TECHNICAL REPORT

Trigger Model for Forecast-based Action (FbA) Systems for Flash Flood in Lohandra, Morang

Nepal Red Cross Society

Finnish Red Cross

Climate Centre

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Executive Summary

This report provides a comprehensive model aimed at mitigating flash flood impacts in Nepal's Terai region, specifically for the flood-prone Jahada Rural Municipality in Morang District. This region faces recurrent flash floods from the Singhia and Lohandra Rivers, mainly during the monsoon season. The model proposes a trigger-based system for Forecast-based Action (FbA), defining flood thresholds to support anticipatory actions and minimize flood risks to life and property.

Key highlights include:

Study Area: Jahada's geographic and climatic profile makes it highly susceptible to flash floods. The study area, which includes the Lohandra and Singhia watersheds, was analyzed for rainfall-runoff responses using hydrological models based on data from local water and weather stations.

Data Collection: Rainfall, water level, and discharge data from local hydrometric stations inform the model. Additionally, topographical data (like soil type and land use) provide context for flood dynamics and potential impacts in the project areas.

Modeling Approach: Using HEC-HMS software, a rainfall-runoff model was developed, simulating the watershed's response to rainfall and allowing for precise flood predictions. Calibration and validation of the model, primarily for the Lohandra watershed, help estimate flood flows and thresholds. Fetching the rainfall forecasts (10-minute interval data) from European Centre for Medium-Range Weather Forecasts (ECMWF) , the same hydrological model was able to predict the river flows of Lohandra for up to 10 days.

Flood Thresholds: Defined flood alert and danger levels are based on return period analysis (e.g., a 1-in-2-year event for the alert level and a 1-in-5-year event for the danger level). For instance, the alert level for Lohandra is set at 3.56 meters of water level or 200 mm of rainfall within 24 hours, while the danger level is set at 4.36 meters of water level or 350 mm of rainfall over 48 hours.

Risk and Impact Analysis: The report examines historical flood events (2017 and 2019) to assess exposure and impacts on communities and infrastructure. Simulations indicate potential inundation levels, guiding early action planning to protect vulnerable buildings and population zones.

Trigger Mechanism: The model employs a two-stage trigger system:

- **Readiness:** Initiates based on river flow forecasts from flash flood model of Lohandra or the ICIMOD's flash flood prediction tool with lead time ranging from 3 to 5 days. DHM's color coded alerts in the case of special weather advisories has also been proposed as a criteria for readiness.
- **Activation:** Activates for imminent flash flood events, leading to quick, protective actions such as evacuations and community alerts. The activation trigger makes the use of both the forecasts and observations data with a lead time ranging from as little as 2 hours to 24 hours. This means, range of early actions need to be associated with the particular trigger criteria and the provided lead time.

The report stresses the necessity of utilizing advanced forecasting techniques, such as ECMWF hourly rainfall predictions, to effectively capture extreme weather events. By integrating real-time data collection and advanced modeling, local authorities can enhance their preparedness and response strategies for flooding. Overall, this technical report report emphasizes a proactive response to flash floods, enhancing community preparedness through advanced forecast models and clearly defined action thresholds, ultimately aiming to reduce the humanitarian impacts of flash floods in flood-prone areas of Lohandra and Singhia watershed.

1. Introduction

Jahada Rural Municipality, located in the Terai region of Nepal, is highly prone to flooding, especially during the monsoon season, which runs from June to September. The municipality is part of the Morang District in Koshi Province and features two prominent watersheds: the Singhia River and the Lohandra River. Heavy rainfall induced flash floods is a recurring natural hazard in this region due to its topography, climatic conditions, and the seasonal inflow of monsoon rains that contribute over 80% of the annual precipitation. Flash floods, in particular, pose significant risks to both life and property in the district's low-lying areas.

Flood forecasting, early warning systems and anticipatory action play a critical role in reducing the adverse impacts of these events. In recent years, advances in hydrological modeling, coupled with improvements in weather forecasting, have enhanced the ability to predict flood events and set critical thresholds for triggering flood alerts and warnings. These thresholds are essential for timely anticipatory actions, enabling local authorities and communities to prepare and respond effectively.

This study was conducted to propose an operational model of Forecast-based Action (FbA) System, particularly the trigger mechanism for flash floods in the Lohandra and Singhia watershed. The primary goal is to establish flood trigger thresholds based on water levels and rainfall intensity, providing vital information for anticipatory actions and flood risk management. By utilizing rainfall, discharge, and water level data from recent years, the study undertook detail analysis on rainfall to runoff responses of the target watersheds, including development of appropriate hydrological model for flash flood forecasting in Lohandra.

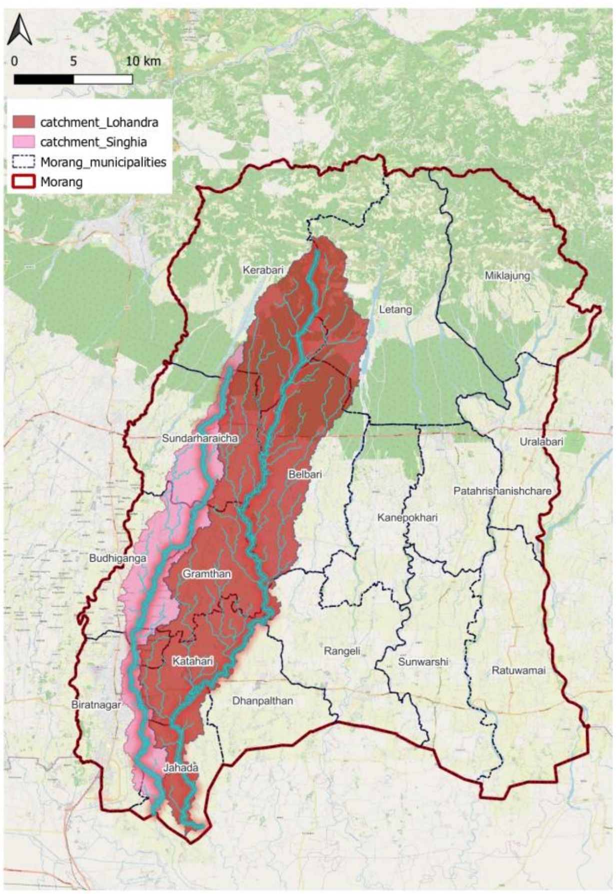
The integration of real-time rainfall and water level data together with advanced hydrological forecasting models can serve a basis for trigger model for forecast based action and improved decision-making processes for flood preparedness and response in Lohandra watersheds, contributing to safeguarding vulnerable communities from the devastating effects of flash floods.

2. Objective

The objective of this study is to propose an operational trigger model for forecast-based action in Jahada and Singhia watershed, with a particular focus on Jahada Municipality of Morang District. Specifically, the study aims to develop a rainfall-runoff model to simulate the hydrological processes in Lohandra and Singhia and define flood trigger thresholds (warning and danger levels) based on rainfall and water level data for Jahada Municipality and other flood prone areas within the watershed.

3. Study Area

The study area is in Morang District, located in the Terai region of Nepal. Covering a total area of 1,855 square kilometers, approximately 80% of the district consists of plains, while the remainder is situated within the Churia and Mahabharat Hill Range. The district's elevation ranges from 60 meters to 2,410 meters above mean sea level. Geographically, Morang lies between latitudes 26.200°N and 26.530°N, and longitudes 87.160°E and 87.490°E. Situated in the Koshi Province of eastern Nepal, Morang District features Koshi rivers and several other small catchments of Chure-fed rivers. The catchments/watershed covered by this study: the Singhia River and the Lohandra River as depicted in Figure 1. The project location, Jahada Rural Municipality lies in the downstream flood plains of these two rivers.



Basin / catchment	Area (km2)
Singhia	150,119
Lohandra	323,360

Figure 1: Study area of Morang district, showing Lohandra and Singhia Watershed and catchment area in square kilometers

4. Data Collection

Various datasets are required to understand the rainfall run-off processes of the study catchments, including rainfall-runoff time series, elevation, land cover, land use, soil, and hydrograph information. These datasets are utilized to determine the characteristics of streams and sub-basins, as well as to estimate hydrologic parameters, eventually informing the trigger model for forecast based action.

4.1 Rainfall-runoff data

4.1.1 Daily Rainfall data

Department of Hydrology and Meteorology (DHM) has been recording the daily rainfall at three stations within or vicinity of these watersheds: Letang, Haraicha, and Biratnagar. Data spanning from 2017 to 2020 were acquired from DHM for these stations. The average annual rainfall for the watersheds comes out to be 2,124 mm.

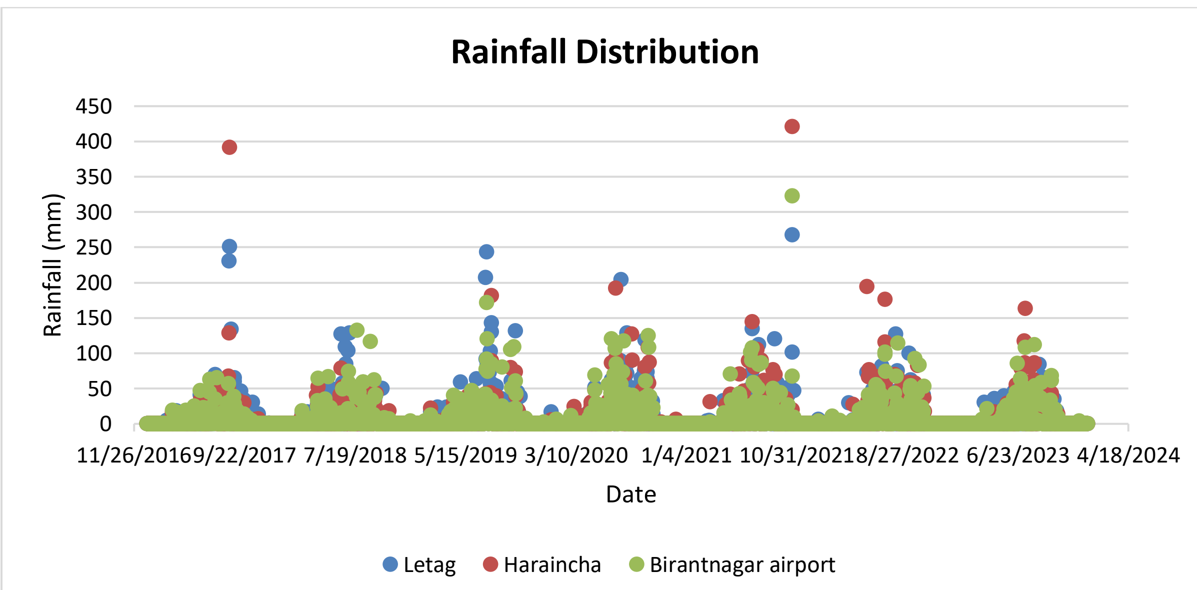


Figure 2: Rainfall distribution plots for three stations in Morang district (2017-2023)

4.1.2 Water level data

DHM has one hydrological station in Lohandra in Shis Beni, Jahada, and has recently upgraded the manual station to telemetric station. Water level measurements for the Lohandra River were obtained this, covering the period from 2017 to 2023. Runoff was estimated by correlating water levels with the reservoir's capacity table.

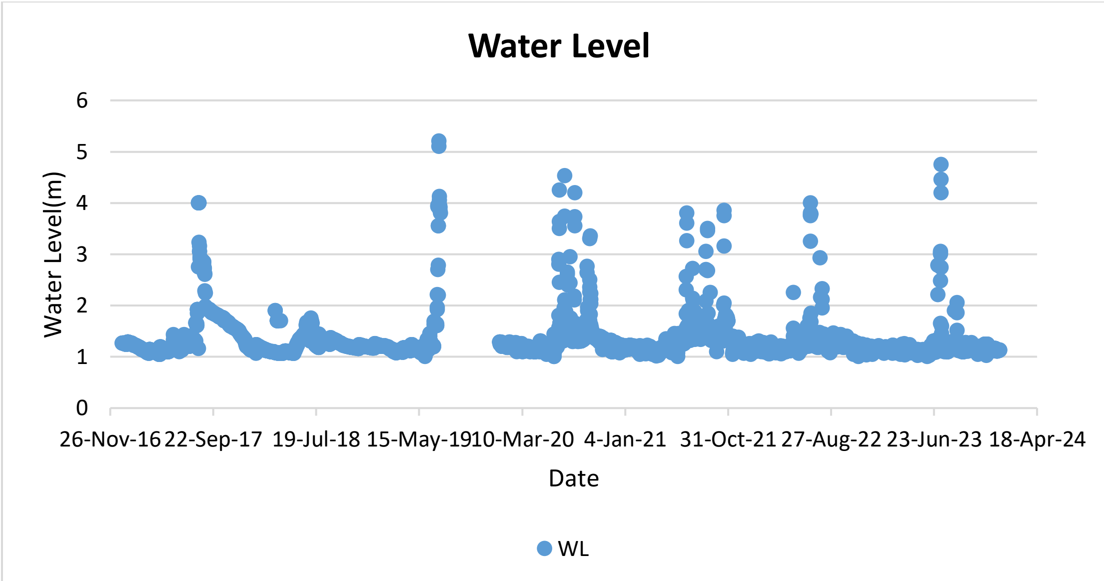


Figure 3: Water level plots for Lohandra River in Morang district (2017-2023)

4.1.3 Discharge data

Discharge data for the Lohandra River was also collected from DHM for the same observatory center in Shisbeni, with records available from 2020 to 2023. Calibrating the rainfall-runoff model using this observed discharge data is essential for enhancing the model's accuracy in simulating the relationship between rainfall and the resulting runoff.

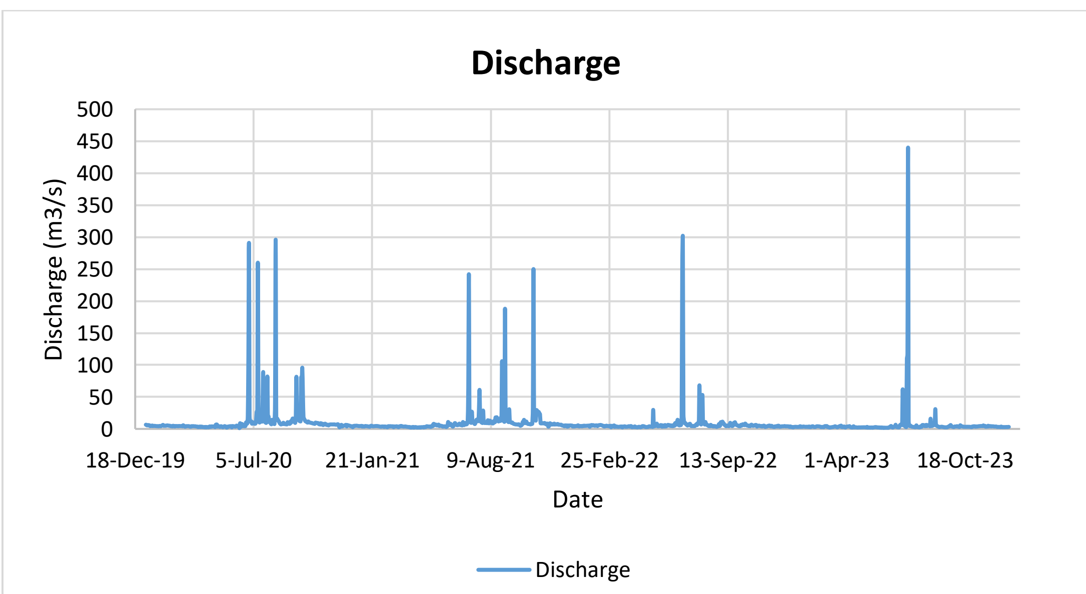


Figure 4: Discharge plots for Lohandra River in Morang district (2020-2023)

4.1.4 Forecast rainfall data

Rainfall forecasts will be acquired from European Centre for Medium-Range Weather Forecasts (ECMWF), utilizing advanced numerical weather prediction models. The ECMWF delivers short- to medium-range forecasts covering hours up to 10 days ahead, as well as long-range forecasts, including extended predictions up to 30 days and seasonal forecasts for several months.

4.2 Topography of the Watershed

The basin's topography was defined using a Digital Elevation Model (DEM) with a resolution of approximately 30 meters, as illustrated in Figure 5. The DEM identifies two major river basins: the Singhia River Basin (highlighted in red) and the Lohandra River Basin (highlighted in yellow). According to the DEM, the highest elevation in the basin is 2,397 meters, while the lowest elevation is 56 meters.

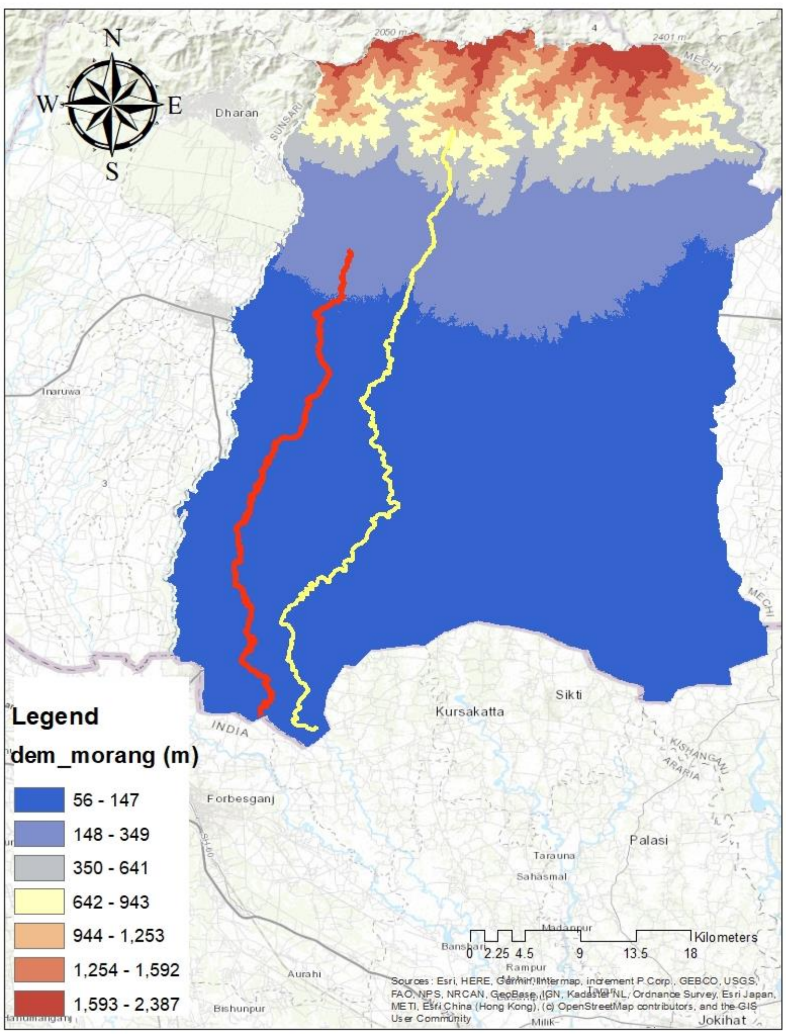
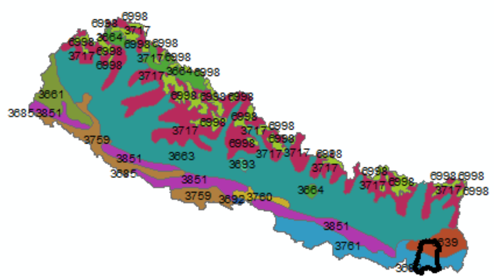


Figure 5: Topography (DEM) of Morang district

4.3 Soil Characteristics of the Watershed

Global soil data, with a cell resolution of 5 arc-minutes (approximately 10 km), prepared by the FAO, is available for download online in shapefile format with a geographic coordinate system. The basin's soil types include clay, silt, and sand. Based on this classification and Hydrological Soil Groups (HSG), Morang District was identified as having one group (Group C) for the soil profile study.



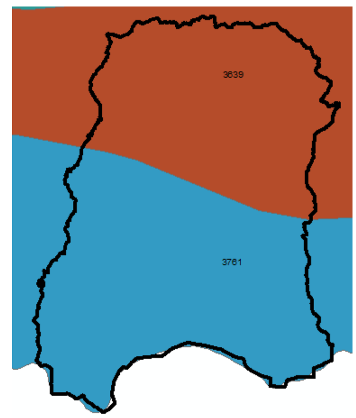


Figure 6: soil map of Morang district

4.4 Land use land cover pattern

A detailed spatial map of land use and land cover (LULC) within the basin classifies the area into cropland, forests, and built-up zones. The data reveals that forests cover the majority of the area (60%), followed by agriculture (40%).

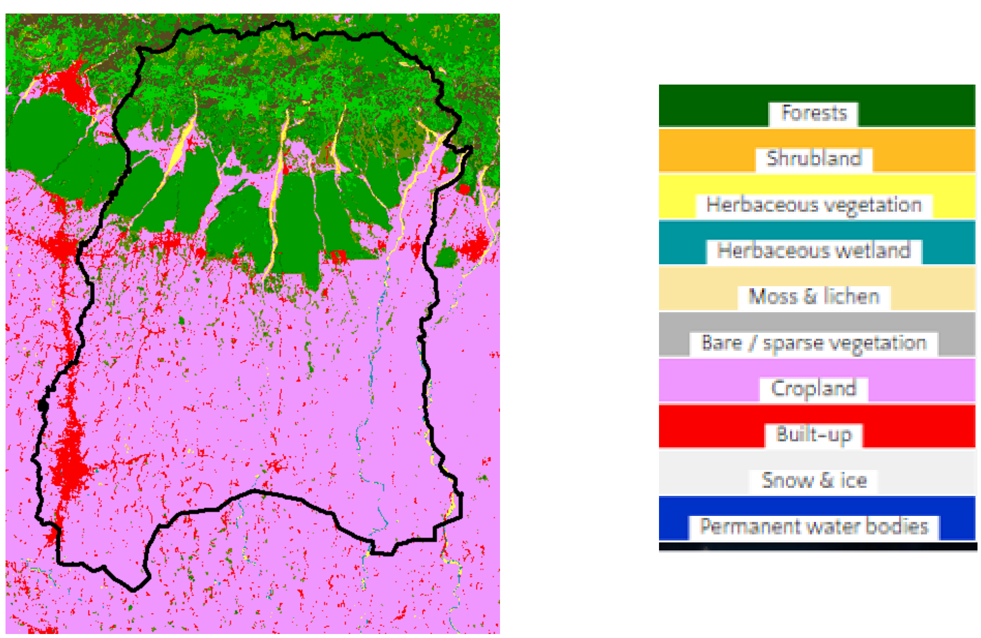


Figure 7: Land use and land cover map of Morang district

4.5 Curve Number

Soil maps and land use datasets were used to generate the Curve Number (CN) grid file, essential for constructing the rainfall runoff model. CN values help determine stream and sub-basin characteristics and estimate the hydrological parameters within the model. CN values range from 30, representing permeable soils with high infiltration rates, to nearly 100, which corresponds to water bodies. The soil parameter was defined according to the Hydrologic Soil Group (HSG), which is based on soil texture. The HSG for various soil textures is detailed in Table 1.

Table 1: Hydrologic Soil Group Description (USDA, 1986)

Soil Group	Description
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay Loam, silty clay loam, sandy clay, silty clay, or clay

The curve number for an average antecedent moisture condition for the different soil and ground cover combinations of the study area was determined based on the classifications in Table 2.

Table 2: Curve numbers for land cover classes and soil groups (Quijano et al., 2014)

Land Use/Land Cover	Hydrologic Soil Group Curve Numbers			
	A	B	C	D
Annual Crop	67	78	85	88
Brush/Shrubs	30	48	65	73
Fishpond	99	99	99	99
Built-up	89	92	94	93
Grassland	30	58	71	78
Inland Water	99	99	99	99
Mangrove Forest	98	98	98	98
Marshland/Swamp	72	81	88	91
Open Forest	36	60	79	79
Open/Barren	63	77	85	88
Perennial Crop	45	66	77	83

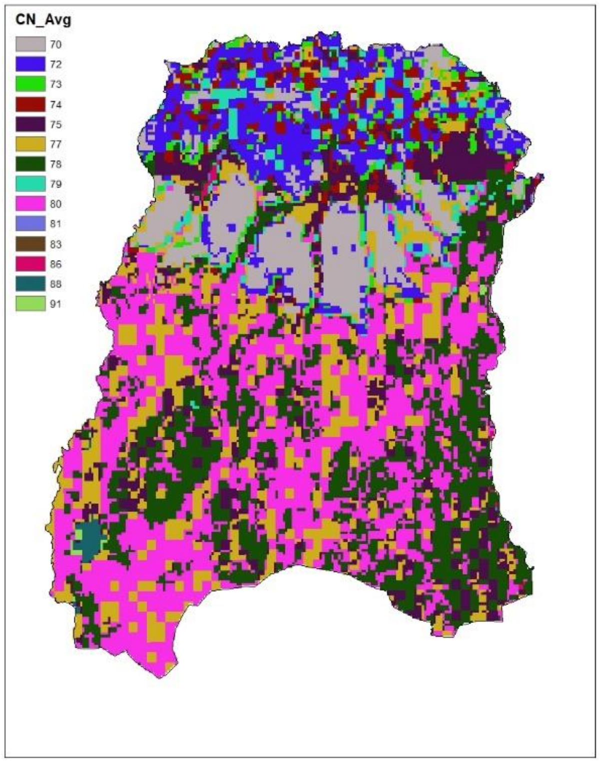


Figure 8: Curve number map of Morang district

5. Hydrological Modelling of Lohandra

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), developed by the US Army Corps of Engineers, is used to simulate rainfall-runoff processes in a variety of areas, ranging from small urban zones to large river basins. HEC-HMS provides tools for simulating rainfall-runoff processes, including open channel routing, water losses, runoff transformation, and parameter estimation. The software also facilitates meteorological data analysis. It employs various models to represent different components of the runoff process, such as base flow, direct runoff, and runoff volume. Each simulation within HEC-HMS requires a combination of a basin model, a meteorological model, and control specifications to generate results.

5.1 Model Setup

The model was set up using HEC-HMS version 4.12, which was downloaded from the USACE website: http://www.hec.usace.army.mil/software/hec-hms. The type of file utilized in the model setup depends on the specific data being input. The model consists of four key components: basin models, meteorological models, control simulations, and input data. The outputs of the model include runoff volume with abstractions or losses from infiltration for each sub-basin, as well as discharge hydrographs at key intersections within the river system (as shown in Figure 8).

HEC-HMS uses various methods to estimate infiltration losses to compute runoff from rainfall. In this case, the Soil Conservation Service Curve Number (SCS-CN) method (US SCS 1986) is employed to estimate rainfall infiltration losses. The following sections provide a brief overview of the activities involved in setting up the model.

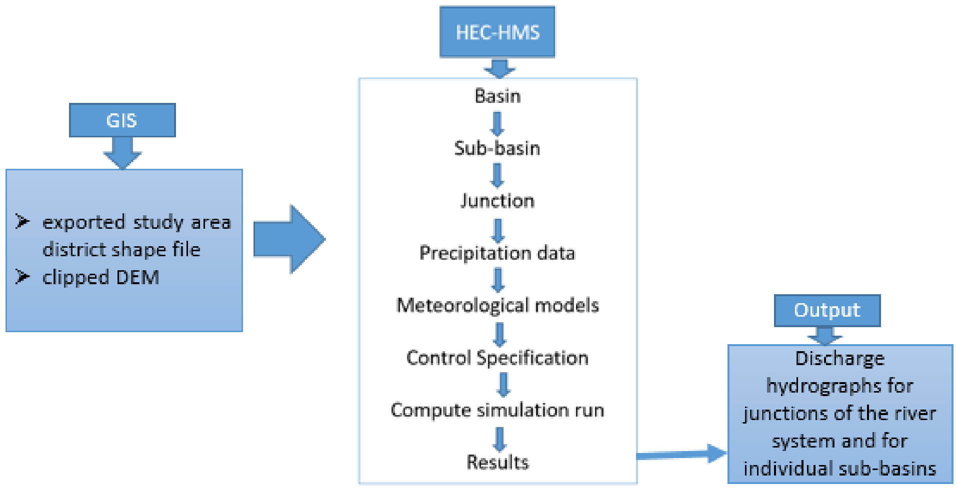


Figure 9: Overview of the HEC-HMS model setup and components

5.1.1 Basin model

In HEC-HMS, the basin model represents the physical characteristics of the basin and its river channels. This landscape is modeled using a series of hydrologic elements that are connected in a dendritic or link-node network (as illustrated in Figure 10). The hydrologic elements include sub-basins, river or stream segments known as reaches, and junctions. Calculations are performed sequentially from upstream to downstream (USACE 2006).

For this study, runoff was simulated using the Soil Conservation Service (SCS) Curve Number method. The transformation of runoff was carried out using the SCS Unit Hydrograph technique, while channel routing was conducted using the Muskingum-Cunge method.

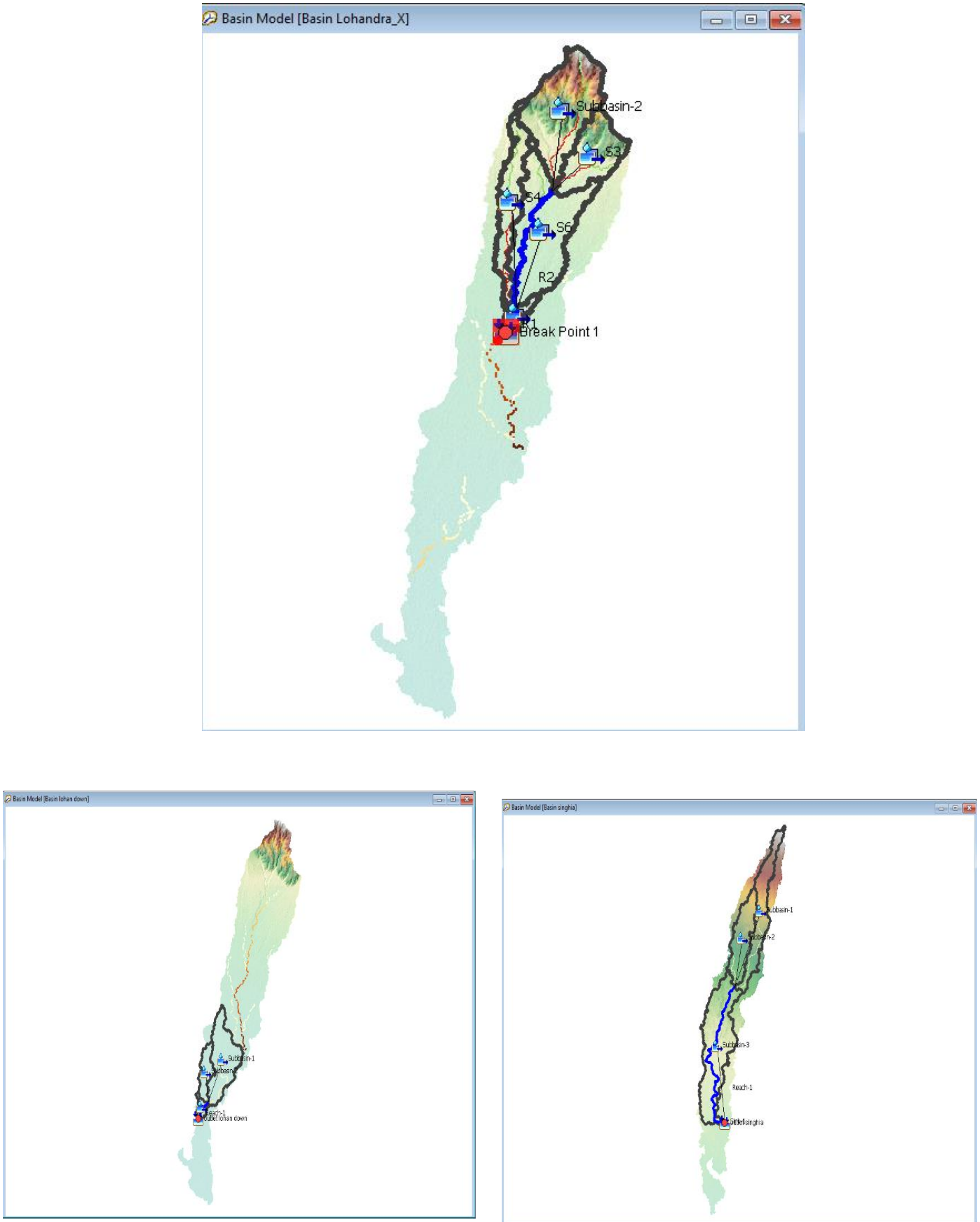


Figure 10: HEC-HMS schematic of Lohandra and Singhia basin

5.1.2 Meteorological model

The meteorological model in HEC-HMS outlines the spatial and temporal distribution of precipitation input to the basin model. This precipitation data can be derived from observed rainfall during historical events or from a hypothetical rainfall scenario based on frequency analysis (as shown in Figure 11). In this study, the specified hyetograph method was utilized, where specific precipitation gauges were assigned to the corresponding sub-basins.

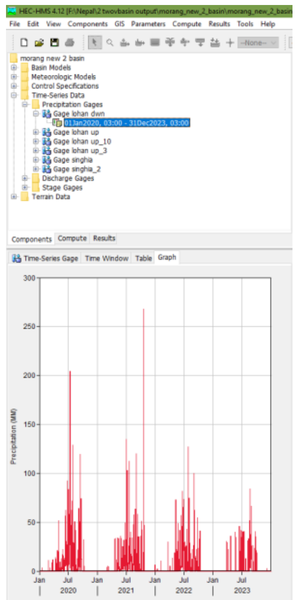


Figure 11: Meteorological model of an HEC-HMS model

5.1.3 Control specifications

The control specifications in an HEC-HMS model define the simulation's start and end dates, along with the time interval for the model outputs. In this study, actual storm dates and times were used for the control specifications. The time interval for the simulation can vary from 1 minute to 24 hours. For this work, a time interval of 24 hours (1 day) was selected (as shown in Figure 12).

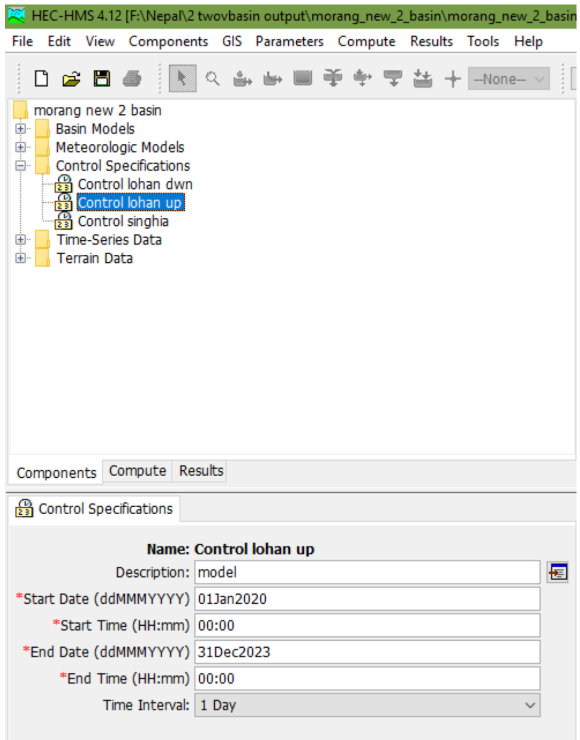


Figure 12: Control specifications of an HEC-HMS model

5.1.4 Model Input Parameters

The parameters required for running the HEC-HMS model are listed in Table 3.

Table 3: The hydrological model (HEC-HMS) catchment model parameters for Lohandra

No.	Model	Method	Parameters Required (Unit)
1	Loss Rate Parameter	SCS Curve Number	Initial abstraction (mm), Curve Number and Impervious area (%)
2	Runoff Transform	SCS Unit Hydrograph	Time of concentration (HR) and Storage Coefficient (HR)
3	Routing Method Constants	Muskingum	Muskingum K (HR) and Muskingum X (HR)

5.2 Calibration and Validation

5.2.1 Calibration and validation of the model (water level)

In this study, the model was validated using water level data. The observed daily precipitation data for the basins in Morang served as input. However, since the water level data used for calibration was available at a 12-hour interval, it presented challenges for calibrating extreme events. Accurate flash flood modeling requires observed discharge data to effectively capture the watershed's response at the outlet during extreme conditions. Despite these challenges, the model was successfully calibrated and validated using water level data from 2017, 2018, and 2019. Representative plots for these years are provided in Figure 13.

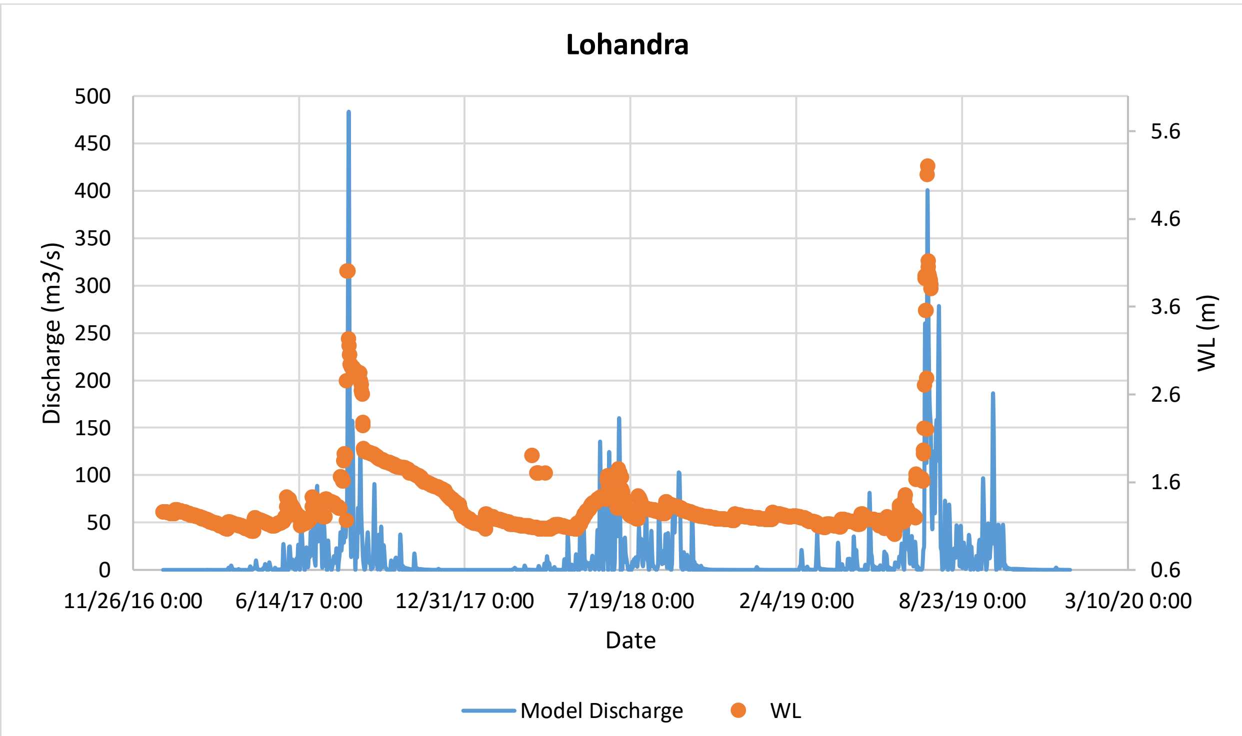


Figure 13: Calibration and validation plots (2018-2019) for Lohandra Catchment

5.2.2 Calibration and validation of the model (Discharge)

In this study, the model was validated using discharge data. The daily observed precipitation data for the basins in Morang served as input. Since the calibration relied on daily water level data, capturing extreme events posed a challenge. For accurate flash flood modeling, daily data is crucial to effectively capture the watershed's response at the outlet during extreme conditions. The model was calibrated using data from January 1, 2020, to December 31, 2021, and was validated using data from January 1, 2022, to December 31, 2023. Representative plots for the years 2020, 2021, 2022, and 2023 are presented in Figure 14.

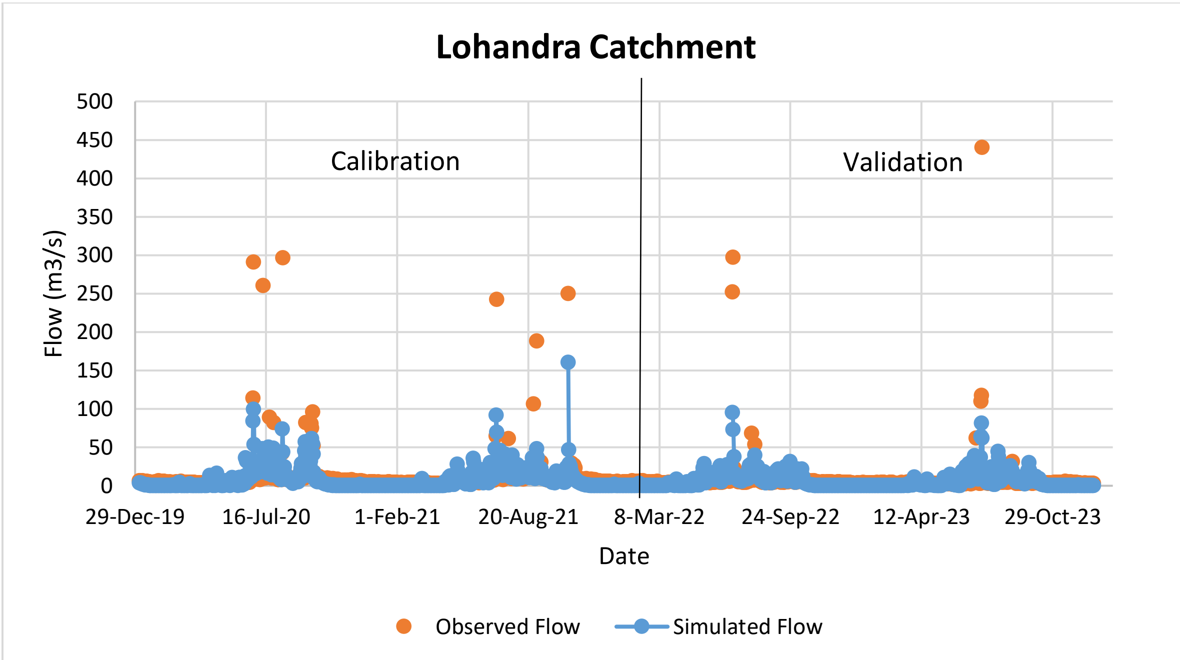
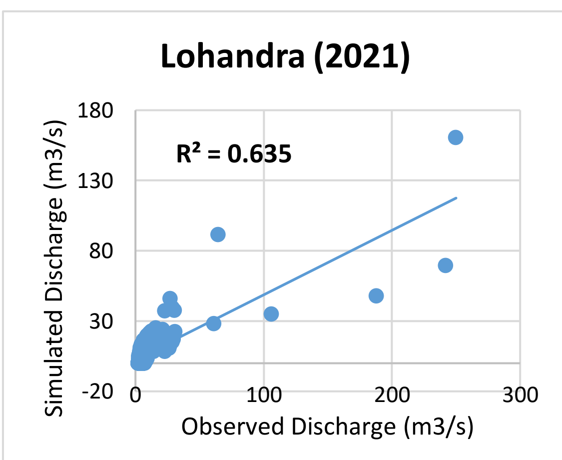


Figure 14: Calibration and validation plots (2020-2023) for Lohandra Catchment

The calibration and validation for hydrological model of the Lohandra catchment was done. However, due to the unavailability of observed discharge data for the Singhia catchment, the model couldn't be calibrated and validated for the Singhia catchment.

5.2.3 Performance of the model

The performance of the model was assessed by comparing the simulated values with the observed values. This evaluation was conducted using metrics like the coefficient of determination (R-squared), as shown in Figure 15.



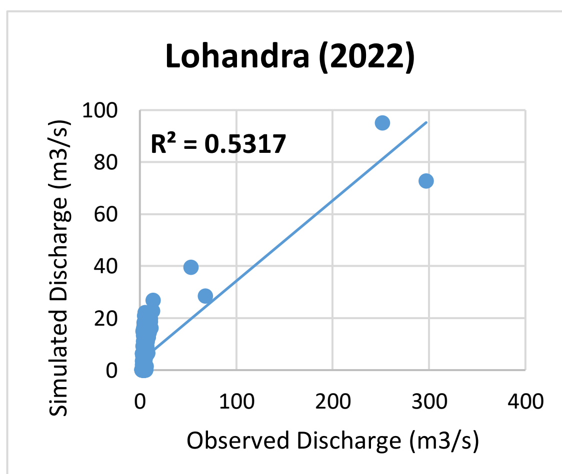


Figure 15: Calibration (2021) and validation (2022) plots model performance of Lohandra

6. Trigger Development

6.1 Menu of Forecasts

6.1.1 Department of Hydrology and Meteorology (DHM)

Department of Hydrology and Meteorology is the national hydro meteorological service (NMHS) of Nepal, mandated to provide weather and flood forecasts and early warning information across the country. DHM issues a **three-day flood and weather bulletin** on a daily basis during the monsoon season and sometimes, special weather advisories are also issued. The flood bulletin includes river level forecast information indicating the likely trend of river levels and a prediction on whether the river will flow above or below the danger level at different river gauge stations across the country. The flood bulletins do not include the small rivers and rivulets like Lohandra. Also, the weather bulletin from DHM only indicates likelihood of heavy rainfall (with color codes), but at district level, making it difficult to relate that with the flash floods at municipal level or small catchment areas like Lohandra and Singhia.

However, DHM has **one telemetric (water level) station in Lohandra**, that monitors water levels at 10-minute intervals in real time in river watch, which can be crucial early warning information for the downstream areas of Jahada, however the lead time can be very less (1-2 hours only). Additionally, there are **three automatic rainfall station** within or in the vicinity of Lohandra and Singhia watershed; Letang, Haraicha and Biratnagar Airport, providing real time observation as in the DHM rainfall map. The rainfall observed in these stations can be representative of the average rainfall in the watershed, so monitoring rainfall in these stations can also provide some increased lead time for potential flooding in catchment.

With regard to flash flood forecasts, DHM is currently operationalizing **Flash Flood Guidance System (FFGS)** supported by World Meteorological Organization (WMO) that supports in the issuance of local flash flood warnings at sub-catchment/watershed level from rainfall events using remote-sensed precipitation (that is, radar and satellite-based rainfall estimates) and hydrological models including adjustments based on the forecaster's experience with local conditions and local data. DHM flood bulletin also includes a **24-hour flash flood forecast** based on the outputs of FFGS, with flash flood risk color coded (red, orange, yellow and green) at district level.

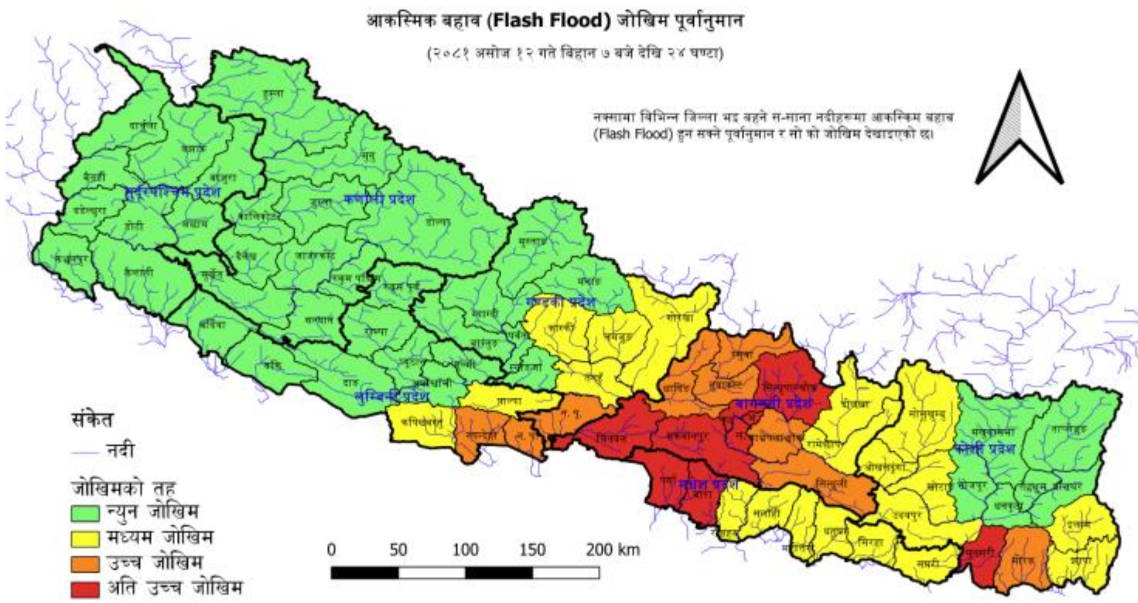


Figure 16: DHM 24-hour Flash Flood Forecast (included in 3-day flood bulletin)

6.1.2 ICIMOD – Flash Flood Prediction Tool

The Flash Flood Prediction Tool for Nepal provides 54-hour flash flood forecasts across the river segments in Nepal. The tool provides predicted estimates for flash floods from localised extreme weather phenomena like convective storms and thunderstorms. Each river segment displayed in the map interface is color-coded daily to indicate streamflow in the segment with respect to flood return periods; yellow, orange and red for river flow equal or greater than return period of 2-year, 10 year and 20 year respectively. If the flow is normal or below 2-year return period, the river segment is indicated by a blue color. Rivers with streamflow exceeding the threshold level for higher return periods are likely to experience flooding. Given that the model is not calibrated and validated for the project river catchments (Lohandra and Singhia), the forecast information needs to be used with caution, and primarily for the guidance and readiness actions.

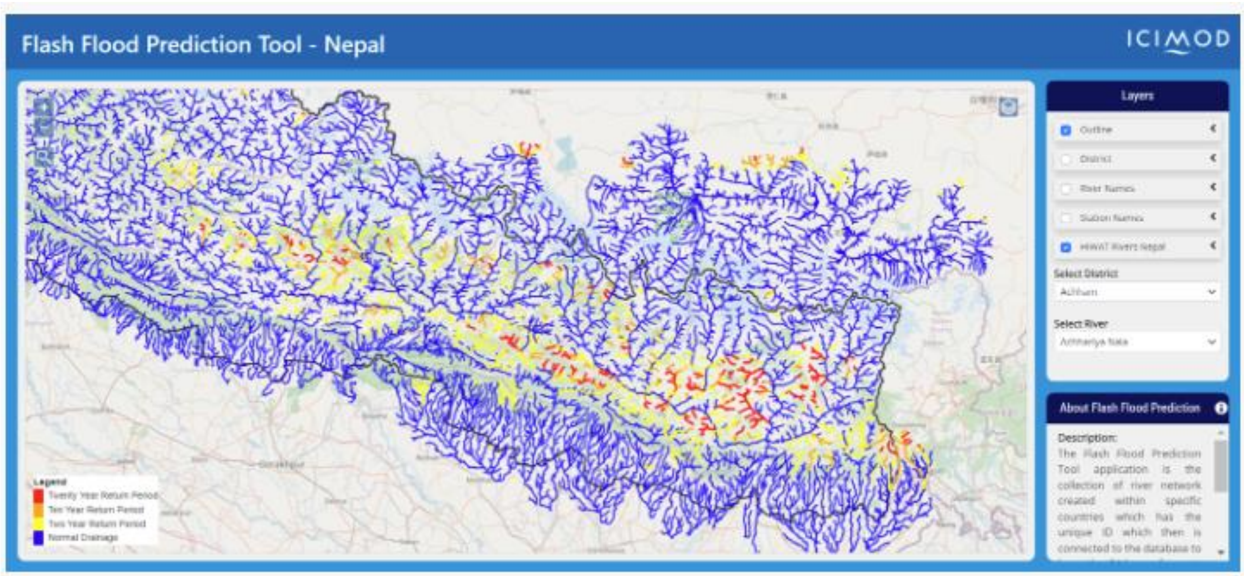


Figure 17: DHM 24-hour Flash Flood Forecast (included in 3-day flood bulletin)

6.1.3 Global & Regional Forecasts

European Centre for Medium-Range Weather Forecasts (ECMWF)

ECMWF aims to provide accurate medium-range global weather forecasts out to 15 days and seasonal forecasts out to 12 months. Its products are provided to give early warning of potentially damaging severe weather. ECMWF Centre provides rainfall forecast from 24 hrs. to 240 hrs. The Centre develops and operates global atmospheric models and data assimilation systems for the dynamics, thermodynamics, and composition of the Earth's atmosphere and interacting parts of the Earth system.

Global Forecast Model (GFS)

The GFS is the most well-known global weather model, and it's updated every six hours by the American meteorological service. Changes are regularly made to the GFS model to improve its performance and forecast accuracy. It is a constantly evolving and improving weather model. Gridded data are available for download through the NOAA National Operational Model Archive and Distribution System (NOMADS). GFS provides rainfall forecast from 24 hrs. to 240 hrs.

National Centre for Medium Range Weather Forecasting (NCMWRF)

The National Centre for Medium Range Weather Forecasting (NCMRWF) is a Centre of Excellence in Weather and Climate Modelling under the Ministry of Earth Sciences, India, providing different short-medium range forecasts on different weather parameter for India and neighboring countries including Nepal. Among several forecasting products from NCMWRF, the special product on extreme weather outlook (rainfall) with 5 days lead time can be more relevant for associated flooding in Nepal and the project areas. Extreme rainfall is color coded by their percentile thresholds; pink for rainfall more than 90th percentile while purple for rainfall more than 95th percentile. Although the information on extreme weather outlook can be a useful, the low resolution of weather model and the percentile thresholds not necessarily co-relating with the ground realities will likely overestimate or underestimate the extreme rainfall in the project areas.

6.1.4 Flash Flood Forecast (Pilot Model for Lohandra Catchment)

The flash flood forecasting model has been developed based on calibrated and validated hydrological model using HEC HMS mathematical modelling tool for the pilot river catchment. The forecasting model used past three months rainfall data and coming 10 days forecast rainfall forecast from ECMWF for the pilot river catchments. Given that the water level measurements are only in Lohandra, the forecast model can be used for the Lohandra catchment only. Forecast capturing the weather extreme events/peak such as flash flood need hourly observed and forecast information. The ECMWF's hourly forecasted rainfall data (*https://www.ecmwf.int/en/computing/software/ecmwf-web-api*) has been proposed for 10-day discharge forecast (as shown in Figure 20).

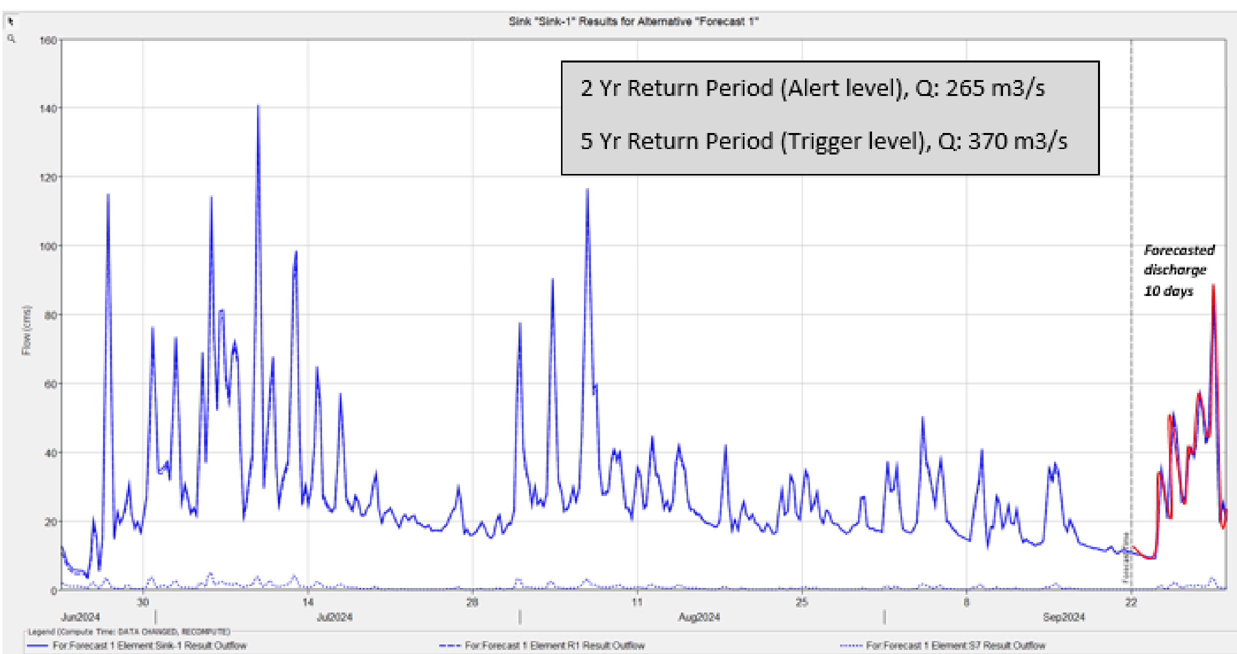


Figure 18: Discharge forecast (22 Sep to 2 Oct 2024) at Morang of Lohandra basin

6.2 Extreme Event

6.2.1 Extreme Rainfall Analysis

The maximum model discharge point rainfall over a 48-hour period varies across the different stations. For the Letang station, the rainfall ranges from 80 mm to 482 mm, for the Haraicha station, it ranges from 81 mm to 520 mm, and for the Biratnagar Airport station, it ranges from 62 mm to 390 mm (as shown in Table 4).

Table 4: Maximum peak point rainfall variation in Letang, Haraincha, and Biratnagar

Year	Stations	Rainfall (mm)		
		24 hrs	48 hrs	72 hrs
2017	Letang	251	482	516
	Haraincha	392	520	571
	Biratnagar Airport	63	108	108
2018	Letang	129	155	177
	Haraincha	42	83	119
	Biratnagar Airport	132	170	171
2019	Letang	244	335	345
	Haraincha	42	81	95
	Biratnagar Airport	172	249	291
2020	Letang	51	94	96
	Haraincha	91	218	219
	Biratnagar Airport	36	62	62
2021	Letang	268	370	388
	Haraincha	421	441	451
	Biratnagar Airport	323	390	391
2022	Letang	74	95	120
	Haraincha	116	292	331
	Biratnagar Airport	99	200	201
2023	Letang	40	80	97
	Haraincha	164	250	367
	Biratnagar Airport	108	148	199

The following Figure 19 represents the 99th percentile of 48-hour cumulative rainfall, highlighting significant rainfall events. Rainfall levels for both the 99th percentile and the 95th percentile have been calculated from the records of the observed stations in Morang District.

Figure 19: Cumulative rainfall percentile over 48 hours for Morang district

6.2.2 Flood Return Period and Rating Curve

The rating curve establishes the relationship between the water level (stage) and discharge in the Lohandra River, Morang District (as shown in Figure 17). It is based on observed water level and discharge data from 2019 to 2023. This curve is essential for converting water levels into discharge estimates.

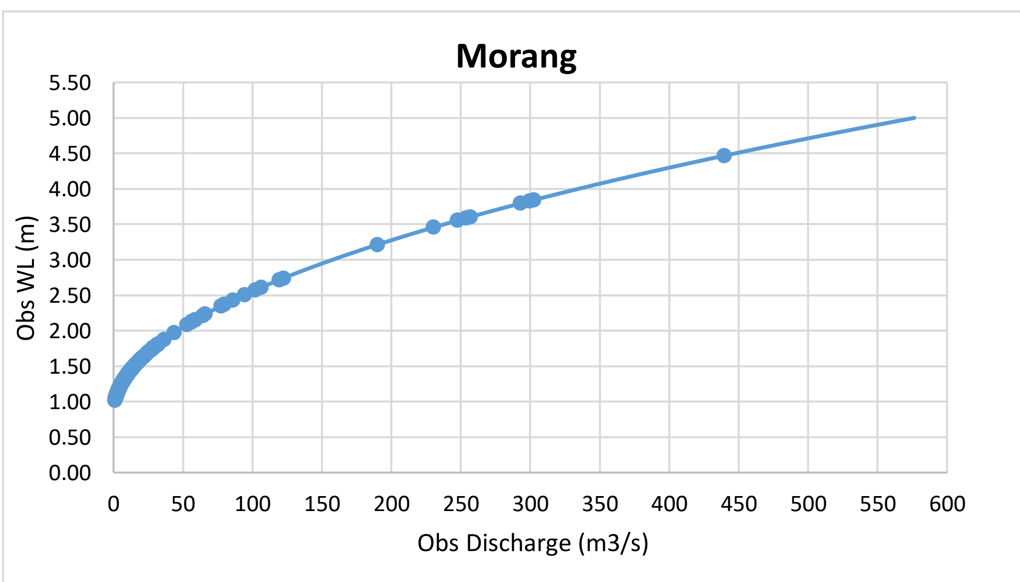


Figure 20: Rating curve analysis for Lohandra basin

Return period analysis using the Gumbel distribution method. The Gumbel distribution is commonly used for modeling the distribution of extreme values, such as annual maximum river WL. A return period analysis with these 18 years of data has been shown in the following figure 18.

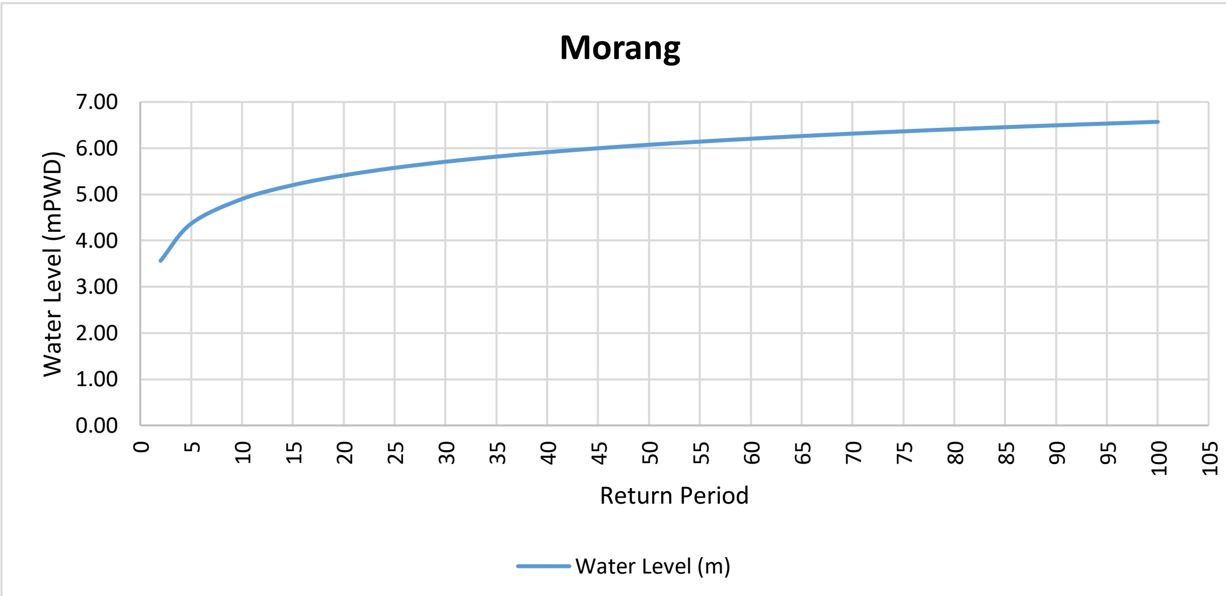


Figure 21: Return period analysis for Lohandra

6.3 Risk and Impact Analysis

6.3.1 Past Flood Events

For the purpose of event analysis, two major flood rainfall/flood events of 2017 and 2019 were studied. During the flood event of 2019, Lohandra watershed received 345 mm of rainfall in three days while Singhia watershed observed almost 250 mm in just 48 hours. The 2017 event was even more intense in terms of rainfall, where Lohandra received 482 mm of rainfall in just 2 days. For both of these events, Lohandra recorded almost 250 mm rainfall in 24 hour.

Table 5: Rainfall Recorded during 2017 and 2019 flood event in Lohandra and Singhia

Year	Basin	24 hrs	48 hrs	72 hrs
2019	Lohandra	244	335	345
	Singhia	172	249	291
2017	Lohandra	251	482	516

	Singhia	63	108	108

The flood extent map from [BIPAD Portal]() clearly indicates the extensive flood footprint in Jahada during these two events. The 2019 event seemed to be more extensive in terms of its extent in the project municipalities

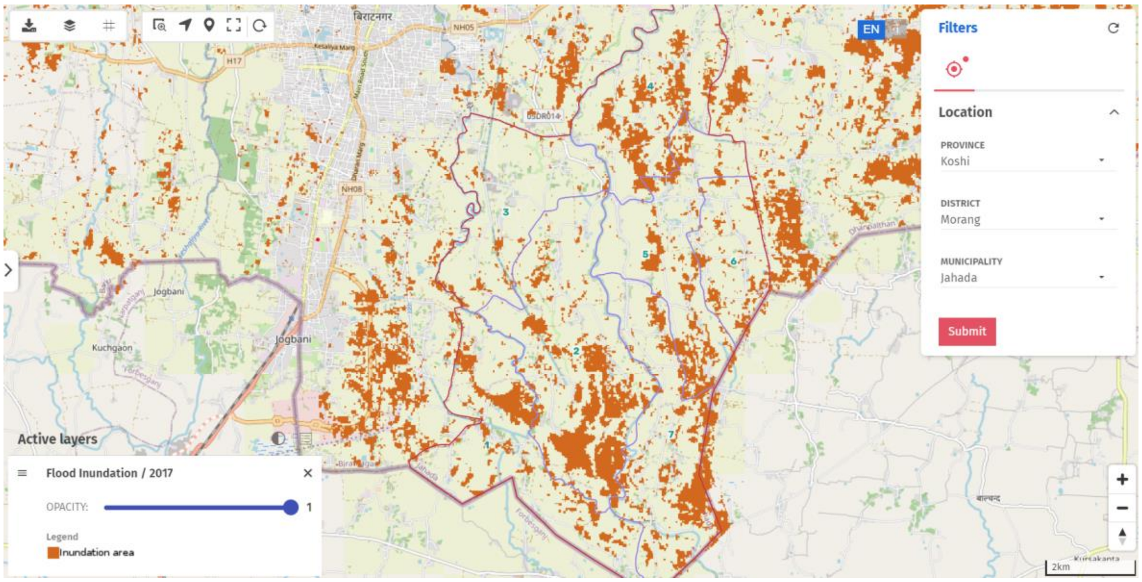


Figure 22 : Floods Footprint in 2017 August Event (2074 B.S) in Jahada

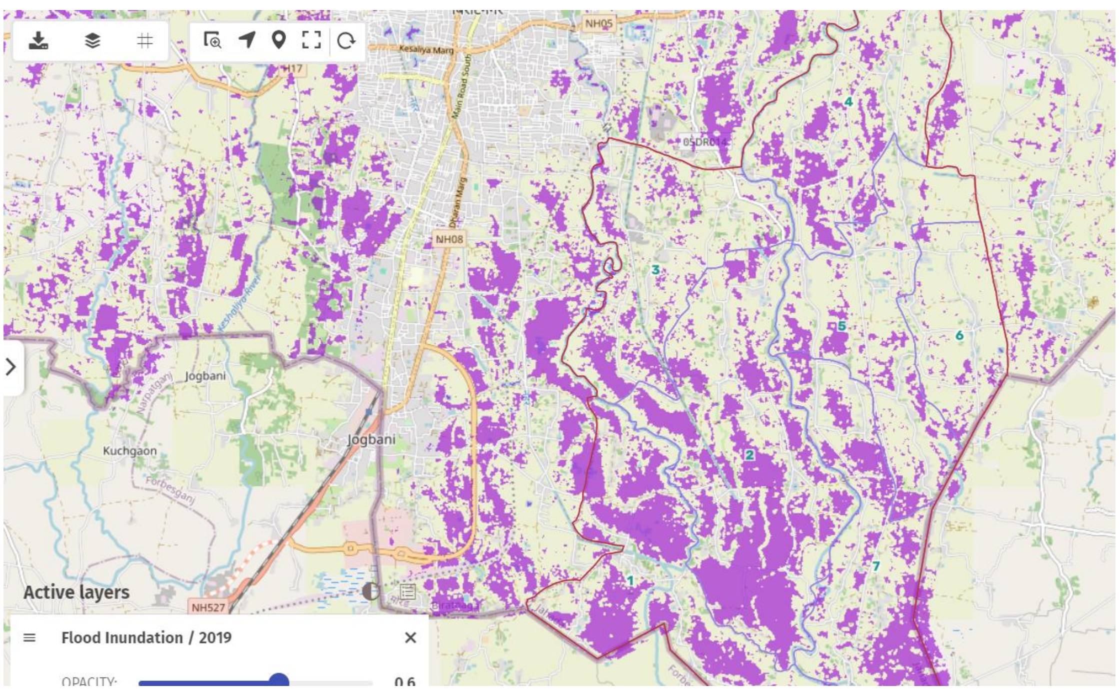


Figure 23: Floods footprint 2019 July Event (2076 B.S) – Jahada

6.3.2 Exposure & Physical Vulnerability

FastFlood Model, a free super-fast modelling tool focused on the simulation of flood processes was utilised to understand the physical exposure level of Morang. The flood inundation was simulated for both the peak rainfall events of 2017 and 2019 to identify the number of buildings in Morang that were potentially subjected to different inundation levels (kneel, hip, chest, head, first floor or second floor). Additionally, the simulation was also undertaken for the 24-hour rainfall values of 150 mm and 200 mm. These simulations are useful to correlate the rainfall values with the associated impacts in the Lohandra catchments, especially in the project areas of Jahada municipality.

Table 6: Building Exposure Level to Flood Inundation for different Rainfall in Lohandra, as calculated by the FastFlood

24 h Rainfall Values *(mm)*	*Number of buildings exposed*					
	Knee Level	**Hip Level**	**Chest Level**	**Head Level**	**First Floor Flooded**	**Second Floor Flooded**
150	309	915	1439	1480	1214	2865
200	280	629	1177	1365	1689	3952
244 (2017 ***Event***)	175	555	1126	1294	1652	4346
244 (***2019 Event)***	172	497	1074	1284	1519	4528

6.3.3 Priority Impacts and Potential Early Actions

The impacts of floods in the Jahada have been observed in multiple areas and dimensions, as listed below

- Loss of lives, injuries and missing
- People Displaced
- House destroyed & damaged
- Cropland affected, loss of livelihoods
- Livestock loss
- Contamination of Drinking water – Waterborne disease outbreak
- Disruption to critical services – e.g., education, healthcare, electricity, transport, water supply, security, communication

During the stakeholder consultation, the participants identified several potential preparedness and early action interventions to mitigate or reduce the different flood impacts in the areas.

Table 7: Early Action + Preparedness Activities for Prioritized Flood Impact

Flood Impacts	**Preparedness Activities**	**Early Action Interventions**
Loss of lives, injuries and missing	Identification of safe place , safe shelters management	• Early Warning Messaging, • Evacuation of most vulnerable/exposed people
House Damage/Destroyed	Embankment protection, identifying flood passing points, drainage management	
Cropland affected, loss of livestocks and livelihoods	Early harvest of mature crops	• Preparation of Go-bags, • Evacuation of livestocks to safe place/shed • Keeping harvested crops and other livelihood/assets in safe/high places
Contamination of Drinking water – Waterborne disease outbreak	Protection of Drinking Water Source Awareness Raising Storing of drinking water in safe place	• Distribution of Water Purification Supplies
Disruption to critical services – e.g., education, healthcare, electricity, transport, water supply, security, communication	Alternative safe routes Dozer, Excavator etc. in standby Alternative energy and telecommunication sources Contingency planning for critical services continuation	

6.4 Defining Threshold

Monsoon rainfall in Nepal, occurring from June to September, is crucial for estimating design floods, as it accounts for about 80% or more of the annual rainfall. This seasonal rainfall impacts the entire country, except for the northern Himalayan region.

The topography of the basin was modeled using a Digital Elevation Model (DEM) with a resolution of approximately 30 meters. It shows that the highest elevation in the Lohandra and Singhia catchment is 2,397 meters, while the lowest point is 56 meters. The Lohandra catchment is divided into three sub-catchments: the upper catchment at 2,300 meters, the middle catchment at 200 meters, and the lower catchment at 70 meters. The lag times for these catchments are 2-3 hours for the upper catchment, 6-9 hours for the middle catchment, and 2-3 hours for the lower catchment.

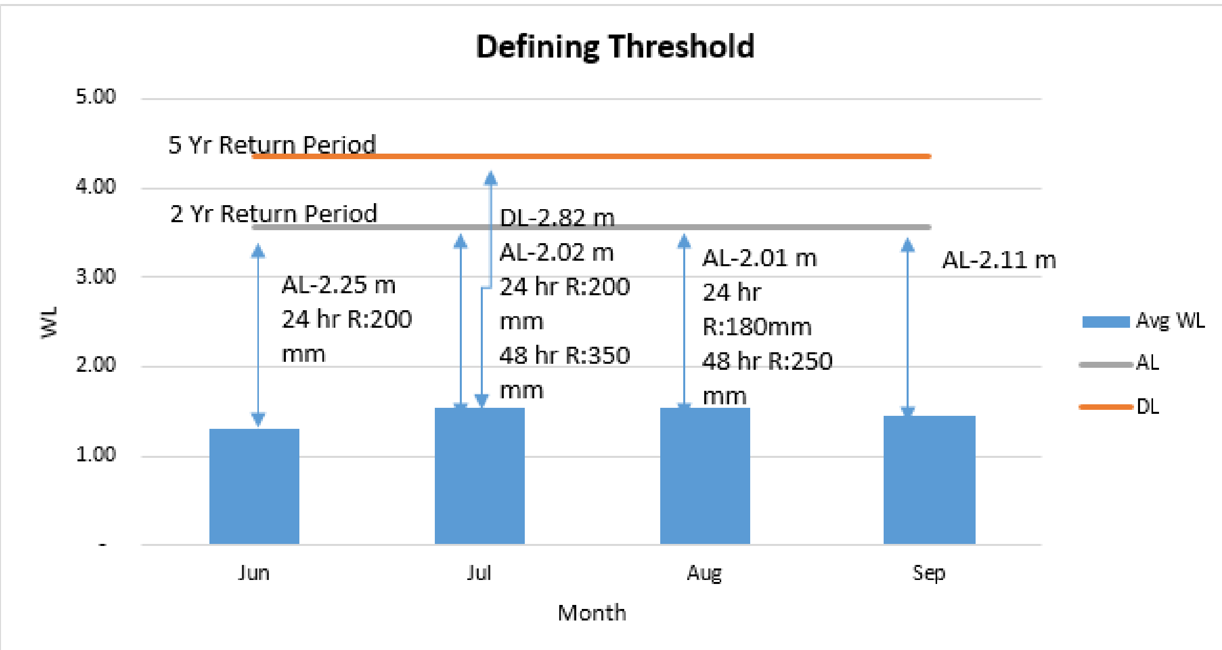


Figure 24: Defining threshold for Morang district

The historical analysis of water level from 1994 shows that, only in the month of July, the water level can cross danger level (5-yr return period flow). On other months of monsoon, the water level generally reaches up-to alert level (2-yr return period flow)

For defining the flash flood threshold, return period analysis for Lohandra river indicates that the 1-in-2-year flood alert level is 3.56 meters, while the 1-in-5-year flood danger level is 4.36 meters. At the alert level, 24-hour rainfall is 200 mm, and at the danger level, 48-hour rainfall reaches 350 mm.

- In June, the average water level is 1.31 m, which is 2.25 m below the alert level and 3.05 m below the danger level. With 200 mm of rainfall over 24 hours, it can reach the alert level.
- In July, the average water level is 1.54 m. With 24-hour rainfall of 200 mm and 48-hour rainfall of 350 mm, the water level can rise to both the alert and danger levels.
- In August, the average water level is 1.55 m, which is 2.81 m below the danger level and 2.01 m below the alert level. With 24-hour rainfall of 180 mm and 48-hour rainfall of 250 mm, the water level can reach the alert level.

6.5 Trigger for Anticipatory Action

6.5.1 The Framework

The framework for trigger model is based on the definition of the extreme event that correlates with the physical exposure/impact level in Jahada and the available flash flood forecasts and observations for rainfall and river levels/discharge in Lohandra. The extreme event thresholds (alert level and danger level) for river levels in Lohandra are based on return periods i.e., 1-in-2-year flood alert level of 3.56 meters, and the 1-in-5-year flood danger level of 4.36 meters at Sisbeni station in Jahada. With 200 mm of rainfall in 24 hours – which is above the 99th percentile value for Lohandra catchment, the river is expected to reach alert level, while anything above 350 mm of rainfall in 48 hours, the river can surpass its danger level. This means, the minimum rainfall to cause flash flood in Lohandra catchment and Jahada is 200 mm. During the 2017 and 2019 events, when the project area witnessed substantial flood inundation and damages, all the above flood and rainfall thresholds were surpassed. This also confirms that the above indicated river level and rainfall thresholds are associated with the humanitarian impacts in flood plains of Lohandra, Jahada in particular.

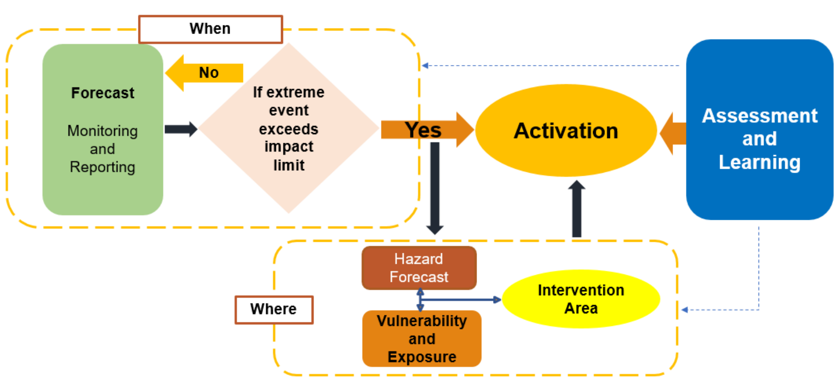


Figure 25: Schematic Diagram of FbA Trigger framework

With regard to the flash flood forecasts, the proposed trigger makes the use of more readily available flash flood and rainfall forecasts in combination with the real time observation of river level and rainfall in Lohandra and Singhia catchment. This means, the range of lead time varies, from as little as 1-2 hours to a maximum of 3 days that will inform different phases of early action. Although the use of observation significantly reduces the lead time, it is to be noted that community perceives serious danger of flood/inundation, only when the flood inundation at homes gets higher than hip level (>3 feet) and when the nearby roads start to get flooded. This means it will take some time to get the flash flood peak its humanitarian impact, allowing us to have few more hours additional for the early action. Given that there is no flash flood forecast model yet operational for the Lohandra and Singhia catchment, the study has tried to develop a flood forecast model (first trial in 2024 monsoon season) based on the ECMWF rainfall forecast (10 days) and local catchment/hydrological model to predict the flood flows /water level in Lohandra.

The focus of the study has not been on the community level risk and impact analysis; however, the trigger framework proposes following criterial for where to act

- Riverine communities that are frequently affected by flood
- Communities or lower elevation points that are in the vicinity of flood passing points
- Connection routes or road vulnerability
- Houses/communities depending on the distance to evacuation points or higher grounds

6.5.2 Trigger Statements

Stage I: Readiness

When the hydrological (HEC-HMS) model of Lohandra predicts the river flow to surpass 1 in the 2-year return period i.e., 265 cubic meters discharge in next 5 days, this will trigger readiness related activities in Jahada and flood plains of Lohandra and Singhia.

Or

When the ICIMDO flash flood prediction tool predicts more than 10-year return period flow (orange color) in the river segments of Lohandra/Singhia in next 72 hours, this will trigger readiness related activities along the associated river segments areas and downstream flood plains of Lohandra and Singhia.

Or

Any special weather advisories/bulletin from Department of Hydrology (DHM) predicts extreme and widespread heavy rainfall indicating red alert for Morang district, readiness related activities in Jahada and flood plains of Lohandra and Singhia will be triggered.

Stage II : Activation

(a) Based on Forecasts

When the hydrological (HEC-HMS) model of Lohandra predicts the river flow to surpass 1 in the 5-year return period i.e., 370 cubic meters discharge in next 48 hours, this will trigger early actions that can be implemented in Jahada within that lead time.

Or

When the 24-hour flash flood forecast (included within 3-day flood bulletin) from Department of Hydrology (DHM) indicates red color warning for Morang, this will trigger relevant early actions that can be implemented in Lohandra flood plains within a day.

(b) Based on the Observations

When any of the three rainfall stations (below mentioned) of DHM in Morang records cumulative rainfall of more than 200mm in the last 24h or 350 mm in the last 48h, then relevant early actions are triggered that are feasible enough to get implemented with a lead-time of 3-10 hours.

Or

When the Lohandra River surpasses the danger level of 4.36 m at Sisbeni station, which is equivalent of 5-year return period flow, then the relevant early actions (for. e.g, last minute evacuation) are triggered that are feasible to get implemented in Jahada within the lead time of 2-3 hours.

Table 8: Proposed Warning Level and Danger Level for Lohandra

River Name	Station Name	Proposed Warning Level (m)	Proposed Danger Level (m)	Recommended Threshold Level (m)
Lohandra	Sisbeni	3.56	4.36	**4.36**

Table 9: List of Automatic Rainfall Stations relevant for Lohandra and Singhia Catchment

Station ID	Station Name	District
1312	Haraincha	Morang
	Letang	Morang
131901	Biratnagar	Morang

7 Conclusion and Recommendations

Jahada Rural Municipality, especially in the Lohandra and Singhia watersheds, is highly prone to flash floods, which pose significant threats to life, property, and infrastructure, particularly during the monsoon season. The hydrological model developed using HEC-HMS has proven effective in simulating rainfall-runoff processes and determining flood trigger thresholds for Lohandra catchment. Calibrated with local water level and rainfall data, this model can forecast potential flood conditions in the catchment and help in informing early actions to mitigate or reduce the potential flood impact in the areas.

The proposed forecast-based action (FbA) trigger model, with defined alert and danger thresholds based on rainfall and water levels, is essential for timely anticipatory actions. The model's predictions, when combined with real-time data, can provide useful lead times ranging from hours to days, enhancing community preparedness and response. However, real-time monitoring and more frequent rainfall and discharge data updates are crucial. While the model has been effective for the Lohandra catchment, limited data availability constrained similar validation for the Singhia catchment.

It is imperative that the Department of Hydrology and Meteorology (DHM) needs to expand the coverage of automated rainfall and river gauge stations across these watersheds. Existing rainfall stations do not necessarily capture the rainfall events within the watershed, while the gauging station at Lohandra is located in the downstream section of the river, providing much less lead time. Nevertheless, ensuring regular maintenance and timely data transmission from these stations is necessary to improve model accuracy and reliability, including monitoring of potential heavy rainfall events and flash floods in the areas.

The dissemination of alerts and early warning messages need to localised using appropriate communication channels across the flood prone communities. Community training and drills based on the proposed FbA framework need to be conducted to ensure effective preparedness, early action and community response during floods. Together with the community involvement, flood-prone areas, the flood passing points and vulnerable households/settlements need to be identified, including safe areas and higher grounds for the timely evacuation when needed. Detailed analysis of socioeconomic impacts can help tailor flood early action measures to community needs, focusing on vulnerable populations and infrastructure in flood-prone areas.

Building on the proposed FbA Trigger model, a brief standard operating procedures (SOPs) is highly recommended that will help to streamline the triggers, early action and necessary resources for the readiness and activation of early action in the project areas and the catchments.