Rogers & Tsirkunov, 2010). The estimated benefit-cost ratio of a flood forecasting system is reported to be as high as 60 based on some calculations, with an average reported benefit-cost ratio being around 11 (Wethli, 2014).

Floods and landslides occupy almost three-fourth of the disasters occurring in Nepal. Nepal has been ranked at twentieth position among the countries in the world in terms of people affected by floods every year.

Disaster awareness, level of preparedness and local socio-economic environment play an important role in the affected communities' involvement in FEWS. Another important factor is the involvement of said communities in the different phases of disaster mitigation and their level of access to climate-related information (Srinivasan, Rafisura, & Subbiah, 2011). Having trusted sources of information is another major criterion that impacts communities' ability to act upon FEWS (Newnham, Mitchell, Balsari, & Leaning, 2017).

The Department of Hydrology and Meteorology has a mandate to issue flood forecasts and flood warnings to the general public and the relevant agencies. Despite DHM's efforts in developing a flood forecasting and warning system, substantial capacity building is still needed for the forecasts to have reliable accuracy as well as for effective dissemination of flood warnings.

Major gaps within DHM must be addressed, specifically in the areas of research and development, human resources and inter-sectoral coordination. Moreover, as a national institute, DHM has limited experience working with local communities. DHM has already begun working with relevant governmental and non-governmental organizations to fill in such gaps. Lutheran World Relief (LWR) is one of the partners that has a Memorandum of Understanding (MoU) with DHM and the two are working together to resolve the existing roadblocks.

Objectives

SOP targets to develop simplified procedures applicable in most of the flood prone areas in Nepal with the least role of involved actors.

The objective of this report is to prepare a Standard Operation Procedure (SOP) for FEWS with defined roles and responsibilities of major stakeholders from national to local authorities and affected communities. The SOP aims to develop simplified procedures that would be applicable in the flood-prone areas of Nepal and have the least amount of intervention required from the parties involved.

Several meetings were held with major stakeholders to discuss the best procedures to be included in the SOP. In addition, discussions were held with selected communities in some of the country's most vulnerable floodplains to assess the nature of problems and understand the affected communities' coping capacity. Checklists were developed beforehand in order to obtain all needed information during these consultative meetings and community-level interactions (Annex II and Annex III, respectively). Details of the outcomes of the meetings and information about the participants are presented in Annex IV.

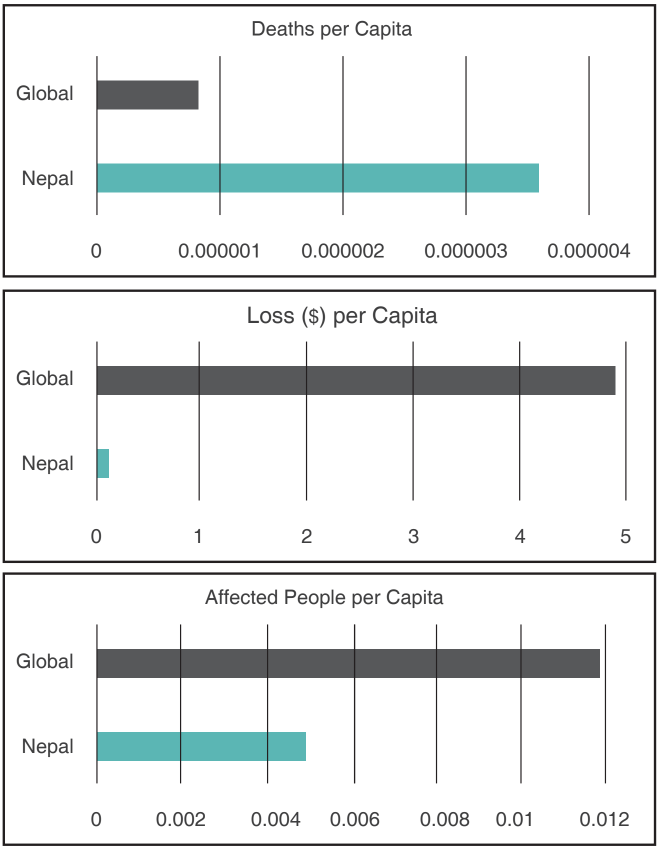


Figure 1. Comparison of flood impacts in Nepal with global statistics.

Precipitation Patterns in Nepal

Precipitation in Nepal is dominated by summer monsoon season that lasts for about four months starting in June. Almost eighty percent of annual precipitation falls during this period. Therefore, floods are generally observed in July and August when the Southwest monsoon is at its peak. In addition, heavy precipitation during the monsoon season quickly limits the land's ability to absorb rainwater thus contributing to water accumulation and subsequent flooding.

Almost all precipitation events that cause severe floods in Nepal occur in the period from July to September. Some extreme rainfall events observed in October have been found to be associated with cyclones that normally occur in post-monsoon periods. The tropical cyclone Hudhud that devastated Nepal's district of Chitwan in October 2004 is one example of such post-monsoon events.

The results of data analyses of extreme precipitation in Nepal indicate that all severe storms with precipitation exceeding 400 mm have occurred within a short period between the third week of July and the second week of October (Sharma, 2015). When evaluating the data from Nepal and its adjacent territories, the list of 82 recorded severe rainstorms indicates that all events occurred between the last week of April and the second week of October, with 80 percent of these events happening within a short period from July through September (MoHA/DPNet, 2010).

Occasional intense precipitation with flooding potential can be observed in Nepal during pre-monsoon periods. Pre-monsoon period precipitation events are usually associated with the mesoscale convective system producing isolated intense rainfalls. The areas effected by heavy pre-monsoon precipitation events are the Siwalik Hills, Mahabharat and the country's middle mountain region where such isolated events have potential to create flash floods.

Floods in Nepal

Although snowmelt-induced flooding is possible in mountainous areas of Nepal, most floods are linked to intense or widespread precipitation events. Almost all types of floods occur in Nepal, with the exception of coastal floods and storm surges. Brief descriptions of typical flood types observed in Nepal can be found below.

Most of the floods in Nepal are linked to intense or widespread precipitation events.

Riverine Flood: This is the most frequently occurring type of flooding in Nepal. These floods have a high degree of predictability as the processes that cause them are based on the distribution of rainfall over the catchment. Such floods are generally observed in large catchments and result from a widespread rainfall over a basin.

Flash Flood: Flash floods are a rather frequent phenomenon mainly occurring in the Siwalik region and small mountainous watersheds. Flash floods are more frequent during convective precipitation season or in areas where rainfall events tend to be more intense but of shorter duration. These floods have lesser predictability compared to the riverine floods and their forecasting requires a denser hydro-meteorological network. In the case of flash flood prediction, a prognosis based on rainfall generally works better than forecasts made using the rain gauge correlation method. Since the river crest time of flash floods is less than six hours, a warning system needs to be much faster and more efficient than the warning system developed for riverine floods.

Landslide Lake Outburst Flood: In Nepal, floods are usually associated with landslides and hence are referred to as Badhipairo in Nepali language. Various technical publications also treat these two separate processes as being correlated (MoHA/DPNet, 2010; DWIDM, 2018). Although different in nature, these two processes happen mostly during the same period and are both triggered by incessant rainfall events during peak summer monsoon season. In some instances, landslides may block a river forming a temporary lake that can burst and generate huge floods, similar to glacial lake outburst floods (GLOFs).

Glacial Lake Outburst Flood (GLOF): Breaching of a moraine dam, formed naturally in the Himalayan region, may create strong floods in downstream Himalayan and other mountainous areas. The loss of multiple bridges and several sections of the Arniko highway as a result of the 1981 GLOF that originated in the Tibetan part of the Bhote Koshi is an example of the devastation a GLOF can bring. Although glacial lake outburst floods are rare, they have caused significant damage in the Himalayan and other mountainous areas of Nepal in the past (ICIMOD, 2011).

Snowmelt Floods: This type of flooding may occur because of the rise in temperature in high Himalayan areas during pre-monsoon periods. Snowmelt floods normally do not do much damage because they occur in remote areas of the Himalayas where there are no settlements or economic activities. The impact of snowmelt floods on the water level of large rivers of Nepal is found to be only about 10 percent (Sharma, 1993), thus their impact on riverine floods is insignificant.

Inundation: Inundation is one of the severe problems occurring in the Terai region. It is more frequent near the border areas. Construction of major embankments leads to poor drainage in many border areas. As demonstrated by the flooding situation in late August 2017, inundation can extend to the major parts of the Terai if it is associated with heavy rainfall events in the Siwalik Hills and Terai region.

The lead time required for flood forecasts ranges from few minutes to about one day.

Breach of Embankment: Several rivers in the Terai region are confined with embankments or by river training work. Any failure of such structures is likely to lead to disastrous flooding in adjacent areas. A typical example is the breach of the Koshi embankment that occurred on 18 August 2008 causing major flooding and resulting in the displacement of about 70,000 people in Nepal.

Table 1 shows the typical range of time of concentration in monitored river basins of Nepal. Considering that necessary lead time is usually about half of the time of concentration, the table shows that the lead time required for flood forecasts ranges from a few minutes to about one day.

Table 1. Time of Concentration of the selected river basins.(DHM,2015)

River Basin with River Gauging System	Area (km2)	Time of Concentration (hour)
Bagmati at Sundarijal	16	0.5
Bagmati at Karmaiya	2,700	12
Karnali at Chisapani	43,000	44
West Rapti at Bagasoti	3,500	10

Table 1. Time of Concentration of the selected river basins.

Early warning system existed in the world in different forms from ancient times as there has been natural hazard in all ages.

Policies and Legal Issues

International Initiatives

Over the past few years, integrated approaches to flood management have begun to gradually replace the more traditional methods that rely on structural interventions. Associated Program on Flood Management (APFM) promoted by the World Meteorological Organization (WMO) and the Global Water Partnership (GWP) considers flood management within the framework of the management of the entire hydrological cycle, recognizing it as a constituent part of the larger process (WMO/GWP, 2018). Flood forecasting is an essential aspect of Integrated Flood Management (WMO, 2011).

Early warning systems existed in some shape or form since the ancient times as natural hazards have always been a threat and people searched for ways to warn others when a disaster was coming. Technologies used in early warning systems have improved over time from primitive bonfires to wind-operated alarms. Audible wind-operated alarms are still used in many parts of the world including Nepal (Practical Action, ND). However, present day alarm systems have been upgraded with event triggered alarms through electronic sirens.

Major international scale disaster-related initiatives with strong EWS components are summarized in Table 2.

Table 2. List of international initiatives in EWS.

1970	UN resolution invites the Secretary-General to submit a recommendation for assistance in cases of natural disasters that includes the improvement of Early Warning System.
1971	Creation of the United Nations Disaster Relief Office (UNDRO)
1990-1999	The United Nations General Assembly designates the 1990s as the United Nations International Decade for Natural Disaster Reduction (UNISDR).
2000	The International Strategy for Disaster Reduction (ISDR) is launched with a mission to respond to the challenge presented to the international community by the increasing incidence and scale of disasters.
2005-2015	Governments around the world commit to take action to reduce disaster risk and adopt the Hyogo Framework for Action (HFA), a guideline to reduce vulnerabilities to natural hazards.
2015-2030	The Climate Risk and Early Warning System (CREWS) initiative is launched at the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change held in Paris. The initiative is being implemented by the World Meteorological Organization (WMO), the World Bank Global Facility for Disaster Reduction and Recovery and the United Nations Office for Disaster Risk Reduction.
2015	The Climate Risk and Early Warning System (CREWS) initiative was launched at the twenty-first session of the Conference of the Parties to the United Nations Framework Convention on Climate Change held in Paris. The initiative is being implemented by the World Meteorological Organization (WMO), the World Bank Global Facility for Disaster Reduction and Recovery and the United Nations Office for Disaster Risk Reduction.

2016	The International Network for Multi-Hazard Early Warning Systems is established to facilitate the sharing of expertise and best practices in close cooperation with CREWS.

With initiative and commitment from the international community, the Hyogo Framework for Action (HFA) is considered to be a key international instrument to addressing issues related to natural disasters on a global scale. One of the five priorities for action outlined in the HFA (2005-2015) is to "Identify, assess and monitor disaster risks and enhance early warning." A key activity under this priority for action is described as follows (UNISDR, 2005):

Develop early warning systems that are people centered, in particular systems whose warnings are timely and understandable to those at risk, which take into account the demographic, gender, cultural and livelihood characteristics of the target audiences, including guidance on how to act upon warnings, and that support effective operations by disaster managers and other decision makers.

The Sendai framework for Disaster Risk Reduction (2015-2030),supported by the United Nations Office for Disaster Risk Reduction,has proposed national and local level actions relating to the preparedness with an early warning system.

Similarly, one of the four priorities for actions outlined in the Sendai Framework for Disaster Risk Reduction (2015-2030) emphasizes "Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction". The framework, supported by the United Nations Office for Disaster Risk Reduction at the request of the UN General Assembly, has proposed national and local level actions related to preparedness with an early warning system, described as follows (UNISDR, 2015) :

To invest in, develop, maintain and strengthen people-centered multi-hazard, multisectoral forecasting and early warning systems, disaster risk and emergency communications mechanisms, social technologies and hazard-monitoring telecommunications systems; develop such systems through a participatory process; tailor them to the needs of users, including social and cultural requirements, in particular gender; promote the application of simple and low-cost early warning equipment and facilities; and broaden release channels for natural disaster early warning information.

Recent technological developments that have potential to be impactful on an international scale include the Global Flood Detection Systems (GFDS) used for monitoring floods around the world. GFDS is an "experimental system to detect and map in near-real time major river floods based on daily passive microwave satellite observations" (GDACS, 2018). Figure 2 and Figure 3 present the area in and around eastern Nepal as an example of how the GFDS system operates. The maps can be downloaded in GIS format and used for detailed analysis.

GFDS is open for collaboration with affected country's authorities, such and DHM in the case of Nepal, and DHM can request access to GFDS data and software. A similar system has been developed by Google and is called Google Public Alerts (Figure 4). The Public Alerts system has already been used in India as part of their Common Alert Protocol (CAP).

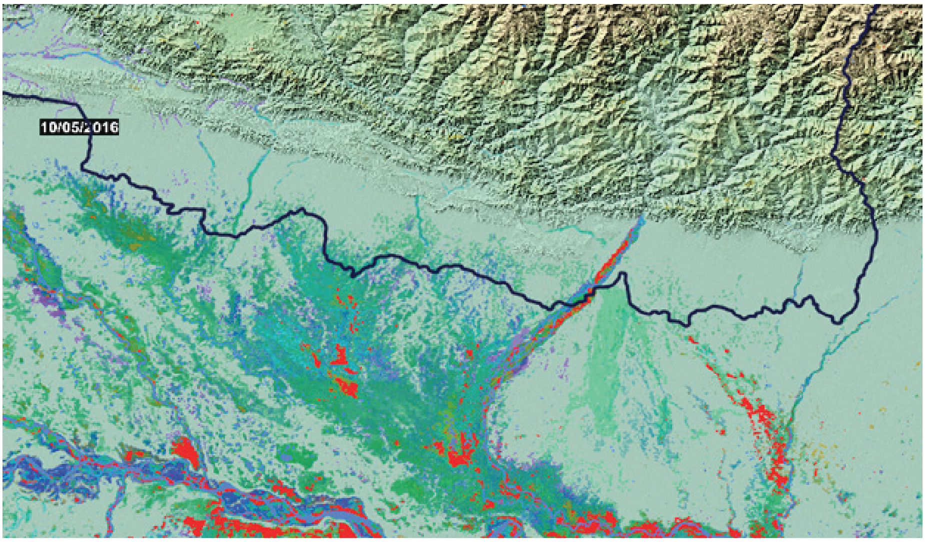


Figure 2.A map of global flood detection system delineating flooded areas on 5 October 2016.

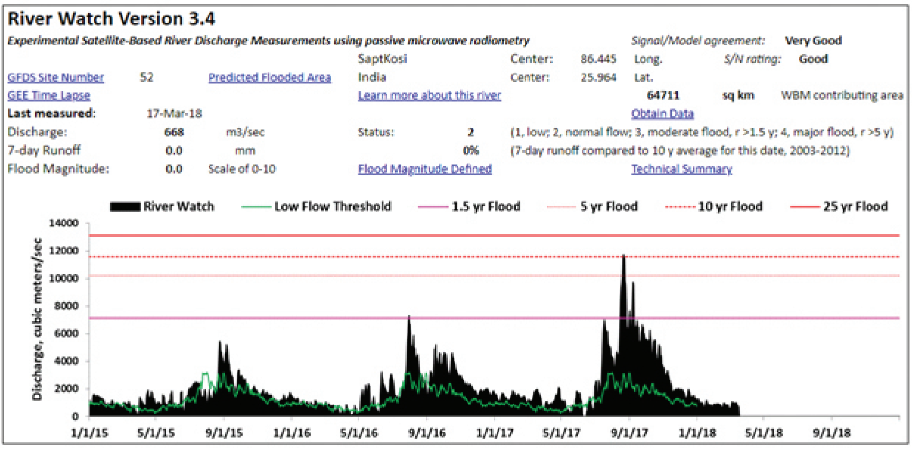


Figure 3. Experimental satellite-based river discharge on the Kosi River at Baltara (India).[1]

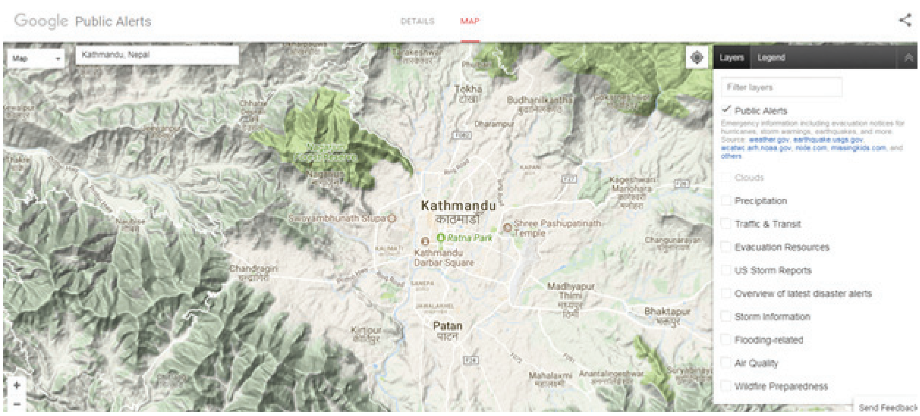


Figure 4. Public alert system in google.[2]

[1]Source: http://floodobservatory.colorado.edu/DischargeAccess.html
[2]Source: https://google.org/publicalerts

National Initiatives

Protecting life and property is one of the directives as described in the Article 50 of the Constitution of Nepal. When it comes to natural resources, one of the policies that covers their protection, promotion and use is "To make advance warning, preparedness, rescue, relief and rehabilitation in order to mitigate risks from natural disasters."

Regarding the government's responsibilities, as described in the Constitution of Nepal, disaster management is listed as one of the "other works" in which the Government of Nepal may mobilize the Nepal Army in accordance with the federal law. Another area related to disaster management that is recognized by the Constitution is the irrigation policy stated in Article 51 (4) that says, "To develop sustainable and reliable irrigation by making control of water-induced disasters, and river management."

The Constitution of Nepal 2015 includes disaster management as one of the executive as well as legislative powers vested to local level governments.

Disaster management is one of the executive as well as legislative powers vested to local level governments. At the same time, the responsibility of disaster management is also shared by all levels of government, from local to state to federal. The issuance of flood forecasts and warnings is a national responsibility as local governments lack the infrastructure necessary to perform these tasks.

It is crucial to note that when compared to most counties, Nepal has been in a better position to issue climatic and hydrological forecasts required for FEWS due to the fact that the country's DHM mandate covers meteorology as well as hydrology. Table 3 summarizes major events that led to the development of flood forecasting activities at DHM in Nepal.

Table 3. List of national initiatives in EWS.

1979	The need for flood forecasting is first expressed in a concept paper by a short-term consultant from United Nations Development Programme (UNDP).
1985	Concept is developed for initiating flood forecasting to meet the needs of Nepal. Assessment of appropriate telemetry system is conducted by a WMO consultant.
1988	Flood Forecasting Section is established under the newly created organizational chart of Nepal's Department of Hydrology and Meteorology.
1998-2002	The ninth five-year plan proposed by the Government of Nepal suggests the development of a disaster management information system.
2002	The Government of Nepal publishes Water Resources Strategy recognizing the issue of "inadequate flood forecasting and warning systems" and proposes an improvement plan. The strategy states that "DHM is to be provided with the mandate and resources to be the lead agency for implementing and managing a flood warning system."
2004	Comprehensive flood forecasting masterplan is executed between Nepal and India.
2006	Policy on water induced disaster management is implemented.

2007	The Department of Water-Induced Disaster Management (DWIDM) is established with a goal to alleviate poverty in Nepal through "minimizing human casualties and damages of infrastructures due to water induced disasters by the appropriate management and conservation of rivers and river basins."
2007-2009	A three-year interim plan proposed by the Government recognizes the institutional development of EWS and the need for information flow. The program has been continued in successive five-year plans.
2009	The Government of Nepal adopts the National Strategy for Disaster Risk Management (NSDRM), which is based on the HFA. NSDRM 2009 proposes community-based early warning systems in priority river basins and requires gender inclusion. NSDRM also proposes the establishment of the National Disaster Management Council (NDMC) chaired by the Prime Minister and the National Disaster Management Authority (NDMA) as a secretariat of the NDMC.
2010	Successful initiation of real-time climatic and hydrological data acquisition at DHM takes place using automatic sensing and mobile telephone technology.
2017	Disaster Risk Reduction and Management Act 2017 (DRRMA 2017) is endorsed by the Government of Nepal. DRRMA 2017, which supersedes the earlier acts such as Natural Calamity Relief Act 1982, is the legal document that any disaster related activity must be based on. The Sub-clause O of Clause 8 of DRRMA proposes the development and operation of a national early warning system. The Act mandates further promotion of EWS through research and development of appropriate technologies.
2018	The reorganized structure of the Government of Nepal implemented on 23 February 2018 brings DHM back under the wing of the Water Resources Ministry after two decades of DHM's association with different ministries including Science, Technology and Environment.

Water Resources Strategy of Nepal 2002 mandates DHM in the promotion of international cooperation for the flood forecasting and warning system.

A key step forward in Nepal's disaster management was the Water Resources Strategy (WECS, 2002) that proposed strengthening disaster networking and information system and described the role of DHM to be as follows:

DHM will be the lead agency to develop flood warning systems for selected rivers and glacial lakes based on flow monitoring, precipitation monitoring, precipitation forecasting, river flow modelling and forecasting and a system of routine and emergency public announcements.

Furthermore, WECS mandated DHM to take responsibility of the "Promotion of international cooperation for flood forecasting and warning system." WECS noted that instead of different agencies developing warning systems for their own water resources projects, all such systems should be integrated in DHM's flood warning system. The Water Plan (WECS, 2005), which followed the Water Resources Strategy set a target, according to which "By 2017, warning system [must be] established and functioning, encompassing the country."

SOP Examples

For most countries in the developing world, flood forecasting and warning practices based on SOP are a fairly recent and innovative method of flood management. Most of the developing countries including Nepal have an SOP for disaster response but do not have one for issuing flood warnings. Currently, only a few countries have already developed their SOPs for FEWS and most others are in the process of creating theirs.

With growing operational flood forecasting systems in the world, many countries have started institutional procedures to ensure timely dissemination of accurate forecasts and warnings.

Many countries with multipurpose reservoirs that include a flood cushion have reservoir operation rules that cover the topic of flood control (Mavalankar & Srivastava, 2008). With a growing emphasis on the importance of operational flood forecasting systems around the world, many countries have initiated institutional procedures to ensure timely dissemination of accurate forecasts and warnings. Some of the recent developments in countries with socio-economic situation similar to that in Nepal can be illustrated using the following examples.

In India, the Central Water Commission (CWC) has recently introduced an SOP for flood forecasting and it is expected to issue more than 10,000 forecasts and three-day advisories at 275 stations in 20 river basins covering India's 24 states (CWC, 2017). The SOP divided the forecasting and warning activities by different levels, from sites to headquarters of subdivisions to divisions to circles and regions and other entities in between. The CWC has also started collaborating with Google to help them issue alerts through the Common Alerting Protocol (CAP) accessible via Internet or a smartphone device.

In Indonesia, the Department of Water Resources Management is in the process of developing their own SOP. Their plan is to disseminate the flood data to local disaster response groups via SMS and radio (Iglesias, Rahayuni, & Sari, 2015).

Laos has been working on developing SOPs for flood and drought under an Asian Development Bank- ADB project (Eptisa, 2017) entitled "Flood and drought risk management and mitigation project." The SOPs are based on the approach of dividing the hydrological process into three major categories: normal stage, alarm stage and flooding stage.

In Central America, several countries now have multi-hazard SOPs. Considering the types of natural disasters that are prevalent in that part of the world, the SOPs in Central America are primarily meant to target cyclones and tsunamis (TSCCH, 2013).

Stakeholders

DHM is the sole organization in Nepal in the field of FEWS. The organizational structure of DHM that combines hydrology and meteorology puts DHM in an ideal position to generate flood forecasts and issue forecasts and warnings. DHM has also been working with MoHA, an organization involved in the entirety of disaster management cycle, on disseminating flood warnings through NEOC and DEOCs.

DHM has been supported by WMO since its establishment through collaboration on different meteorological activities and activities related to operational hydrology. As a member of WMO, Nepal has access to global and regional meteorological data required for monitoring and forecasting floods. Furthermore, DHM has received several projects from WMO in the past, including projects on upgrading meteorological observation systems, weather forecasting, agriculture meteorology and hydrological services. In collaboration with the International Center for Integrated Mountain Development (ICIMOD) and countries in the Hindu Kush-Himalayan (HKH) region, WMO has been promoting the World Hydrological Cycle Observation System (WHYCOS) under the name of HKH-HYCOS. DHM has been contributing to this program by sharing real-time data for effective flow forecasting for the rivers originating from the Hindu Kush-Himalayan region.

Nepal,being a member of WMO,has access to global and regional meteorological data required for monitoring and forecasting floods.

With the implementation of the project 'Building Resilience to Climate Related Hazards' (BRCH), the World Bank has supported DHM by upgrading the existing flood forecasting system. This five-year project started in 2013 and its goal is to upgrade the real-time data acquisition system and establish an end-to-end flood forecasting system that is supposed to be piloted in two major river basins: Koshi and Rapti. Nepal was also able to receive small grants from the Danish and Finnish governments for promoting DHM's flood forecasting capabilities.

Besides collaborating with the international community, Nepal has also been working closely with their neighbor countries on upgrading its hydrological and meteorological monitoring systems. Since all the rivers of Nepal merge into the Ganga-Brahmaputra river system, Nepal has bilateral arrangements with India and Bangladesh that support the sharing of hydro-meteorological data and flood information.

Several INGOs are involved in disaster mitigation in Nepal. Nepal Red Cross Society (NRCS) and UNDP are involved in most of the disaster mitigation activities in Nepal. UNDP has been working with DHM on strengthening Nepal's hydrological services and promoting community-based flood warning systems. Similarly, small-scale community-based flood warning systems have been implemented by other INGOs either in collaboration with DHM or in collaboration with other government agencies and NGOs. The INGOs that have an MoU with DHM are Lutheran World relief (LWR) and Practical Action.

Since flood forecasts and warnings are widely used by communities and with several organizations simultaneously involved in disaster management, there are innumerable stakeholders involved. Annex I lists major stakeholders actively working on different phases of the disaster management cycle with direct or indirect involvement in FEWS.

Partnership Process

Since SOP intends to promote a bottom-up approach, it relies on communities taking initiative and getting involved in disaster management activities. CDMCs contact the local government to discuss the proposals and finalize the implementation plan through annual programs. Based on the legal mandates described earlier, local governments need to provide financial and administrative support. Local governments can request the central government's assistance for technical support as well as additional resources if needed. Advice and support from NGOs that work directly with local communities can be instrumental in situation analysis, awareness building and proposal development. INGOs and NGOs can play an important role in bridging gaps between communities, local governments and the central government through additional technical inputs, interaction programs, workshops and seminars. Nepal Red Cross Society has been implementing the community-based disaster management program in 11 districts of Nepal and serves as an excellent example of success that community-based efforts in disaster management can achieve with support from the NGOs (NRCS, 2018). Figure 5 illustrates the partnership process among communities, NGOs, local governments and central government agencies for the implementation of FEWS in different communities of Nepal.

I/NGOs can play important roles in bridging gaps among communities, local governments and central governments through additional technical inputs, interaction programs, workshops and seminars.

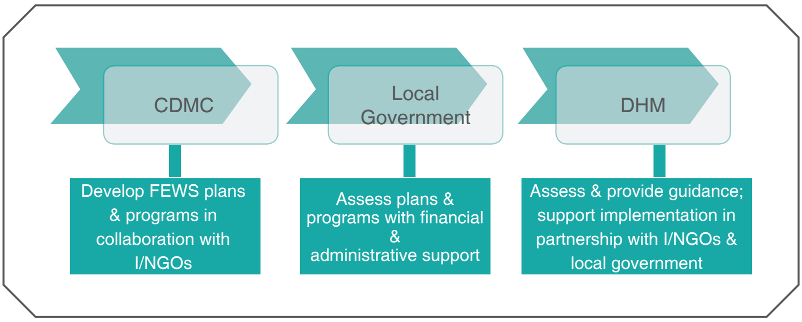


Figure 5. Partnership process among CDMC, local governments and DHM.

Flood Early Warning System

Flood Early Warning System (FEWS) is a major component of the preparation phase of disaster management cycle,although it has important role to play in all phases of a disaster cycle.

Disaster management cycle is generally described in terms of its four pillars: preparedness, response, recovery and mitigation. Flood Early Warning System (FEWS) is a major component of the preparedness phase although it plays an important role in all phases of the disaster cycle. As illustrated in Figure 6, FEWS itself is divided into four components: monitoring, risk assessment, dissemination and activation. The first component deals with the detection, monitoring and forecasting of events. Risk assessment is the second component and it is followed by dissemination of flood forecasts and warnings, leading to the activation of the whole FEWS. Figure 7 shows major components within each component of Figure 6.

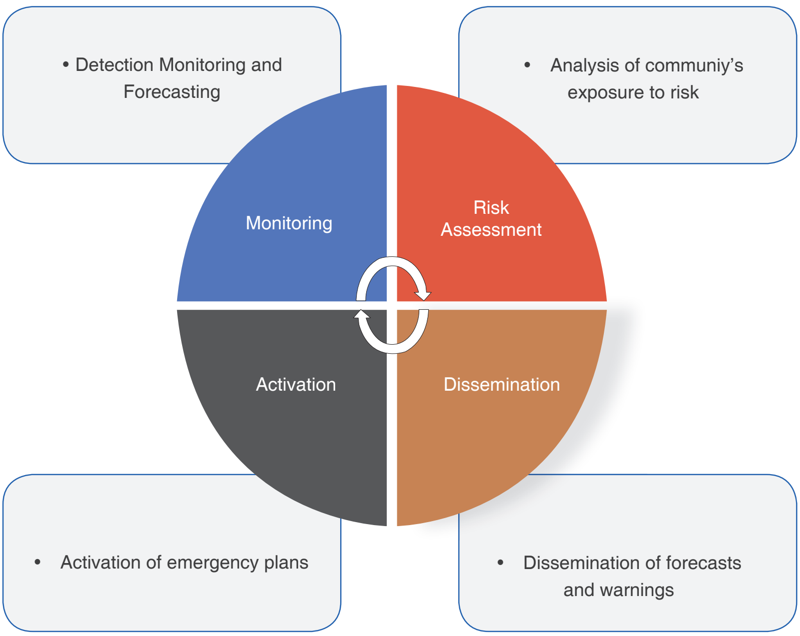


Figure 6. The four components of early warning system.

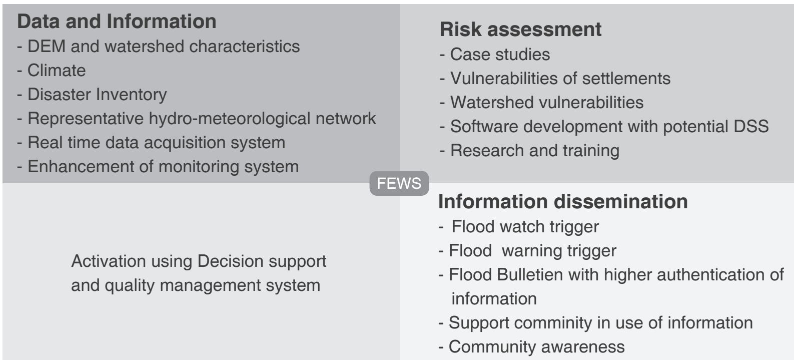


Figure 7. Practical aspects of the four FEWS components.

Based on the Sendai framework, flood forecasting needs to be integrated into multi-hazard early warning systems. Box 1 lists the 10 principles of a developing a multi-hazard early warning system as recommended by the World Meteorological Organization (WMO). The development of an SOP is primarily based on these same 10 principles. The essence of the 10 principles can be summarized in the form of a checklist and adjusted for the context of an SOP applicable in Nepal:

1) Organizational arrangement established;
2) Natural hazards identified;
3) Community vulnerability analysed;
4) Risk assessed;
5) Information stored in an accessible manner;
6) Monitoring system developed;
7) Forecasting and warning system established;
8) Decision making process institutionalised;
9) Effective communication system installed; and
10) Public awareness enhanced.

Based on the Sendai framework,flood forecasting needs to be integrated with multi-hazard early warning systems.

Disaster management has many possible applications of Management Science and Operations Research (MS/OR). Development of a Decision Support System (DSS) within a conceptual framework based on MS/OR can provide a sustainable operational procedure in FEWS (Mavalankar & Srivastava, 2008).

Developments in Nepal

> *A network of real -time stations has been established in Nepal using mobile phone technologies supported by Nepal Telecom (NTC) and Ncell Company*

Primary data obtained through real-time monitoring exists in Nepal and can be an important tool for developing a DSS. A network of real-time stations has been established in Nepal using mobile phone technologies supported by Nepal Telecom (NTC) and Ncell Company (Figure 8 and 9).

Figure 10 shows a real-time station network under the management of DHM, whereas Figure 11 illustrates an example of the equipment installed and the flow of information. Figure 12 presents the online display of a river watch system which is used to generate siren alerts marking critical stations in red. Figure 12 also presents the flood alert systems used by DHM that leverage the Internet and mobile devices for alert delivery.

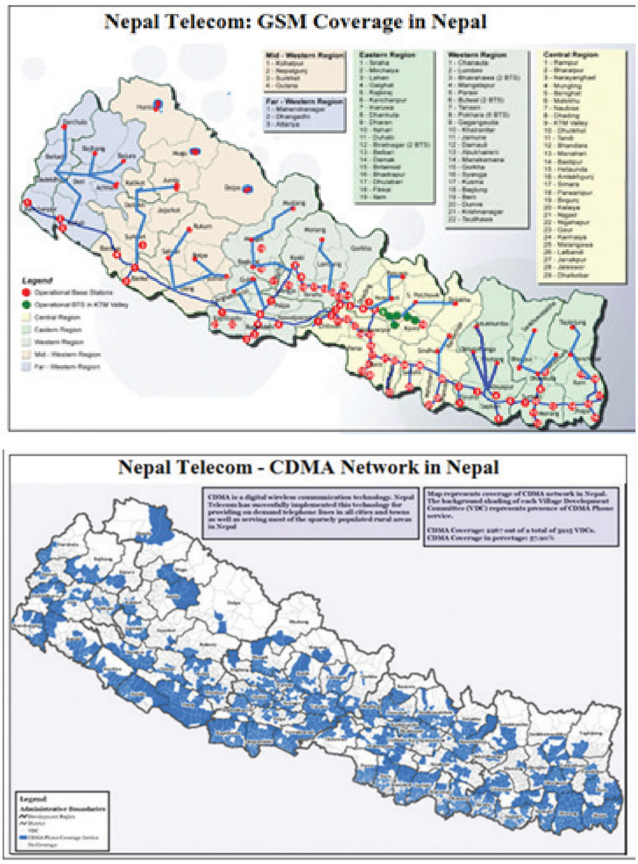


Figure 8. Mobile telecommunication Network under Nepal Telecom: Source: NTC

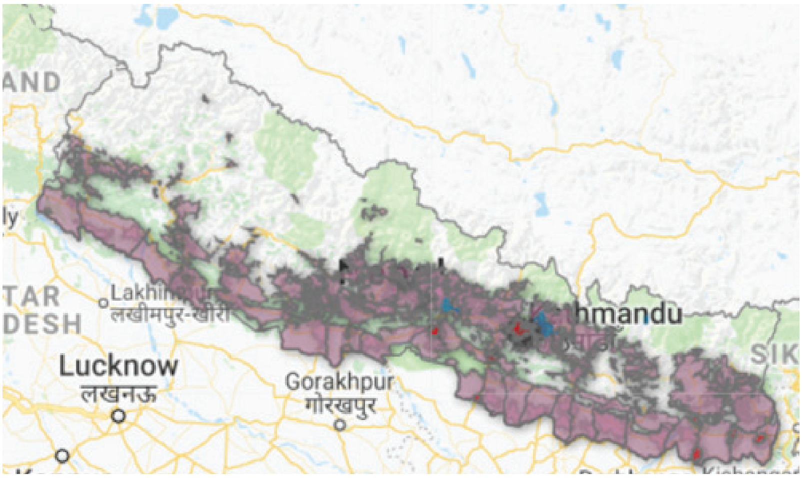


Figure 9. GSM coverage under Ncell-Axiata: Source Ncell

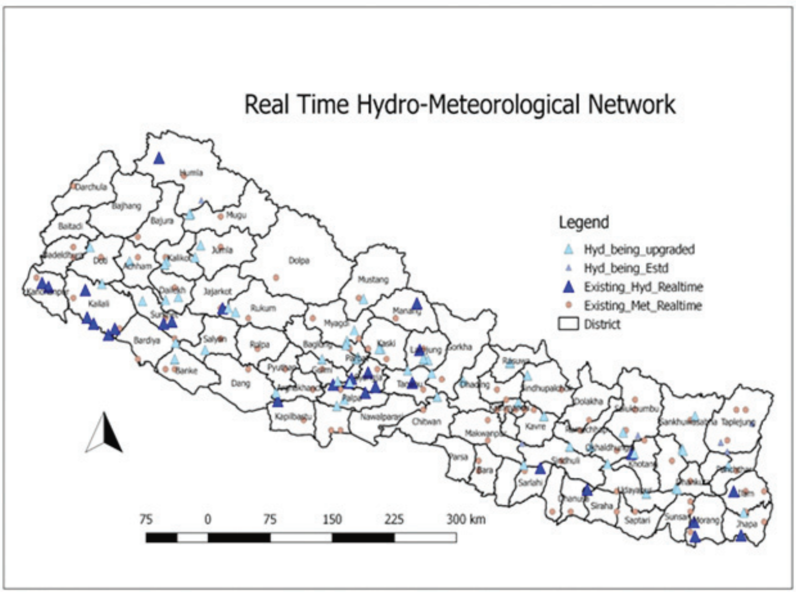


Figure 10. Hydrological and meteorological network of Nepal with online data system managed by DHM.

Figure 11. Existing real time data transmission system with online acquisition

Decision Support System (DSS) can be a significant tool to obtain required information by integrating meteorological model, hydrological model and hydraulic model.

Technological advancements in earth science, computer software and telecommunication systems have made it possible to prepare and issue forecast in a very short time. Decision Support System (DSS) can be a valuable tool to obtain required information by integrating a meteorological model, a hydrological model and a hydraulic model. To operate effectively, DSS may need detailed assessments of meteorological parameters (precipitation, evaporation), watershed parameters (soil, land-use, reservoirs, ponds and hydraulic constructions) and downstream parameters (flood plains, flood-prone areas, settlement patterns, infrastructures). DSS can be particularly helpful for avoiding false alarm as a double-check mechanism can be integrated into it.

The downsides of DSS are related to the challenges in its application. DSS is meant only for providing support; in other words, it cannot make decisions. Wrong outcomes can be produced if inaccurate, biased or wrong data is input into the system. Similarly, DSS scale dependency and resolution may not be adequate for decision making. Finally, while DSS is being considered as part of this study, the level of expertise and in-depth research needed for DSS development are two major prerequisites that require strong institutional support.

Display of river watch on internet

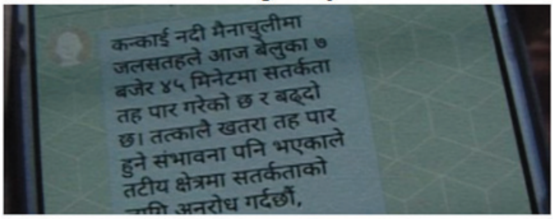
Indication of normal flows

S.N	Basin Name	Station Index	Station Name	Water Level (m)	Approx Flow (m3/sec)	Warning Level (m)	Danger Level (m)	Trend	Status	O & M by
1	Mahakali	105	Mahakali at Darchula (Dattu) Tue, Mar 20, 2018 4:45 AM	0.656	-	5.80	6.50	STEADY	BELOW WARNING LEVEL	DHM
2	Mahakali	178	Mahakali at Pargaon Tue, Mar 20, 2018 2:15 AM	1.67	-	5.80	7.00	STEADY	BELOW WARNING LEVEL	DHM
3	Karnali	259.5	Seti at Dipayal Tue, Mar 20, 2018 5:50 AM	1.234	-	8.60	9.00	STEADY	BELOW WARNING LEVEL	DHM
4	Karnali	280	Karnali at Chisapani (Water Level) Tue, Mar 20, 2018 4:45 AM	2.791	-	11.9	12.9	STEADY	BELOW WARNING LEVEL	DHM
5	Babai	289.95	Babai at Chepang Tue, Mar 20, 2018 5:40 AM	2.47	-	5.50	6.10	STEADY	BELOW WARNING LEVEL	DHM

Indication of warning level

7	239.95	Babai at Chepang 2017-08-13 07:35:00	8.54	-	5.50	6.10	Falling	Above Danger Level
8	291	Babai at Bhada Bridge 2017-08-13 08:15:00	9.30	-	7	8	Rising	Above Danger Level

SMS message in Nepali



Twitter message in Nepali

Nepal Flood Alert! @DHM_FloodEWS · 1 Sep 2017

आगामी २४ घण्टा देशैभरका चुरे र महाभारतबाट बहने नदीहरूमा बहाब बढ्ने अनुमान भएकाले नदी तटिय क्षेत्रमा बस्नेहरूलाई सतर्क रहनहुन अनुरोध ।

Flood Bulletin

बाढी पूर्वानुमान शाखा

E-mail: floodhydrology@gmail.com, Site: http://hydrology.gov.np Tel: 01-4428236, Toll Free: 1155

Facebook Page: Nepal Flood Alert (नेपाल बाढी सूचना), Twitter: @DHM_FloodEWS (Nepal Flood Alert)

बाढी पूर्वानुमान वुलेटिन

जारी मिति: १७ भाद्र २०७४, बिहान ६ बजे

आगामी २४ घण्टाको पूर्वानुमान

१) आज देशको अधिकांश भू-भागमा हल्का देखि मध्यम वर्षाको संभावना छ भने एक दुई स्थानमा भारी वर्षा समेत हुन सक्ने छ। आज राती पनि देशको धेरैजसो स्थानहरुमा हल्का देखि मध्यम वर्षाको संभावना देखिन्छ। (स्रोत: मौसम पूर्वानुमान महाशाखा)

Figure 12. Existing river watch and flood alert system at DHM

Ten principles common to development of Multi-Hazard Early Warning Systems.

1. There is a strong political reecognition of the benefits of EWS reflected in harmonized national and local disaster risk management policies, planning, legislation and budgeting.
2. Effective EWS are built upon four components:(i) hazard detection, monitoring and forecasting: (ii) analyzing risks and incorporation of risk information in emergency planning and warning:(iii) disseminating timely and "authoritaive" warning, and (iv) community planning and preparedness.
3. EWS stakeholders are identified and their roles and responsibilities and coordination mechanisms clearly defined and documented within national and local plans, legislation, directives, MOUs, etc.
4. EWS capacities are supported by adequate resources (e.g., human, financial, equipment, etc.) at the national and local levels and the system is designed and for long-term sustainability.
5. Hazard, exposure and valnerability information are used to carry-out risk assessments at different levels as critical input into emergrncy planning and development of warning messages.
6. Warning messages are; (i) clear, consistent and include risk information, (iii) designed with consideration for linking threat levels to emergency preparedness and understood by authorities and the population, and (iii) issued by a single (or unified), recognized and "authoritative" source.
7. Warning dissemination mechanisms are able to reach the authorities, other EWS stakeholders and the population at risk in a timely and reliable fashion.
8. Emergency response plans are developed with consideration for hazard/ risk levels, characteristics of the exposed communities.
9. Training on hazard/ risk/ emergency perparendness awareness integrted in various formal and informal educational programmes with regular drills to ensure operational readiness.
10. Effective feedback and improvement mechanisms are in place at all levels of EWS to provide systematic evaluation and ensure improvement over time.

Source: Institutional Partnerships in Multi-Hazard Early Warning Systems, Golnaraghi, M (Ed.), Springer Veriag Publishers, ISBN 978- 3-642-25372-0(2012).

Institutional Arrangement

The Ministry of Home Affairs (MoHA) has been designated as the lead agency responsible for disaster-related activities by the Natural Calamity (Relief) Act, 1982.

The Disaster Risk Reduction and Management Act 2017 (DRRMA 2017) proposed the creation of a high-level National Council for Disaster Risk Reduction and Management under the chairmanship of the Prime Minister, which is in its implementation phase. An executive committee under the chairmanship of the Minister of Home Affairs is responsible for implementing the plans and policies formulated by the council. The committee is supported by the National Disaster Management Authority (NDMA). NDMA is responsible for promoting EWS through research and development of the necessary technologies.

Province-level disaster management, as proposed by DRRMA 2017, will be executed by a provincial council under the chairmanship of the Chief Minister. The province-level council is mandated to develop province-level EWS and manage its operations.

Clause 11-T of DRRMA 2017 presents a list of disaster-related rights and duties of Nepal's local governments. The list includes the local governments' right to implement a disaster early warning system.

Ministry of Home Affairs

According to the Natural Calamity (Relief) Act of 1982, the Ministry of Home Affairs (MoHA) has been designated as the lead agency responsible for disaster-related activities. MoHA, in collaboration with DHM, has already established a web-based National Emergency Operation Centers (NEOC) in Kathmandu (Figure 13)

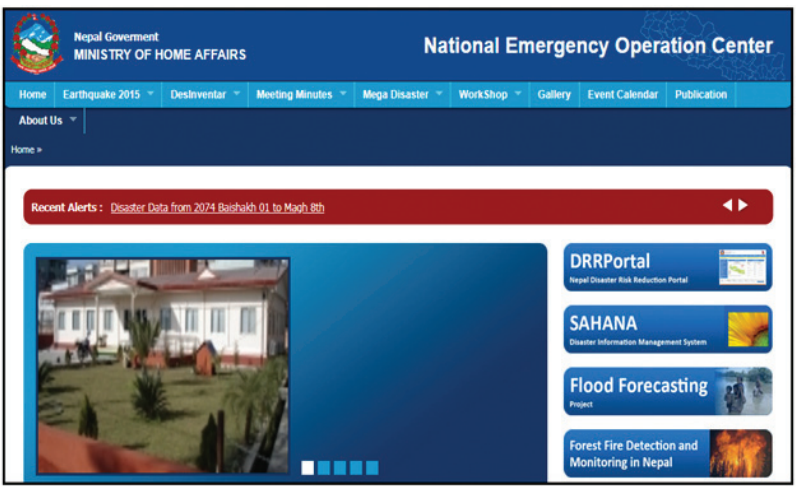


Figure 13. web site maintained by the National Emergency Operation Center at Singha Durbar, Kathmandu.

and District Emergency Operation Centers in 54 districts of Nepal tasked with coordination of disaster information systems. NEOC is open 24 hours a day all year. NEOC is managed by 14 employees, four of which are equipped with a radio set to ensure prompt communication.

Department of Hydrology and Meteorology

DHM is the designated government agency for predicting and disseminating weather-based forecasts and warnings. DHM has been maintaining a network of 28 hydrological stations and 88 meteorological stations equipped with telemetry system (Figure 10). DHM is further upgrading 59 hydrometric stations with telemetry and an additional seven stations are under consideration for this upgrade. In total, 182 hydro-meteorological stations are scheduled to become operational and use real-time data acquisition systems in the near future (Annex V; Figure 10).

The reorganized structure of the Government of Nepal implemented on 23 February 2018 has created the Ministry of Energy, Water Resources and Irrigation (MoEWI). DHM used to operate under the Ministry of Environment and Population but now has been brought under the wing of MoEWI with a mandate to provide weather and flood forecasts. With a new regulatory setup in place, DHM has also been mandated to develop EWS including its information dissemination component.

Based on its current mission and goals, DHM has a number of important responsibilities related to assessing and forecasting water-induced disasters such as floods, droughts and extreme weather events. DHM is also equipped to contribute to the assessment of other disasters such as landslides, severe winds, erosion and sedimentation. At this time, DHM maintains 175 stream gauging stations, 337 precipitation gauging stations, 68 climatological stations and 15 synoptic stations. The status of a flood forecasting center in DHM's organization chart is illustrated in Figure 14. Figure 15 shows the units within the Ministry of Home Affairs whose operations are related to flood forecasting and Figure 16 shows how disaster management is handled within a newly formed Province Number 5.

Based on the existing mandates, DHM has important responsibilities particularly in assessing and forecasting water induced hazards, such as, floods, droughts, and extreme weather events.

Major Supporting Institutions

The Ministry of Federal Affairs and General Administration (MoFAGA), previously known as the Ministry of Federal Affairs and Local Development (MoFALD), and the Department of Water Induced Disaster Management (DWIDM) are the two other government agencies handling programs related to disaster management. Neither of the two organizations deals with early warning systems but both are tackling several other cross-cutting issues within disaster management discipline including formulation of policies and organization of training programs and awareness-building activities. DWIDM operates under the Ministry of Energy, Water Resources and Irrigation and is responsible for disaster management through the management of watersheds and river training work. DWIDM has also been involved in managing disaster-related data and organizing regular training programs.

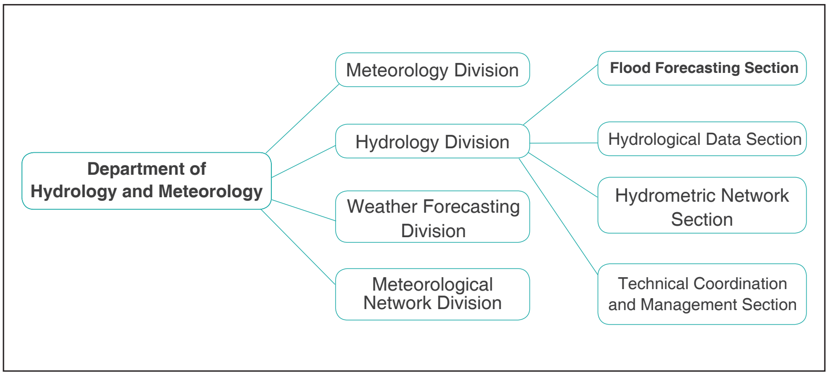


Figure 14. Position of Flood Forecasting Activity with the DHM's organization chart.

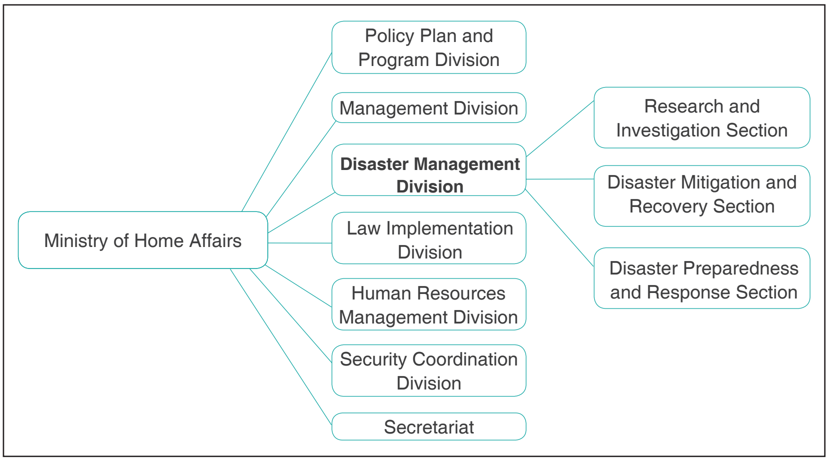


Figure 15. Position of Disaster Management in the organization structure of the Ministry of Home Affairs.

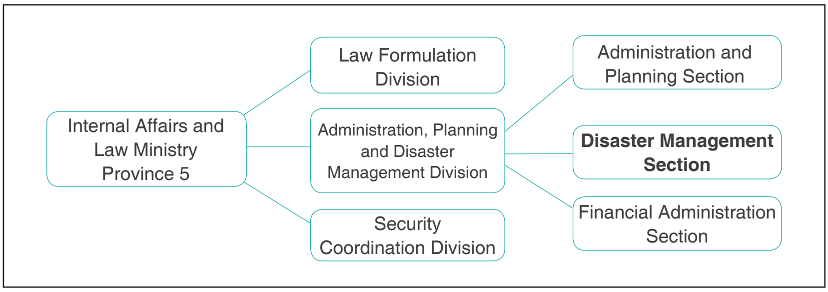


Figure 16. Position of Disaster Management within the organization chart of Province Number 5.

GAP Assessment

Although EWS is widely recognized as a potential solution to saving more lives and protecting properties during natural disasters, its success depends on effective implementation and execution of well-coordinated activities. Failures of EWS are often linked to failure of monitoring the network, scarcity of quality data, inadequate technical capacity, communities' poor access to forecasts and warnings and lack of accountability on the part of the implementing agencies. Such gaps can be minimized as a result of effective involvement of affected communities in all phases of FEWS development (Marchezini, et al., 2017).

One of the major gaps in FEWS is the lack of information of past events. In addition, existing infrastructures are frequently inadequate for properly assessing flood events. Information of past events is a major prerequisite for developing a reliable flood prediction system. One example is the flood data reported in publications issued by the Department of Water Induced Disaster Management (DWIDM) that combines flood and landslide information in one subheading while also reporting casualties and damages. However, there is room for improvement. For instance, the publications separate the reporting on landslides and avalanches, which could technically be combined in one group due to the similarity of the nature of these events. Also, the disasters reported in the DWIDM publications differ from the disaster definitions used in standard international reporting such as the Emergency Events Database (EM-DAT). The Government of Nepal needs to introduce a system of flood assessment that follows the standard international practices.

Failures of EWS are often linked to: failure of monitoring network, paucity of quality data, inadequate technical capacity,poor access of communities to forecasts and warnings, and lack of accountability of the implementing agencies.

The hydrological services of Nepal have been able to maintain a reasonable network of hydrometric stations covering the whole country. Nepal was also able to develop a database with records going back more than half a century, which can serve as a basis for planning and design of new natural disaster mitigation measures. A major gap in Nepal's hydrological services is their reliance on existing outdated infrastructure for the development of an operational flood forecasting system.

DHM has been able to establish a Flood Forecasting Section but they are operating with limited infrastructure which makes it difficult to build a fully operational flood forecasting and warning system. Also, the hydrological system of assessing flood damage immediately after the flooding event needs improvement. Current deficiencies in flood forecasting are being addressed through several projects such the Building Resilience to Climate Related Hazards (BRCH) project supported by the World Bank, the ICIMOD-supported HKH-HYCOS and Kailash Sacred Landscape Conservation Initiative (KSLCI) and UNDP-supported Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). In addition, to improve the efficiency of the flood forecasting and warning system, DHM is in the process of rethinking its structure and reorganizing the department with the support of human resources experts.

Because of recent changes in the political setup of the Government of Nepal, the Province Offices and local government offices (municipalities and rural municipalities) are in the process of being reorganized and reestablished. Although these government entities have various roles in disaster mitigation, the disaster sections of these offices are currently not operating. A typical organization chart of Province 5, which is still under review, shows how the Disaster Management Section that is headed by a Section Officer is intended to operate under the Secretary in charge of the Administration, Planning and Disaster Management Division (Figure 16). Nevertheless, the NEOC and DEOCs remain fully operational.

As shown in Figure 14 and the Section on Institutional Arrangements, DHM has been able to provide services for the general public and relevant agencies concerned with the mitigation of flood disasters. The services provided, however, are very generic and the information DHM makes available has a limited level of detail. There is an urgent need for DHM to become enabled to provide communities with customized products and information specific to their location. Disseminating flood information to every household within affected communities is one of the major challenges ahead.

Bottom-up approaches are limited in the existing infrastructural arrangement.

The effectiveness of a bottom-up approach is limited due to the existing infrastructural arrangement. No mechanism currently exists for regular interactions among DHM, service providers and communities and forecasting and warning service beneficiaries. There is a better chance of success if the process is demand-driven rather than supply-driven. Therefore, an efficient flood warning system needs to involve communities from the beginning planning stage all the way to the operational stage. When community members are engaged from the beginning, they have ample opportunity to get trained and thus raise their awareness level. Overall, the success of FEWS relies on the involvement of communities and local governments.

FEWS, however, is only one component of a flood control program. The other major component is the structural approach, which is being managed by DWIDM. Since what Nepal needs is an integrated flood management system, one major challenge consists of addressing and reconciling the diverse interests of key stakeholders involved. Coordination among different stakeholders can be a rather complex process.

The flood forecasting section under DHM is headed by a Senior Divisional Hydrologist. The section is run by five professional staff members and six hydrological technicians. Staffing is one of the major hindrance to the smooth operation of FEWS. The section needs to be upgraded to a departmental division level and it requires oversight from a higher level of authority and during flood season, it needs to be supported by at least five times as many staff members as it currently has.

Besides the need for appropriate infrastructure, other equally important elements of developing a reliable FEWS include education, skills and experience. Existing

DHM capacity is limited in all three of these aspects and needs to be strengthened through recruitment of qualified professionals and continued training and research.

FEWS is primarily based on the code-division multiple access (CDMA) and Global System for Mobile communication (GSM) technologies. CDMA technology has been used by NTC while the GSM technology is supported by other mobile providers in Nepal. Ncell is one of the companies with the largest GSM networks in Nepal. Both companies are providing services to DHM for real-time data acquisition. However, these service providers have several gaps in their network coverage (Figures 8 and 9). In these gap areas, the hydro-meteorological stations cannot transmit data on a real-time basis. Since these technologies are based on the line-of-sight communication, some of the hydrometric stations located in deep gorges do not have communication even within the area of their coverage.

Global and Regional Context of Flood Forecast

Development of remote sensing tools that can assess precipitation, watershed moisture conditions and river discharges is leading the hydrological forecasting on a global scale (Lettenmaier, Roo, & Lawford, 2006). Real-time global-scale flood assessment and flood prediction based on remote sensing have been described in the Section on International Initiatives.

All South Asian countries are dominated by monsoons which are mesoscale processes that often become the key driving force behind floods in the region. Joint efforts to deal with disasters have already been highlighted during South Asian Association for Regional Cooperation (SAARC) forums and the need for collaboration lead to the establishment of SAARC Disaster Management Center (SDMC) in India. In addition, several regional activities focused on sharing flood information have been put in place, with some of them being bilateral arrangements and others being multilateral with inputs from international organizations.

Cooperation in the region is primarily based on bilateral arrangements; although regional and international organizations, such as WMO and ICIMOD are attempting to develop a regional database system with some success in providing flood information in the Hindu Kush- Himalayan region.

Floods plays an important role in highland-lowland interaction. Increasing floods in the highlands of the Hindu Kush-Himalayan region can have adverse impacts on the low-lying plains of the Ganga-Brhmaputra basin. Such impacts are not limited to flood-caused damages but also include increased soil losses in the highland areas and sediment deposits in downstream areas. Direct impacts of such changes caused by increased intensity of precipitation and increased flood magnitudes in the context of climatic changes are losses in agriculture production, losses in reservoir storage, changing courses of rivers and damages to flood control and other hydraulic structures on and along the rivers.

Countries in the South Asian region are cooperating with each other to improve the sharing of meteorological and hydrological information. At this time, however, the information shared is only used for flood forecasting purposes. Notable developments of these collaborative efforts between Nepal and neighboring countries have been reported by the Bangladesh-Nepal Joint Study Team (MoIWF/MoWR, 1989) and in the Nepal India Flood Forecasting Master Plan (DHM/CWC, 2004). Besides, such cooperation in the region is primarily based on bilateral arrangements; although regional and international organizations such as WMO and ICIMOD are attempting to develop a broader regional database that would enable the countries to share more flood-related information and do so more efficiently.

Sustainability

Sustainability is one of the central concerns of FEWS because of the application of modern technologies and the involvement of multiple stakeholders. Sustainability needs to consider three major factors: affordability, motivated and trained human resources and communities with high-level of awareness.

FEWS must be developed using affordable technologies. Certain higher-level investments may be difficult to avoid as they may be required for the system to be effective, but the running costs should be manageable for the long-term success of FEWS. For instance, a high-resolution Digital Elevation Model (DEM) is essential for reliable floodplain mapping in the Terai, which may not be achievable with freely available cheaper DEMs. Developing a high-resolution DEM is a one-time cost that is worth the investment. However, the DEMs up to the resolution of 12 m can be downloaded online free of cost and should have sufficient quality to provide reasonably accurate inundation modeling for Nepalese watersheds. Higher resolution DEMs must only be acquired for some flat vulnerable floodplains.

The system must be developed on the base of affordable technologies. Some level of high investment in an initial phase may be difficult to avoid for an affective system but running cost should be manageable for the long-term success.

Hydrological models, hydraulic models and Geographic Information System (GIS) are all available through web-based systems and often come with necessary support literature and instructions. Therefore, to ensure the system's long-term sustainability in a country like Nepal, it is not advised to use high-cost software when a cheaper or even free option is available and meets the need. A major disadvantage of acquiring high-cost software is its limited application in terms of the number of platforms it can be used on and recurrent annual license fees. On the other hand, open source software can be installed on an unlimited number of computers giving more people an opportunity to use it.

Some examples of open source software that is widely used by hydrologists and meteorologists include HEC-HMS for hydrological modeling, HEC-RAS for flood propagation modeling in floodplains and QGIS for spatial modeling. HEC-based software also comes integrated with a database management software that could be used directly to run the HEC-based program which saves input-data preparation time.

One of the major challenge associated with managing FEWS is the maintenance of the telemetry system. Flood forecasting centers need to work closely with national telephone service providers to ensure effective operations of their network. Failure of the telemetry parts of a monitoring system can be avoided by outsourcing some of the telecommunication tasks where DHM may not have adequate capacity.

Gender Issue

"Women and vulnerable groups should not be seen only as victims of emergencies but also as critical change agents who can and do make a significant contribution at each stage of any early warning system."

Involvement of women in Community-based Disaster Management Committees can be very encouraging. The visited sites in Nepal's Parasi district indicated a high level of involvement of women in CDMCs. The percentage of female members exceeded 60 percent in one of the CDMCs (Annex IV). Participation of female members of community shows their enthusiasm and women's involvement supports the gender inclusive philosophy of the Global Crisis Response Support Program (GCRSP) which states that "Women and vulnerable groups should not be seen only as victims of emergencies but also as critical change agents who can and do make a significant contribution at each stage of any early warning system (GCRSP, 2017)."

Participation of people of diverse ethnicities could be observed in all the visited CDMCs, although local population was dominating the group. For instance, the visited CDMC in the northern part of the Susta Rural Municipality (Mahalbari) was dominated by hill-origin people, whereas the southern part of the Rural Municipality was dominated by Madhesis.

Compared to community-level staff, women were less widely represented in the central offices. The DHM staff only had about 20 percent of women. The percentage of women occupying the part-time gauge reader positions in DHM was only about 10 percent.

Strategies

When a disaster is approaching, every minute is important and no time can be wasted. Preparedness is paramount to ensure flood-related information is delivered quickly and affected communities receive the forecasts and warnings without hindrances or delays. Below is a list of strategies necessary for proper preparedness and successful operation of FEWS:

1) Establish process ownership among key stakeholder involving them in all phases of FEWS development and implementation.
2) Create tailored warning messages. For instance, the existing system of flood watch used by DHM generates a siren at all DEOCs when water level exceeds the set flood warning level anywhere in Nepal.
3) Avoid cluttered information on display board and web page. The website should provide the most relevant information but keep the message short and clear. Administrative users could have an added capacity to obtain addition data on the screen.
4) Incorporate the use of flags along with flood information.
5) Implement principles and nomenclature consistent with international practices.
6) Institute local level awareness programs.
7) Achieve active participation in national and international flood disaster mitigation programs (workshops, seminars etc.) for sharing of experiences and best practices.
8) Investigate major flood events and make learnings available in publications.
9) Maintain a resourceful website that provides opportunities for user feedbacks and serves as a forum for sharing of experiences and information.

Every minute is important as we need to deal with disastrous situations. Preparedness is,hence,the most important strategy to deliver flood related information,forecast and warnings to the communities overcoming any possible hindrances.

A flood forecasting center must be running around the clock (24/7) during flood seasons. Since a center needs to operate full-time during the southwest monsoon season (Mid-June to Mid-October), the center's staff can dedicate more of their time during the rest of the year to enhancing flood forecasting and information dissemination systems. In addition, any developed strategy should include a backup plan for every component of FEWS.

Strategy for GLOF Warning

A Glacial Lake Outburst Flood (GLOF) is a sudden outburst causing catastrophic flooding with huge amount of sediment transport that can change the river morphology. ICIMOD lists 24 GLOFS that occurred in Nepal in the past causing loss of life and resulting in damages to villages, bridges, roads and farmlands (ICIMOD, 2011). The report also identifies 21 potentially dangerous glacial lakes.

The Tsho Rolpa and Imja glacial lakes are some of the most dangerous lakes being studied in detail by DHM. DHM has provided an automated EWS in downstream areas of these lakes.

Forecasting of the formation of glacial landslide dammed lake and its breaching time is practically difficult to achieve,however, such events can be monitored with the help of satellite images.

Since the time of an outburst has a very low predictability, EWS needs to be based on a triggering mechanism. Since such warnings need to reach communities quickly without there being time to verify the threat first, automatic self-verification systems need to be installed. A system of multiple self-verifications is useful to avoid false warnings. This is a practical strategy for mitigating potential GLOF disasters and downstream impacts of a situation similar to a dam breakdown can be modelled for preparedness.

Another process comparable to GLOF are the Landslide Lake Outburst Floods (LLOF) which are common in the mountainous areas of Nepal. Such impoundments may last from a short period of time to several hundred years, making it difficult to integrate them into a flood forecasting system. An LLOF may occur because of a heavy rainfall that triggers landslides or it may be associated with rock avalanches as observed on 2 August 2014 in the Sindhupalchok district. The rock avalanche was responsible for submerging a hydropower station on the bank of the Sunkoshi river that was storing about eight million cubic meters of water (DoI, 2014). Aside from damages and lost properties, this event resulted in 156 deaths. Another example of a LLOF is the 1968 event on the Budhugandaki river that generated flooding that exceeded 5,000 m3/s following a breach after three days of ponding (DHM, 1969). Accurate forecasting of the formation of landslide dams and their breaching time is very difficult to achieve, however, such events can be monitored with the help of satellite images. Inundation modeling could be a useful tool to provide flood advisory in downstream areas. Continuous monitoring of a remote sensing analysis system within DHM is beneficial for monitoring both GLOFs and LLOFs.

Backup System

Major problems in an operational FEWS have to do with failures of telemetry systems that are usually the result of a power failure, poor charging of power supplies at telephone towers, washing away of monitoring stations, failure of hydro-meteorological monitoring sensors or disruption of Internet connectivity. Such situations may create havoc as the agencies running the FEWS have to deal with inadequate information when speed and accuracy become most urgent. For this reason, flood forecasting centers need to be equipped with backup systems that can help protect FEWS from a complete collapse. Some of the suggested backup systems include:

Flood forecasting centres need to be equipped with backup systems that can help saving FEWS from complete collapse.

1) Adequate power backup at the forecasting center
2) Dedicated Internet supplier
3) Access to regional and international facilities to access analyses of atmospheric processes made available via Internet
4) Connecting local observers and members of CDMC to local police posts where help can be requested via voice communications through a wireless sets (SSB transmission)
5) GSM system at monitoring stations configured to use alternate service providers in case of a failure of one system
6) Providing a satellite-based telephone system at one location, at least, on all major basins and most vulnerable areas. Although such systems are relatively expensive, prices are coming down with recent technological developments and growing competition among service providers. Two stations each in eastern Nepal, central Nepal and western Nepal could provide reasonable coverage for generating approximate forecasts in case of failure of available GSM.

Preparatory Stage

Preparation is necessary for the operational FEWS before flood seasons so that floods forecasts and warnings can be generated without any obstacles.

Careful preparation before the flood season is necessary for the FEWS in order to guarantee that flood forecasts and warnings can be generated without any obstacles. It is important to achieve the best possible accuracy with the maximum lead time available and avoid any false alarms. Some of the prerequisites for the FEWS preparation process are as follows:

1. Mapping flood-prone areas and assessing their level of vulnerability.
2. Mapping key stakeholders, relevant experts and coordination mechanism. Besides vulnerable populations and infrastructures, stakeholders may include managers of water resources projects.
3. Establishing close links with major international and regional flood-related websites and organizations such as WMO, RIMES, ICHARM, NOAA, SDMC, the University of Colorado, etc.
4. Developing a Decision Support System (DSS) to help make warning decisions as computer software can handle complex processes in short time intervals and provide information on uncertainty indicators. DSS may simultaneously take advantage of multiple approaches to flood forecasting.
5. Creating a well-defined quality management system in all components of flood forecasting cycle including observation, data transmission, modeling and information dissemination.
6. Establishing a feedback mechanism based on experiences of stakeholders.
7. Conducting annual assessment of FEWS before and after the implementation of programs based on feedback received from affected communities and implementing agencies.
8. Conducting computerization of all catchment characteristics required for hydrological and hydraulic modeling.
9. Determining lag time of the watershed to adopt the best time interval for modeling. It will help to decide the best forecast and warning lead time.
10. Developing DEMs with highest resolution possible, suitable for small watersheds as well as large catchments considering the time required for computation. GIS system is an essential aspect of a DEM, hence it should be integrated into FEWS.
11. Selecting models, which need to be flexible in terms of data need and missing data.
12. Selecting simple black-box models as backup for deterministic hydrological models. Such models could be gauge correlation models or antecedent precipitation index models widely used in hydrological forecasting.
13. Enhancing hazard forecasting capabilities by taking advantage of additional data, observations and experiences.

Figure 17 presents the basic concept used in FEWS. A simple configuration of the FEWS is illustrated by the model in Figure 18. Details of the flood forecasting aspects of an SOP within DHM are illustrated in Figure 19.

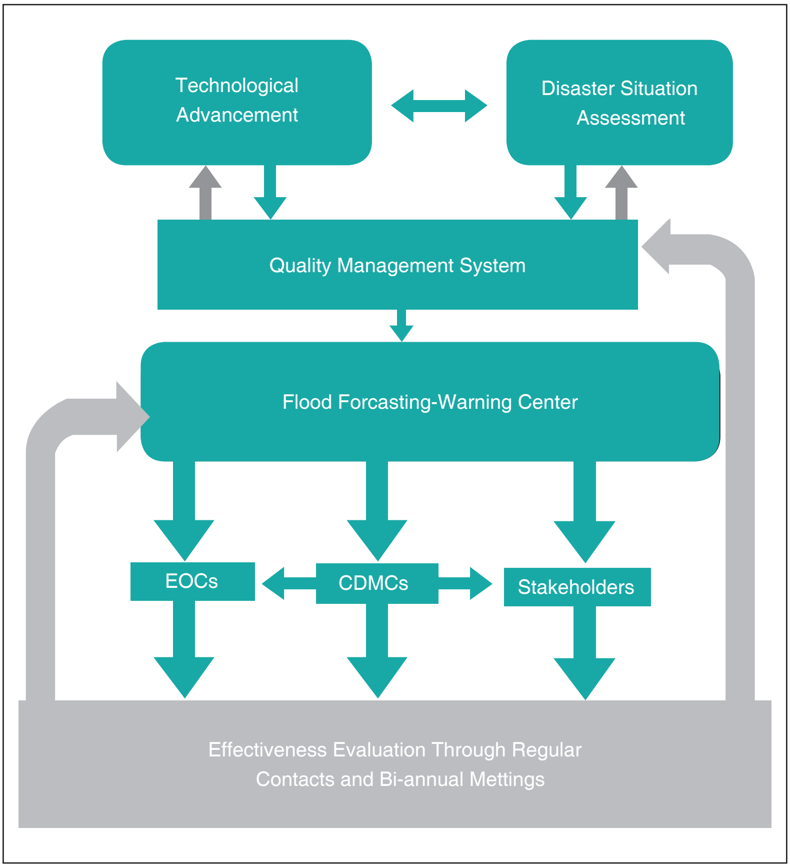


Figure 17. Feedback mechanism in the information flow diagram of SOP.

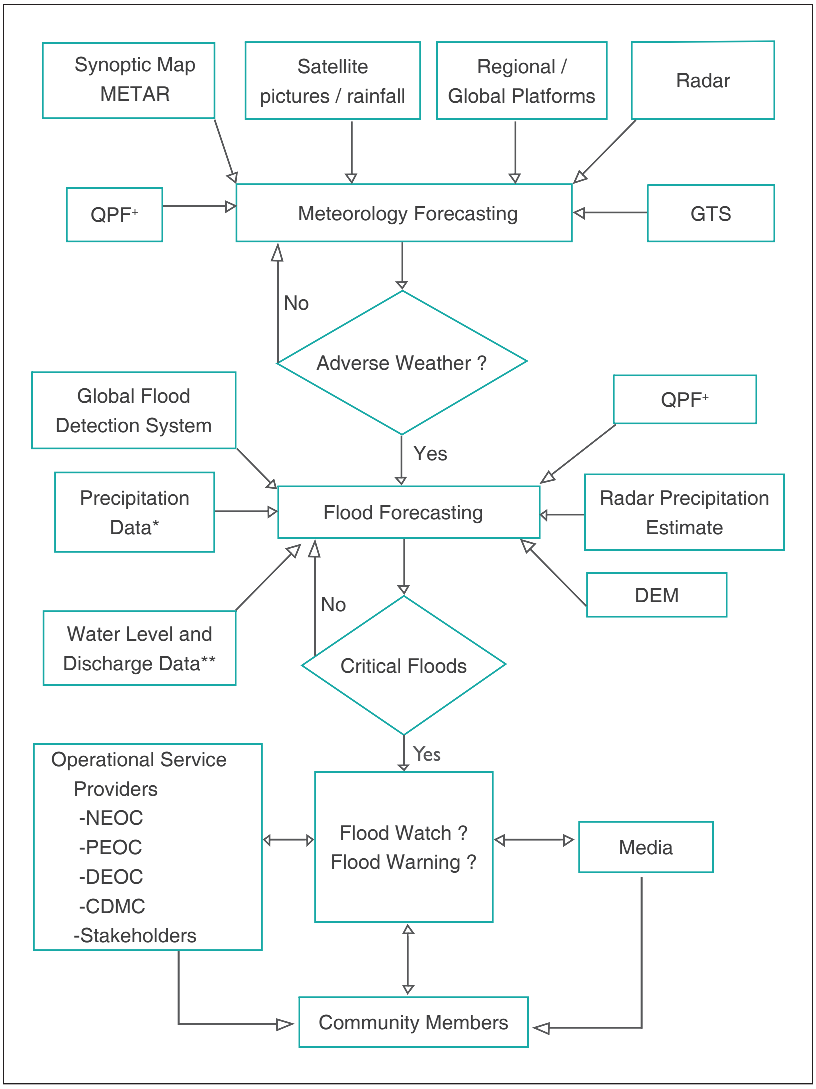


Figure 18. Flow diagram of a generated warning dissemination system.

** Preferably 1-hour interval * Preferably 15-minute interval

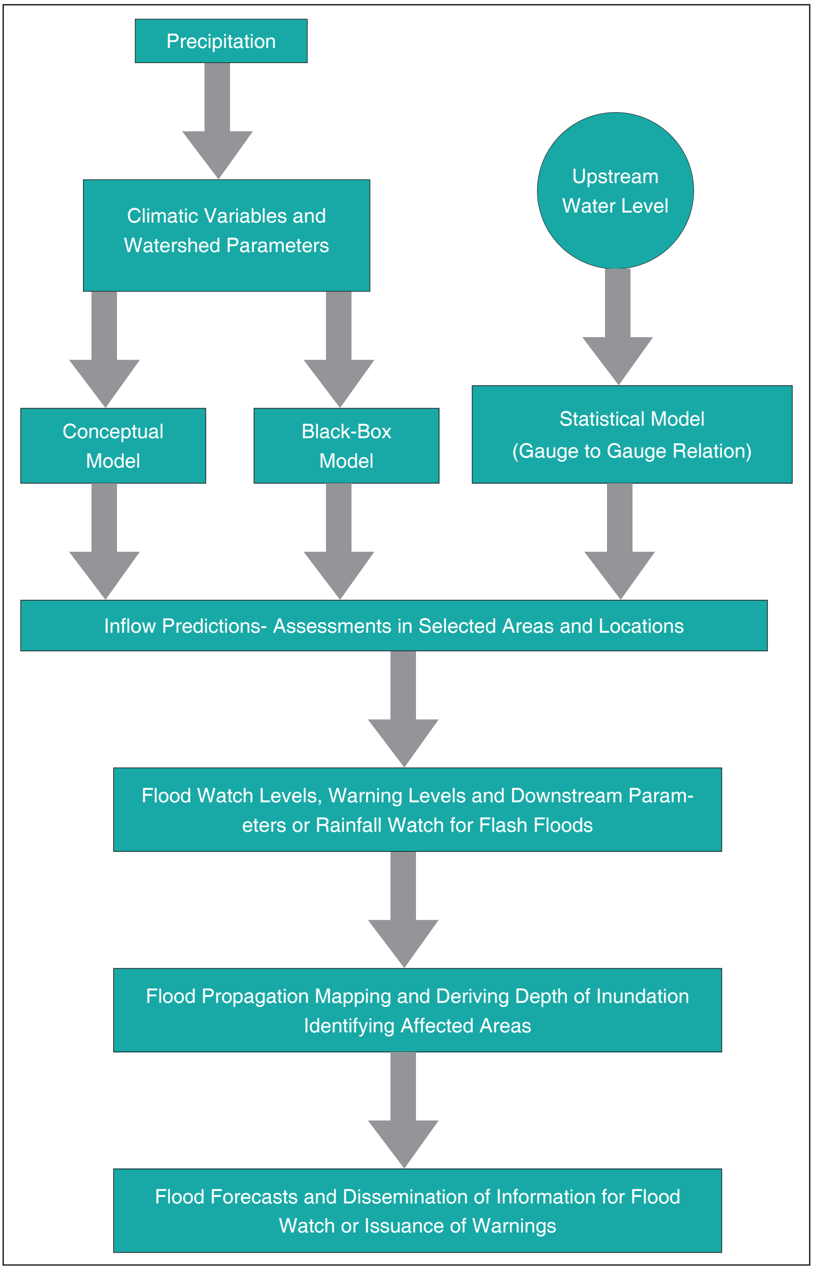


Figure 19. Flowchart of flood forecast and dissemination

Figure 20 presents the general composition of a flood warning center and identifies the minimum requirements for running FEWS. The figure also indicates the required expertise and lists the responsible parties. The individual in charge of the center will be responsible for overall activities of the center.

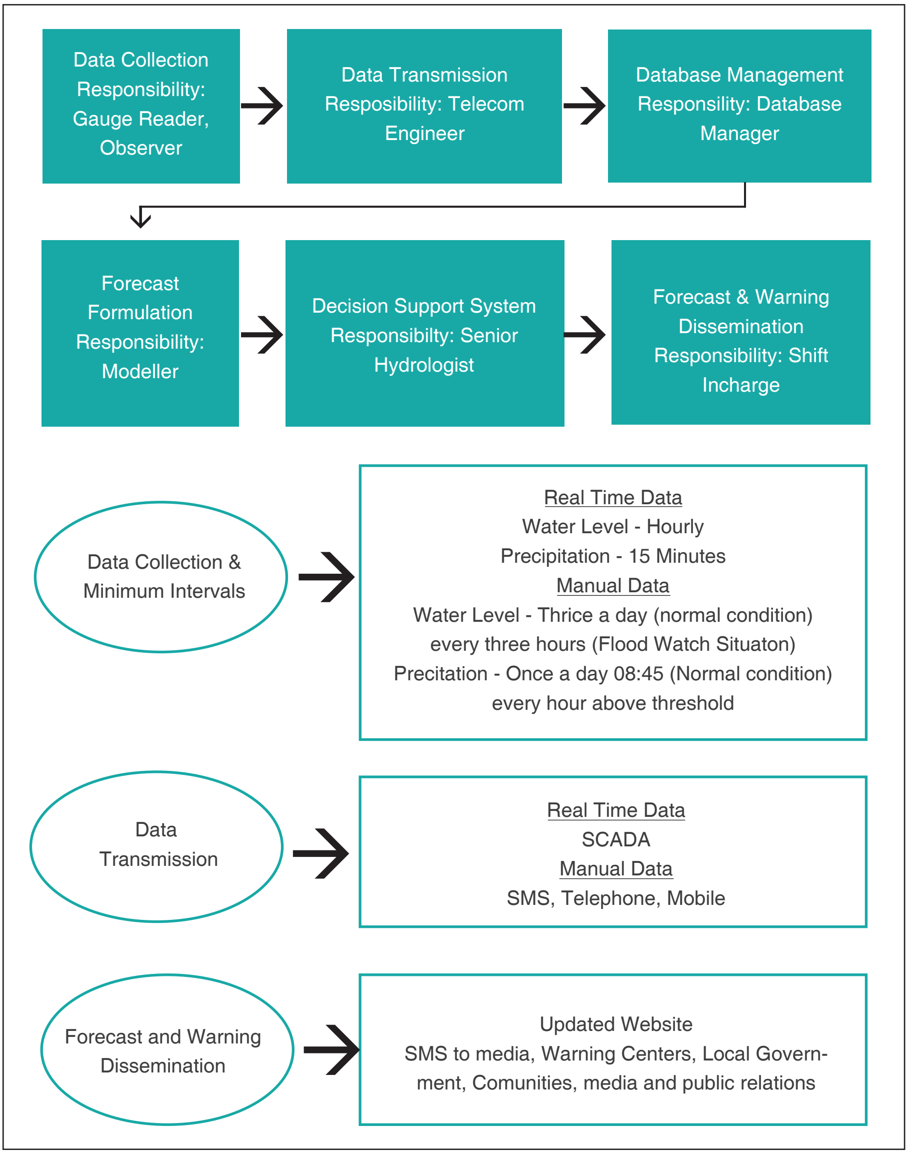


Figure 20. SOP within the flood forecasting centre.

Flood Information Dissemination

Flood information is disseminated via Internet, display boards and SMS when the water level crosses a specified flood watch mark. Flash flood information is disseminated when three-hour precipitation exceeds a threshold value specified for a given precipitation station or, alternatively, using a black-box model such as an API model. Flood information dissemination has three major stages:

1) Flood Watch: Be prepared to act.
2) Flood Warning: Act. It suggests acting in response to advisories. Detailed advisories are disseminated and contain the detailed actions necessary for safety.
3) Severe Flood Warning: Act in cooperation with others. It suggests a serious flooding situation when access to basic utilities is lost. It will be necessary to cooperate with agencies involved in emergency services.

Flood Watch: Be prepared to act.

Flood Warning: Act in response to advisories.

Severe Flood Warning: Act in cooperation with others including emergency services.

Box 2: Water Power
15 cm of flowing water can carry away an adult
30 cm of flowing water can carry away small cars
50 cm of flowing water can carry away large vehicles
Source: NWS-NOAA

Figure 21 presents the situational assessment of riverine flow. Flood watch information and warning information may be disseminated to communities and relevant agencies.

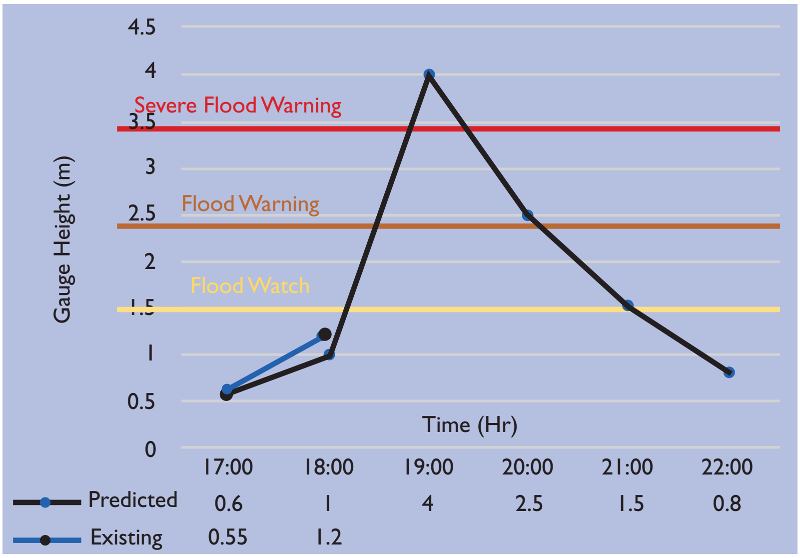


Figure 21. Example of a proposed display in website after selecting the station for riverine floods

In the case of flash floods,flood watch levels and flood warning levels need to be triggered based on the amount of precipitation in a suitably selected duration or on Antecedent Precipitation Index (API)

Hydrometric monitoring is usually not practiced on small streams and rivulets. However, several of such streams have potential to generate flash floods. A typical examples are the streams originating in the Siwaliks. Floodplains of such streams are illustrated in Figure 28. In these scenarios, situational assessments of flash floods are not practical based on the monitoring done by hydrometric stations. Flood forecasting in such catchments must be based on rainfall stations. In such situations, instead of watching water levels, flood watch levels and warning levels need to be determined based on the amount of precipitation over a selected duration (Figure 22) or Antecedent Precipitation Index (API) as presented in Figure 23 (Linsley, Kohler, & Paulhus, 1988). A threshold value of rainfall may depend on the location of a rain gauge and the season. Figure 25 presents the proposed flags that can be displayed along with the forecasts as a quick visualization tool that helps indicate vulnerable areas. Figure 24 offers a proposed modification to the data display system on the DHM website to suit the requirements of a flash flood watch system.

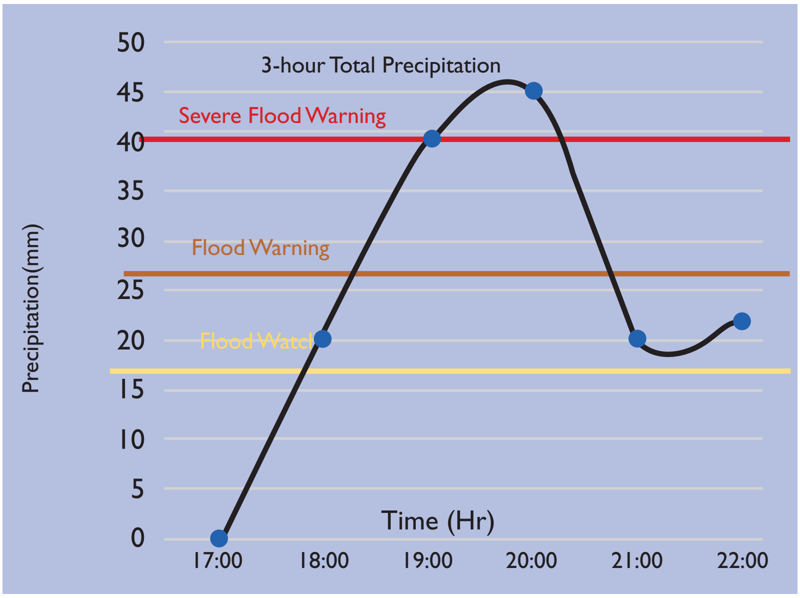


Figure 22. Example of a proposed display in in website after selecting a precipitation station for flash floods.

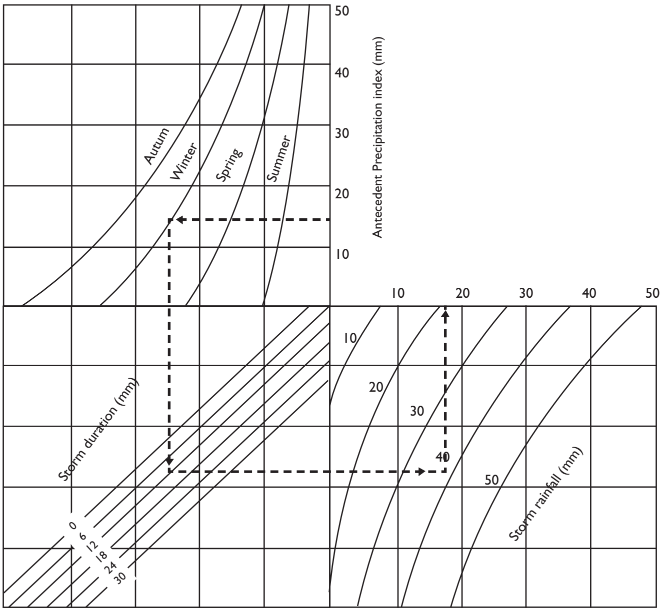


Figure 23. Antecedent Precipitation Index (API) model.

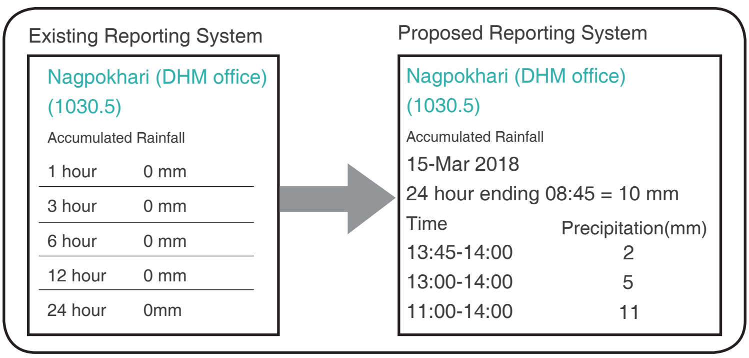


Figure 24. Proposed changes in the existing online precipitation data display system.

Be prepared for the worst	
Move valuables and pets to safe area; turn off gas; shut sown electricity and coperate with neighbours and incapables	
Be ready with flood plan listening media; be informed calling flood information centres	
No flood watch Necessary	ALL CLEAR
Avoid flood zone during the flood warning and flood watch period	
Move to or remain in safe places during flood warning	
Follow the direction showing evacuation route	

Figure 25.Recommended informative flags for display at identified locations in vulnerable areas.

FEWS Operation Responsibilities

Operational responsibilities of the major stakeholders can be explained as presented in Table 4.

Table 4. Proposed responsibilities for different components of FEWS

Component	Task	Responsibility
Monitoring	Provide manuals, guidelines, trainings and instructions for quality management of EWS operations for riverine floods, flash floods and GLOFs	Flood Forecasting Section (Division), DHM
	Operation, maintenance and upgrading of stations; maintenance of hydrological and meteorological equipment	Provincial DHM offices
	Operation of telecommunication tools and software management	Outsourcing with supervision from DHM
	Maintain and operate manual observation systems at monitoring sites	Community
	Processing data received from a telemetry system and manual observation with necessary validation and processing	Flood Forecasting Section (Division), DHM
	Development of high resolution DEMs	DHM
Risk Assessment	Hydrological and hydraulic modeling using alternate means using simple as well as complex models for comparing results and for quality management	Flood Forecasting Section (Division), DHM
	Floodplain mapping and risk identification with adequate field verification	Flood Forecasting Section (Division), DHM
	Obtaining additional support from Common Alerting Protocols (CAP) such as the Google alert and GFDC: (http://floodobservatory.colorado.edu/DischargeAccess.html) (https://google.org/publicalerts).	DHM
Forecast dissemination	Disseminate flood watch, warnings and severe flood warnings to communities and relevant agencies	DHM, NEOC, DEOC/PEOC
	Feedback through self-assessment and obtaining comments and reviews from beneficiary communities	Flood Forecasting Section (Division), DHM
Capacity Building	Training	Training Section, DHM
	Awareness Programs: piloting, preparation of awareness materials, seminars, workshops and interaction programs, mock-drill exercises, etc.	All key stakeholders and NGOs
	Provide aid to handicapped members of community	Local government and NGOs
	International collaboration and management of information (DSS, GFDC, QPF from RIMES, NOAA, TRMM etc)	DHM
Coordination	Coordination among major stakeholders involved in flood forecasting and warning dissemination; social mobilization	DHM and NGOs

Feedback Mechanism

Feedback helps to review FEWS for its reliability,accuracy and usefulness.

Feedback mechanism should include self-assessment as well as responses from stakeholders and communities. Feedback helps to review FEWS and assess its reliability, accuracy and usefulness. Table 5 template may be used for self-assessment of predictions including the level of uncertainty.

Table 5. Self-assessment of the accuracies and uncertainties of flood forecasts and warning.

Date	River	Site	Province	Flood Alert Level (m)	Flood Warning Level (m)	No of Flood Watch Issued	Accuracy of Warning Level (%)			No of warning issued	Accuracy of Warning Level (%)		
							Ave	Max	Min		Ave	Max	Min

Communities need to be asked about their impressions about the usefulness of FEWS. Interaction programs may be used as platforms to ask participants to complete the survey in Table 6.

Table 6. Format for obtaining feedbacks from communities and stakeholders.

Name	Contact Number	Impression about EWS	Quality of service	Level of involvement in the process
. . . . .	. . . . . .	a) Received forecasts, warnings and information when needed b) No information received when needed. c) Not applicable	d) Satisfied with the system e) Not satisfactory f) Not applicable	g) Active involvement h) Satisfactory involvement i) No involvement

Communities should be encouraged to establish a weather and river monitoring system that could equip them with important information. Such data may not need to be included in the DHM network but could nevertheless provide valuable additional insights. Educational institutes at local levels such as schools, colleges and research institutions should be encouraged to establish hydro-meteorological monitoring systems for educational and research purposes. Aside from generating fact-based information, such activities will contribute to awareness-building at a local level. Communication with communities should also be established via phone for obtaining field-level data and information useful for updating flood forecasts during a flood watch situation. Pre-monsoon meetings and post-monsoon meetings could be organized on a regular basis to obtain feedback from stakeholders.

Conclusions

The climatic system of Nepal has created a strong need for disaster preparedness. Floods generally occur during the four months of Southwest monsoon season. The remained of the year is fairly dry and has ideal conditions for all preparatory work such as data analysis, model developments, training, awareness campaigns, interactions among stakeholders and communities, etc. The opportunities this timing provides should be fully utilized for the continuous enhancement of FEWS in Nepal.

Flood forecasting and warning systems are a widely accepted means of flood disaster mitigation. FEWS is a non-structural measure with huge potential to save lives and protect properties.

Since most of the rivers of Nepal are relatively small,real time data is the most important prerequisite for a reliable flood warning system.

In the case of Nepal, the infrastructure required for an efficient flood forecasting system is still in its infancy; however, it has drawn a lot of attention from the Government of Nepal and there is strong interest in its implementation. Building Resilience to Climate Related Hazards (BRCH) is one of the major projects implemented by the Government of Nepal from 2013 to 2018. The project has been successful in developing the infrastructure necessary for nation-wide real-time data acquisition.

Since most of the rivers in Nepal are relatively small, real-time data is the most important prerequisite for a reliable flood warning system. Recent advancement in data transmission through mobile technologies and advents in computing systems have made it possible to implement and manage a flood forecasting system even with fairly limited resources. Furthermore, the continuously improving accuracy and resolution of DEMs have provided ample opportunity for capability improvements of hydraulic modeling. Figure 26 summarizes the processes required for an operational FEWS.

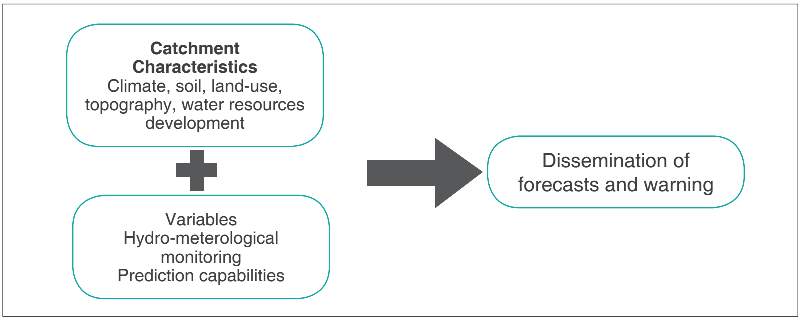


Figure 26. A simplified model of processes required for a FEWS.

An effective FEWS primarily depends on the quality of the hydro-meteorological monitoring network. Major emphasis should be placed on developing a representative precipitation network supported with a high-resolution DEM for hydraulic modeling. A detailed survey of vulnerable areas is necessary and participation of community members in identifying the vulnerable areas is preferred. Research and development of hydrological tools with best approaches to identifying hydrological parameters should be the key components of FEWS. Benefits of an early warning system depend on the response programs. If warnings do not reach the beneficiary community and relevant agencies in time, such systems are not worth investing in.

Continued research, training and awareness programs are the keys for developing and updating FEWS.

Continued research, trainings and awareness-building programs are key for developing and updating FEWS. Since the major activities are within the jurisdiction of DHM, facilities at DHM should be upgraded for this purpose. Since flood forecasting staff need to be actively involved in flood forecasting and warning dissemination tasks during summer monsoon season, they can dedicate more of their time during the remained of the year to research. Research and development in this sector are especially important in the context of rapidly changing technologies and advancements in software development. A Research and Investigation Section already exists at the Disaster Management Division under MoHA and DHM should leverage it and collaborate on joint research activities.

Involvement of communities must be ensured during all phases of FEWS development and implementation. The role of community members is particularly important during the delineation of vulnerable zones. Community-based disaster management units are particularly helpful in the operation of field stations and dissemination of flood forecasts and warnings.

Regular interactions among communities and major stakeholders must be organized and incorporated into annual programs under FEWS. Feedback from users of the FEWS services can contribute towards the enhancement of FEWS. SOP must be revisited and reviewed on a regular basis, taking into account the interactions with stakeholders, changing organizational strengths and latest advancements in the field of hardware and software.

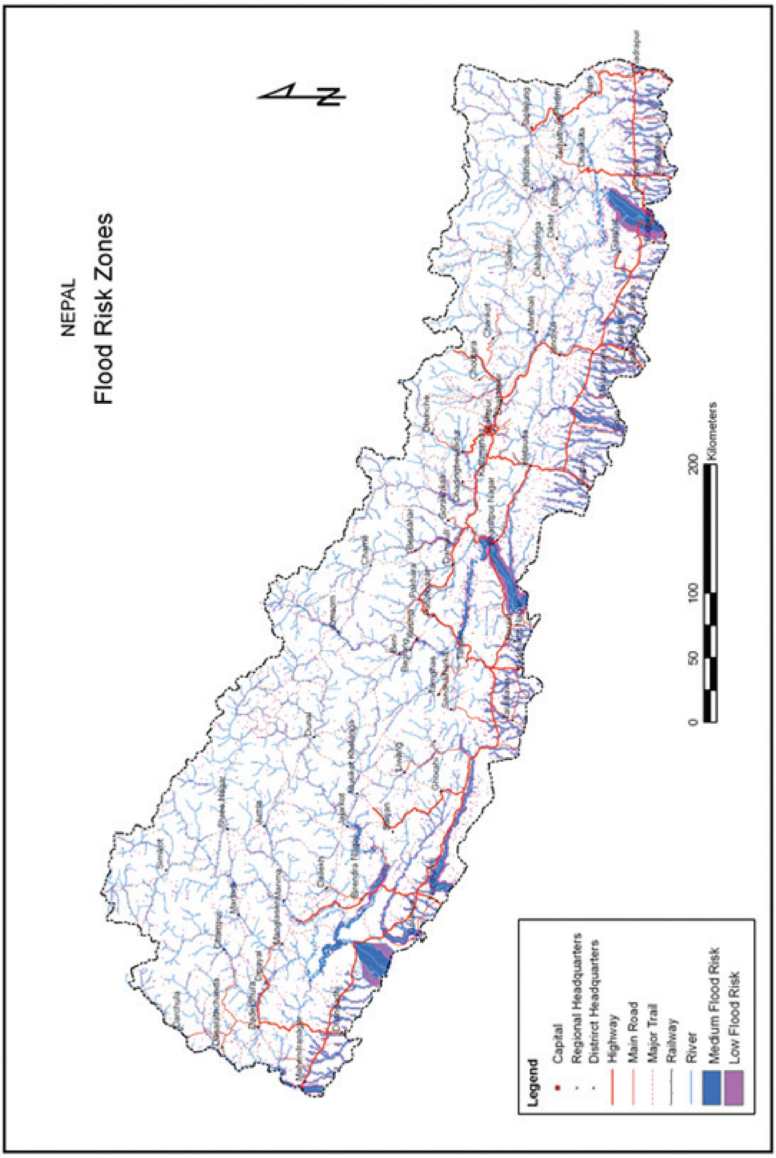


Figure 27. Medium and low flood risk zones of Nepal.

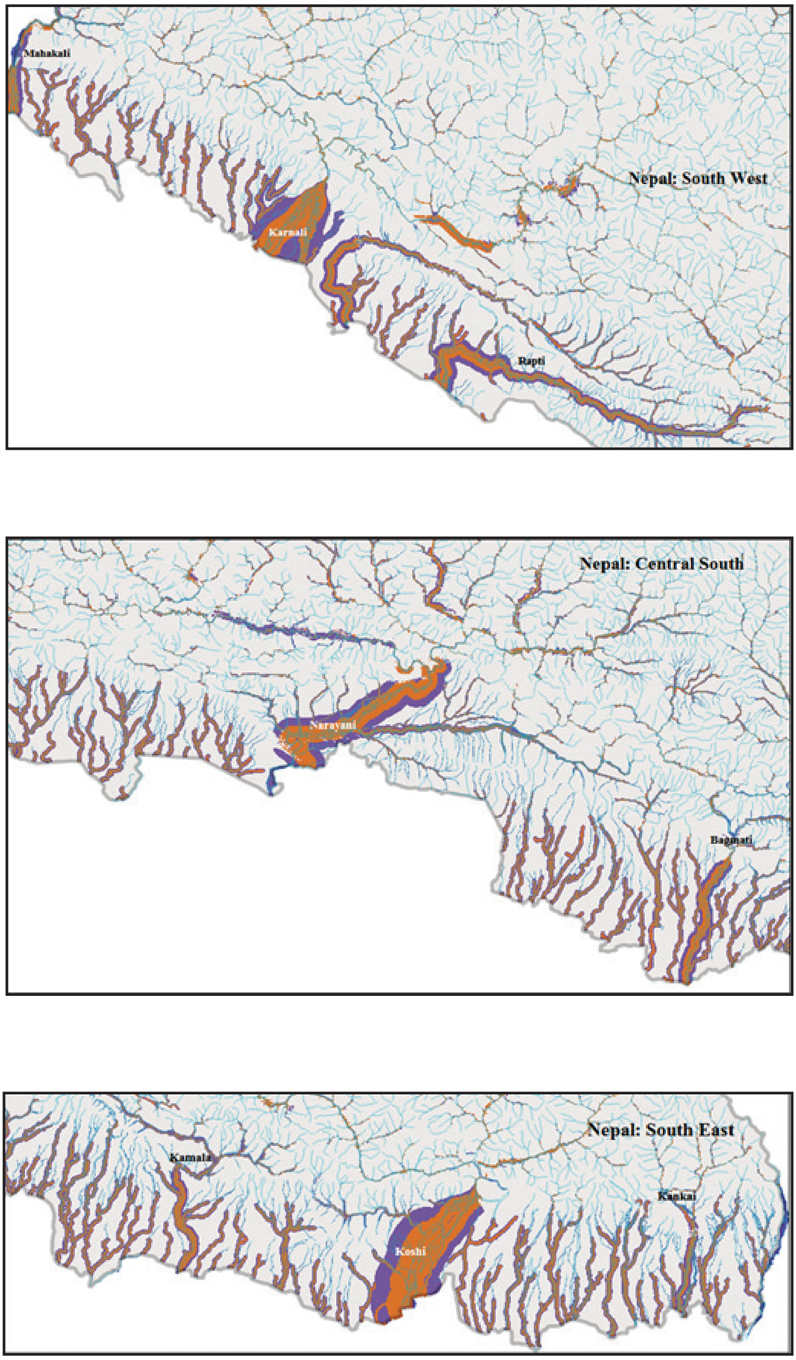


Figure 28. Major Floodplains in the western, central, and eastern Nepal.

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Annex I: Stakeholders

Major Stakeholders in Flood Forecasting

1) International Government Organization: World Meteorological Organization (WMO), Geneva
2) Regional Government Organizations:
   a. International Center for Integrated Mountain Development (ICIMOD), Kathmandu
   b. Regional Integrated Multi-hazard Early Warning System (RIMES), Bangkok
   c. SAARC Disaster Management Center, Gandhinagar (India)
3) National Government Organizations:
   a. Department of Hydrology and Meteorology (DHM), Kathmandu
   b. Ministry of Home Affairs (MoHA), Kathmandu

Major Stakeholders in Flood Forecast Dissemination and Flood Warning Dissemination

1. National Early Warning Operation Center (NEOC), Ministry of Home Affairs, Kathmandu
2. District Early Warning Center (DEOC), District Administration Office, Nepal

Government Organizations

3. Department of Water-Induced Disaster Management (DWIDM), Kathmandu
4. Ministry of Federal Affairs and General Administration (MoFAGA), Kathmandu
5. Water and Energy Commission Secretariat (WECS), Kathmandu

International Government Organizations

1. Asian Development Bank (ADB)
2. Asian Disaster Prevention Center (ADPC)
3. Food and Agriculture Organization (FAO)
4. International Telecommunication Union (ITU)
5. Office for the Coordination of Humanitarian Affairs of the UN Secretariat (OCHA)
6. The World Bank
7. United Nations Operational Satellite Applications Programme (UNOSAT)
8. The UN University Institute for Environment and Human Security (UNU-EHS)
9. United Nations International Strategy for Disaster Reduction (UNISDR)

INGOs working in Collaboration with DHM for Community-based EWS

1. Lutheran World Relief (LWR)
2. Practical Action

INGO

1. Action Aid
2. Care – Nepal
3. Handicap International Nepal
4. Lutheran World Federation (LWF)
5. Mercy Corps-Nepal
6. Nepal Red Cross Society
7. Oxfam – Nepal
8. UNICEF – Nepal
9. World Wildlife Fund (WWF) – Nepal

NGOs and Companies

1. ADAPT – Nepal
2. DPNet
3. Eco-Nepal
4. Nepal Center for Disaster Management
5. Nepal Disaster Management Forum
6. Nepal Forum of Environmental Journalists (NEFEJ)
7. Telecom (NTC, Ncell)

Annex II: Checklist for interviews in consultative meetings

1) Organization
2) Contact Person
3) Relevant department/section
4) Priority areas
5) Organizational chart of EWS
6) Flow of real-time data and information
7) Human resources staff and their level of education
8) Level of financing in EWS
9) Role in FEWS
10) Sustainability of program
11) Effectiveness of the programs
12) Quality management system
13) Process of emergency preparedness
14) Nature of collaboration and working relations with NHMS and other organizations
15) Role of NHMS in disaster mitigation program
16) Expectations from provincial centers
17) Expectations from local governments
18) Studies and publications and availability of reports
19) Experiences: success and challenges faced
20) Any noteworthy event that saved significant lives and properties
21) Any noteworthy event that merited subsequent significant reevaluation

Annex III: Checklist of questionnaire at community levels

1) Livelihood pattern
    a. Agriculture
    b. Livestock
    c. Services
2) Settlement pattern
    a. Highland
    b. Lowland
    c. Flood-prone areas
3) How many houses are flooded during floods
4) River bank cutting?
5) Sedimentation problems? Debris flows?
6) How stable are the river banks?
7) Flood inundation or riverine floods?
8) Level of awareness about floods and other disasters
9) Response of the community to past events
10) What type of information would the community like to have?
11) When do the community need information?
12) What type of communication channel they prefer during dissemination of flood early warning message.
13) Current practice of the community during the flooding for the dissemination of flood early warning messages.

Annex IV: Field Visits and Consultation Meetings

Visits were made to the local Disaster Management Committees (DMCs) that are active in different communities in the Susta Rural Municipalities. Photograph 1 presents the discussions being held with the community at Pratapur in Susta rural municipality. Similarly, consultation meetings were held with relevant government and non-government agencies including the officials of the Department of Hydrology and Meteorology (DHM), District Administration Office (DAO) of Parasi, District Coordination Committee (DCC) of Parasi and the provincial Ministry of Internal Affairs and Law.

Mr Ram Gopal Kharbuja, DDG, DHM accompanied the consultant (Dr Keshav Prasad Sharma) and the LWR officer (Mr Santosh Dahal) during all field visits and was present during the interactions with the communities and consultations with relevant organizations. Field visits were made to Tribeni and Pratappur in Susta. The flood-prone areas, the Narayani river and the canal were observed and community members and community-based DMC members provided their insights.

Photograph 1. A discussion with the local DMC at Pratappur.

The sites selected for field visits are the areas suffering recurrent floods almost every year with huge damages and fatalities. Damages that occurred during the 2017 monsoon season are a typical example of food-related struggles the community experiences nearly every year. The floods that followed the incessant rainfall of 13-14 July 2017 caused extensive damage to about 500 hectares of agricultural land. A community-based early warning system is in place in four of the flood-prone areas of Susta, and these systems are primarily based on the information received online from the DHM stations located upstream in the Narayanu basin. Lutheran World Relief has been working with the Sahamati (a local NGO) on implementing the system with support from DHM.

Northern side of the Susta area was found to be relatively safe compared to its Southern parts. Almost 25 percent of the houses on the northern side were RCC structures, about 10 percent of which were two-storied buildings. Southern parts of Susta were more vulnerable as most of the houses were built low in flood-prone areas and many constructions are mod-mortar one-story houses. Besides, some of the communities with poor educational backgrounds are geenrally less capable of coping with disasters as they lack awareness, knowledge and proper infrastructure to ensure the safety of their people and properties. For example, most members of the Musahar communities live on daily wages they earn working in the fields of their landlords. Almost 80 percent of the population in Pratappur area of Susta work on the fields in exchange for small wages that are barely enough to survive.

Gender issues were addressed in the formation of DMCs. Participation of females in the management of flood disasters was encouraged in most communities. A visited community-based DMC in Tribeni consisted of 64 percent female members. More than 50 percent female members represented the DMC in Pratapur.

The most accessible communication system available in the region is the GSM provided by NCELL and NTC. Almost all houses have at least one member with a mobile device. There are very few individuals with capability to use social media or Internet.

Major Facts, Issues and Observations of the Field Visit in Susta Rural Municipality

1) Communities are receiving flood information disseminated by DHM. Most of them are satisfied by the quality of information, which they say is useful for their preparation. They think that the accuracy of weather forecast and flood forecasts is improving with the passage of time.

2) LWR has been working with Sahamati on implementation of a community-based early warning system in the flood-prone areas of the Susta rural municipality. A display board and a siren have been established on the roof-top of the Narsahi police station. Similarly, a pillar with flood mark has been established on the right bank of the Narayani (27o25'20.6"N 83o51'34.7"E) with the marks that identify medium flows and high flows. The tower is located at about 85 meters above sea level.

3) Warning system established at the Narsahi police post is likely to be ineffective in a situation of severe flooding. Flood plain at Narsahi is lower than the adjacent Narayani river bed level.

4) The communities here consider the 1977 flood as the most severe flood observed in the past in this area.

5) Flash floods originating from the Siwaliks such as the floods occurring in the Shir Khola are a concern. Flash floods are considered as much more dangerous than the Narayani floods. A flood that occurred on 12-13 July 2017 is an example of when a severe flood occurred in the rural municipality without there being a similar major flood on the Narayani at Narayanghat. Flood waves spilled over the bank of the Narayani during the 2017 flood. The flood level crossed the red mark on the flood watch pillar erected on the bank of the Narayani at Narsahi Police station. Flood marks could be seen just below the window of a temple as was illustrated on the cover photograph. The Narayani river flood entered into Susta located on the left bank of the Narayanu, creating an inundating that was two to three meters deep.

6) Bed level on the Narayani was rising as the embankments prevented the sediment from spreading over the flood plain due to the restricted river flows. Floods and river flow issues were becoming more and more hazardous each year with increasing bed level of the Narayani.

7) The barrage constructed at the Nepal-India border and the canals constructed in the Susta area of Nepal are under the control of the Indian government. As reported by the locals, Indian authorities open the barrage gates on the Nepalese side more often than the Indian side during floods. Such patterns of barrage operation caused more negative impacts on the Nepal side.

8) No flood warning was obtained as the water was below warning level at Narayanghat while severe flooding was occurring in Susta area. Flood information obtained from the existing flood hydrometric station at Narayanghat on the Narayani was not useful as 2017 floods originated from the rainfall occurring in the Siwalik areas.

9) Inundation caused by the canal is one of the most serious problems experienced by the communities. Almost all the flat lands get inundated during flood periods and inundations can go on for several days.

10) Conflicts exist between the Susta communities and Indian authorities managing the Gandak Barrage as the barrage and canals are found to be amplifying flood hazards in the Susta area. There were examples of communities breaking the embankments and roads to channel flood water in 1998-1999 and 2003.

11) The government of India has been allocating a significant amount of financial resources to maintain the barrage and the canal but the quality of work is not satisfactory.

12) Technologies used for flood warning and flood information dissemination often fail during severe floods due to failure of power supply and telecommunication systems. Washing away of hydro-meteorological stations transmitting data may also disrupt the flood warning system, which is an important factor that needs to be carefully addressed.

13) Major demands from the communities included efficient and reliable flood watch and flood warning systems, plastic boats for communities in low-lying areas, life jackets and emergency shelters.

14) The communities would like to have a hydro-meteorological monitoring system in the Susta area as well as the upstream because at this time, the information provided is not sufficient, particularly when flash floods are happening and when floods originate from precipitation occurring in areas that lack DHM coverage.

15) Language is not a major issue in the region. Although most of the inhabitants of the southern part of Susta speak Bhojpuri language, almost all of them can understand Nepali. Several of them do have difficulties speaking Nepali.

Major facts, Issues and Observations of the Consultation Meetings during Field Visits

Discussions were held on different aspects of flood preparedness and enhancement that could be made possible with the help of an early warning system. The role of DHM in providing reliable early warnings and the role of local-level organizations in ensuring preparedness were highlighted in all the consultative meetings with the local, provincial and central-level organizations

1) Floods are major disasters in the region. Since floods occur most of the time at night, people have a hard time sleeping peacefully.

2) The warning system installed at DEOC is not tailored to affected regions. It triggers sirens even if there is no flood in the basin of interest. For example, sirens are activated for all the stations in Nepal when the water level crosses the preset warning level.

3) Awareness about the importance of an early warning system and preparedness are lacking in the region. Reluctance of people to leave their houses during floods was one of the issues that needed a better awareness-based management. Several community members would refuse to rely on the warnings due to their lack of education in this field.

4) Simple rainfall-runoff relation at a single hydrological monitoring site is not adequate for any flood watch program, as floods in the Terai can occur with one or multiple impacts of rainfall, flash floods, inundation and barrage operation. The Shir Khola, Rayapurba Khola and Sidha Khola were some of the rivers causing flash floods with huge damages.

5) The areas with embankments and canals are susceptible to floods caused by inundation as such structures are responsible for obstructing the natural flow of water. One such flooding instance was observed in 2017 during the flood in the Susta areas.

6) Capacity of the barrage to discharge flood water has diminished. The barrage that had the capacity to discharge the floods exceeding 2000 m3/s can now discharge only about 1500 m3/s.

7) Display board is only able to display data from the Narayani and the Riu Khola. The information on rainfall from different upstream stations would provide additional useful information to the DMCs.

8) Sustainability issues brought up in the meeting included the maintenance of installed equipment, spare parts and mobile recharge. Mobile recharge alone costs about Rs 800 ($8) per month.

9) Embankments and canals flood watch requires improvement.

10) Local government needs to hire an IT expert trained in managing real-time data acquisition and dissemination.

11) The chairperson of the Susta rural municipality was also the owner of a boarding school. The school was located in a place safe from major floods. Similar approach needed to be promoted for providing additional shelters to local inhabitants during severe floods.

12) Need for detailed mapping of vulnerable areas with regular updates using best available DEMs.

13) Ongoing research on appropriate technologies (technologies being practiced and technologies being rested) needs to be integrated in EWS along with proper feedback mechanisms.

14) Adequate storage for hardware and supplies is required to run EWS in an effective manner.

15) Financial aspects need to be clearly defined in relevant acts. For example, financial planners need to allocate a certain percentage of annual budget to disaster-related activities.

16) All the relevant committees at all levels of government need to be active and work in a coordinated manner.

17) Backup communication system needs to be an integral part of FEWS. DHM needs to maintain portable radio sets (SSB transmission) in addition to the telephone-based data dissemination system.

18) Flood maps need regular updating as most of the rivers deliver huge amount of sediment changing the river flow.

19) Success of FEWS is highly dependent on preparatory work such as well-planned evacuation routes, well-equipped evacuation centers, etc.

20) NEOC has already been able to establish the supporting DEOCs in 54 districts. NEOC is planning to establish a DEOC in all 77 districts of Nepal.

21) Besides NEOC and DEOCs and CDMCs, Nepal is likely to establish Provincial Emergency Operation Centers (PEOCs) in all seven provinces and Local Emergency Operation Centers in all 753 local units of the Government of Nepal.

22) In 2017, coordinated efforts of DHM and NEOC were instrumental in saving several people from the extreme flood on the Babai River in Bardia.

23) Several NGOs are involved in disaster management activities in Nepal including the establishment of EWS. Since some of these activities are neither being coordinated with DHM nor with MoHa, the lack of collaboration results in weak sustainability potential. Standard operation procedure needs to bring all these efforts under one umbrella so that duplications are avoided and long-term sustainability ensured.

24) Copy of all flood-related messages transmitted to the communities should also be sent to NEOC.

Department of Hydrology and Meteorology (DHM) : 23 February 2018

Participants:

1) Dr Rishi Ram Sharma, Director General, DHM
2) Mr Ram Gopal Kharbuja, Deputy Director General, Hydrology Division, DHM
3) Mr Binod Parajuli, Hydrologist, Flood Forecasting Section, DHM
4) Mr Santosh Dahal, Lutheran World Relief

Mahalvari, Tribeni, Susta Rural Municipality: 10 March 2018

Participants:

1) Pampha Aryal, Chair, CDMC
2) Mahalvari, Susta Rural Municipality, Nawalparasi
3) RP Upadhaya, Journalist, Ghatma Ra Vichar
4) Khimananda Aryal, Secretary, CDMC
5) Radhika Pandeya, Member, CDMC
6) Yasodha Pathak, Member, CDMC
7) Sita Pandeya, Member, CDMC
8) Gauri Pande, Member, CDMC
9) Savita Panjiyar, Rescue Assisstant, CDMC
10) Padam Kumari Mahato
11) KuShuma Mahato, Rescue Assisstant, CDMC
12) Mahato, Member, CDMC
13) Rakesh Shrestha, WWTR Program, Sahamati
14) Rishi Ram Giri, Member, Sahamati
15) Laxmi Bhandari, Agriculture-Sector Coordinator, Sahamati
16) Manshi Kumar Harijan, Member, Sahama

Meeting at Pratappur (Pasauni, Motipur), Susta 6: 10 March 2018

Participants:

1. Participants:
2. Jagadish Kurmi
3. Raj Dev Kewat
4. Ram Bilash Rajbhat
5. Ramawati Harijan
6. Sabita Bin
7. Panwati Thakuri
8. Chandrawati Harijan
9. Lilawati Lonoya
10. Lilawati Bin
11. Bishma Lonia
12. Saraswoti Kurmi
13. Kishori Kurmi
14. Kaushilya Kurmi
15. Draupadi Kewat
16. Chandwati Kewat
17. Jayantri Kewat (Contact Person): 9805445362
18. Sahabuddin Musalman
19. Kaetawar Kurmi
20. Jyoti Kewat
21. Mahadev Kurmi
22. Marathi Rajbhar
23. Babita Kayastha
24. Sumitra Rajbhar
25. Mahanga Rajbhar
26. Santosh Dahal
27. Laksmi Bhandari
28. Manshi Harijan

Meeting at the Susta Rural Municipality: 11 March 2018

Ram P. Pandeya, Chairperson, Susta Rural Municipality
(Contact Person: sustagaunpalika@gmail.com; 9857080137)Rakesh Shrestha, WW/TBR/ PC
Khimananda, Aryal, Secretary, CDMC
Manshi K. Harijam, WW/TBR/SM (Mob #9844763235)

Narsahi Police Post, Susta: 11 March 2018

1. Ashok K. Gurung Ward Chair Person, Susta 4
2. Ran Kishen Koiri, Chair, CDMC
3. Bushnu Upadhaya, Member, CDMC
4. Ram Bali Kohar, Coordinator, EWS, CDMC
5. Nanda L. Harijan, Secretary, CDMC
6. Nil B. Gurung, Member, Susta 4
7. Rshul Koiri
8. Raju Poudel, Chief, Police Post Narsahi
9. Ram Gopal Kharbuja, DDG, DHM
10. Dil B. Mahato,, Member, CDMC
11. Laxmi Bhandari, WW/TBR, Sahamati
12. Mansi K, Harijan, WW/TBR, Sahamati
13. Santosh Dahal, LWR

DEOC: 11 March 2018

Meeting with Sunil Yadav and Madhav Wagle, Chullu Chaudhari, the incharge of the DEOC was on Leave. 11 March 2018

Office of the Chief District Officer (CDO): 11 March 2018

Meeting with Uddhav B. Rana Magar, CDO.
Meeting with Shiva Shankar Prasad Raya, Chief, District Coordination Committee

Meeting at The Ministry of Interior Matter and Law, Province Number 5: 12 March 2018

Participants:
Durga Datta Poudel, Under Secretary, Administration, Planning and Disaster Management Division (Contact Person)
Madhu Poudel, Under Secretary, Law Formulation Division
Jyoti Raj Aryal, Section Officer, Disaster Management Section
Sabina Maharjan, Law Officer
Ram Gopal Kharbuja, DDG, DHM
Santosh Dahal, LWR

Meeting at the Ministry of Home Affairs: 29 March 2018

Participants:
Shankar Hari Acharya, Under Secretary, Disaster Management Division, Ministry of Home Affairs
(Contact person)
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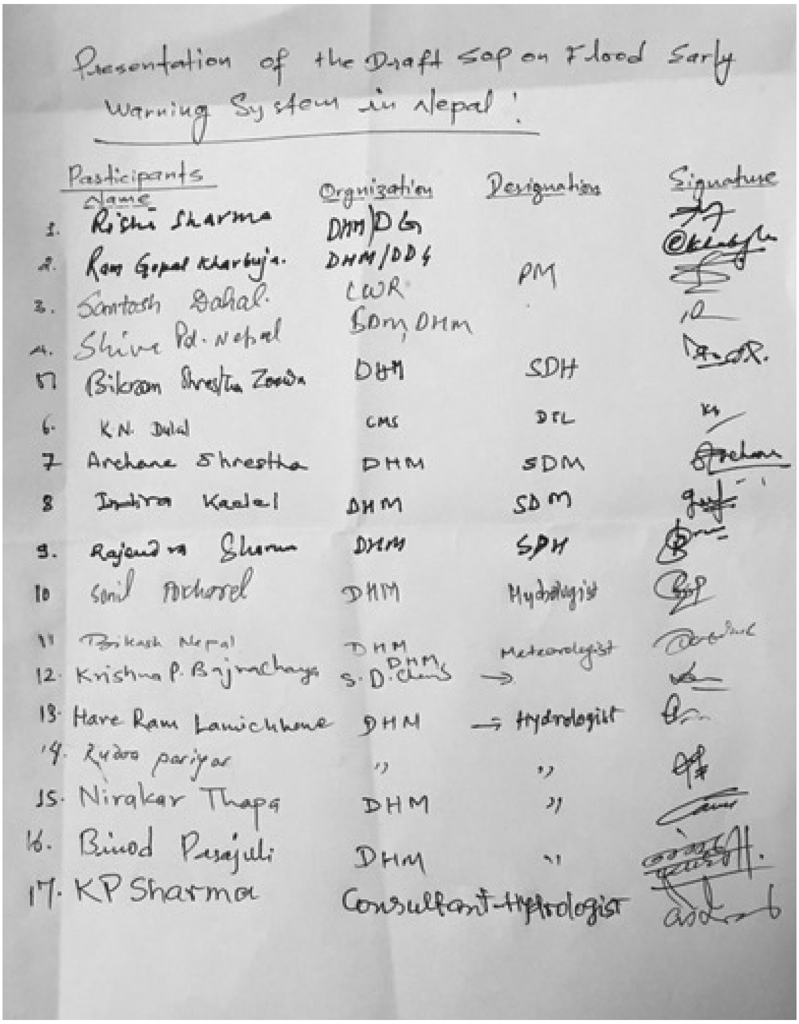
Mr Ram Gopal Kharbuja, Deputy Director General, DHM
Mr Binod Parajuli, Hydrologist, DHM
Mr Santosh Dahal

Department of Hydrology and Meteorology, Naxal: 17 April 2018

The submitted draft SOP was presented to the senior officers, hydrologists and meteorologists at DHM for their comments and suggestions. The document was emailed to them before the presentation. List of the participants follows.



Presentation of the Draft SOP on Flood Early Warning System in Nepal.

	Participants Name	Organization	Designation	Signature
1.	Rishi Sharma	DHM/DG		
2.	Ram Gopal Kharbuja	DHM/DDG	PM	
3.	Santosh Dahal	CWR		
4.	Shiva Pd. Nepal	SDM, DHM		
5	Bikram Shrestha Zoowa	DHM	SDH	
6.	K.N. Dulal	CMS	DTL	
7	Archana Shrestha	DHM	SDM	
8	Indira Kadel	DHM	SDM	
9.	Rajendra Sharma	DHM	SDH	
10	Sunil Pokharel	DHM	Hydrologist	
11	Bikash Nepal	DHM	Meteorologist	
12.	Krishna P. Bajracharya	S.D. DHM Clim	→	
13.	Hare Ram Lamichhane	DHM	→ Hydrologist	
14.	Rudra Pariyar	"	"	
15.	Nirakar Thapa	DHM	"	
16.	Binod Parajuli	DHM	"	
17.	KP Sharma	Consultant Hydrologist		

Annex V : Stations Equipped with Real Time Data Acquisition System

Existing Real Time Hydrometric Stations						Meteorological AWS Station			
	River	Location	Lat	Long				Lat	Long
1	Chaudhar river	Daiji	28.95	80.26		1	Humde Airport (Manag)	28.64	84.09
2	Sihali Nadi	Arjuni	28.91	80.33		2	Aiselukhark	27.35	86.75
3	Khutia Khola	Mudivabar	28.88	80.73		3	Baglung	28.27	83.60
4	Panchamukhi Khola(Humla)	Panchmukhi B.C.	30.18	81.53		4	Bajura (Martadi)	29.38	81.32
5	Saru Gad	Jajarkot	28.70	82.22		5	Bandipur	27.93	84.42
6	Karai Khola	Gumantar	28.57	81.67		6	Bhairahawa Agromet	27.53	83.47
7	Nikash Khola	Latikoili	28.55	81.58		7	Bhairahawa Airport	27.51	83.42
8	Ghurra Khola	K-Gaon	28.61	80.75		8	Bharatpur Airport	27.68	84.43
9	Kateni River	Ratanpur	28.55	80.82		9	Bhojpur	27.18	87.05
10	Kandra River	Ghumnebahkal	28.44	80.98		10	Bijuwatar	28.10	82.87
11	Pathariya River	Chhachharawa	28.50	81.05		11	Biratnagar Airport	26.48	87.27
12	Ransing Khola	Tinkunne	27.79	82.82		12	Chandragadhi Airport	26.57	88.08
13	Seti Khola	Seti Beni	28.01	83.62		13	Dadeldhura	29.30	80.58
14	Daraun Khola	Arjun choupari	28.07	83.80		14	Dailekh	28.85	81.72
15	Andhi Khola	Andhi Muhan	27.97	83.59		15	Daman	27.60	85.08
16	Ridi Khola	Ridi Bazar	27.95	83.42		16	Dang Agromet	28.05	82.50
17	Jyagdi Khola	Dansing	27.93	83.88		17	Darchula Agromet	29.85	80.57
18	Madi River	Beni Patan	27.97	84.28		18	Dhangadhi Airport	28.80	80.55
19	Dona Khola	Dharapani	28.75	84.33		19	Dhankuta	26.98	87.35
20	Khudi Khola	Khudi Bazar	28.29	84.36		20	Dharan Bazar	26.79	87.28
21	Lakhandehi khola	Pattathkote	27.13	85.67		21	Dhunibesi Agromet	27.72	85.16
22	Kamala Nadi	Chisapani	26.92	86.18		22	Dipayal Agromet	29.23	80.93
23	Kamala Nadi	Inarwa	26.60	87.34		23	Gaira	29.17	80.60
24	Imja Khola (Khumbu)	Pangboche	27.87	83.77		24	Gamgadi Shree-nagar	29.55	82.15
25	Dudhkoshi River	Rabuwa Bazar	27.27	86.66		25	Ghorepani	28.40	83.73
26	Lohandra Khola	Shisbeni	26.46	87.35		26	Gorkha Agromet	28.00	84.62
27	Deumai Khola	Aangdang	26.90	87.77		27	Gulariya	28.17	81.35
28	Kankai River	Kumarkhod	26.47	87.85		28	Gumthang	27.87	85.87

Stations Being Upgraded to Real Time under the BRCH project.					29	Gurja khani	28.60	83.22
					30	Hetaunda N.F.I.	27.42	85.05
1	Humala Karnali	Bihichhada	29.63	81.87	31	Ilam Tea Estate Agromet	26.92	87.90
2	Mugu Karnali	Dhain	29.62	81.86	32	Jalesore Agromet	26.65	85.78
3	Humla Karnali	Lalighat	29.16	81.61	33	Janakpur Airport	26.72	85.97
4	Tila Nala	Nagma	29.32	81.98	34	Jiri Agromet	27.63	86.23
5	Sinja Khola	Diware	29.20	81.92	35	Jomsom Airport	28.78	83.72
6	Tila Nadi	Serighat	29.13	81.59	36	Jumla Airport-Agromet	29.27	82.18
7	Lahare khola	Dungeswor	28.78	81.60	37	Juphal Airport	28.99	82.82
8	Lohare Khola	Dailekh	28.81	81.74	38	Kakani	27.80	85.25
9	Budhi Ganga	Chitre	29.16	81.21	39	Kankai Agromet	26.65	87.86
10	Seti River	Gopaghat	29.30	80.78	40	Kanyam Tea Estate	26.87	88.08
11	Thuli Gad	Khanayatal	28.94	80.91	41	Karmaiya	27.12	85.47
12	Thulo Bheri	Rimna	28.70	82.28	42	Kathmandu Airport AWOS	27.70	85.37
13	Sano Bheri	Simlighat	28.66	82.36	43	Khajura Agromet	28.10	81.57
14	Bheri	Jamu	28.77	81.35	44	Khalanga (Jajarkot)	28.70	82.20
15	Sarada Khola	Daredhunga	28.29	82.03	45	Khanchikot	27.93	83.15
16	Babai River	at Chepang	28.36	81.71	46	Khudi Bazar	28.28	84.37
17	Rapti River	Bagasotigaun	27.87	82.80	47	Khumaltar Agromet	27.67	85.33
18	Dundawa River	Masurikhet	28.20	81.70	48	Lahan Agromet	26.73	86.48
19	Dumre Khola Kalimati	Kalimati	27.80	83.54	49	Liwang	28.30	82.63
20	Tinau	Butwal	27.74	83.46	50	Lukla Airport	27.69	86.73
21	Kali Gandaki	Jomsom	28.79	83.75	51	Lukla valley	27.69	86.73
22	Kali Gandaki	Tatopani	28.48	83.65	52	Lumle Agromet	28.30	83.82
23	Raughat Khola	Raughat	28.38	83.57	53	Mangalsen	29.15	81.28
24	Myagdi Khola	Mangalghat	28.34	83.56	54	Manma	29.15	81.60
25	Kali Gandak	Modi beni	28.20	83.67	55	Manthali	27.47	86.08
26	Modi Khola	Nayapul	28.22	83.69	56	Musikot Agromet(Rukumkot)	28.63	82.48
27	Andhi Khola	Borlangpol	27.97	83.60	57	Nagarkot	27.70	85.52
28	Daaram Khola	Wamitaksar	28.20	83.30	58	Nepalgunj Airport	28.10	81.67
29	Badigad Khola	Rudra Beni	27.98	83.47	59	Num Agromet	27.55	87.28
30	Seti Gandaki	Ghan Chowk	28.30	83.94	60	Nup	27.72	87.87
31	Madi River	Sisa Ghat	28.09	84.23	61	Nuwakot	27.92	85.17
32	Mardi Khola	Lahachowk	28.30	83.92	62	Okhaldhunga	27.32	86.50
33	Marsyangdi	Bhakundebesi	28.20	84.41	63	Olangchung gola	27.68	87.78
34	Dordi Khola	Ambote Bazar	28.19	84.45	64	Pakhribas Agromet	27.05	87.29
35	Marshyandi River	Bimal nagar	28.20	84.40	65	Panchkhal Agromet	27.65	85.62
36	Chepe Khola	Garambesi	28.06	84.49	66	Parwanipur Agromet	27.07	84.97

37	Ankhu Khola	Ankhu bagar	27.99	84.83		67	Phidim	27.14	87.75
38	Lantang Khola	Shyaprubesi	28.16	85.34		68	Pokhara Airport AWOS	28.20	83.98
39	Bhote Koshi	Shyaprubesi	28.17	85.34		69	Rajbiraj Agromet	26.66	86.70
40	Trisuli River	Kali Khola	27.83	84.55		70	Rampur Agromet	27.65	84.35
41	Bagamati River	Sundarijal	27.77	85.43		71	Salleri	27.50	86.58
42	Bagamati River	Rai goan	27.16	85.49		72	Salyan Bazar	28.38	82.17
43	Arun River	Uwa Goan	27.64	87.35		73	Shyano Shree Chepang	28.35	81.70
44	Sabhaya Khola	Tumlingtar	27.32	87.21		74	Simara Airport	27.17	84.98
45	Hinwa Khola	Pipletar	27.30	87.22		75	Simikot Airport	29.97	81.82
46	Arun River	Simle	26.93	87.15		76	Sindhuli Madhi	27.22	85.92
47	Sunkoshi River	Dolalghat	27.64	85.71		77	Sundarpur Agromet	29.03	80.22
48	Melamchi Khola	Helambu	28.04	85.53		78	Surkhet Airport-Agromet	28.60	81.62
49	Indrawati	Dolalghat	27.64	85.71		79	Syangboche Airport	27.82	86.72
50	Sunkoshi River	Khurkot	27.34	85.99		80	Syangja	28.10	83.88
51	Likhu Khola Sangutar	Sangutar	27.34	86.22		81	Tamghas	28.07	83.25
52	Sunkosi	Tokshelghat	27.17	86.40		82	Tansen Agromet	27.86	83.54
53	Solu Khola	Salme	27.48	86.57		83	Taplejung	27.35	87.67
54	Rawa khola Gaikhure	Gaikhure	27.27	86.69		84	Tarahara Agromet	26.70	87.27
55	Sunkoshi River	Kamphughat	26.88	86.82		85	Taulihawa	27.55	83.07
56	Sunkoshi River	Hampachuwar	26.93	87.14		86	Thakmarpha Agromet	28.75	83.70
57	Tamor River	Majhitar	27.15	87.71		87	Tikapur Agromet	28.53	81.12
58	Tamur River	Triveni	26.92	87.16		88	Udayapur Gadhi	26.93	86.52
59	Kankai River	Mainachuli	26.69	87.88					

New Real Time Stations Being Established under BRCH project			
Tamor River	Taplejung	27.38	87.63
Kabeli Khola	Taplejung	27.29	87.70
Mewa Khola	Taplejung	27.38	87.63
Hongu Khola	Lokhim	27.45	86.73
Sinwa Khola Tsheram	Tsheram	27.57	87.97
Humla Karnali	Jaur	29.76	81.99
Khokhajor Khola		27.37	85.47

Note

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