Flood risk mitigation by inundation mapping and socioeconomic analyses in two river basins of Nepal

（ネパールの 2 つの河川流域における浸水域予測地図作成と社会経済分析による洪水リスク軽減）

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1. Introduction

Floodplains of many rivers around the world have been considerably modified due to various global issues i.e., population and economic growth, and degradation of ecosystem services. Floods can cause detrimental consequences on society, the economy and the environment in many parts of the world. On average, about 21 million people worldwide are affected by river floods each year (Luo et al., 2015).

Depending on the type of floods, one or more structural measures can be used to manage flood hazards. As mentioned above, only structural measures are not enough; effective flood management includes the use of non-structural measures which include: use of natural systems, mapping of risks, early warning system and forecasting of flood hazards, emergency plans, land use planning and zoning, building and construction standards and codes in the flood prone areas and relocation (Martinez et al., 2020).

Adequate warnings allow people to protect themselves and their property from the harmful effects of floods. Flood risk management systems (FRMS) emerged as a response to the increase in floods and to satisfy community safety and property-protection expectations (UNISDR & WMO, 2015). These FRMS are based on the execution of systematic actions of preparedness, response, recovery, and mitigation. Flood risk assessment, analysis, and reduction through suitable policies and practices are developed within FRMS as a combined effort between decision-makers and experts (Schanze et al., 2006).

Nepal, a country characterized by the occupation of the central part of the Himalayas, is extremely vulnerable to natural disasters due to its fragile geology and topography such as steep slopes and high relief as well as a monsoon climate. Intensive rainfall caused devastation due to floods and landslides in the major parts of the country (Paudel et al., 2003). Recent flood disasters in Nepal have been the result of a combination of a fast-growing vulnerability of the local population and variable, possibly changing climatic conditions (Delalay et al., 2018). Nepal is severely flood-prone and ranked as the 20th flood-affected population in the world, and the frequency and intensity of natural hazards are increasing (Rai et al., 2020).

Institutional factors of disaster risks have rarely been studied for GLOFs, which are threatening high mountain regions such as the Andes, Alps, and the Himalayas (Thompson et al., 2020). Exacerbated by climate change, much of the focus in the Himalayas so far has been on GLOF risk anticipation. However, flooding events are common in the lower region such as the hill area and Terai area in Nepal.

Flash floods are severe flood events that are caused by intensive rainfall, dam failure and GLOFs. They can also be caused by the failure of artificial dams, poor management of hydraulic structures, rapid melting of snow and ice, quick release of stored glacial water, and others (Shrestha et al., 2008).

As measures against such events, several flood early warning systems have been established in Nepal over the last decade, helping reduce the number of people affected and killed by floods. However, there are still challenges in communicating flood warnings to the most vulnerable (Shrestha et al., 2021). Therefore, flood management planning is an urgent need for Nepal.

2. Objectives

This study aimed to (1) estimate the inundation area by future floods using HEC-RAS to identify vulnerable locations and houses in three settlements in the Seti River basin, Pokhara, and thirteen settlements in the Tamakoshi River basin, Dolakha; (2) create an evacuation route maps in potentially dangerous sites for emergency use; and (3) analyze the vulnerability situation in term of socioeconomic context of the people residing in the areas prone to inundation. This study also identifies and develop evacuation routes and suggests a safe place for temporary evacuation and shelter houses. Based on these analyses, a series of flood risk reduction strategies and measures will be identified and recommended.

3. Study areas and methodology

3.1 Seti River Basin, Pokhara

Pokhara is situated approximately 200 km west of the capital city Kathmandu in Kaski district, Gandaki province with an area coverage of 464.24 km^2. Pokhara Metropolitan city was formed in 2017 with 33 wards. It is the largest metropolitan city in terms of area and the second-largest in terms of population with a population of 4,13,397 according to CBS data of 2011 AD. It is surrounded by Madi and Rupa Rural Municipality in the East, Annapurna Rural Municipality, Parbat and Syangja districts in the west, Machhapuchchhre, and Madi Rural Municipality in the North, and Syangja and Tanahun districts in the South. The elevation ranges from 827 to 1511m. It has a humid and sub-tropical climate with an average annual temperature of 21.9 ^{0}C and mean annual precipitation of 3899 mm, but the nearby station Lumle has a very high mean annual precipitation of 5515 (CBS, 2019).

3.2 Tamakoshi River Basin, Dolakha

Dolakha District lies in the Bagmati Province and is approximately 181 km northeast of the capital city Kathmandu. It covers an area of 2,191 km^2 and has a population of 186, 557 according to the National Planning Commission Secretariat Central Bureau of Statistics Kathmandu Nepal, (CBS, 2011). The study area covers Bhimeshwor Municipality, Kalinchowk rural municipalities, Gaurisankar rural municipalities, and Biju rural municipalities. The study area is well accessible because the Charikot-Lamabagar Highway links with the major cities of the country. The highway runs 365 days and passes through Charikot, the distinct headquarters. The elevation of the district ranges from 732 to 7,134. m a.s.l. (Kandel et al., 2019) . It has a humid subtropical, dry climate with an annual mean temperature of 15.02 ^{0}C and yearly precipitation of 2353.2 mm (CBS, 2019).

3.3 Methodology

This research prepared a detailed hazard map with combined approaches of an analysis of photographs taken by a drone (UAV), remote sensing, field survey, and HEC-RAS modeling. Interview surveys and questionnaire surveys were conducted to understand the current situation of the area and to identify the settlements that high risk of flood. This research follows the two major methods for the Seti River basin: (1) inundation mapping, and (2) Socioeconomic survey.

Inundation Mapping

HEC-RAS Model

In the present study, flood hazard maps were obtained by using HEC-RAS, HEC-GeoRAS, and ArcGIS. The methodology for developing a flood hazard map can be get by three phases: (a) preparing a digital elevation model using ArcGIS, (b) simulation of flood flows using HEC-RAS, and (iii) preparing flood risk maps by at combine. HEC-RAS model needs details of river cross-sections and streamflow data. HEC-RAS calculates the water levels' variation and water level with help of a digital elevation model (DEM). Spatial data like Geometric data, flow data, critical water depts, and others have been obtained using HEC-GeoRAS (Arc-GIS extension) and these data are then transferred to HEC-RAS. The results obtained from the hydraulic model can be converted to GIS format by using HEC-GeoRAS and thus flood mapping and flood depth maps can be obtained. I used the existing topographic maps and detailed 5-m contour intervals DEM. The cross-section data and riverbank locations at intervals of about 50 m were collected using topographic data. A handy GPS device was used to obtain the coordinates points. Topographic maps of the study area (sheet no. 2786-01D,2786-05A, 2786-05B, and 2786-05C of scale 1: 25,000) were collected from the Survey Department of Nepal. HEC-RAS 6.1 was used to calculate water surface profiles and ArcGIS 10.2 was used for GIS data processing

The cross-section point filter was used to remove the duplicate points, or the high number of points (over 1000) created across some cross-sections as the GIS system generated it. The inundation mapping was based on a peak discharge value of 1450 m^3/s (Kathmandu University, 2012) for the Seti River. Similarly, I used peak discharge of 1940 m^3/s for Tamakoshi River (taken from the rainfall data at Busti Station from 1970 to 2006). A flood inundation map was prepared using both the topographic maps from the drone survey and the DGPS survey at 1-m contour intervals. A DEM map was also prepared at 1-m contour intervals to delineate watershed boundaries.

UAV (drone) Photogrammetry

In the first stage of the drone-based aerial survey (DJI Phantom 4 Pro), the ground control point (GCP) locations were finalized. The flight route was planned using Google Earth (v.2.3) to help determine the overall flight number, height, estimated time, and image percentage overlap. GCPs must be visible from the nadir view of the drone and evenly distributed to achieve a uniformly high accuracy throughout the study area.

In the Seti River basin (all three settlements), after the 21 GCP locations were identified and finalized, they were marked with a 60 × 60–cm red flag and white enamel cross to assist with drone image identification. The center of the white cross was marked as the GCP, and the *.kml* file of the site was imported into the Drone Deploy software. The flight plan was set for a front overlap of 75% and a side overlap of 70% at the height of 55 m. A total of 25 flights were flown. A differential GPS survey (Stonex DGPS) of the established GCPs was carried out to identify their proper position. The easting, northing, and elevation of the GCPs were also measured, and 21 points were utilized for 3D georeferencing. After the geotagged images were captured onsite, they were processed to obtain a digital surface model (DSM), contour lines, a digital terrain model (DTM), and orthophoto maps. A DEM is a bare-earth raster where non-ground (man-made) features such as roads and buildings are not included.

DEMs are useful for hydrological modeling, surface analysis, and soil mapping. A DTM is a 3D model visualizing surface elevation data; its structure is based on a TIN composed of vector data. A Triangulated Irregular Network (TIN) represents the terrain surface as a set of interconnected triangular facets. The TIN structure is a vector-based alternative to the traditional raster representation of terrain surface Digital Elevation Model (DEM). A DTM reinforces a DEM by including man-made features of the bare-earth terrain. Irrelevant images were removed before processing with Agisoft Photoscan (v.1.4.0). The overlapped and geotagged images were processed using image matching algorithms, i.e., the SIFT (Scale – Invariant Feature Transform) algorithm. The SIFT algorithm is used to detect and describe local features in digital images. The output data from the initial image processing represent the tie points that were initially matched by the algorithm. These tie points were generated by matching the same features within the overlapped images. Subsequently, point cloud and mesh processing was carried out. The dense stereo matching algorithm generates 3D-textured point clouds to replicate the ground surface. These points were triangulated to obtain the 3D mesh of the project area. The output accuracy of the DSM was modified according to $x \cdot$ *Ground Sampling Distance* (GSD), where GSD is the distance between the centers of two adjacent pixels in the photo and x is a multiplier. The DTM was generated as per requirement. It is a mathematical model of the ground surface, most often in the form of a regular grid, in which a unique elevation value is assigned to each pixel. The contours derived from the DTM were used to prepare the topographic map. Major and minor contours of 5 and 1 m were used for this research, respectively. Government data have not been updated and for the detailed survey, the accuracy is not sufficient. So, UAV data are more accurate and reliable for this type of detailed survey. A georeferenced orthophoto was also generated. Houses, roads, rivers, and other features were digitized and integrated with the contours to prepare the final topographic map of the project area using ArcGIS (*v.*10.2).

In the Tamakoshi River basin, the flight covered a front overlap of 75% and a side overlap of 70% at the height of 100 m. A total of 7 flights and 5 flights were made in Singati and Gongar, respectively. I used 5-meter contours for both areas. The houses, bridge, road, and riverbank all are marked with the help of drone photos in two settlements. In other settlements, GPS was used for obtaining the coordinate points. Major contours of 20 m were used for the rest of the settlements. A georeferenced orthophoto was also generated. Houses, roads, riverbanks, bridges, temples, and other features were digitized and integrated with the contours to prepare the final topographic map and toposheet from the survey department. All topographic map components were in the standard format (land use map 1996 corrected in 2021) as provided by the Government of Nepal.

Evacuation-Route Mapping

This study extracted the road network (for pedestrians) of three settlements using data from an orthophoto digital map using ArcGIS 10. First, the length and width of each road were obtained and measured from a digital map. Next, the road width and length at some sites were measured again in the field to confirm the data from the digital map. Afterward, the number of people able to use the existing road at once during a flood hazard was determined. Finally, a new evacuation route was suggested, depending on the existing topography and population. The evacuation route for pedestrians was based on UAV photogrammetry and the shortest route with respect to the existing road network. During the field survey, local people were asked about the nearest safe site during flood occurrence. At first, existing road conditions were inspected and measured manually in all three settlements (Masinabagar, Laltinbazar, and KI-sing) to identify all possible routes for assisting with the traffic flow from the origin (disaster area) to the destination (safe area). The inundation risk area was initially identified. Afterward, the disaster vulnerability areas that needed evacuation plans were identified. Then, the safe place and exit route were located using the drone photos obtained via ArcGIS. The shortest and easiest route from each house (origin) to a safe location was determined.

The evacuation route map of Tamakoshi River basin was based on UAV photogrammetry, toposheet, land use landcover map, fields survey, and the shortest route, according to the existing road network. During the field survey, local people were asked about the nearest safe site during the occurrence of floods or any other disaster. At first, existing road conditions have inspected in all settlements along with Tamakoshi River, to identify all possible routes for assisting with the traffic flow from the origin (disaster area) to the destination (safe area). The inundation risk area was initially identified; the disaster vulnerability area was identified subsequently, for which an evacuation plan was needed. Then, the safe place and exit route were located using the drone photos in Singati and Gongar and the rest of the area I combine the topographic map and field survey data to obtain results via ArcGIS. The shortest and easiest route from each house (origin) to a safe location was determined.

Socioeconomic Survey

Primary and secondary information was used to prepare community profiles and assess the vulnerability of the three settlements. Published and unpublished documents containing relevant information were collected and reviewed. The questionnaire survey covered all households within 100 m from each side of the river in Masinabagar, Laltinbazar, and KI-sing. Basic income information, migration status, family size, education status, knowledge of hazard risks, evacuation sites, primary occupations of the head of households, and house type (permanent or temporary) were collected from the heads of the households. Migrant or non-migrant statuses were based on a 20-year residency period. Per capita incomes were categorized based partially on a United Nations criterion, in which low income (i.e., extreme poverty) was defined as an annual income of ≤ 1025 USD, lower-middle-incomes were those with a per capita gross national income between 1026 USD and 3995 USD, upper-middle-incomes were between 3996 USD and 12,375 USD, and high-incomes were those > 12,375 USD.

Focus group discussions in two settlements of Masinabagar and Laltinbazar were conducted in November 2015 to collect information on community-level problems faced after the 2012 flood, infrastructure development, and other related activities, institutions, hazards, risk evacuation sites, and refugees. Lecturers from Prithivi Narayen Campus, Pokhara, a local primary school teacher, and NGO staff helped as facilitators. There were 12 participants in Laltinbazar and 43 in Masinabagar. The discussions ranged from 1 to 3 hours about flood risk, mitigation measures, and preparedness. The questionnaire survey covered 10 houses in Gongar, 28 houses in Purano Jagat, 5 houses in Jagat, 10 houses in Manthali, 3 houses in Jamune, 4 houses in Suri Dobhan, 10 houses in Bhorle, 4 houses in Olitar, 66 houses in Singati, 17 houses in Kattike and 6 houses in Tamakoshi (total 163). I chose a face-to-face survey. Furthermore, teachers, administrative officers, local political leaders, NGOs, international non-governmental organizations (INGO) staff, and FM radio employees were interviewed to collect information on flood disaster challenges and future disaster mitigation efforts.

3.4 Statistical Analysis

I used SPSS version 17 for all statistical analyses. A Mann-Whitney U test, Fisher's exact test, ANOVA, and chi-square test were used to compare the inundation values, the distance between houses from the river, and social parameters. Data are presented as median (interquartile range), and $p < 0.05$ (two-tailed) is considered significant in all analyses. I used a simple linear regression model to estimate the relationship between two variables (slope and walking speed) for calculating the time for the evacuation routes as mentioned above.

4. Results

The inundation maps created in this study show that the Masinabagar, Laltinbazar, and KI-sing areas are highly susceptible to future flooding. Flood-inundation and evacuation-route maps were prepared from Masinabagar to KI-sing. Based on the inundation maps showed a maximum depth of inundation water level of 13 m in Masinabagar, 17 m in Laltinbazar, and 21 m in KI-sing.

In Masinabagar, a total of 268 buildings that house a population of 1294 are in danger, including 229 households, 13 livestock farms, 9 school buildings, 9 restaurants, 4 crematoriums, 2 churches, and 2 warehouses. The present routes of these residents are insufficiently prepared for emergency evacuations, as previously stated. The situation in Laltinbazar is similar, where 232 buildings were within the inundation zone and exhibited a population of 1240; these included 225 households, 4 schools, and 3 warehouses. In KI-sing, the situation is slightly better; however, 68 buildings, including 32 households, 18 community centers, 11 temples, 4 crematoriums, and 3 research centers (total population of 130), will potentially be inundated by flooding.

Evacuation routes in the three settlements were either inadequate or absent. No flood hazard maps are available in the study area. There are no evacuation routes designated by the city or central government. This study, therefore, identified the existing pedestrian routes, which can be used as evacuation routes by the locals. There is insufficient route space for all residents in an emergency evacuation situation; therefore, multiple routes were suggested to reduce the traffic flow from houses to safe destinations. This study suggested that both the existing pedestrian routes and new pedestrian routes to be created can be used for emergencies.

In Masinabagar, 27 new routes are suggested to be created, in Laltinbazar, 25 routes, and in KI-sing, 9 routes should be created. This study also found that all of the Masinabagar, Laltinbazar and KI-sing areas are highly susceptible to future flooding. Moreover, lower-income residents were at much higher risks, as most houses near the riverside area belonged to impoverished migrants and laborers. The results highlighted that immigrant households were at the highest risk ($p<0.001$ for both factors). Similarly, 455 laborers' houses by occupation were also significantly correlated with inundation risk ($p<0.001$). The correlation between income and migration was statistically significant for all households ($p<0.001$). Similarly, the correlation between income and occupation was also significant ($p<0.001$).

In the Tamakoshi River basin, the inundation maps showed that Gongar, Singati, Jagat, Bhorle, Jamune, Kattike and Tamakoshi are highly susceptible to future flooding. The maximum inundation depth was calculated as 19 m in Gongar, 10 m in Jagat, 6 m in Bhorle, 10 m in Jamune, 39 m in Singati, 14 m in Kattike, and 19 m in Tamakoshi. In Singati out of 659 houses, 220 houses are situated in the inundation zone. Of the 17 houses in Kattike (population 61), 6 houses (population 23) are situated in the inundation zone. In Tamakoshi all 6 houses (population 17) are situated in the inundation zone. It was suggested that the number of newly created evacuation routes should be 9, 25, 3, and 2 in Gongar, Singati, Kattike, and Tamakoshi, respectively.

To understand the current evacuation situation, a total of five routes were examined and the population was classified into four groups: <5-years, 15–40-years, 40–65-years, and >65-years old. The walking speed of the different age classes were examined in the field with the help of resident volunteers. The result showed the <15 years age class and the >65 age class needed a longer time to walk all five routes. The result also showed that the average evacuation speed was 2.28 m/s for the elderly class (>65), 1.09 m/s for adult class (15-40), 1.95 m/s for middle-aged class (40-65), and 1.22 m/s for child class (<15). Crossing time depends on the degree of slope and route length. Based on the results crossing time decrease with increasing slope and age classes.

Moreover, near the riverside residents were at much higher risk. Altogether 46.01% were extremely poor, 28.83% were low-income people, 12.88 % were lower-income people, and 12.27% were people found in the study area. No high-income people are living in the entire study area. The business (small vendor) industry was the most popular, accounting for 50.92%. The number of employees in different offices and small farms, a government office, and in small NGOs is 19.63%. Agriculture-based households varied from 15.95%. Remittance provided a sustainable form of income for 5.52% of households. Labor-related occupations were 4.29% and pension contributes 3.68% of the household's income. Mostly the non-migrated people are living in this area (57.67%). Altogether, 42.33% of the residents within the study area had migrated within the last 20 years. The result highlighted the relationship between education and occupation. Similarly, the result presents the relationship between education and income. The correlation between education and occupation was significantly correlated ($p<0.002$). Similarly, the correlation between education and income was significantly not correlated ($p<0.219$). The result highlighted that the relationship between occupation and income was statistically not significant ($p<0.839$).

The early warning system helps reduce economic losses and mitigate the number of injuries and deaths, allowing the downstream communities to protect their lives and properties. Therefore, the study suggests the implementation of a mobile phone-based early alarming system, which is cost-effective and easy for all those areas connected to the network coverage. Results show that among the 15- to 64-year-olds, 98.61%, 98.80%, and 99 % in Masinabagar, Laltinbazar, and KI-sing, respectively, have a mobile phone. Altogether 98.68 % of 15- to 64-year-old people have a mobile phone. Similarly, NTC has been expanding a lot in remote areas, to meet mobile coverage in all parts in Dolakha. Therefore, an early warning system through mobile phones would be the best solution.

5. Discussion

In Kaski, people's knowledge about evacuation safe sites is 53.22% (p<0.001). They consider outside of the house and a little higher place is a safe place. In total 46.78% of the people are unaware of the evacuation process and safe places. They never practice or participate in the evacuation drill. In total 99.11% of the population is completely unaware of the regular drill and they are not statistically correlated (p<0.479). In all three settlements, 69.37% of permanent houses be inundated. Semi-permanent type houses were in the second most danger (29.21). The relationship between house type and inundated houses was statistically correlated (p<0.001).

Regarding disaster preparedness training 80.89% of the people have no idea. After the 2012 flood, some NGOs provides preparedness training (3.22%). People get some ideas from Radio, TV, and FM (12.44%). The correlation between disaster preparedness training and safe/inundated houses is statistically correlated (p<0.001). Even 44.11% of the people have not any knowledge about such kind of training (p<0.001). They are not well prepared for disaster. Only 55.89% of the people are mentally prepared for disaster (p<0.001), but they don't have any tool or an emergency supply kit for an emergency. In terms of the safe site near the houses 24.54% are inundated houses and 73.71% of safe houses have no idea. Other 75.46% of risk houses know about safe sites (p<0.001). They never participate or practice any drill. Almost 100% of people are unaware of the hazard map (p<0.504).

In Dolakha only 3.7% of the people had knowledge about evacuation. In total 96.3% of the people are unaware of the evacuation process and safe places. In total, 87 households didn't have livestock, 20 families lost their livestock, and 56 households marked their livestock as safe. The Chi-square test shows a correlation between livestock farming to education status is statistically significant and the income of the households is not correlated (p<0.170). In total, 87 households didn't have livestock, 20 families lost their livestock, and 56 households marked their livestock as safe. The Chi-square test shows a value less than (p<0.001); therefore, livestock and income of the households are highly correlated and the result is significant. Similarly, 113 households had no idea about disaster preparedness training while 35, 2, and 4 households had gone through government, INGO, and NGO disaster preparedness training respectively. Additionally, 9 households had taken disaster preparedness training from other different agencies. Lastly, knowledge about the safe site also shows that 140 households had no idea knowledge about safe sites while 23 were aware of safe sites. Similarly, supply kits, evacuation, and discussion are also not correlated with income. All 23 households were supplied with the kit and had discussions whereas 140 were empty-handed and went through no discussion. Six families were evacuated while 157 were left unattended. Moreover, the meeting point outside doesn't show any correlation. Total of 43 households had meeting points outside and 120 did not have the meeting points outside. Surprisingly, only 2 households had an idea about the hazard map out of 163 households.

The ratio of poverty and getting training is statistically correlated (p<0.001). A total 73 extremely poor households don't get any disaster training. Therefore 75 households of extremely poor don't have any idea regarding preparedness. Similarly, 66 were extremely poor, 39 were low income, 19 were lower-middle and surprisingly 16 upper-middle people don't have an emergency kit. Therefore, the correlation between income group and disaster preparedness is statistically significant (p<0.001). In the context of knowing a safe site near the house, 73 are extremely poor, 43 are low income, 14 of the lower-middle-income and 10 upper-middle families are not aware of it (p<0.001). For the proper evacuation regular drill is the key to safe life during a disaster but in the research area 75 are extremely poor, 45 are low income and 21 the lower-middle-income and 16 upper-middle families had never practiced.

This study designed an evacuation system to focus on immediate relief (short-term) and considered the most pertinent factors for alleviating flooding vulnerability to reduce the risk to life and create safe and organized evacuation routes (long-term). Based on research, temporary safe places were identified in the proximity of settlements, even though they do not at present, contain any form of shelter. Land that is outside the inundation area and at a higher altitude was assumed a temporary safe place. The evacuation route was also designed based on that. Social networking service (SNS) as early warning system is suggested. Using SNS through a mobile phone would be the most effective and quick way for the people in the study area. Therefore, using mobile phones for early warning is strongly recommended not only in the study area but also in downstream communities in other parts of the country.

The focus group discussions revealed a lack of adaptive capacity-building strategies and risk reduction knowledge among the locals. Furthermore, locals must participate in disaster preparedness training and awareness programs to increase their safety. In addition, any relocation strategy put forward by the government would likely require an extended period, during which the construction of a river embankment may be one of the realistic alternatives for decreasing flood disaster risks in the shorter term. As a result, people started to build new houses in the risk zone. Therefore, the government should strictly prohibit and regulate this type of encroachment near the risky riverside and local people should learn and be aware of disaster preparedness, prevention, and mitigation measures.

6. Conclusions

The inundation maps created in this study show that the Masinabagar, Laltinbazar, and KI-sing areas are highly susceptible to future flooding. In Seti River basin, inundation maps showed a maximum depth of inundation water level of 13 m in Masinabagar, 17 m in Laltinbazar, and 21 m in KI-sing. In Masinabagar, 268 of the 466 buildings, including 229 houses, churches, crematoriums, livestock farms, restaurants, warehouses, and schools, were situated in the inundation zone. In Laltinbazar, of 329 buildings, 232 buildings, including 225 houses, warehouses, and a primary school were situated in the estimated flood-prone zone. Similarly, in KI-sing, of the 210 buildings, 68 were located in the inundation zone, including 32 houses, a research center, community centers, and temples. Evacuation routes in the three settlements were either inadequate or absent. Moreover, lower-income residents were at much higher risks, as most houses near the riverside area belonged to impoverished migrants and laborers. A safe destination is considered as a place at an altitude at least 1 m higher than the altitudes of existing houses. This study suggested that both the existing routes and routes to be created can be used for emergency. Therefore, in Masinabagar 27 routes are to be created, and in Laltinbazar 25 and KI-sing 9 new routes are to be created. The return period for the Seti River is expected to be 50 years and the Tamakoshi River basin that for is 10 years. The results highlighted that immigrant households were at the highest risk ($p<0.001$ for both factors). Similarly, 455 laborers' houses by occupation were significantly correlated with inundation risk ($p<0.001$). The correlation between income and migration was statistically significant for all households ($p<0.001$). Similarly, the correlation between income and occupation was also significant ($p<0.001$).

The inundation maps created in this study show that the Gongar, Singati, Jagat, Bhorle, Jamune, Kattike, and Tamakoshi are highly susceptible to future flooding. The maximum inundation depth was calculated as 19 m in Gongar, 10 m in Jagat, 6 m in Bhorle, 10 m in Jamune, 39 m in Singati, 14 m in Kattike, and 19 m in Tamakoshi. In Gongar 3 houses, in Singati 220 houses were situated in the inundation zone. In Bhorle 1, Jamune 3, Jagat 1, Kattike 6, and Tamakoshi 6 houses were situated in the estimated flood-prone zone. The evacuation route height from households to a safe place (destination) is a minimum of 14 m to 280 m maximum. Similarly, the total distance from a household to a safe place is a minimum of 53 m to a maximum of 276 m. The study suggested that the evacuation routes should be created as many as 9, in Gongar, 25 in Singati, 1 in Jagat, Jamune and Bhorle each, 3 in Kattike, and 4 in Tamakoshi. The return period for the Tamakoshi river is expected to be 10 years. In order to calculate the necessary time for evacuation by age, the population was classified into four groups: <15-years old, 15–40-years old, 40–65-years old, and >65-years old groups. Walking speed on the uphill slope became slower, whereas it became faster on flat or down slope. The 40-65 years age people and >65 age people took a long time to finish all five routes: the evacuation time the elderly (>65) was 2.28 m/s, the middle-aged person (40-65) 1.95 m/s, adults (15-40) 1.09 m/s and children (<15) was 1.22 m/s.

Socioeconomic survey showed that 46.0% were extremely poor, 28.8% were low-income people, 12.8% were lower-middle and 12.3% were upper-middle people in the study area. No high-income people are living in the entire study area. The correlation between education and occupation was significantly correlated ($p<0.002$). The correlation between education and income was significantly not correlated ($p<0.219$). The result highlighted that the relationship between occupation and income was statistically not significant ($p<0.839$).

Therefore, this study concludes that in both river basins most riverside residents remain unaware of the preparation and risk associated with flood emergency evacuation; thus, adaptive capacity-building strategy programs, disaster preparedness training, and evacuation drills must be urgently incorporated. This research contributes to reducing the impact of flood disasters, and the proposed evacuation system will help save lives. This study will be useful for planners with respect to preparedness, early warning systems, and safe evacuation and will serve as a guide for sustainable development in the region. Accordingly, this study recommends applying a combined approach that uses modeling and socioeconomic surveying in other parts of the Himalayan region and impoverished areas around the globe.