Bhutan Flood Hazard Atlas

A Visual Guide to Flood-Prone Areas

2025

National Centre for Hydrology and Meteorology (NCHM)
Thimphu, Bhutan

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Bhutan Flood Hazard Atlas: First Edition

National Centre for Hydrology and Meteorology
Thimphu, Bhutan

Foreword

Bhutan, with its rugged terrain and dynamic river systems, is highly vulnerable to flood hazards, which pose significant risks to lives, livelihoods, and infrastructure. As climate change intensifies extreme weather events, the need for accurate and reliable flood hazard mapping has become more critical than ever. Recognizing this urgency, the National Center for Hydrology and Meteorology (NCHM) has developed the **Flood Hazard Atlas of Bhutan**, a comprehensive resource aimed at identifying and assessing flood-prone areas across the country.

This publication provides flood hazard maps that will serve as a vital tool for policymakers, planners, and local communities in making informed decisions on disaster preparedness and risk reduction. By integrating scientific data, hydrological modeling, and geospatial analysis, the atlas enhances our understanding of flood risks and supports adaptive planning for resilient development. The insights drawn from these maps will be instrumental in guiding infrastructure development, land-use planning, and emergency response strategies.

I extend my gratitude to 'Strengthening Risk Information for Disaster Resilience in Bhutan (RIR)' project, funded by the World Bank for the financial support for the activity and my appreciation to the team at NCHM for their invaluable efforts in producing this atlas. It is our hope that this publication will contribute to a safer and more resilient Bhutan by fostering proactive flood risk management and sustainable development.

Karma Dupchu
Director
National Center for Hydrology and Meteorology

Table of Content

1. Introduction

Bhutan's unique topography, characterized by its mountainous terrain and vulnerability to seasonal rainfall patterns, exposes the country to significant flood risks. The occurrence of flash floods, riverine flooding, and Glacier Lake Outburst Floods (GLOFs) is prevalent, particularly during the summer months. These hydrological events are not only destructive in nature but also present substantial challenges to public safety, infrastructure, and economic stability.

The rapid socio-economic development of Bhutan, coupled with urban expansion into flood-prone areas, has increased the exposure of communities to flooding. Low-lying river valleys, where much of the population resides, are particularly vulnerable to riverine floods, while the risk of GLOFs presents additional hazards due to glacier melt and altered precipitation patterns. These flood hazards have resulted in significant loss of life, infrastructure damage, and economic disruption, necessitating more effective disaster risk reduction strategies.

In this context, the "Flood Hazard Atlas" aims to provide a comprehensive and systematic approach to mapping flood-prone regions in Bhutan. By integrating hydrological, meteorological, and geospatial data, this publication seeks to improve the understanding of flood frequency, magnitude, and spatial distribution across the country. The ***Figure 1*** shows the areas where the hazard maps had been developed.

The GLOF hazard maps has been developed for Pachhu, Punatsangchhu and Chamkharchu where flow from the glacial lake outburst is estimated using the BREACH model and for the other selected areas, rain-storm induced flood hazard maps were developed for different return periods of flow.

This Atlas would serve as a vital tool for policymakers, disaster management agencies, and local communities, supporting informed decision-making for flood risk mitigation, preparedness, and climate adaptation, ultimately contributing to the resilience and sustainability of Bhutan's socio-economic development.

Figure 1: Flood Hazard Mapping Locations

1.2 Historical Flood Events in Bhutan

Bhutan is recognized as a carbon-negative country due to its rich natural environments and resources. Nevertheless, Bhutan is not immune to the adverse impacts of climate change-induced natural disasters, particularly flooding. Most flooding incidents are recorded during the monsoon.

Bhutan's fragile landscape presents both opportunities and challenges of higher magnitudes of disaster and socioeconomic development. The flood caused by Cyclone Aila in 2009 affected Bhutan extensively, leading to the loss of 12 lives and causing damage exceeding Nu. 700 million.

In recent decades, natural calamities such as the Glacier Lake Outburst Floods (GLOFs) of 1994 and recurrent flash floods have resulted in substantial loss of life and property, amounting to millions. The Table 1 shows the record of flood events from 2017 to 2021 in Bhutan.

Year	Date/Month	River/ Basin	Dzongkhag
2017	April 25	Punatshang Chhu	Gasa
2017	May 5	Manas	Trashigang
2017	June 26	Kholong Chu	Trashi Yangtse
2017	July 18	Mangdichhu,	Trongsa
2017	July 17	Khomachhu,	Lhuentse
2017	July 22	Phuntshang Chhu	Wangdue
2017	July 28	Manas	Lhuentse
2017	August 30	Aichhu	Gelephu
2017	August 8	Dhaula River	Gelephu
2017	August 10	Maochhu	Gelephu
2017	September 4	Dhaula River	Sarpang
2017	August 13	Cherichhu, Wangchu	Thimphu
2017	October 12	Manas	Mongar
2017	August 9-11	Punatsang chhu	Punakha
2018	June 13	Manas	Lhuentse
2018	July 22	Mithimdrang stream,	Trashigang
2018	August 1	Buna Stream	Trashigang
2019	June 24	Aichhu	Gelephu
2019	April 29	Lekpagangchhu	Lhuentse
2019	July 25	Manas	Lhuentse
2019	July 26	Wangchhu	Chukha
2019	August 6	Punatsangchhu	Punakha
2020	July 20	Maochhu	Gelephu
2020	October 1	Chamdey Gangchu Stream	Trongsa
2020	October 4	Puntsangchu	Wangdue Phodrang
2021	June 15	Khenbachhu	Trongsa
2021	June 16	Punatsangchhu	Gasa
2021	August 8	Serkang stream	Trashiyangtse
2021	August 26	Punatsangchhu	Gasa
2021	August 25	Maochhu	Sarpang

Table 1: Flood events record from 2017-2021 (Source: Compendium of Climate and Hydrological extremes in Bhutan (2017-2021),NCHM

2. Data and Information

The development of flood hazard maps involve gathering extensive accurate data and information from various sources and field surveying. The observed hydro-meteorological data, including discharge, and water level data are being used for the purpose. Additionally, a high-quality digital elevation model (DEM) with a horizontal resolution of 1m resolution DEM from MAXER satellite, 10 m resolution from ALOS-2 and high-quality aerial Drone Survey images are collected to ensure the accuracy and reliability of flood hazard maps.

The development of accurate and reproducible flood models, which are crucial for creating effective flood management strategies, relies on high-quality data from credible sources.

Despite the limited availability of data and information for the study region, efforts are made to gather all necessary data through ground observations, surveys, satellite products, and aerial drone surveys.

Data	**Source**	**Spatial resolution**
Drone images	UAV survey by NCHM	1m
Digital Elevation Model (DEM)	MAXER	1m
Digital Elevation Model (DEM)	ALOS-2 (Open source)	10m
River Cross-sections	NCHM	
Discharge (m^3/s) & Water level (m)	NCHM	Daily

Table 2: List of required data

3. Methodology

A high-resolution Digital Terrain Models (DTMs) sourced from MAXAR imagery are used, and where unavailable, Unmanned Aerial Vehicle (UAV) surveys were conducted to develop quality DTMs. For rainstorm-induced floods, flood frequency analysis is performed using statistical distributions to estimate peak discharges corresponding to return periods of 1-in-20 and 1-in-100 years, tailored to each hydrological station. These discharge values are input into a two-dimensional hydrodynamic model developed using the HEC-RAS software. A 20m x 20m grid is established to simulate overland flooding, with model calibration achieved by adjusting sensitive parameters to improve accuracy. The output includes flood hazard maps for the selected return periods.

For the Glacial Lake Outburst Flood (GLOF) hazard assessment in the Pachhu, Chamkharchhu, and Punatsangchhu basins, the BREACH model is used to simulate potential dam breach scenarios. This model estimates the outflow hydrograph resulting from a lake breach based on geotechnical and hydrological characteristics. The predicted GLOF flows are then routed downstream using HEC-RAS, and corresponding GLOF hazard maps are generated.

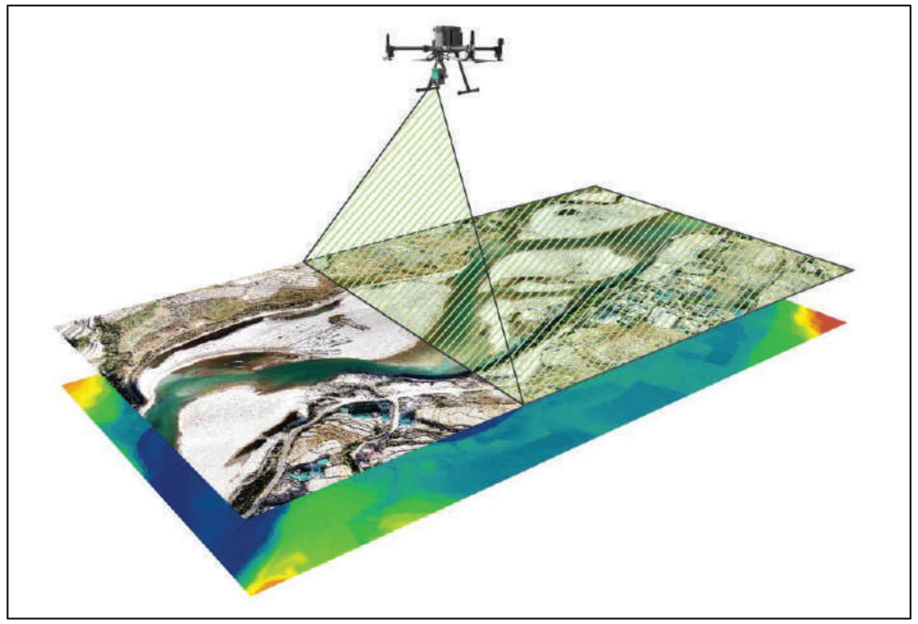


Figure 2: Drone capturing photos of Punatsangchhu

3.1 Aerial Survey to develop DTM

For the Areas where high resolution satellite imageries are not available, the images were collected through the use of Unmanned Aerial Vehicle(UAV). The first step involved carefully planning and executing surveys over selected areas. The UAV deployed was DJI Matrice 300 RTK. This UAV, equipped with high-resolution RBG cameras and LiDAR sensors, captured detailed images of the terrain, ensuring comprehensive coverage.

The collected imagery serves as the basis for further analysis. The imageries were processed using an image processing software (Agissoft Metasahpe) and the Digital Terrain Models (DTMs) at a 1-meter resolution were genrated, which provided a three-dimensional view of the terrain's topography and elevation variations.

DTMs produced through UAV technology provide a highly accurate representation of the ground with the most recent land use changes and developmental activities which is essential for understanding and mapping high flood-risk areas and inundation extents for flood disaster management.

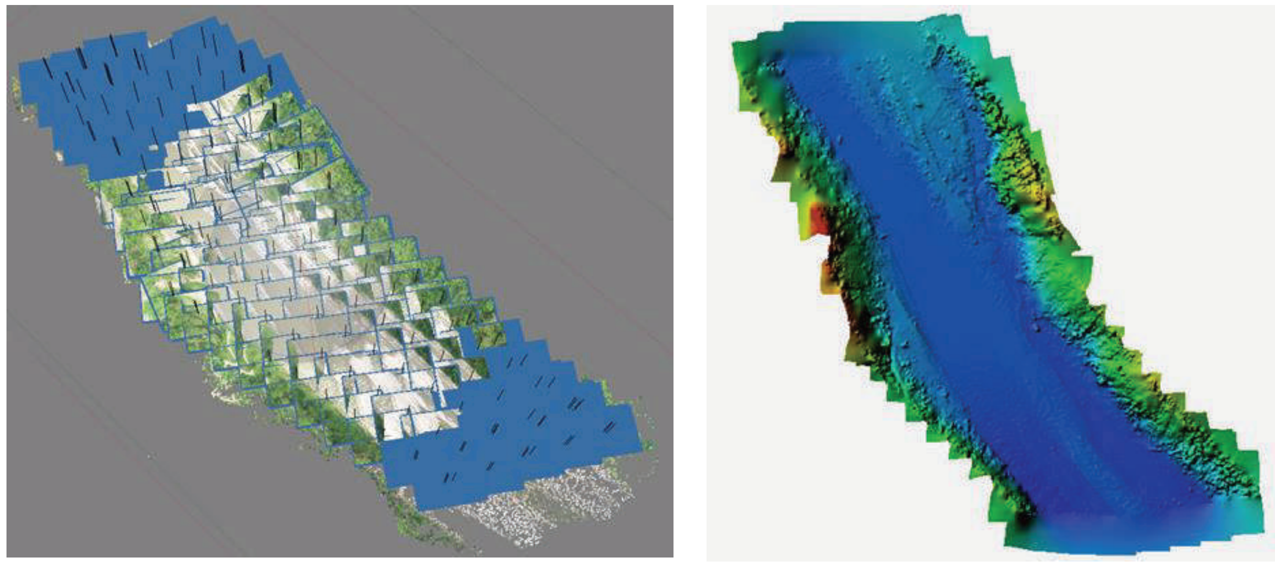


Figure 3: DTM processing from drone imageries in Agisoft Metashape Professional photogrammetric software

3.2 Flood Return Period calculation

Next, utilizing available discharge data, return periods were calculated for the surveyed areas where discharge data is available. The appropriate distributions were fitted to the annual peak discharge values using Hydrognomon 4 software. And the Cumulative Distribution Function (CDF) values are utilized for flood return period calculation. Return periods are calculated only for the rainstorm induced flood hazard map development.

This flood hazard mapping considered a set of probability density functions (PDFs) to derive the discharge for various return periods (in years). These distribution functions were tested for the discharge data and the most appropriate distribution is selected for the calculation of the return periods.

Hazard maps are generated for different return period scenarios for the areas based on their inundation differences in each scenario. This analysis helped in assessing the frequency and magnitude of potential hazards such as flooding, enabling a more informed understanding of the risks associated with the terrain.

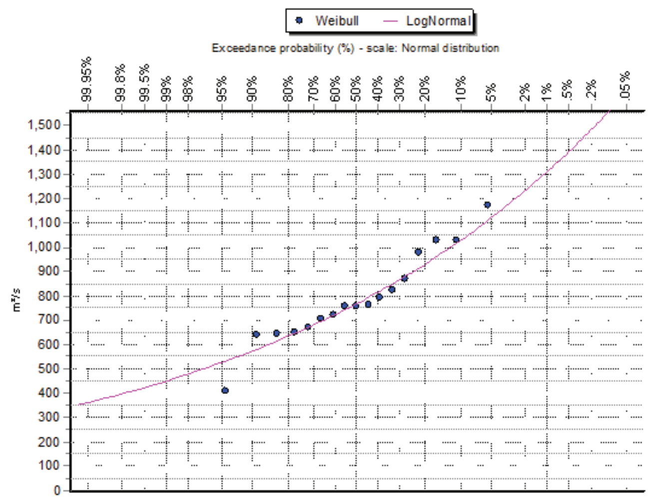


Figure 4: Statistical distribution fitted to the peak discharge values at Sumpa station in Kurichhu Basin

Return Period (Years)	Flow (m^3/s)
2	767.76
20	1119.11
50	1223.22
100	1301.29

Table 2: Flood Return period calculation at Sumpa Station

3.3 Development of GlOF model using BREACH

Since GLOF hazard maps were generated for Pachhu, Punatsangchhu and Chamkharchu, GLOF Model was developed to estimate the flow from the glacial lake outburst using the BREACH model.

The BREACH model is a physically-based tool designed to simulate breach formation and outflow hydrographs from failing earthen dams, whether man-made or landslide-formed. Key input data for the model include the cross-section of the lake outlet, lake volume, and geotechnical properties of the dam material.

The model accounts for breach initiation by overtopping or piping, structural collapses, and slope failure. It handles both cohesive and non-cohesive materials and uses a stable, time-stepping algorithm to quickly generate outflow hydrographs. BREACH has been validated using real dam failures, including the Teton and Lawn Lake Dams, and is useful for assessing potential downstream flood risks due to dam failure.

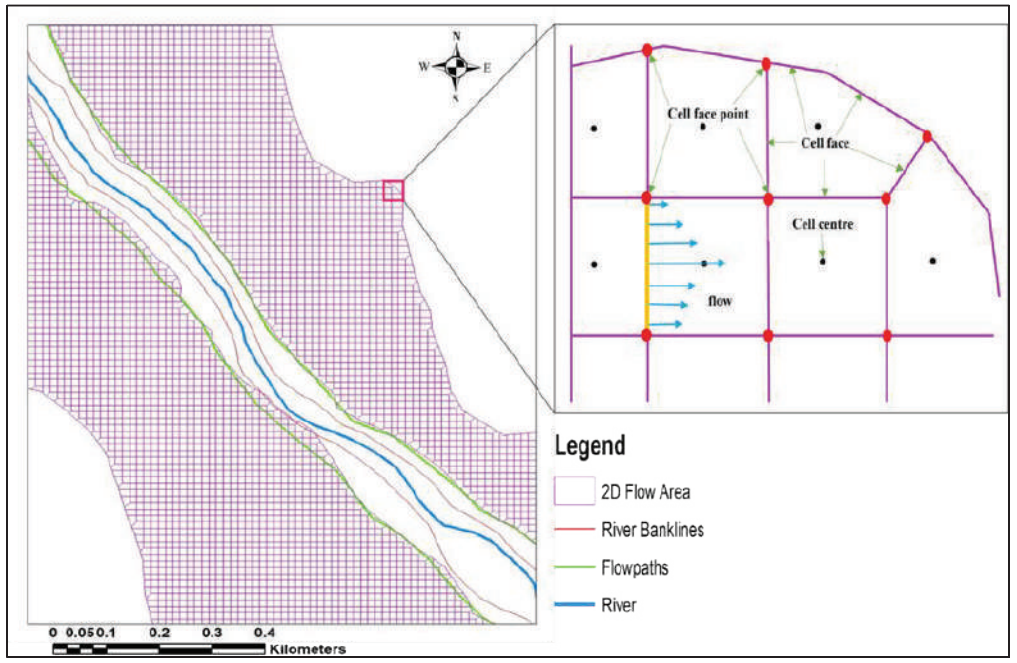


Figure 5: HEC-RAS v6.3 2D flood model setup and flow of water in 2D grids (Namgyal et al., 2023)

3.4 Development of Hydrodynamic Model Using Hec-Ras

The latest version of HEC-RAS (Hydrologic Engineering Center's River Analysis System) modeling software is employed for the development of hazard maps. It is an open-source and cost-effective river modeling software extensively used for various river-related applications, such as 1D, 2D, and combined 1D-2D flow computations, water quality monitoring, and sediment transport analysis.

In this current hazard assessment, the two-dimensional flood model was developed to simulate the flood water in the overland flood plains on either side of the river channels. The discharges for different return periods, flow calculated from the BREACH model, DTMs developed using high resolution images and river cross sections are used as an input data while developing the hydrodynamic model using Hec-Ras. Most 2D hydrodynamic models solve the Navier-Stokes equations, assuming shallow water depth (h) relative to horizontal velocities (u and v). The 2D region is discretized into a grid of rectangular hydraulic cells (20m × 20m), each defined by points (x, y, z). Hydraulic parameters and precipitation are assumed to be spatially uniform within each cell.

4. Flood Hazard Maps

The hazard maps were developed for the following areas and the maps are also presented in the following order:

4.1 Amochhu Hazard map

4.2 Thimchhu and Pachhu (GLOF) Hazard map

4.3 Punatsangchhu (GLOF) Hazard map

4.4 Mangdechhu Hazard map

4.5 Chamkharchhu Hazard map

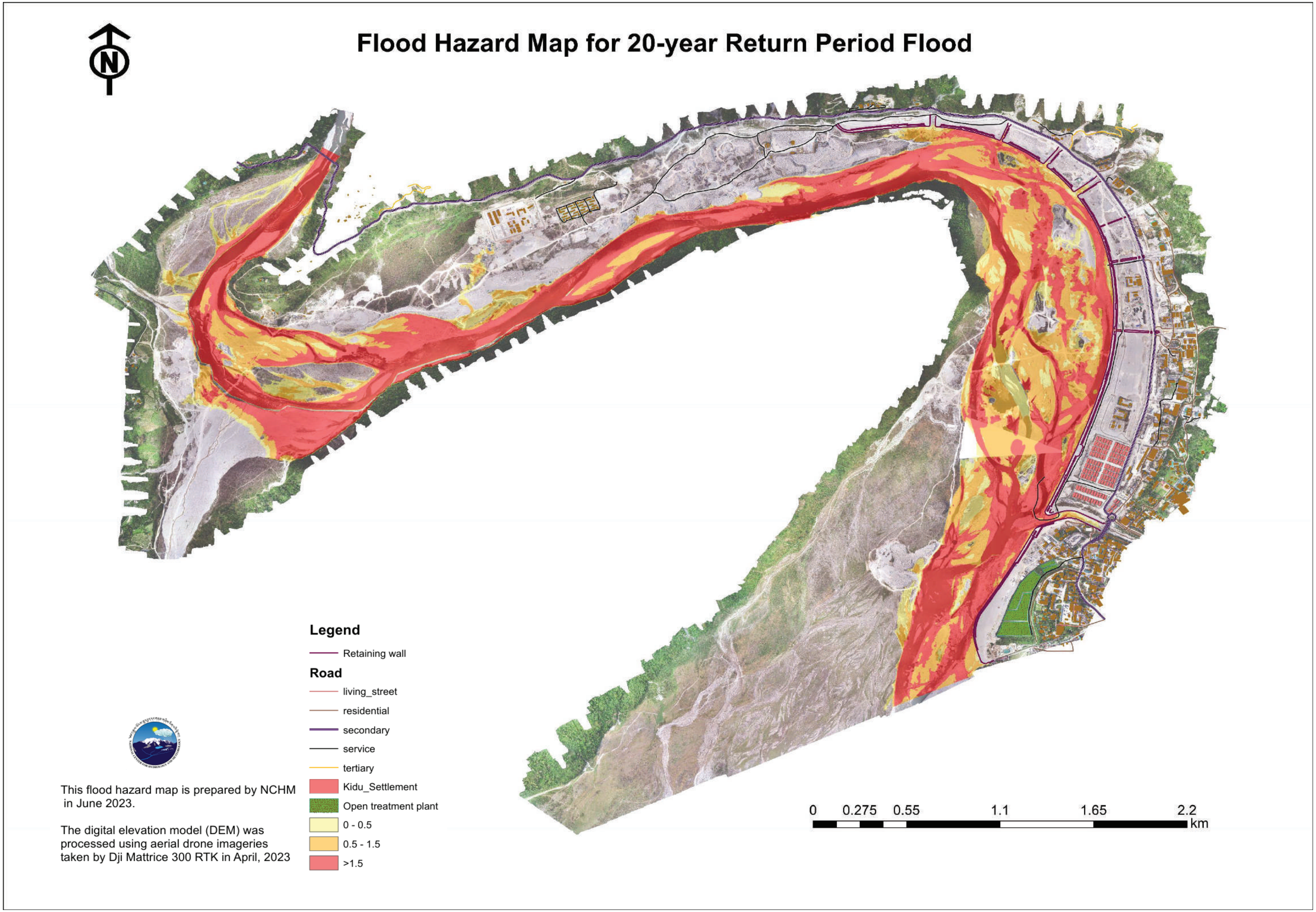
4.6 Kurichhu Hazard map

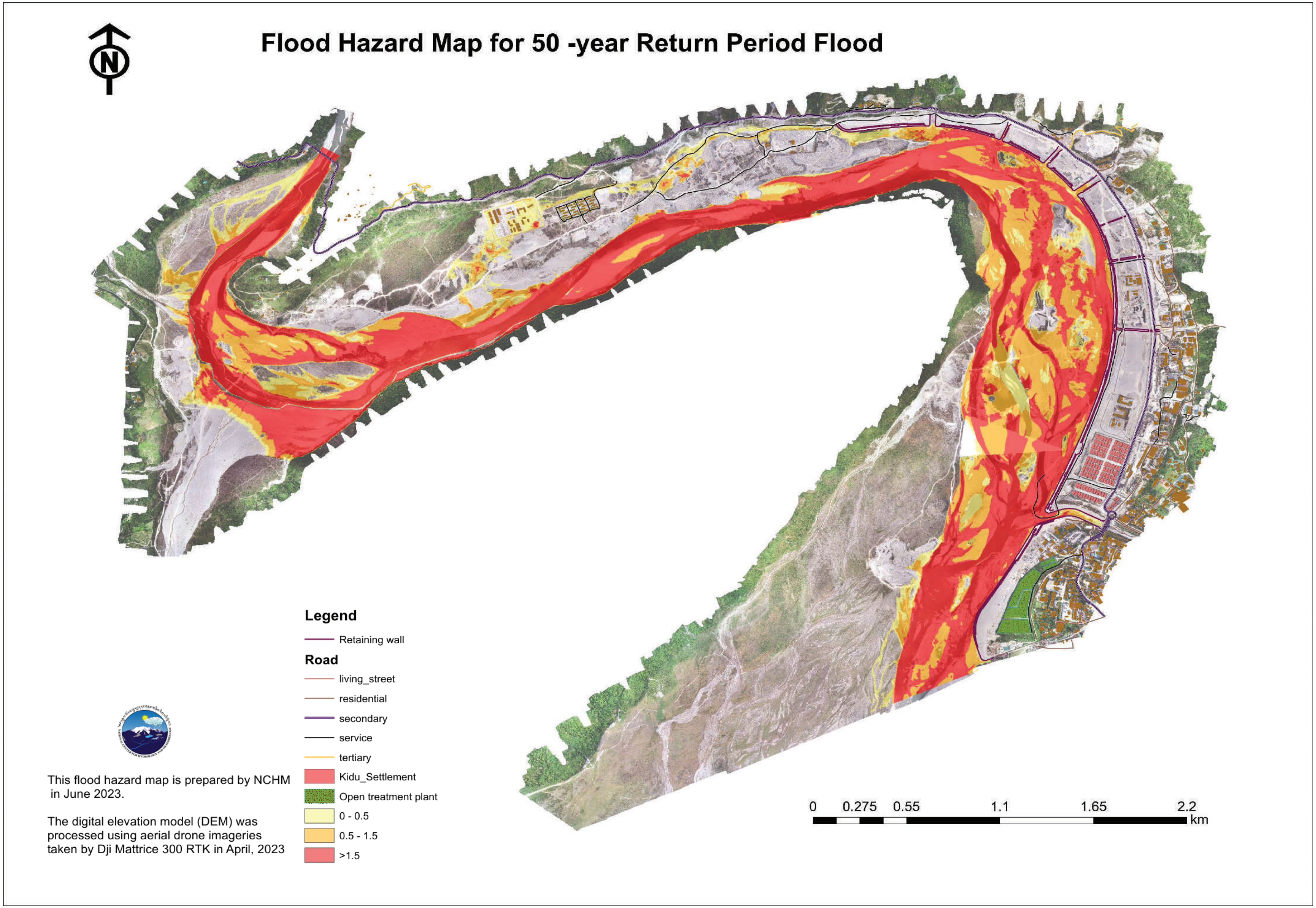
4.7 Drangmechhu (Panbang) Hazard map

4.8 Nyera Amari (Gomdhar) Hazard map

Google satellite image showing the Amochhu temporary shelter at Phuntsholing

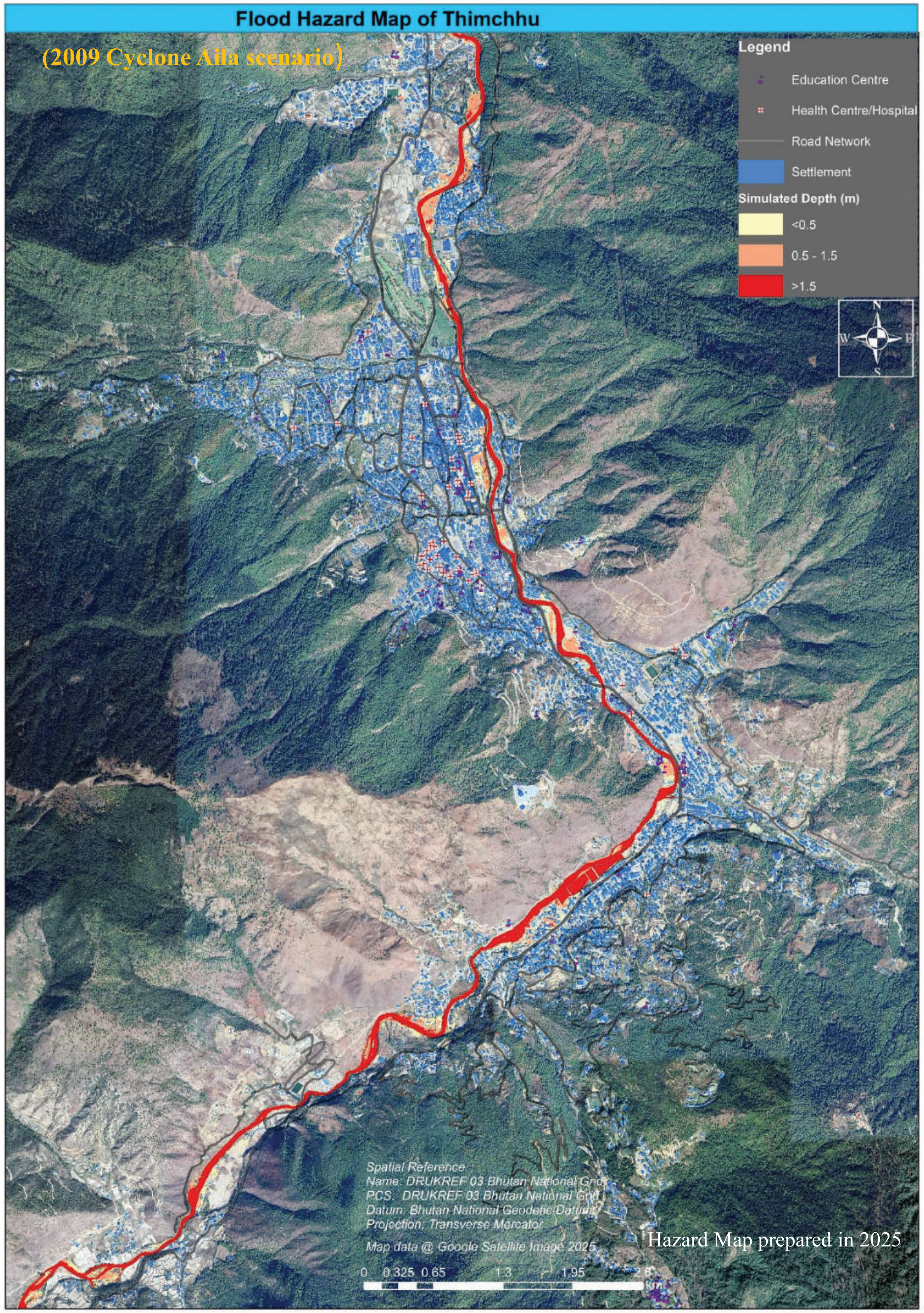
4.1 Amochhu Hazard Map


Flood Hazard Map for 20-year Return Period Flood
N
Legend
Retaining wall
Road
living_street
residential
secondary
service
tertiary
Kidu_Settlement
Open treatment plant
0 - 0.5
0.5 - 1.5
>1.5
This flood hazard map is prepared by NCHM in June 2023.
The digital elevation model (DEM) was processed using aerial drone imageries taken by Dji Mattrice 300 RTK in April, 2023
0 0.275 0.55 1.1 1.65 2.2
km

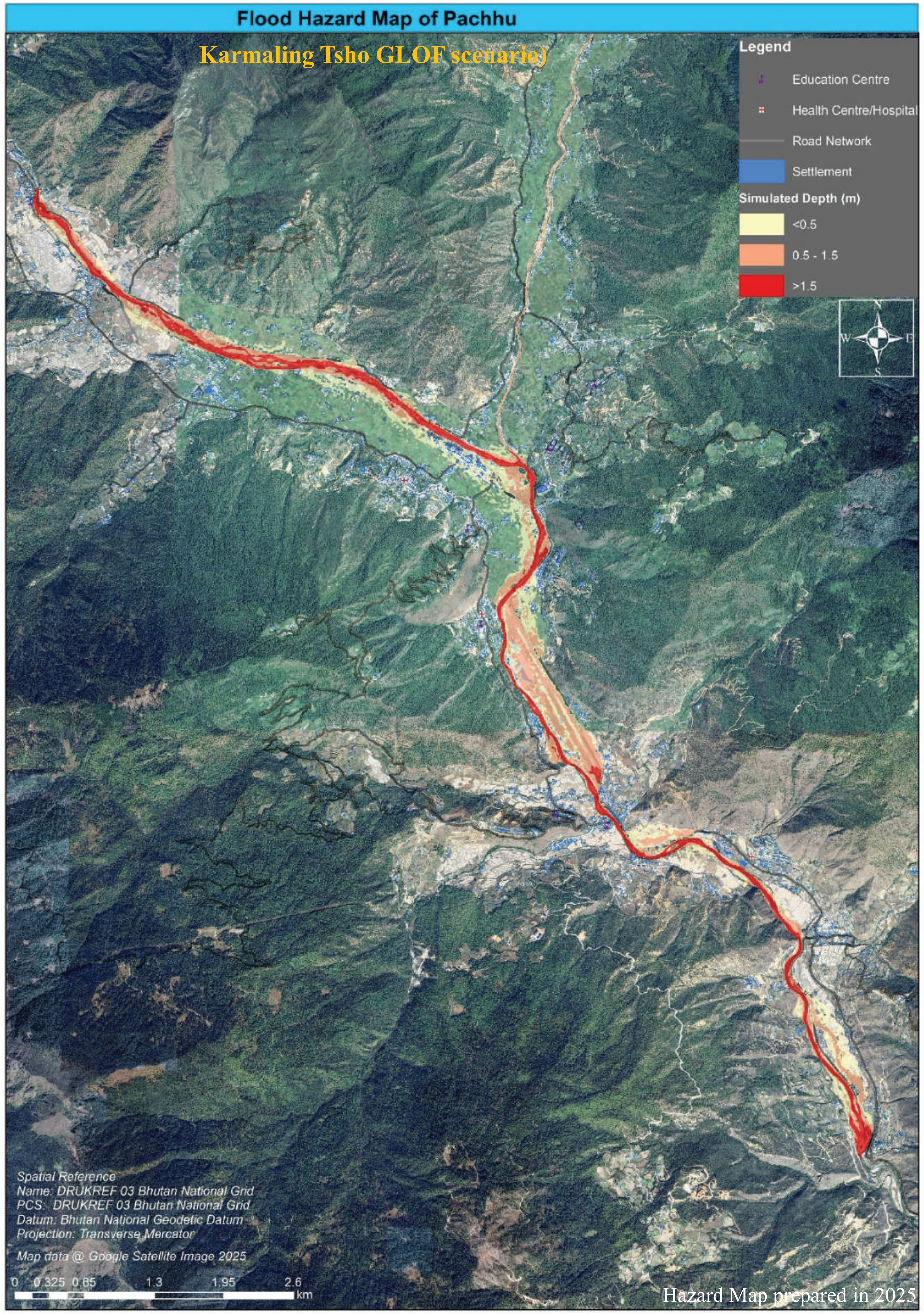

Flood Hazard Map for 50 -year Return Period Flood
N
Legend
Retaining wall
Road
living_street
residential
secondary
service
tertiary
Kidu_Settlement
Open treatment plant
0 - 0.5
0.5 - 1.5
>1.5
This flood hazard map is prepared by NCHM in June 2023.
The digital elevation model (DEM) was processed using aerial drone imageries taken by Dji Mattrice 300 RTK in April, 2023
0 0.275 0.55 1.1 1.65 2.2
km

Google satellite image capturing Thimphu Dzong and Langjophaka areas in Thimphu

4.2 Thimchhu and Pachhu(GLOF) Hazard Map



Flood Hazard Map of Thimchhu
(2009 Cyclone Aila scenario)
Legend
Education Centre
Health Centre/Hospital
Road Network
Settlement
Simulated Depth (m)
<0.5
0.5 - 1.5
>1.5
Spatial Reference
Name: DRUKREF 03 Bhutan National Grid
PCS: DRUKREF 03 Bhutan National Grid
Datum: Bhutan National Geodetic Datum
Projection: Transverse Mercator
Map data @ Google Satellite Image 2025
Hazard Map prepared in 2025

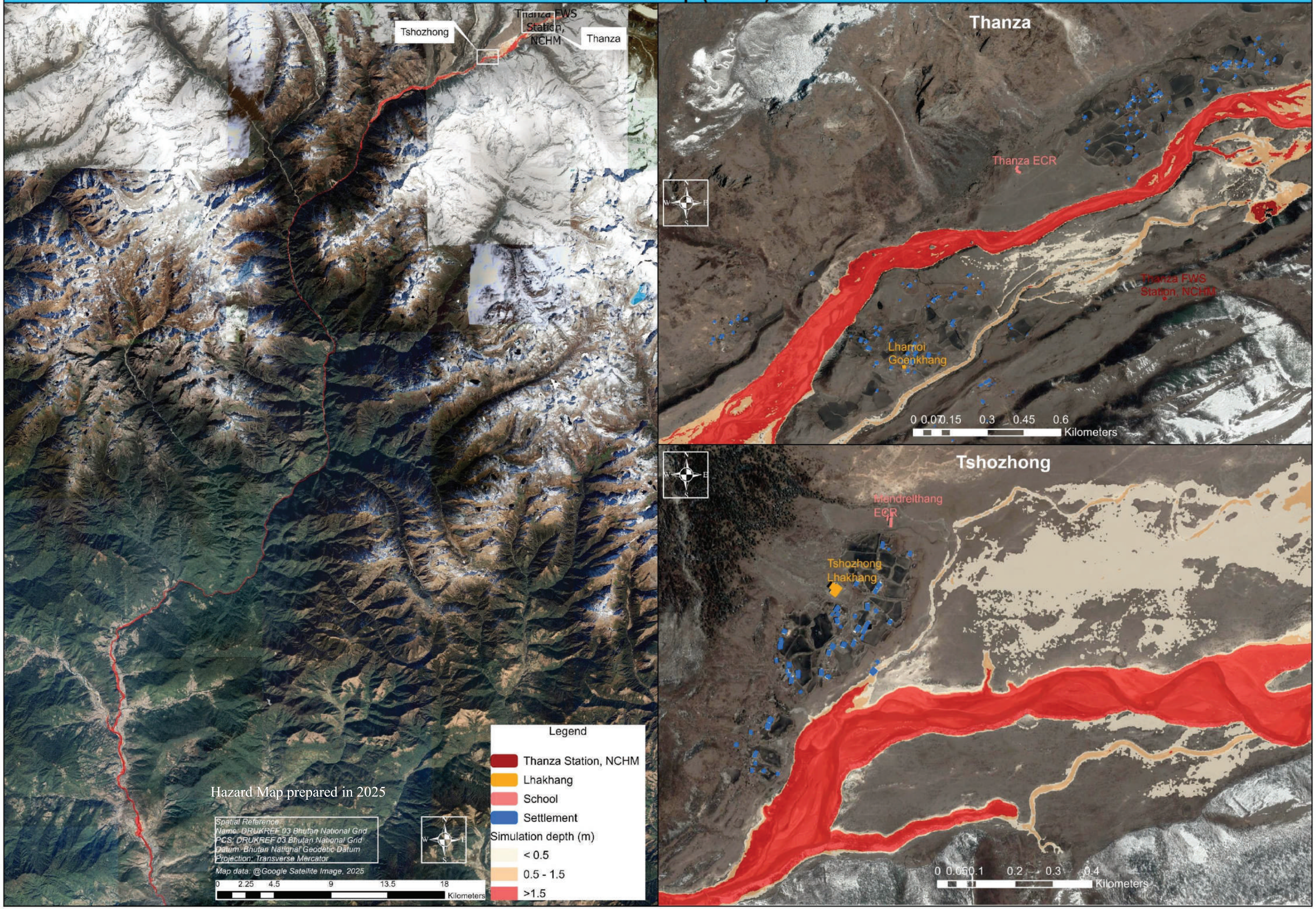


Flood Hazard Map of Pachhu
Karmaling Tsho GLOF scenario)
Legend
Education Centre
Health Centre/Hospital
Road Network
Settlement
Simulated Depth (m)
<0.5
0.5 - 1.5
>1.5
Spatial Reference
Name: DRUKREF 03 Bhutan National Grid
PCS: DRUKREF 03 Bhutan National Grid
Datum: Bhutan National Geodetic Datum
Projection: Transverse Mercator
Map data @ Google Satellite Image 2025
Hazard Map prepared in 2025

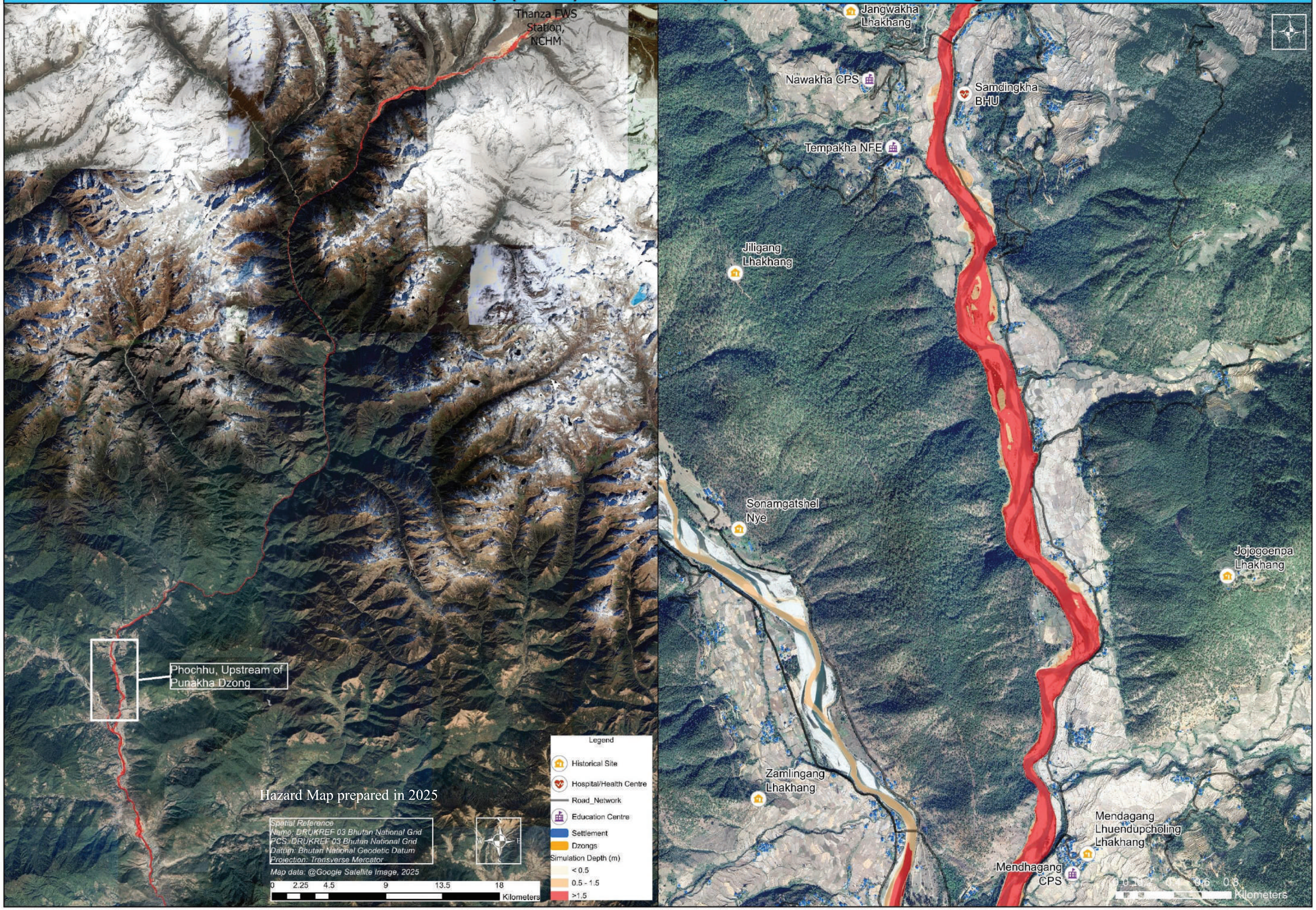
4.3 Punatsangchhu (GLOF) Hazard Map

Drone Image of Bajo Thangu, Wagdue Phodrang

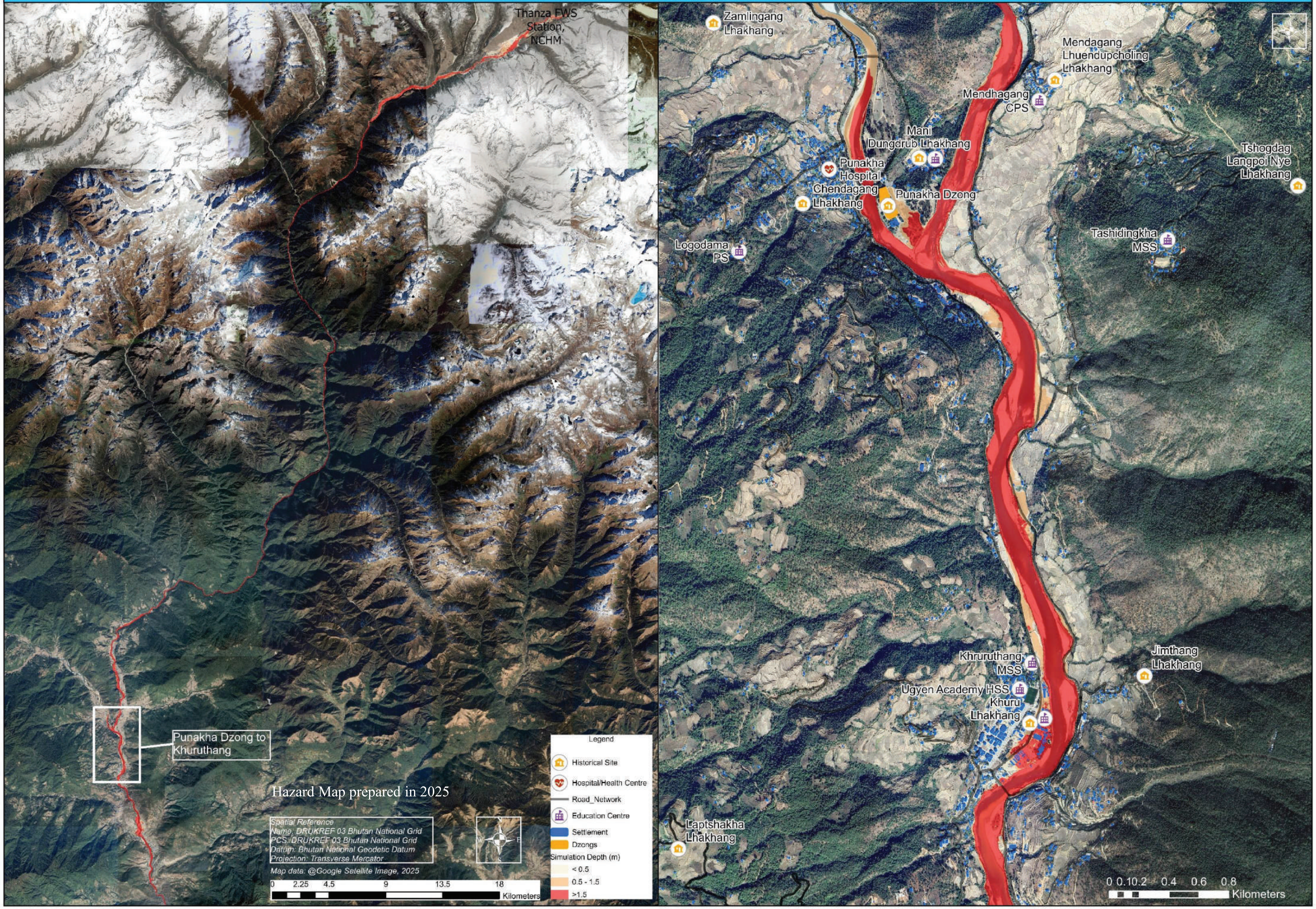
Flood Hazard Map (GLOF) of Lunana



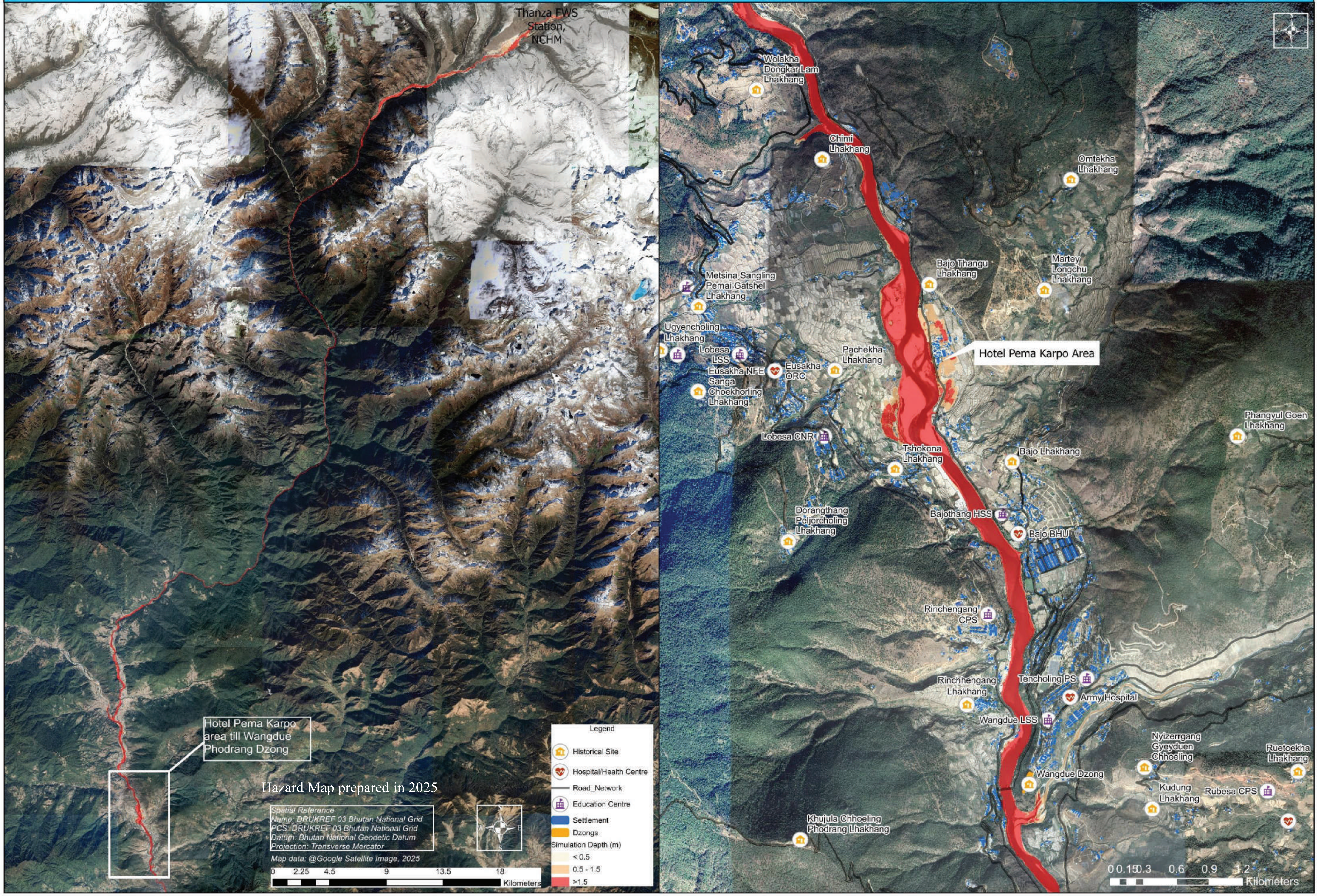
Flood Hazard Map (GLOF) of Phochhu, Upstream of Punakha Dzong



Flood Hazard Map (GLOF) of Punatsangchhu from Punakha Dzong to Khuruthang



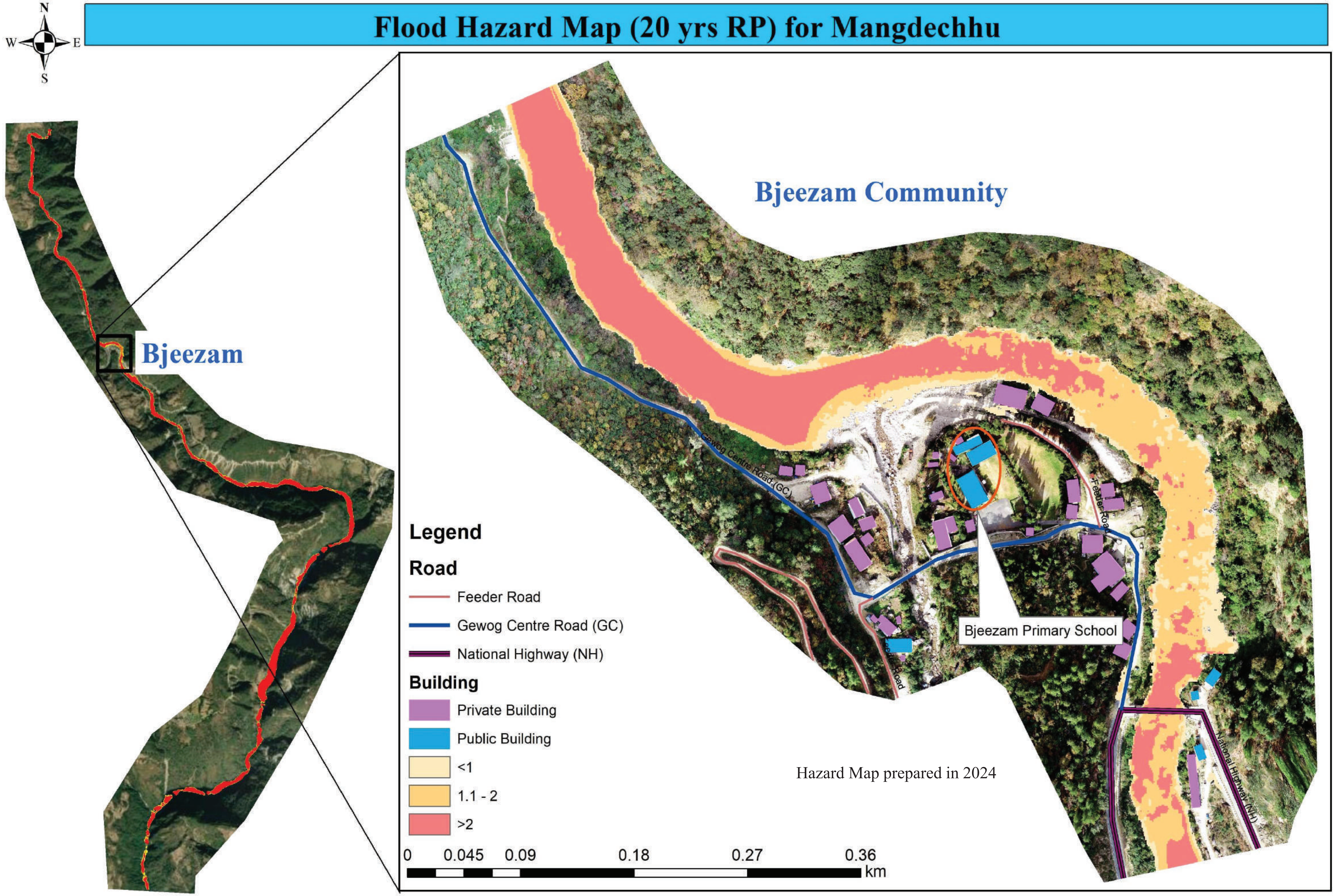
Flood Hazard Map (GLOF) of Punatsangchhu at Hotel Pema Karpo area till Wangdue Phodrang Dzong



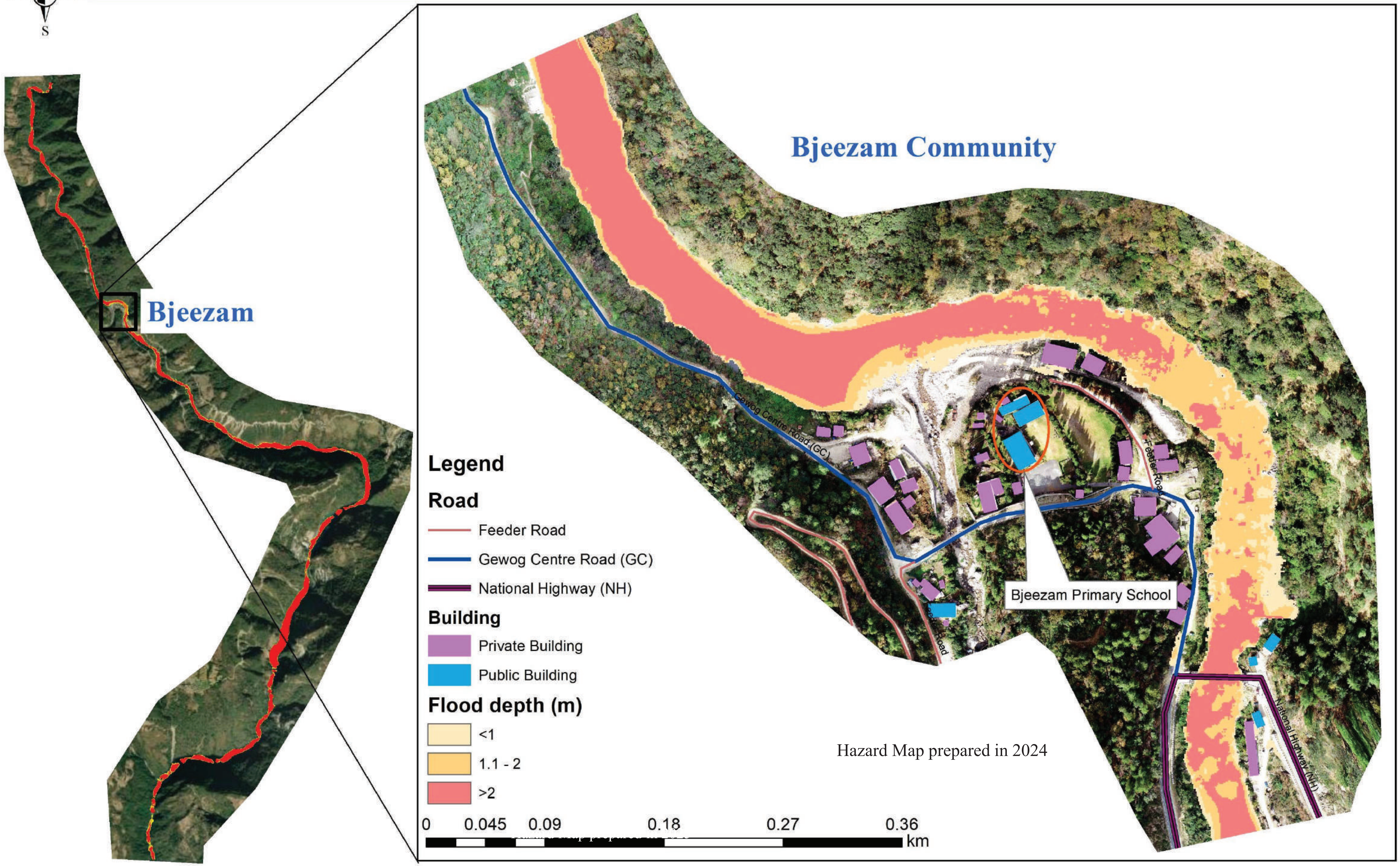
4.4 Mangdechhu Hazard Map

Drone Image of Bjizam Community in Trongsa

Flood Hazard Map (20 yrs RP) for Mangdechhu



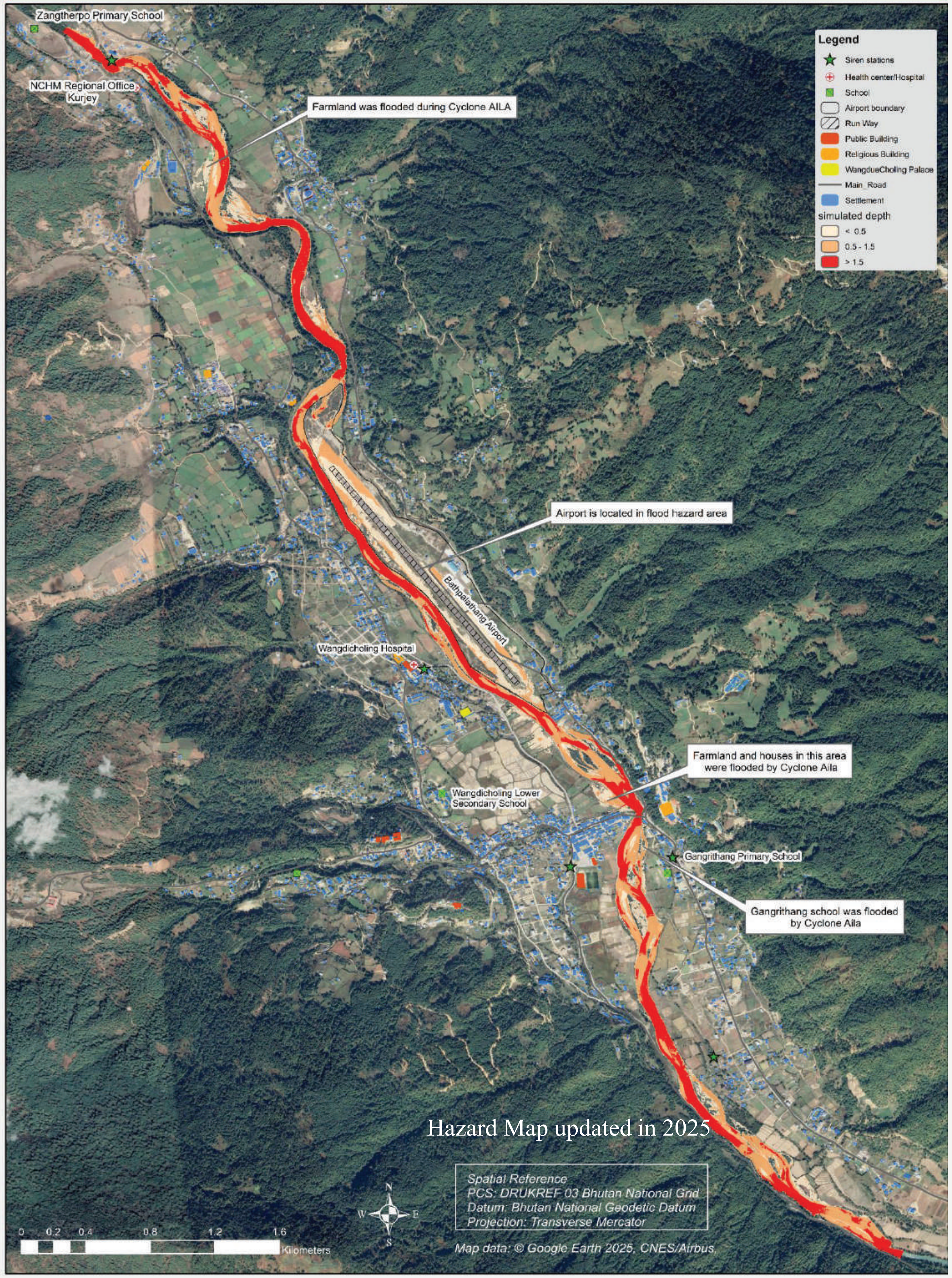
Flood Hazard Map (100 yrs RP) for Mangdechhu



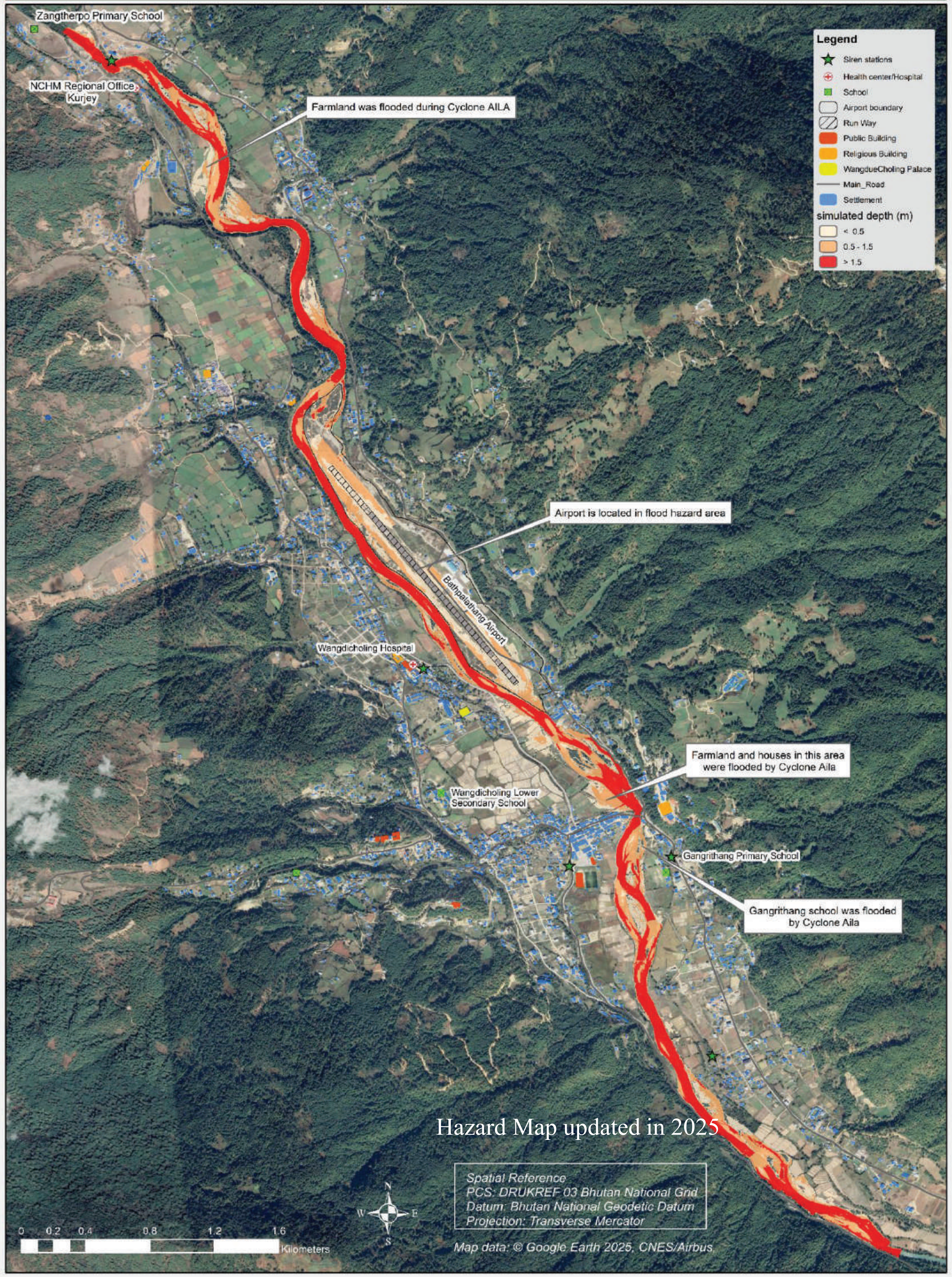
4.5 Chamkharchhu Hazard Map

Google earth image of Chamkhar and Bathpalathang Airport in Bumthang

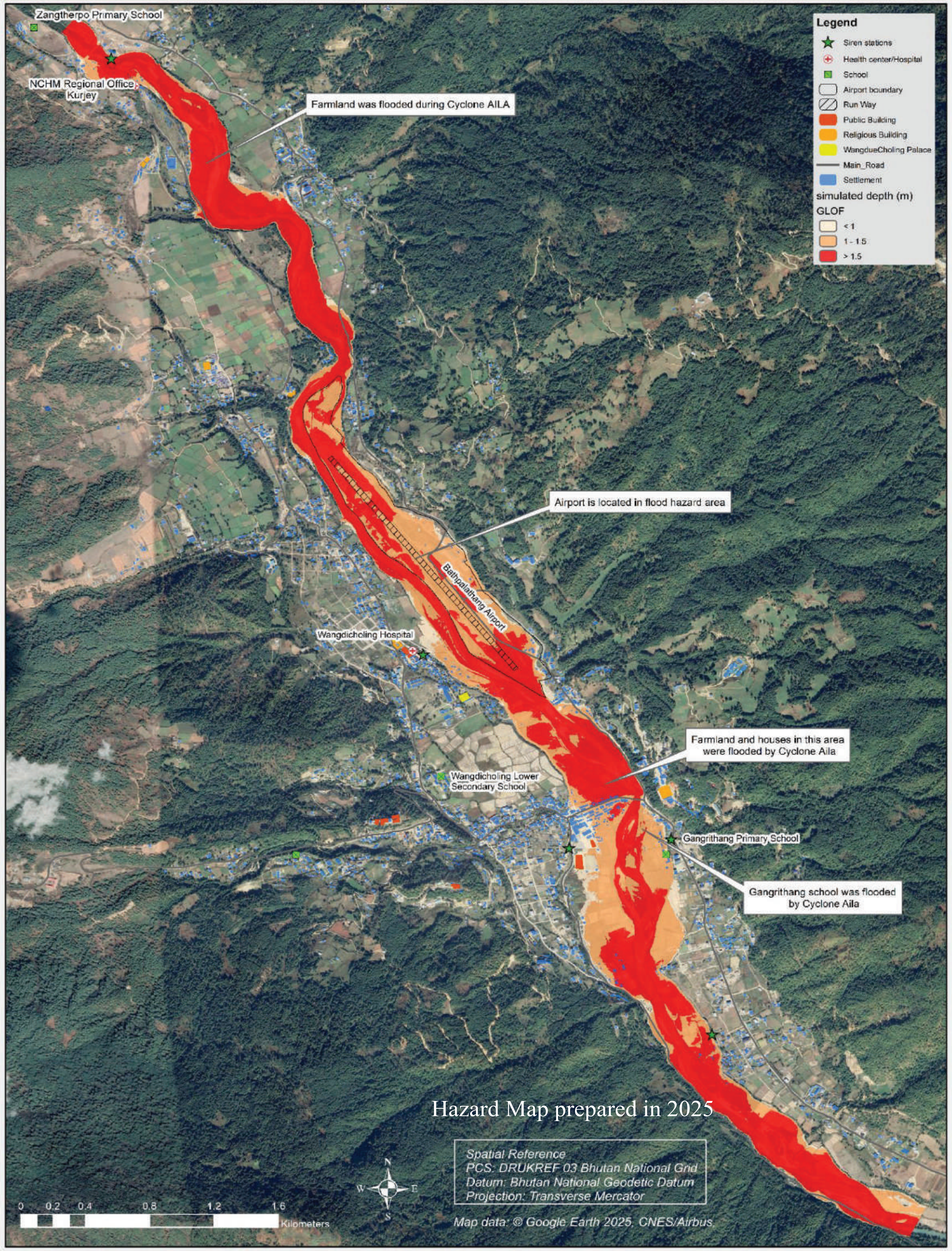
Flood Hazard Map (20 years RP) for Chamkharchhu, Bumthang



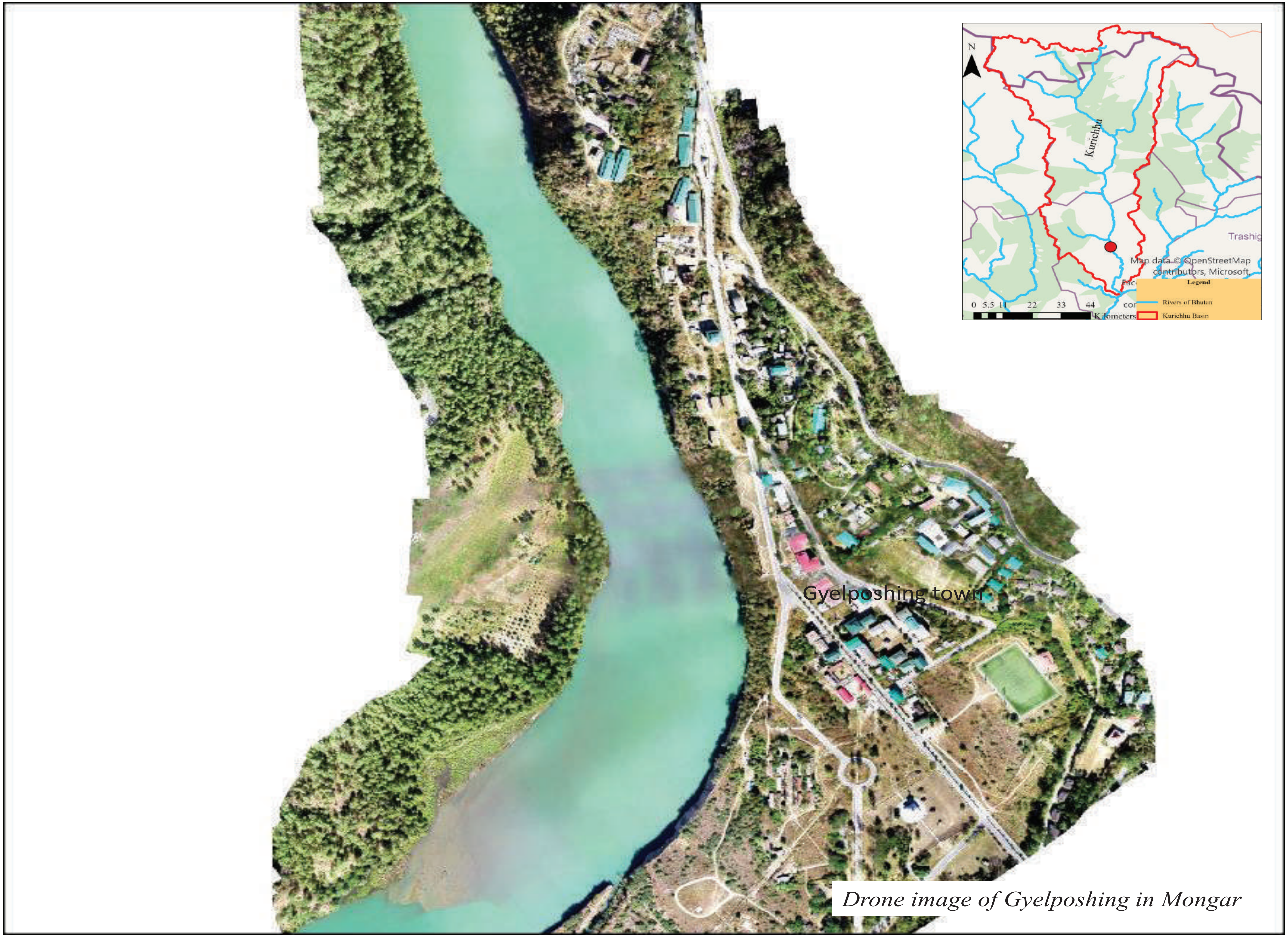
Flood Hazard Map (100 years RP) for Chamkharchhu, Bumthang



Flood Hazard Map (GLOF) for Chamkharchhu, Bumthang

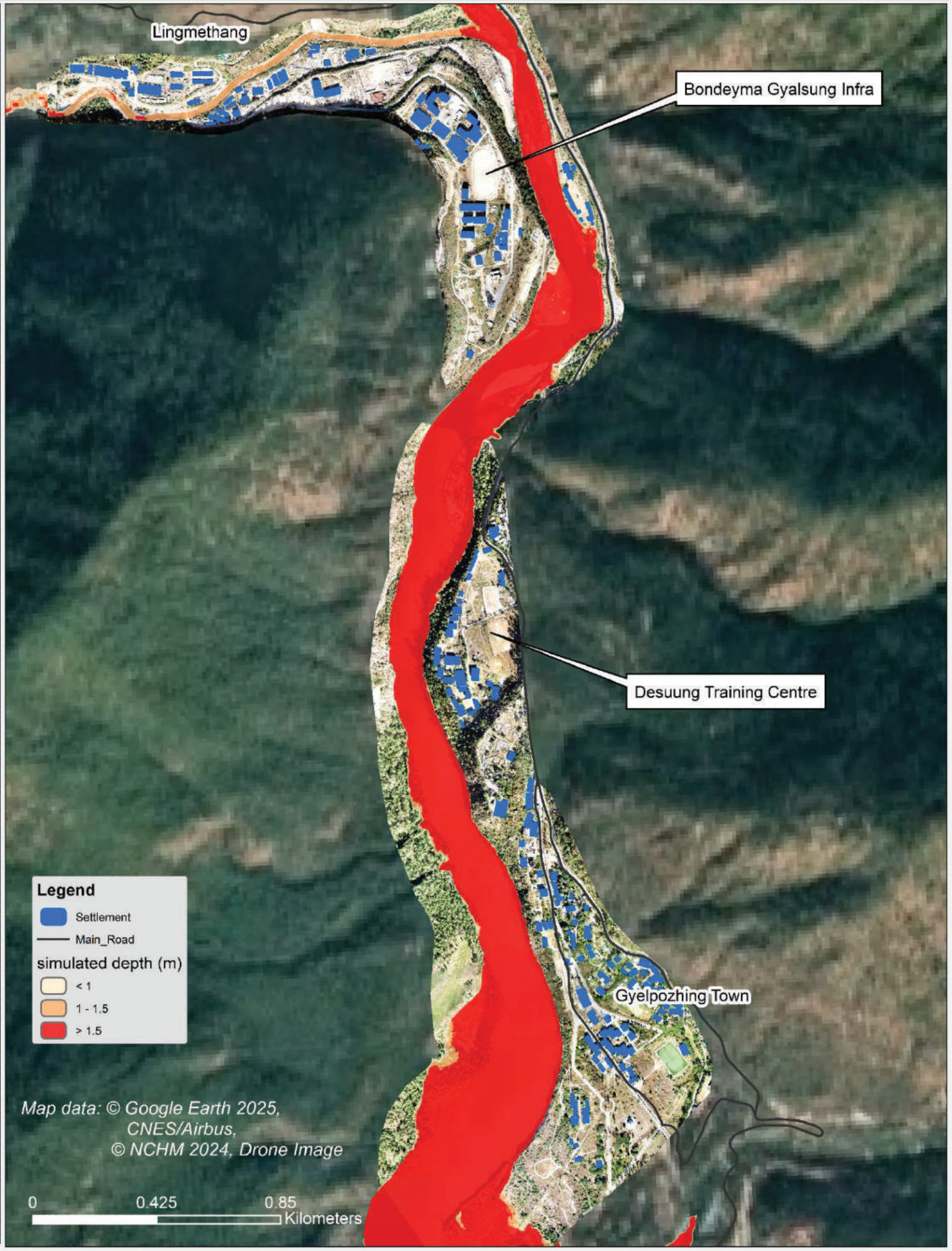


4.6 Kurichhu Hazard Map

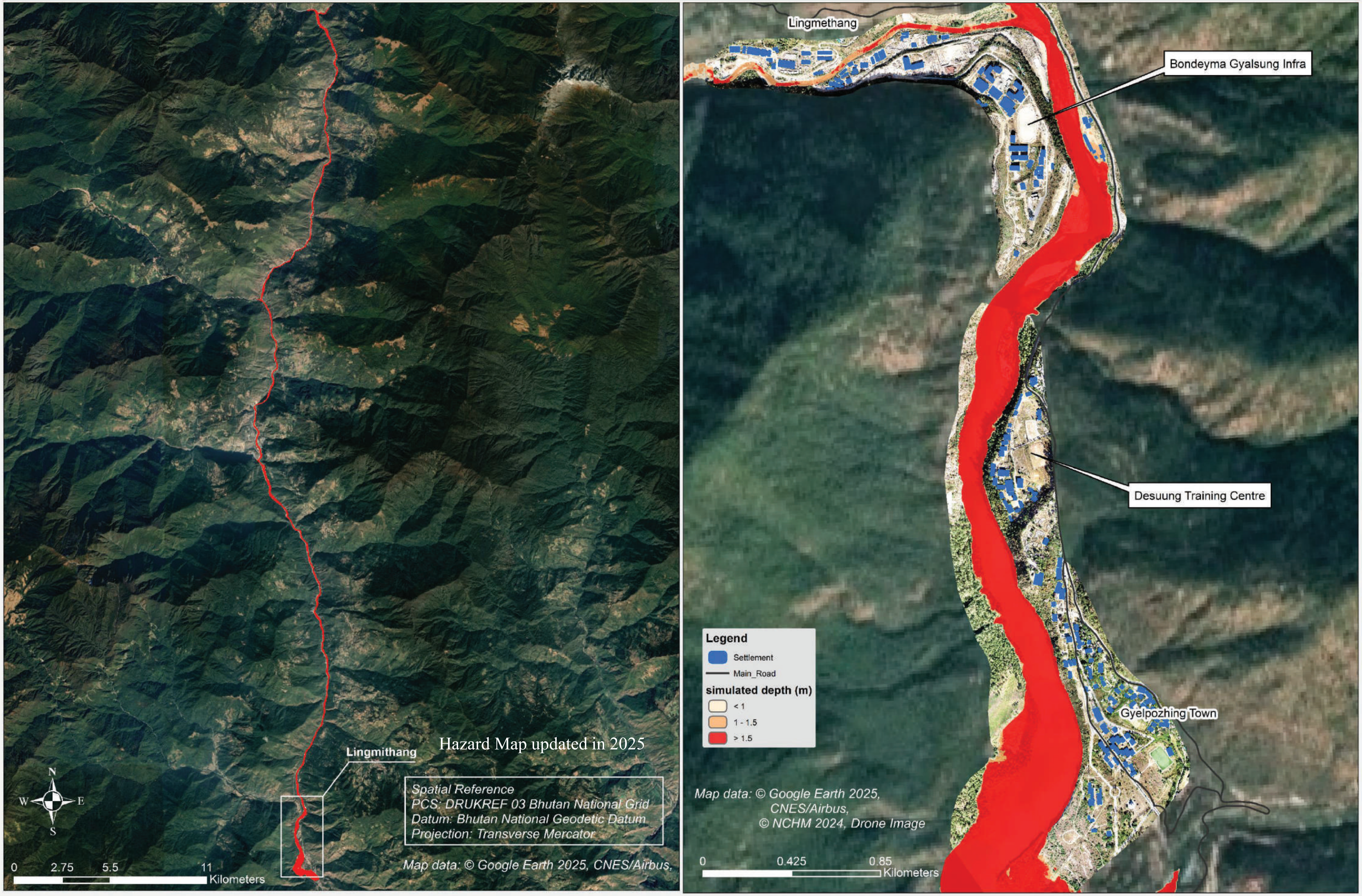


Drone image of Gyelposhing in Mongar

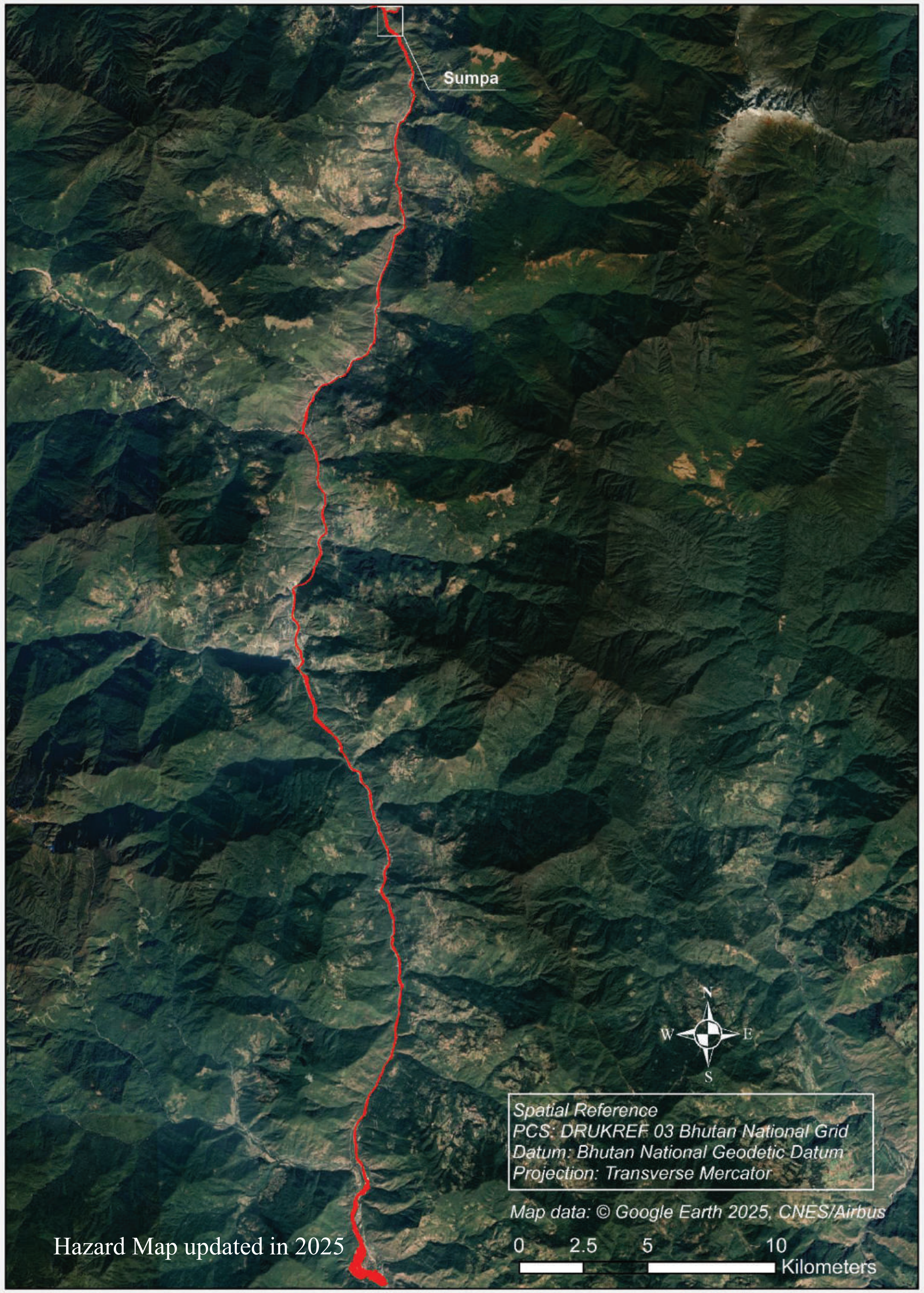
Flood Hazard Map (20 years RP) for Kurichhu basin, Lingmethang & Gyelposhing



Flood Hazard Map (100 years RP) for Kurichhu basin, Lingmethang & Gyelposhing

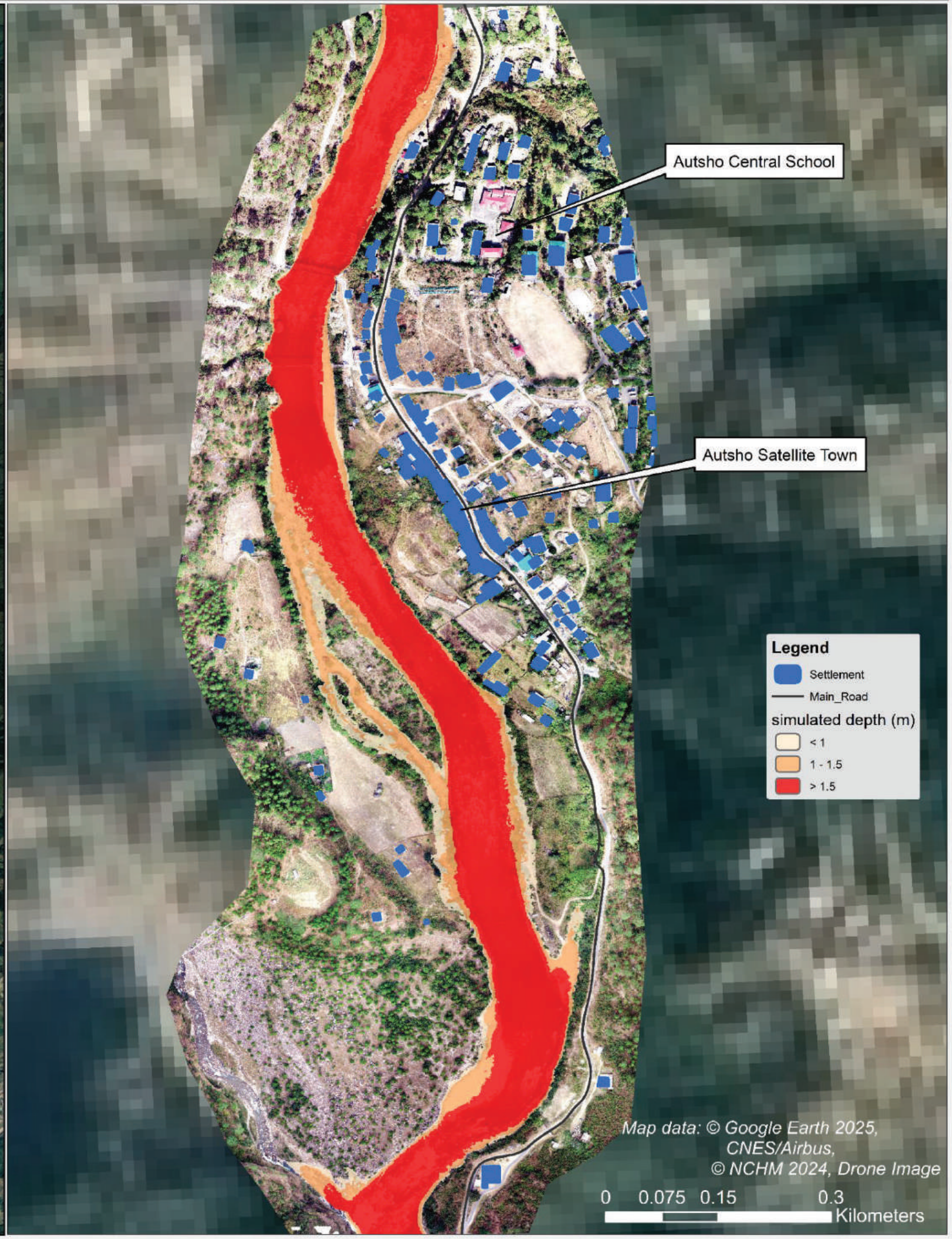


Flood Hazard Map (20 years RP) for Kurichhu basin, Sumpa



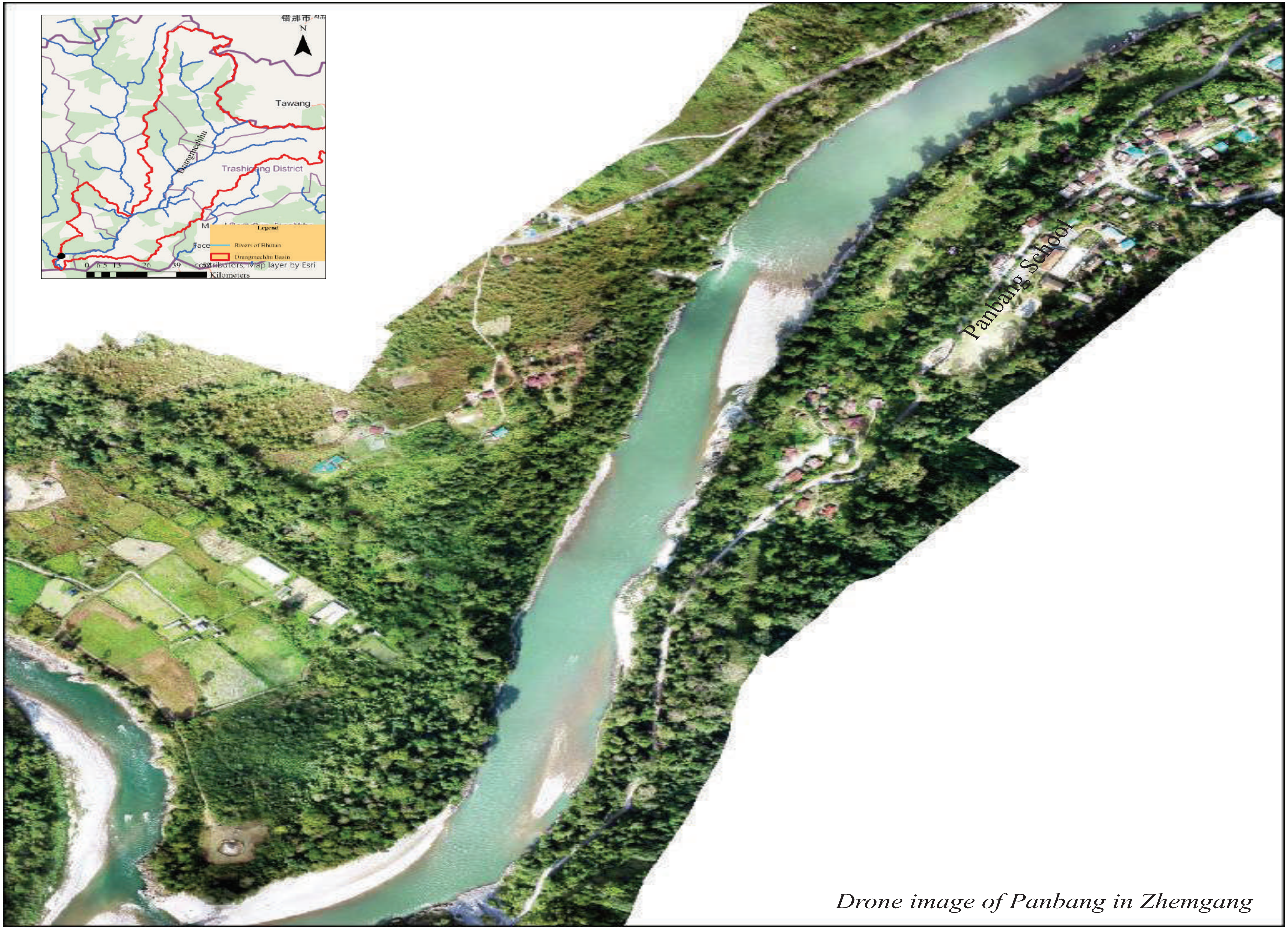
Flood Hazard Map (100 years RP) for Kurichhu basin, Sumpa

Flood Hazard Map (100 years RP) for Kurichhu basin, Autsho



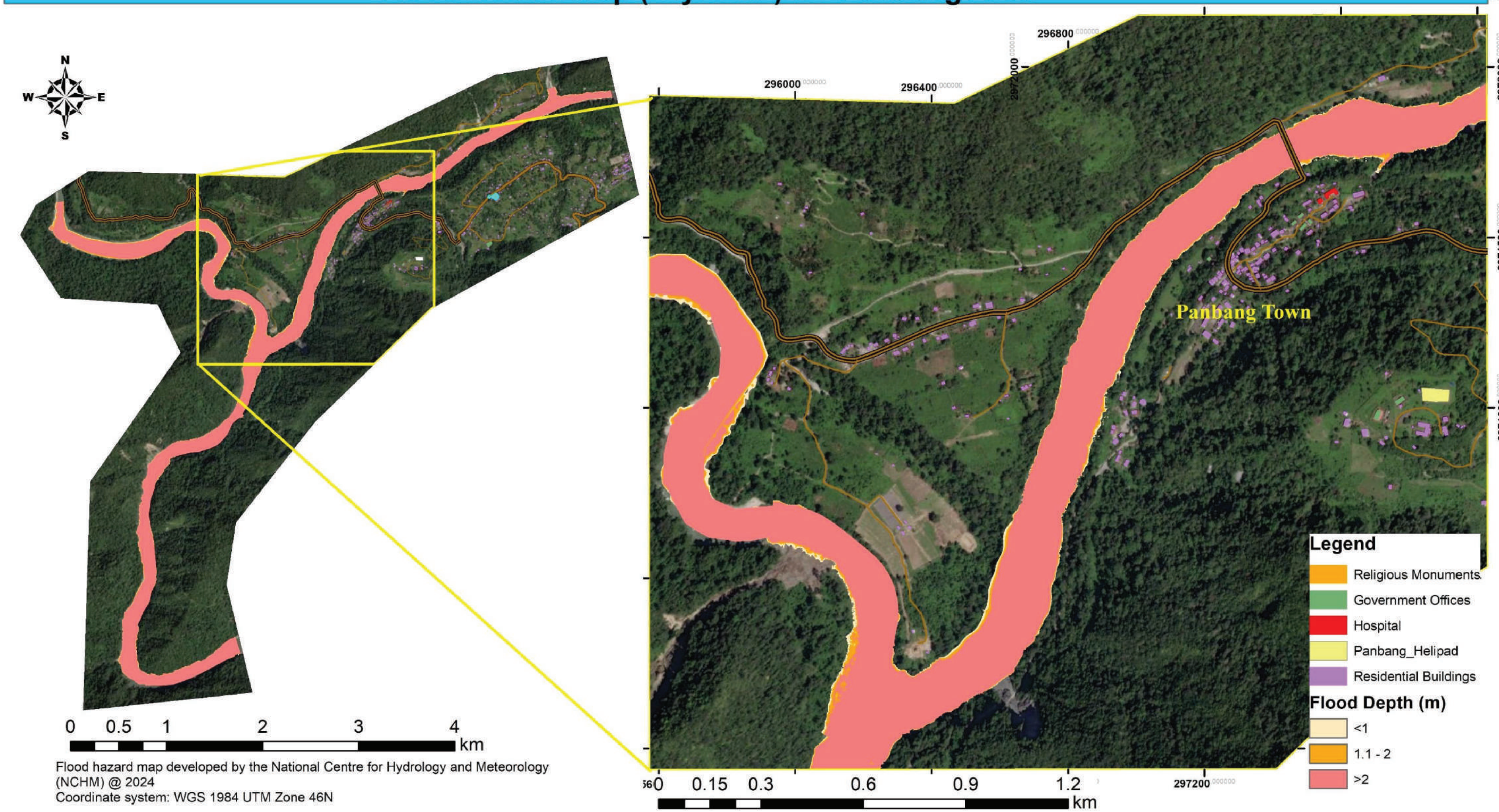
Flood Hazard Map (100 years RP) for Kurichhu basin, Autsho

4.7 Drangmechhu (Panbang) Hazard Map

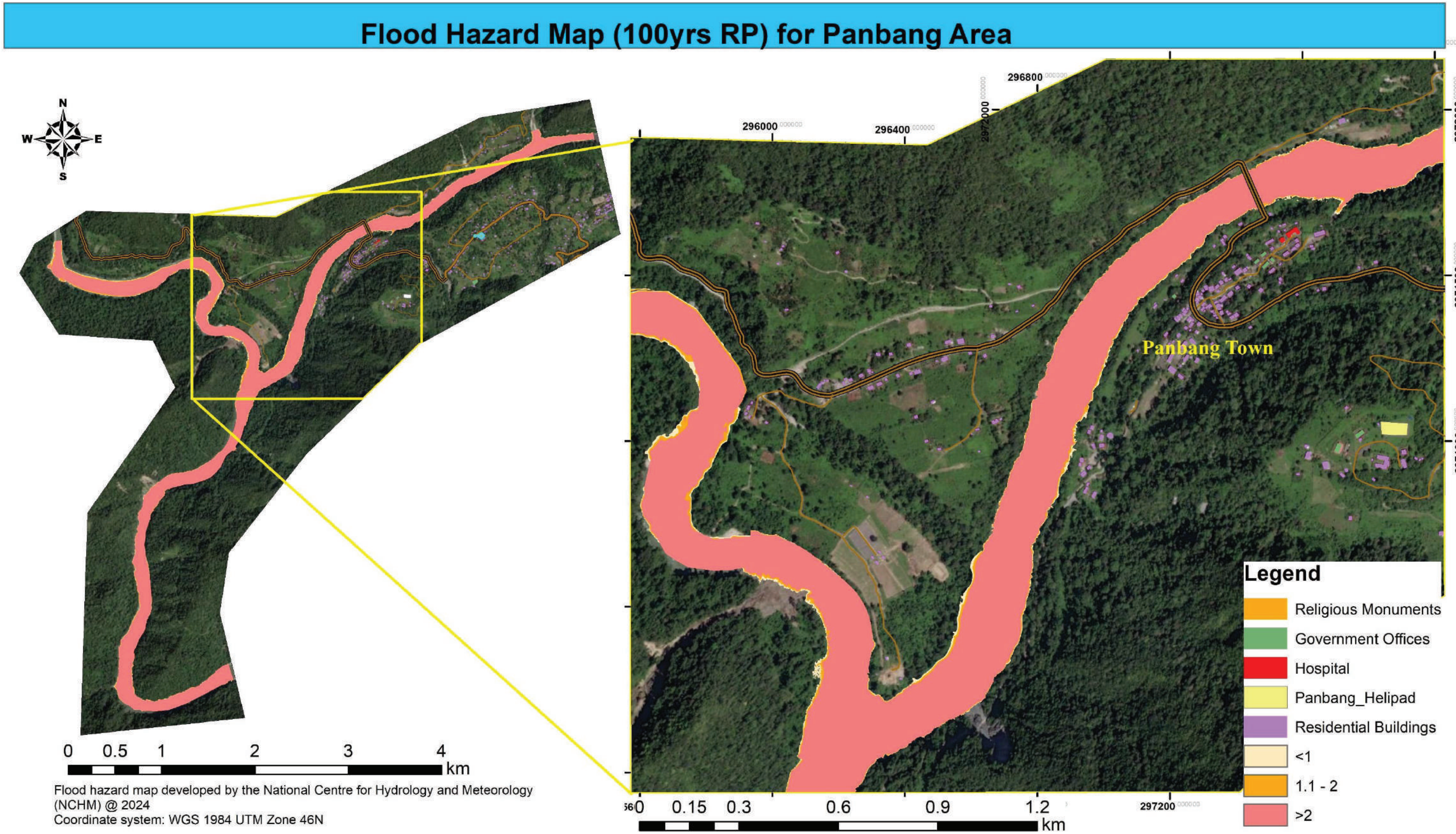


Drone image of Panbang in Zhemgang

Flood Hazard Map (20yrs RP) for Panbang Area



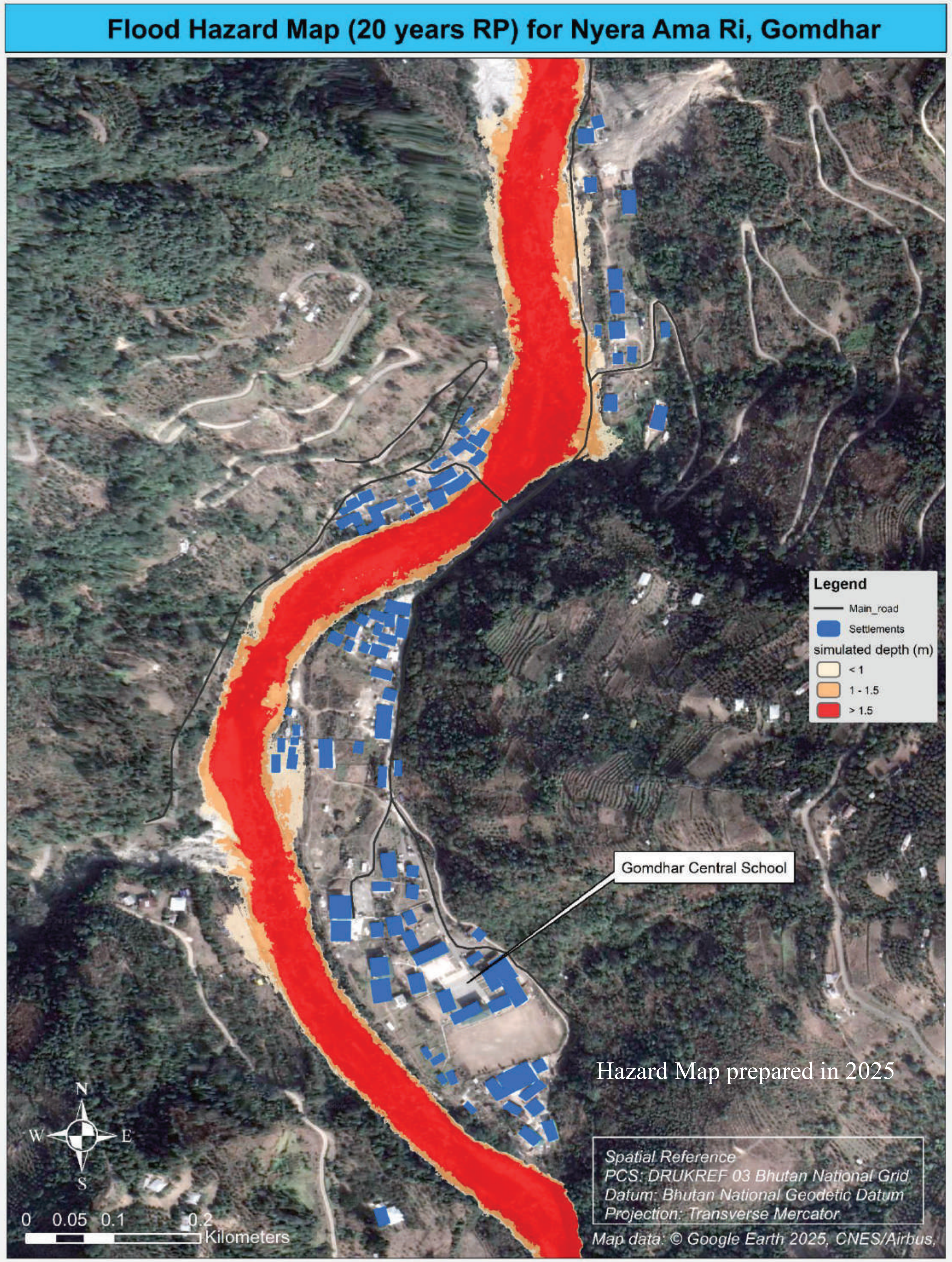
Hazard Map prepared in 2024

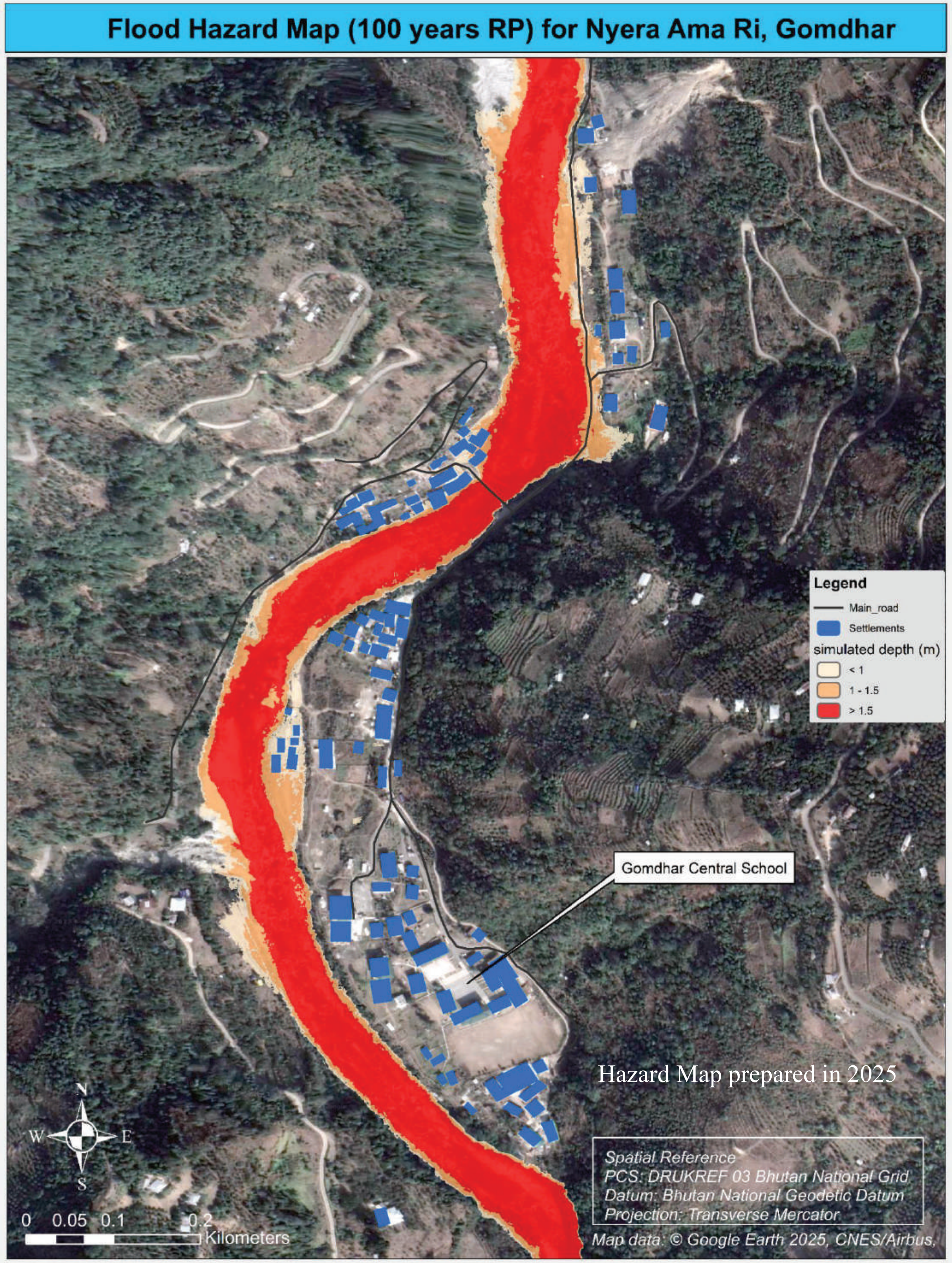


Hazard Map prepared in 2024

4.8 Nyera Amari (Gomdhar) Hazard Map

Drone image of Gomdhar school in Samdrup Jongkhar


Flood Hazard Map (20 years RP) for Nyera Ama Ri, Gomdhar
Legend
Main_road
Settlements
simulated depth (m)
< 1
1 - 1.5
> 1.5
Gomdhar Central School
Hazard Map prepared in 2025
N
W
E
S
0 0.05 0.1 0.2
Kilometers
Spatial Reference
PCS: DRUKREF 03 Bhutan National Grid
Datum: Bhutan National Geodetic Datum
Projection: Transverse Mercator
Map data: © Google Earth 2025, CNES/Airbus.


Flood Hazard Map (100 years RP) for Nyera Ama Ri, Gomdhar
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Settlements
simulated depth (m)
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1 - 1.5
> 1.5
Gomdhar Central School
Hazard Map prepared in 2025
N
W
E
S
0 0.05 0.1 0.2
Kilometers
Spatial Reference
PCS: DRUKREF 03 Bhutan National Grid
Datum: Bhutan National Geodetic Datum
Projection: Transverse Mercator
Map data: © Google Earth 2025, CNES/Airbus.

5. Conclusion and Limitation

The Bhutan Flood Hazard Atlas is a significant step toward understanding and mitigating flood risks in the country. By identifying flood-prone areas and providing crucial spatial information, the atlas serves as a valuable tool for policymakers, disaster management agencies, and urban planners. It enhances preparedness and response strategies, ultimately contributing to safer communities and sustainable development.

However, this atlas also has certain limitations. While a few high-resolution satellite images were procured, their high cost made it impractical to achieve comprehensive coverage across the entire country. Moreover, the available high resolution satellite images do not provide full coverage of all river basins nationwide. Consequently, drone-based surveys—essential for generating detailed spatial data—were conducted only in selected high-risk areas. This has limited the spatial extent of the current mapping and underscores the need for more extensive data collection in the future to ensure nationwide flood hazard assessment.

That said, this atlas is only the beginning. Given the dynamic nature of flood hazards driven by climate change and evolving land-use patterns, regular updates are essential to maintain its accuracy and relevance.

Furthermore, efforts must continue to expand the mapping to other vulnerable regions not yet covered, ensuring a more comprehensive understanding of flood risks across Bhutan. Continuous research, improved hydrological modeling, and updated datasets will be critical to enhancing the effectiveness of flood hazard assessments. With these efforts, Bhutan can strengthen its resilience to floods and better safeguard its people, infrastructure, and development progress.

Aerial picture of Khuruthang, Punakha

National Centre for Hydrology and Meteorology (NCHM)
Thimphu, Bhutan