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STATE OF KNOWLEDGE

Exploring flood modelling in the Koshi River Basin

Challenges and the way forward

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Flooding in the Koshi River

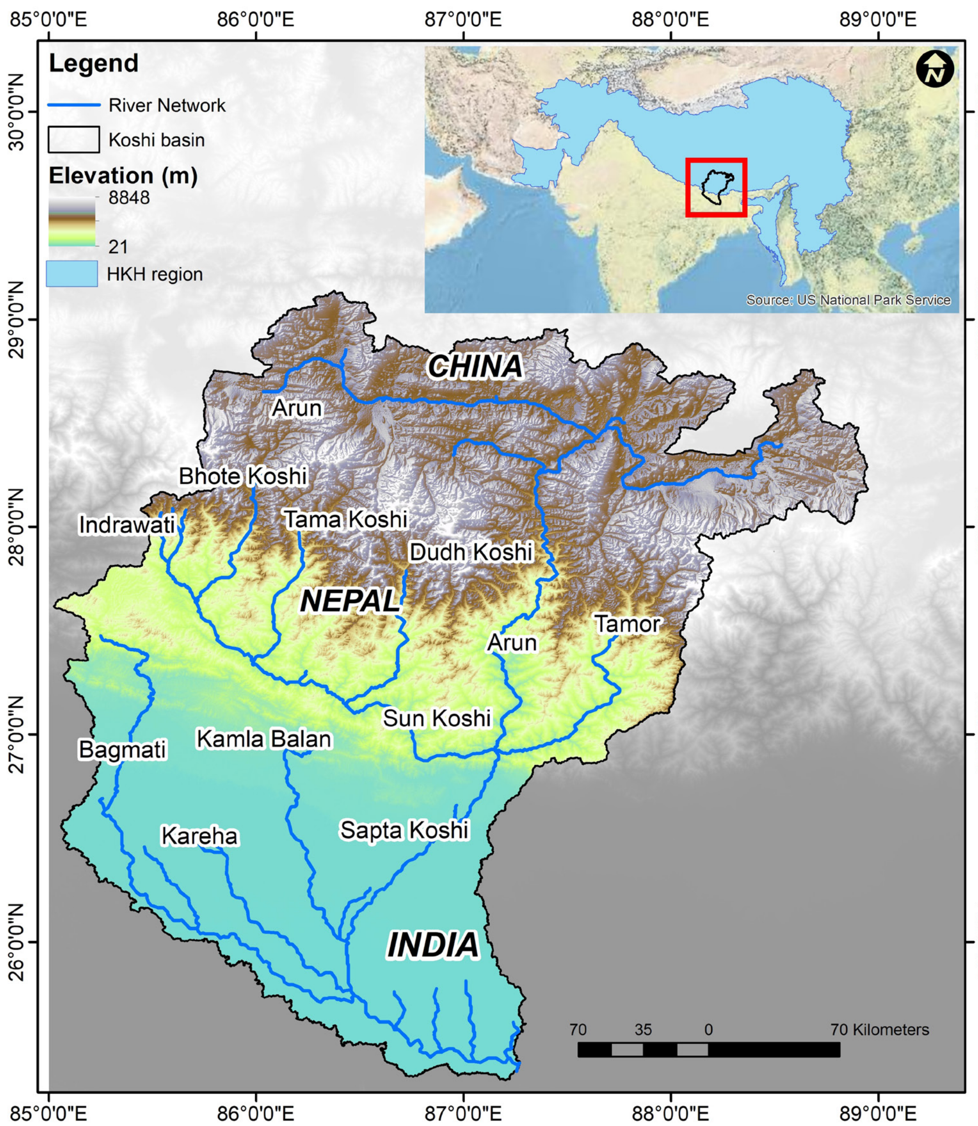
Originating in the Tibetan plateau in China, the Koshi River flows southward, carrying water from several rivers in Nepal and India and draining into the Ganges River. The Koshi is one of the largest transboundary rivers in the Hindu Kush Himalaya (HKH) region (Figure 1), covering an area of about 88,000 km^2. Of the nearly 88,000 km^2 area of the Koshi basin, 32.4% lies in China, 45% in Nepal and 22.6% in India (Wahid et al., 2017). The basin can be divided into three major physiographic zones: (a) the Trans-Himalaya, which covers the high mountainous areas of Tibet, (b) the High and Middle Himalaya, mostly situated in Nepal, and (c) the alluvial part consisting of the Terai region of Nepal and the flat plains of India. The variations in elevation and climate make the basin rich in biodiversity, which sustains the livelihoods of almost 40 million people (Neupane et al., 2015).

The Koshi River system plays a vital role in the socio-economic development of the region. It supplies water for agriculture, hydropower generation, and fisheries, and it also has cultural and religious significance. However, due to the rugged and fragile topography and the impact of the monsoon season, the basin is prone to natural disasters such as floods and landslides. These hazards primarily occur during the monsoon season, which lasts from June through September.

The region has experienced several devastating floods in the past, causing a significant loss of life and property. In 2008, a breach in an embankment close to the Nepal-India border caused a flood that resulted in the loss of more than 500 lives and displaced thousands of families (Kafle et al., 2017). The glacier lake outburst floods in the Bhote Koshi in 2016 and Barun Khola in 2017, the Terai floods in 2017, and the Melamchi flood

The 2019 flood in Bhittamore, Bihar. *(Photo: Ranjeet Jha)*

FIGURE 1 THE KOSHI RIVER BASIN AND ITS MAJOR TRIBUTARIES



disaster in 2021 are some of the major flood events in the upper Koshi basin (Kafle, 2019; Maharjan et al., 2021). Similarly, in Bihar state, downstream of the Koshi basin, floods occur almost every year, which has earned the river the nickname 'the sorrow of Bihar'. The flood of 2019 inundated 12 out of 38 districts of Bihar, affecting 2.5 million people and damaging crops and infrastructure. Over the years, several efforts have been made to develop flood forecasting systems in the Koshi basin to minimise the impact of floods. This state-of-knowledge report sheds light on the available flood forecasting and early warning systems in the Koshi basin, related challenges, and the way forward.

Flood management in the Koshi basin

Early developments

Given the Koshi basin's vulnerability to flooding, several efforts have been made to mitigate the impact of floods in the basin. The initial flood warning system in the Koshi basin relied on the observation of the river level. A watchtower ('machan' in the local language) was used to observe the water level and disseminate flood information to the community. This system provided a very short lead time (only a few minutes) and relied on manual data collection and analysis.

In 1954, the governments of India and Nepal signed a bilateral agreement known as the Koshi Agreement to regulate the flow of the river. As part of the agreement, a barrage was constructed at the Nepal-India border

The Koshi barrage located near the Nepal-India border *(Photo: ICIMOD)*

to control floods and harness the water for agriculture and hydropower (Bagale, 2020). Since the 1960s, several manual gauge stations have been installed in the tributaries of the Koshi, increasing the lead time by up to an hour. Telemetry and satellite-based systems were introduced in the basin in the early 2010s (Kafle, 2019). As part of the HKH Hydrological Cycle Observing System (HYCOS) project implemented by the Department of Hydrology and Meteorology (DHM) of the Nepal government, three automatic weather stations, 12 rain gauges, and seven real-time water level sensors were installed in the various tributaries (Shrestha et al., 2015). The transmission of real-time water level information enabled timely warning and the system was able to increase the lead time by up to four hours depending on the location of the community.

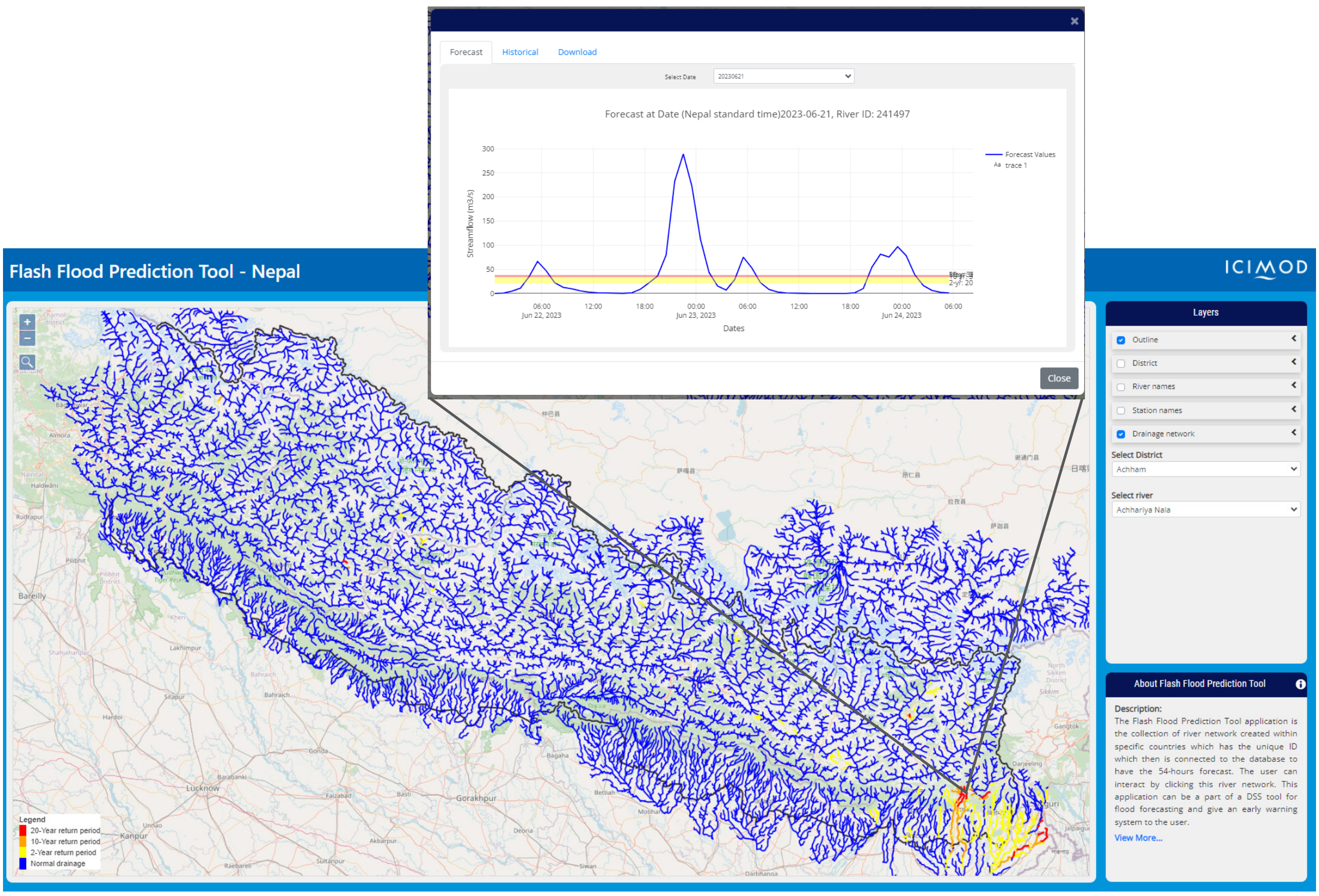
Left: Watchtower (also known as 'machan'); and Right: Radar sensor for water level observation
(Photo: Karen Conniff and Pradeep Dangol)

Development of flood forecasting and warning system

As the most significant non-structural measure for flood control, Flood Forecasting and Early Warning Systems (FFEWS) play an important role in supporting decision-makers for mass evacuation, rescue, and relief. The availability of telemetry and satellite data and high-performing computers paved the road for the development of flood forecasting models (Shrestha et al., 2020). The main objective of the FFEWS is to provide timely and reliable prediction and alerts on potential flood events (Tsering et al., 2022). The system uses hydrological models that represent the basin properties to simulate its water cycle and a system to disseminate flood information. To provide accurate information, a flood model requires precise real-time and forecasted weather information as well as the biophysical data of the basin.

Several hydrological and hydrodynamic models have been developed and are operated by the respective government departments of the member countries. The flood forecasting and warning service in China is managed by the Flood Control and Drought Relief Headquarters hosted in the Ministry of Emergency Response (Office of the State Council, 2020). The Headquarters receives information on weather services and flood forecasting from the China Meteorological Administration and the Ministry of Water Resources, respectively. In Nepal, the DHM under the Ministry of Energy, Water Resources and Irrigation is the key authority for collecting, forecasting and analysing flood hazard-related information. Similarly, in India, the Central Water Commission (CWC) and the Ministry of Jal Shakti provide near real-time and five-day advisory flood forecasting at the national and basin level. In addition, the India Meteorological Department (IMD) under the Ministry of Earth Sciences provides flash flood guidance. IMD issues the flash flood bulletin for India and the broader South Asia region. There are also other non-government agencies that provide early warning services to the authorised agencies of countries that share the Koshi basin (Figure 2). A list of flood forecasting systems for the Koshi River Basin is provided in the table below.

FIGURE 2 **ICIMOD'S FLASH FLOOD PREDICTION TOOL – NEPAL**



LIST OF FLOOD FORECASTING SYSTEMS CURRENTLY USED IN THE KOSHI RIVER BASIN

System	Developer	Data Interval/ Resolution	Lead time	Domain	Website
Satellite data	Satellite Meteorological Centre, China Meteorological Administration, China	4 min	Real-time	China	http://en.weather.com.cn/satellite/
Surface, upper-air, and radar observation	National Meteorological Information Centre, China Metrological Administration, China	0.0625°×0.0625° 1 hour	Real-time	China	http://data.cma.cn/en/?r=site/index
China flash flood hazard early warning	China Institute of Water Resources and Hydropower, Ministry of Water Resources, China	Daily	1 Day	China	http://cdr.iwhr.com/fhkhjzzx/index.htm
Real-time ground observation system for rainfall	Flood Forecasting Section, DHM, Nepal	10 min 42 Stations	Real-time	Nepal	http://hydrology.gov.np/#/rainfall_watch
Real-time ground observation system for water level	Flood Forecasting Section, DHM, Nepal	10 min 13 Stations	Real-time	Nepal	http://hydrology.gov.np/#/river_watch https://www.dhm.gov.np/hydrology/floodMonitoring
Mike 11, NAM model for Koshi	Flood Forecasting Section, DHM, Nepal		3 days	Koshi basin	
RIMES WRF model	Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)	6 hours 9km X 9Km	72 hours	Asia	
Global Flood Awareness System (GLOFAS)	European Commission's Copernicus Emergency Management Service	Daily 7 (Nepal) + 1 (India) stations	30 days	Global	https://www.globalfloods.eu/glofas-forecasting/
GEOGloWS ECMWF Streamflow Model	ESRI, European Centre for Medium-Range Weather Forecasts, and Brigham Young University	Daily	10 days	Global	https://apps.geoglows.org/apps/geoglows-hydroviewer/
South Asia flash flood guidance system	World Meteorological Organization (WMO)/ IMD	3 hrs	24 hrs	South Asia	https://mausam.imd.gov.in/responsive/flashFloodBulletin.php
Regional flood outlook	ICIMOD	3 hrs	72 hrs	Ganges and Brahmaputra	http://hkhhycos.icimod.org/GB/Source/GB_new.htm
High-Impact Weather Assessment Toolkit (HIWAT)	ICIMOD	1 hr 4kmX4Km	54 hrs	Nepal, Bhutan, Bangladesh, and NE India	https://servir.icimod.org/science-applications/high-impact-weather-assessment-toolkit-hiwat-nepal/
Flash flood prediction tool – Nepal	ICIMOD	1 hr	54 hrs	Nepal	https://servir.icimod.org/science-applications/flash-flood-prediction-tool-nepal/
Streamflow prediction tool – Nepal	ICIMOD	1 hr	10 days	HKH region	https://servir.icimod.org/science-applications/streamflow-prediction-tool-nepal/
Five-day advisory flood forecast	Central Water Commission, India	6 hrs	5 days	India	https://aff.india-water.gov.in/
Real-time ground observation system for rainfall	Indian Meteorological Department	Districts	Real-time	India	https://mausam.imd.gov.in/imd_latest/contents/districtwisewarnings.php
Satellite data	Indian Meteorological Department	30 min	3-7 days	India	https://mausam.imd.gov.in/imd_latest/contents/satellite.php
Koshi flood forecasting and early warning system	Water Resources Department, Government of Bihar	Hourly 17 locations	72 hrs	Koshi basin	https://www.fmiscwrdbihar.gov.in/KosiFews/Home

Challenges and the way forward

There has been substantial improvement in flood management in all three countries that share the Koshi basin. However, flood forecasting models currently in place are within each country's boundaries. Although some models capture the entire basin, most of them are either at a global or regional scale. As a result, these models don't capture the bio-physical properties at a basin scale. In addition, most of these models lack infrastructure components like the control flow from the Koshi barrage, and glacier, snowmelt and lake simulation. These components play a vital role in the accuracy of flood forecasting. Land-use changes also have a profound impact on the flow of the river (Shrestha et al., 2020). The rapid changes in the landscape of the Koshi pose a challenge to modelling forecasts. One major reason behind the lack of a holistic flood forecasting system is the lack of data and data-sharing mechanisms among the member countries.

Communication of early warning to the public is another major component of FFEWS. The warning is broadcasted via different channels like websites, radio, TV, mobile apps, and SMS to the communities. The information shared usually includes near-real-time rainfall, trend of water level, and forecasted rainfall and water level in the rivers. These warnings are more generic and don't have the element of exposure, vulnerability and risk. Impact-based Forecasting (IbF) focuses on communicating the potential impact of the forecast rather than on providing technical information. IbF aims to bridge the gap between the forecast, decision-makers, and the public by providing more actionable information about the potential hazard event. It helps us identify more vulnerable areas by providing critical information, such as when and to what extent the flood might inundate the exposed communities and infrastructures.

FFEWS is extremely useful in providing people the time needed to evacuate and prepare for relief, but it doesn't prevent a flood. The use of both grey infrastructures (such as dams and embankments) as well as Nature-based Solutions (NbS) (e.g., the construction of bio-dykes, wetlands, and afforestation upstream) can help prevent floods from entering settlements. In addition, zoning the floodplain areas and avoiding building settlements in high-risk areas can help minimise both human and economic losses.

Initially relying on manual observation, FFEWS has advanced to incorporate a sophisticated modelling system. However, in addition to flood hazards, the Koshi faces several other hazards like GLOF, landslides, and morphological changes. The GLOF in the Zhangzangbu region of China caused massive damages to the Sunkoshi hydroelectric plant in Nepal, claiming 200 lives (Campbell & Pradesh, 2005). Similarly, the Jure landslides of 2014 resulted in the loss of 156 lives, destroyed 120 houses, and obstructed the flow of the Sunkoshi River. Subsequently, this led to a flood that inflicted damage upon the Sunkoshi hydropower project (Panthi, 2021). The Koshi River is a highly dynamic and sediment-charged river and has changed its course 115 km westwards in the last 200

The aftermath of the Melamchi disaster of 2021 in Melamchi bazaar, Nepal *(Photo: Sudan Maharjan)* years (Baniya et al., 2023). As a result of this active shift, flood plains and agricultural lands are destroyed every year. In 2020 floods and landslides damaged the Middle-Bhotekoshi project, inundating the powerhouse. The Melamchi disaster of 2021 occurred as a result of several cascading hazards (Maharjan et al., 2021). Multi-hazards in the region are becoming more common. Therefore, a more holistic approach to multi-hazard and risk management is extremely important.

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