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

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Abstract

Floods often cause enormous damage to lives, property, and infrastructure. Sudden floods frequently occur in the Himalaya under changing climates. This study, focusing on flood issues in the mountains of Nepal, aimed to identify safe and at-risk houses and the availability of routes for emergency evacuation and to analyze the relationships between the inundation risk and socioeconomic situation. This study chose three settlements (Masinabagar, Laltinbazar, and KI-sing) in the Seti River basin (Kaski District) because these settlements are densely populated and situated in the sub-urban area along the river, and 11 settlements in the remote rural area in the Tamakoshi river basin (Dolakha District). Detailed hazard maps were created based on the results from aerial vehicle (UAV) photogrammetry and the Hydrologic Engineering Center River Analysis System (HEC-RAS). Agisoft Photoscan (v.1.4.0) and ArcGIS (v.10.2) were used for the mapping. For inundation mapping, the flood level (peak discharge) was assumed to be the same as that observed on May 5, 2012, i.e., 1450 m^3/s for the Seti River basin. In the Tamakoshi River basin, peak discharge from the Department of Hydrology and Meteorology (1940 m^3/s) was used for inundation mapping. The return period is expected to be 50 years for the Seti River and 10 years for the Tamakoshi river basin. Evacuation route mapping was done based on the UAV photogrammetry, toposheets, and field surveys. The questionnaire, focus-group, and key-informant surveys helped identify the socioeconomic situation in both basins.

In the 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 among 466 households (population: 976 among 2303) are situated in the inundation area. Laltinbazar with 232 of 329 households (population: 1800) is located either on the floodplain or along the slopes with a small relative height to the river water

surface. Similarly, 68 households are situated in the inundation zone in KI-sing (population: 786).

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 evacuation 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 the Masinabagar, Laltinbazar and KI-sing areas are highly susceptible to future flooding.

The socioeconomical survey result highlighted that low-income residents, primarily migrants and laborers, were in the danger zone near the riverside. Highly impoverished and immigrant households were at the highest risk for both factors: income and migration ($p<0.001$). The locations of laborers' houses were also significantly correlated with inundation risk ($p<0.001$). The relationship between occupation and income was statistically not significant ($p<0.839$).

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 evacuation routes that should be newly created was 9, 25, 3, and 2 in Gongar, Singati, Kattike, and Tamakoshi, respectively.

To evaluate the proposed evacuation routes, walking speed of 31 resident volunteers were measured on five experimental routes. The people walked on the routes were classified into four groups: <15-years, 15–40-years, 40–65-years, and >65-years old

groups. The result showed that the average evacuation speed was 2.28 m/s for the elderly group (>65 years old), 1.95 m/s for middle-aged group (40-65), 1.09 m/s for adult group (15-40), and 1.22 m/s for child group (<15). Based on the results, the adequacy of the proposed evacuation routes was evaluated.

This study developed an evacuation system by considering short-term and long-term measures. Land located outside the inundation area and at a higher altitude was assumed as safe places for temporary evacuation; however, most such places do not have shelters. Establishing adequate evacuation routes and shelter houses is one of the most pressing needs. This study suggested an implementation of a mobile phone-based early alarming system, which is cost-effective and easy for all areas connected to the network coverage. Results in the Seti Khola basin showed that 98% of the interviewed households have mobile-phone handsets, indicating the realization of the mobile phone-based early alarming system. This study also found that most riverside residents in both river basins 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 flood-disaster mitigation, and the proposed evacuation system will help save lives. This study recommends applying a combined approach that uses flood modeling and socioeconomic surveys to other parts of the Himalayan region and impoverished areas around the globe.

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Chapter 1 Introduction

1.1. Flood risk mitigation and flood forecasting in the world

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).

According to Juarez-Lucas et al., (2019), flood management means adopting strategies that can lower the effects and likelihood of flooding. Effective flood management systems should have the ability to adopt flood control measures that work in terms of reducing the level of damage caused by flooding. The measures include both structural and non-structural measures (Juarez-Lucas et al., 2019; Li et al., 2016). Structural measures are commonly used to decrease the risk of flood hazards by means of controlling flow of floodwater in a particular area, whereas non-structural measures supplement the structural measures with the aid of keeping people safe from flooding through better planning and management (Juarez-Lucas et al., 2019; Kovář et al., 2014; Li et al., 2016). Bubeck & Thieken, (2018) also says that a credible flood control system should include structural and non-structural measures of flood management.

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).

According to Rosbjerg et al., (2013), the implementation of a flood risk plan requires knowledge of water levels or flood peaks. Two types of flood predictions are required. One is the prediction of floods in terms of magnitude and timing at a particular location, together with its inundation extent during its occurrence (i.e., flood water level). This type of prediction is often required in short-term flood preparedness systems to raise timely flood warnings. The second one is the prediction of a high-water level or peak discharge likely to occur in the future i.e., improving knowledge of the frequency of occurrence of floods of different magnitudes.

Asian countries such as Thailand, India, Nepal, China, and Japan have been encountering floods in many regions. Different countries have different flood management approaches to prevent and mitigate flooding events to reduce the impacts of such hazards (Nguyen et al., 2021; Thanvisitthpon et al., 2018). The ancient flood management practices of China started 4000 years ago and focused on building canals to prevent flooding. China had also built upstream reservoirs for the sake of storing water. From then until now, these structure-based strategies were modified to cope better with the emerging risks. All strategies and approaches adopted failed after the Yangtze River flooding event in 1998 (Du et al., 2019). This event acted as an alarm that revealed the only structural measures cannot solely mitigate flood hazards. Therefore, the most recent policies and guidelines regarding flood management encompass both structural and non-structural solutions and measures (Lei et al., 2022). Examples of non-structural solutions are modifying land use by converting urban and agricultural lands to forests, resettling people in safer areas, providing an emergency plan, and developing new strategies to protect the environment (Lashford et al., 2019).

In Japan, old approaches implemented to manage floods were similar to those of China, later this approach was also insufficient; therefore, a new concept was developed focusing on the idea of directing flood water to the sea (Luo et al., 2015). However, this method damaged river morphology and ecosystems. Since then, this approach was changed and shifted towards the execution of the concept of integrating rivers and constructing dams. Additionally, the increase in flood occurrences that are associated with typhoons initiated the Green Dam concept which counts on forests to control floods (Kimura et al., 2018). Moreover, the Japanese Ministry of Construction's River Council has introduced many policies that are part of the flood preparedness phase, to protect vulnerable areas against extreme floods. The main aim is to develop as land use management, planting trees, and warning people while conserving the environment (Luo et al., 2015).

The Netherlands is considered one of the world's most vulnerable countries to floods: due to a large land proportion, approximately 60% of the territory susceptible to floods (Wiering & Winnubst, 2017). Different strategies had been adopted to reduce the risk of these flood-prone areas by implementing the Delta works. The country experienced a serious flood event in 1953 which created an urge to establish the "Delta program” for flood management. The program suggested and implemented structures such as storm surge barriers, dikes, and coastal dunes as a mitigation measure to flooding and storm surges (Malecha et al., 2018). Later on, a reassessment of the strategies was conducted and several science-based evidence indicated that the hydraulic baseline conditions seemed to be more intense than the pre-assumed ones. The debate was intensified by the flooding events of the Meuse and Rhine rivers in 1993 and 1995, respectively. The rise of water levels in these rivers, which affected the built dikes leading to its failure, triggered the development of new strategies (Hoeksema, 2007). Accordingly, the second Delta Committee was established in 2009. Its Act was then approved in the Dutch Senate in 2011 and was also funded by €1bn per year. The core of the program was resilience which aims to accomplish adequate measures that balance between protecting, preventing, and preparing against current and future events (Stive et al., 2011). The two main approaches that are being implemented by the program are the “Building with Nature" concept which involves coastal aspects and the “Room for the River” concept which is concerned with river aspects (Klijn et al., 2018). The concept behind these strategies was to encourage flexible building and make the foundation of flood protection infrastructures through natural procedures and also to consider sustainability while planning for land use.

The UK has a more cohesive flood management framework, supported by law and overseen by a government department. Flood management in the UK incorporates local communities and has policy and resource mechanisms to incorporate inputs from local communities (Forrest et al., 2018). It has a mix of 'top down' and 'bottom up' management, with each Local Resilience Forum connecting those two flows of information and proceed.

1.2. Background

Climate-induced natural disasters and extreme events are escalating with the increased variability of climatic parameters due to climate change (Devkota et al., 2014). Within the past decades, glacial lake outburst floods (GLOFs) endanger thousands of people, hundreds of villages, and basic infrastructure such as trails and bridges (Kattelmann, 2003). Climate change has increased the threats of global flooding disasters, as indicated by the rising frequency and greater spatial coverage during the last decade when compared to those observed in previous decades (Elalem, 2015). Global warming is generally expected to increase the magnitude and frequency of extreme rainfall events, thus potentially impacting riverine disasters (Dankers et al., 2008). Furthermore, increases in air temperature and heavy rainfall on a regional scale also influence flooding frequency and intensity (Field et al., 2014). Floods often cause enormous damage to lives, property, crops, and infrastructure, and the number of casualties by floods could increase in the future (Mirza, 2011; Hirabayashi et al., 2013; Towfiqul et al., 2021).

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.

1.3. Hazards related to heavy rainfall

Intensive rainfall is a common cause of flash floods, which may last from one day to several days (Shrestha et al., 2008). Monsoons, responsible for a large fraction of the annual rainfall of the Himalayan region, are the most crucial mode of seasonal climate variation. As increasing air temperature is leading to an increment in atmospheric moisture, the monsoon precipitation is projected to become more intense in the future affecting larger areas (Christensen et al., 2013). Numerous studies (Nayava, 1974; Higuchi et al., 1977; Acharya et al., 2018) show that the monsoon accounts for about 80% of the annual precipitation in Nepal. Monsoonal rainfall is very important in terms of sustaining the livelihoods of the people in the Himalayas; however, intensive monsoon rainfall or cloudbursts can cause devastating flash floods and cascading disasters (Shrestha et al., 2008). Events such as landslides, debris flows, floods, and the destruction of agricultural land in the HKH region are costing hundreds of lives, billions of dollars in wealth, and investment in expensive infrastructure every year.

Flood alone is responsible for almost half of the water-induced disasters, claiming about 100,000 people and impacting 1.4 billion people worldwide in the last decade of the 20th Century (Jonkman, 2005). Floods have hit Nepal numerous times, for instance, the 1993 flood across Nepal killed 1170 and damaged 32,765 buildings, pouring almost 4.8 million m^3 of sediment into the reservoir. Similarly, the Koshi flood in 2008 displaced around 65,000 people in eastern Nepal, the 2012 Seti River flood claimed 72 lives (Kargel et al., 2013), and the flood in 2017 resulted in an overall loss of $187.9 million (Gautam et al., 2018).

Many studies suggest that extreme events are observed mostly in the major rainy period (Kattel et al., 2018; Shrestha et al., 2019). The recent devastating flood destroyed 259 enterprises, and 508.74 m^2 cropland, displaced hundreds of families, and claimed several lives in Melamchi (Maharjan et al., 2021). This flood was triggered by the high-intensity rainfall in late pre-monsoon. The occurrences of Cyclones Phailin, Hudhud, and Feni in October 2013, October 2014, and April 2019, respectively, suggest that the frequency of extreme events in another season is also increasing in the recent decade. For instance, recent cases of heavy rainfall in October 2021 adversely affected thousands of hectares of paddy plantations, inundated airports, blocked highways, and killed several people throughout the country.

Climate change can influence precipitation patterns as it affects the land-sea temperature contrast, atmospheric aerosol loadings, atmospheric moisture content, land cover and land use, and other factors. Numerous climate model projections display that the monsoon will have a longer duration because of early-onset and later retreat although many models predict that the monsoon circulation weakens (Christensen et al., 2013).

1.4. Glacial lake outburst floods (GLOFs)

Glacial lake outburst flood (GLOF) is a prominent water-induced hazard in many parts of the world including Nepal. It is defined as a catastrophic outburst from a proglacial lake, typically from a moraine-dammed lake. It occurs when the hydrostatic pressure exceeds the restraining lithostatic pressure due to lake water overflowing and the erosion of the moraine dam (Richardson et al., 2000; Bajracharya et al., 2020). GLOFs, usually with very high traveling speeds ranging from tens of km to more than 100 km per hour, are responsible for serious devastations in terms of loss of life, livelihoods, and properties, and the socioeconomic disturbance is yet another challenge to go through (Vuichard et al., 1987; Richardson et al., 2000; Worni et al., 2014; Bajracharya et al., 2020). The accelerated rate of glacier melt in the Himalayas as well as the alarming high emission scenario projections will lead to an increment in the size and number of supraglacial lakes that advance and merge to form a bigger glacier lake with loose dammed moraine (Field et al., 2012; Worni et al., 2014).

Nepal has several scars because of GLOFs in the past years: at least 26 GLOF events have been experienced in Nepal since 1977, of which 14 of them were supposed to be originated from Nepal itself (Bajracharya et al., 2020). GLOFs on 3 September 1977 and 4 August 1985 in the Mount Everest region of Nepal have dramatically modified channels and valleys in the region by eroding, transporting, and depositing huge quantities of sediment for tens of kilometers along their flood paths (Cenderelli et al., 2001). Moreover, Dig Tsho GLOF on 4 August 1985 destroyed many properties including bridges, tens of houses, and a nearly completed hydroelectric power plant (Vuichard, et al., 1987; Khanal, et al., 2015). Tampokhari's outburst in 1998 also claimed considerable loss of lives, and infrastructural damage, and adversely affected livelihoods (Khanal, et al., 2015). The Ci-RenMa-Co (Zhangzangbo) outburst in 1981, which originated in the Tibet Autonomous Region, adversely affected the downstream areas in Nepal leading to significant destructions to the Nepal-China Friendship Bridge, Araniko Highway, Sunkoshi hydropower dam, and the transport services with an economic loss of around USD 3 million (Mool et al., 2011).

History shows that in Nepal at least six major GLOFs have occurred including two smaller events not mentioned that had occurred before 1962 (Byers et al., 2020). Nepal consists of 2,070 such glacial lakes, of which 21 are found to be potentially dangerous glacial lakes (PDGLs) (Maskey et al., 2020). Very few PDGls in Nepal have been studied and gone through some treatment to reduce future disasters. Tsho Rolpa Glacial Lake was studied in detail by the combined effort of the Water and Energy Commission Secretariat (WECS), and the Japan International Corporation Agency (JICA) (Kazuhisa et al., 1997). Although the lake level was suggested to be lowered by 4 m, the lake was lowered only by 2.8 m in late 2000 (Reynolds, 1999; Rana et al., 2000; Mool et al., 2011). Glacial Lake Imja Tsho was also lowered by 3.4 m in 2016. Some researchers (Hambrey et al., 2008; Watanabe et al., 2009; Fujita et al., 2013) have concluded that the Imja Tsho is relatively stable, and no immediate danger of catastrophe was detected. A study by (Maskey et al., 2020) shows that the lake area of Thulagi has increased to 0.94 km^2 in 2018 from 0.72 km^2 in 1988 and the Lower Barun which was 0.64 km^2 in 1989 has increased to 2.0 km^2 in 2018 depicting how fast PDGLs are advancing. Chen, 2022 (Chen et al., 2022) developed a new framework for GLOF exposure and impact assessment. They applied the framework to Tsho Glacial Lake for different GLOF scenarios and worst-case scenarios.

History depicts that there is an increment in the frequency and magnitude of GLOFs in recent decades with catastrophic consequences. If the climate continues to change at its present speed, rates of glacier mass loss, fragmentation and shrinkage, and the formation and advancement of glacial lakes will increase more, which could escalate the occurrence of GLOFs and may affect the hydrological regime of the region that ultimately affects the ecosystem services (Bajracharya et al., 2020). The GLOF caused severe damage to 77 houses and 3 bridges downstream of Bhote Koshi and destroyed the intake dam of the Upper Bhote Koshi Hydropower Project in Nepal. The 2016 GLOF damage sits within the area affected by the Gorkha earthquake (magnitude M 7.8 in 2015), where extensive landslides and rockfalls were triggered on the slopes, and some landslide deposits even blocked the river (Khanal et al., 2015; Guo et al., 2017). GLOF from the small glacial lake GBTSC also caused a serious disaster, which recalled us of the need for reconsideration of the small-lake-induced GLOF hazards after earthquakes (Liu et al., 2020).

Socioeconomic vulnerability assessment is another critical component of comprehensive flood risk assessments, which are aimed at estimating a loss of life and economic damage (Khanal, et al., 2015). Social vulnerability highlights differences in the capacity to prepare for, respond to, and recover from disasters related to time, social groups, and demographic characteristics (Hummell et al., 2016). The International Centre for Integrated Mountain Development (ICIMOD) researched the socioeconomic vulnerability of communities potentially affected by GLOFs (Mool et al., 2011). In particular, Nepal has experienced multi-hazard risks and socioeconomic losses in the recent decade (Aksha et al., 2019). Furthermore, riverine floods are one of the major weather-related disasters in Nepal, affecting agriculture production and physical infrastructure (Pathak et al., 2020).

1.5. Landslide dam outburst Flood (LDOFs)

The surge of large landslide debris into a river is one of the most important conditions for this kind of disaster. Such debris temporarily blocks the water flow and creates a reservoir in the upstream reach. When the water level rises above the dam or when the weight of water exceeds the holding capacity of the created reservoir, the dam bursts to cause a flash flood downstream. Such dams are commonly formed in very steep and narrow valleys where there is less space for the spread of landslide debris. Apart from heavy rainfall, soil erosion and earthquake are responsible for the sliding of large landmass from the steep topography into the rivers in the narrow valleys (Shrestha et al., 2008; Baniya et al., 2019; Thompson et al., 2020). Several hazards have happened in Nepal due to LDOFs. On May 5th, 2012, a flash flood in Seti killed 72 people. This disaster is also supposed to be initiated by rockfall/avalanche in the Seti River gorge impounded meltwater and spring snowmelt water (Regmi et al., 2012; Kargel et al., 2014; Oi et al., 2014).

A rainfall-induced massive landslide occurred at Jure Village on 2nd August 2014, claiming the lives of 156 people. This landslide blocked the Sunkoshi River completely forming a 3-km long and 300- to 350-m wide lake with a volume of 8 million m^3 that took nearly 12 hours to fill the lake and overflow the debris dam. The lake affected five Village Development Committees (VDC) including a highway, school, health post, postal service, police station, VDC office, and temple upstream (Acharya et al., 2016). After the Gorkha earthquake in 2015, Nepal received several aftershocks, which weakened the steep hillslopes (Kargel et al., 2015). On May 24th, 2015, the damaged slope failed and a landslide mass blocked the Kali Gandaki River. Fortunately, casualties were prevented because officials were quick in evacuating the low-lying areas of Beni and Maldhunga (Bricker et al., 2017).

1.6. Snow and ice Avalanches

An avalanche is one of the hazardous natural disasters in mountainous terrain like the Nepal Himalaya. Avalanches are highly dependent upon fixed and varying properties of the topography and snow cover. Slope, curvature, elevation, and aspect of the topography are some determining fixed variables whereas new snow, wind, rain, and liquid water content and snowpack properties are the major varying parameters (Ancey, 2001). Avalanches affect lives, livelihoods, and infrastructure worth millions of US dollars. On average 250 people die every year because of avalanches in the world (Schweizer et al., 2015).

The average annual death caused by avalanches in Nepal is not documented properly. An earthquake-triggered ice avalanche in 2015 in Langtang claimed over 350 people (Kargel et al., 2015). In the same year, 23 people died in the Everest region, where 16 people had already lost their lives by another avalanche in 2014. The Annapurna region often experiences snow avalanches. One of the avalanches killed 7 people on October 10, 2018, and 7 people on January 17, 2020 (Thakuri et al., 2020). The 2012 Seti flood was also associated with the avalanche upstream (Kargel et al., 2014).

1.7. Flood disaster in Nepal

Flood is regarded as one of the oldest and most devastating natural disasters in human history (Ferreira et al., 2011; Sanyal, 2004). Changes in land use land cover patterns and rapid population growth around the world have significantly increased the vulnerability towards floods typically since the mid-20th century (Rimal et al., 2018). During the 1950s, about 2% of flood events were recorded, and thereafter it started rising vigorously in recent decades, such that 3.9%, 6.6%, 13.2%, 21.9%, and 52.2% for the 1960s, 1970s, 1980s, 1990s, and 2000s, respectively (Dewan, 2015a). Flood incidents alone accounted for more than two-thirds of hydrological disasters in 2012-2014 and

90.9% in 2015-2016 during 2012-2014 (Guha-Sapir et al., 2014) (Guha-Sapir et al., 2015).

Floods adversely affect the lives and livelihoods of the people with the destruction of infrastructure, cropland, economic empires, and billions of properties (Dewan, 2015b; IPCC, 2007; Mirza, 2011; MoHA, 2019). South Asian countries ,i.e., Nepal, Bangladesh, Afghanistan, and India yearly experience floods as they are traversed by the rivers and the tributaries of the rivers, mostly originating from the Himalayas, and people in the floodplains of South Asia suffer through their negative impacts (Dewan, 2015b). The frequency of flooding events is increasing in the South Asian region; for instance, Bangladesh experienced five big floods from 1987 to 2007. Cases are also significantly increasing in Pakistan and India (Mirza, 2011). Likewise, a flood inundated a large area of Gujarat in July 2005 killing 132 people (Mirza, 2011). Out of all Asian floods, South Asia alone accounts for 33%, with 50% fatalities. Nepal, being fifth in rank based on flood events in South Asia, accounts for 7.2%, 7.4%, 3.1% of fatalities, victims, economic losses, respectively whereas India is the number one country to be affected by the floods in South Asia (Shrestha, 2008).

Another report (UNDP & NSET, 2009) mentions that out of 5 million Nepalese people were affected by natural hazards between 1971 and 2007, of which 68% were flood-based. Between 1982 and 2014, floods and landslides killed nearly 9000 Nepalese (DWIDP, 2013; MoHA & DPNet-Nepal, 2015).

Floods in Bagmati and others rivers in 1993 due to heavy rainfall brought devastating effects on lives, properties, and infrastructures of Central Nepal. The Kulekhani River basin received 540 mm of rainfall in just 24 hours. This flood with cascading disasters like landslides killed 1170 people including four Chinese engineers and sabotaged 32, 765 homes. In addition, major bridges and highways linking

Kathmandu to the rest of the country were destroyed. Districts of Sarlahi and Rautahat also experienced major floods in the same year (MoHA & DPNet, 2009). The breaching of a flood control embankment along the Koshi River on August 18, 2008 adversely affected both Bihar, India, and eastern Nepal. Over 90% of its discharge started to flow through the abandoned river courses. Around 65, 000 in Nepal and more than 3 million people in Bihar were directly affected by the Koshi Flood in 20,2008, 284 people from the Saptari District and 43,917 people from Sunsari were displaced in Nepal while Bihar was affected badly and people from Bihar even had to stay in refugee camps set up in Nepal for weeks, and then they returned to Bihar later (MoHA & DPNet, 2009). Floods and landslides in West Nepal in September 2008 killed 40 people, many people were injured and 47 people were claimed to be missed. Kailali, Kanchanpur, and Bardiya were the most affected and damaged districts while districts such as Dadeldhura, Dang, Salyan, Doti, and Gulmi were also found to be significantly affected by floods and landslides in the same year (MoHA & DPNet, 2009). Flood in 2017 leading to an overall loss of $187.9 million (D. Gautam & Dong, 2018; Thapa et al., 2020). The recent devastating flood that destroyed 259 enterprises, and 508.74 m^2 cropland, displaced hundreds of families, and claimed several lives in Melamchi which was caused by high-intensity rainfall in late premonsoon (Maharjan et al., 2021).

A recently published IPCC report elucidated that changing climate has caused multiple changes throughout the world. Increased warming, extreme precipitation and associated changes have caused mountainous terrain to experience cascading consequences of floods, landslides, and other hazards. More than 70% of 700,000 disaster-related deaths between 2005 and 2014 occurred in mountainous regions and are associated with compounding multi-hazard events (UNISDR & WMO, 2015). The 2015 Gorkha earthquake that claimed almost 9000 people triggered over 24,000 landslides which amplified the disastrous effects of the earthquake. Another event, triggered by the heavy rainfall in 2013 in the Garhwal Himalaya, destroyed over 200 buildings and killed several people because of landslides and flash floods (Bhambri et al., 2015). A recent flood event in February 2021 in Chamoli District of Uttarakhand killed 70 people and sustained more than 100 injuries, was found to be caused by a glacial lake outburst flood in the initial investigation. However, later Shrestha et al 2021 concluded that it was caused due to rapid fluidization of ice from the kinetic energy of the rockfall uniting with a stream down.

Multiple hazards hit Nepal every year with many human casualties, billion worth of properties, and significant socio-economic disturbances. Geological features, geography, changing climate, unplanned urbanization and environmental degradation are regarded as the major factors contributing to the disasters. According to MoHA, (2019), out of 6,381 disaster incidents in 2017-2018, 968 lost their lives, and 3, 639 were injured where 94% of NPR 6.84 billion was accounted for by fire hazards alone. Apart from fire hazards and lightning hydro-meteorological accounts for a large number of casualties and causes significant damage, mostly during the monsoon season. Out of 968 disasters flood alone has accounted for 183 deaths, landslide accounts for 161 deaths, and 30 people lost their lives due to heavy rainfall: 38.64% accounts for hydrometeorological hazards (MoHA, 2019).

Nepal has recived several scars because of GLOFs in the past years. Twenty-six GLOF events have been experienced by Nepal since 1977, 14 of which them were supposed to be originated from Nepal itself (Bajracharya et al., 2020). GLOFs on September 3rd, 1977 and August 4th,1985 in the Mount Everest region of Nepal have dramatically modified channels and valleys in the region by eroding, transporting, and depositing huge quantities of sediments for tens of kilometers along their flood paths

(Cenderelli & Wohl, 2001). Moreover, Dig Tsho GLOF on August 4, 1985 destroyed millions of properties including bridges, tens of houses, and a nearly completed hydroelectric power plant (Vuichard & Zimmermann, 1987; Khanal et al., 2015). Tampokhari's outburst in 1998 also claimed considerable loss of lives, and infrastructural damage (Khanal et al., 2015). Another event, the Ci-RenMa-Co (Zhangzangbo) outburst in 1981, which originated in the Tibet Autonomous Region, adversely affected the downstream areas in Nepal leading to significant destructions to the Nepal-China Friendship Bridge, Arniko Highway, Sunkoshi hydropower dam, and transport services with an economic loss of around USD 3 million (Mool et al., 2011). Several hazards have happened in Nepal due to LDOFs. A rainfall-induced massive landslide occurred at Jure Village on 2nd August 2014, claiming the lives of 156 people. This landslide blocked the Sunkoshi River completely forming a 3 km long, 300-350 m wide lake with a volume of 8 million m^3 that took nearly 12 hours to fill the lake and overflow the debris dam. The lake affected five Village Development Committees (VDC) including a highway, school, health post, postal service, police station, VDC office, and temple upstream (Acharya et al., 2016). After the Gorkha earthquake in 2015, Nepal got several aftershocks, which weakened the steep hillslopes (Kargel et al., 2015). On May 24th, 2015, the damaged slope failed and a landslide mass blocked the Kali Gandaki river, a day later it got breached Fortunately, casualties were prevented as officials were quick in evacuating the low-lying areas of Beni and Maldhunga (Bricker et al., 2017). Moreover, an earthquake-triggered avalanche in 2015 in Langtang claimed over 350 people (Kargel et al., 2015), in the same year 23 people died on Everest, where 16 people had already lost their lives in 2014 (Thakuri et al., 2020). Moreover, the Seti flood of 2012 was also associated with the avalanche upstream (Kargel, 2014).

1.8. Disaster risk reduction, mitigation, and planning policies in Nepal

Nepal is exposed to multiple hazards, which create a multitude of disasters throughout the country (MoHA, 2019). As a country with diverse typography, complex geology, and highly varying climate, Nepal is experienced many natural and human-induced hazards. In a global comparison, Nepal ranks 4th in terms of climate risk according to the Global Climate Risk Index which assesses the impacts of meteorological events concerning economic losses and human fatalities (Eckstein et al., 2019).

Also, the country of Nepal ranks 11th in terms of global risk for earthquake occurrence and impact and the country is in the top 20 of all the multi-hazard countries in the world (UNDRR, 2019). More than 80% of the population is exposed to the risk of natural hazards (MoHA, 2017) which include earthquakes, droughts, floods, landslides, extreme temperatures, and glacier lake outburst floods (GLOFs). Hydro-metrological hazards, including droughts and floods, have already caused widespread damage, and loss of livelihoods, lives, and property, but the intensity of such hazards is expected to increase in the future (UNDRR, 2019).

Although, Nepal is one of the most disaster-prone and vulnerable countries in the world, studies, policy analysis, and field experience show that community-led initiatives of disaster risk resilience are not well recognized (Pandey, 2018). Nepal has prepared various disaster plans and policies at the national, provincial, and local levels. However, there are major gaps in disaster risk preparedness, with annual floods and landslides continuing to be responsible for the loss of lives and heavy infrastructure damages (Vij et al., 2020).

Effective policies for disaster risk reduction (DRR) can reduce the loss of life and property caused by disasters (Williams, 2011). Some governments have successfully adopted and implemented DRR policies, but others leave their citizens highly vulnerable.

Many factors explain these differences in how countries adopt disaster risk reduction policies, including financial constraints, variations in the level of risk, and the significant technical and organizational challenges inherent in DRR (Williams, 2011). As a post-conflict country in the early stages of democracy with a weak system of governance, Nepal offers an interesting case study on DRR implementation (Jones et al., 2014). The political competition and the quality of a country's institutions play a key role in determining the effectiveness of disaster risk reduction (Williams, 2011).

Nepal's disaster risk reduction program is guided by the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 (UNDRR, 2019). The four priority actions of the SFDRR to prevent new disasters and reduce existing disaster risks are: (i) understanding disaster risk; (ii) strengthening disaster risk governance to manage disaster risk; (iii) investing in disaster reduction for resilience; and (iv) enhancing disaster preparedness for effective response and "Build Back Better" in recovery, rehabilitation, and reconstruction (Dinanath et al., 2020).

There is some clarity on the roles of departments in hazard monitoring and forecasting (MoHA, 2019). For example, the Department of Mines and Geology (DMG) is responsible for monitoring earthquakes in Nepal. Forest fire and air pollution are monitored under the Ministry of Forest and Environment (MoEF). The Department of Hydrology and Meteorology (DHM) has developed a 3-day flood forecasting system and provides weather forecasts and flood early warnings. The Department of Water Resource and Irrigation Department of Hydrology and Meteorology (DHM), and Department of Mines and Geology (DMG) have put together hazard maps for different parts of the country (Dinanath et al., 2020). However, there is no clarity on how any of this information will be used at the local level for disaster management during disaster and post-disaster.

The Disaster Risk Reduction and Management (DRRM) Act, 2017 came into action, replacing the response and relief-centric law, the Natural Calamity Nepal Disaster Report 2019 Page 2 Relief Act, 1982 (MoHA, 2019). The new Act provides a comprehensive outlook to capture different dimensions of disaster risk management (DRM). It is a more progressive approach to reducing and managing disasters by introducing the ‘whole of society approach in disaster risk management. Based on the disaster risk reduction and management act 2015, the highest body for disaster risk reduction is the National Council for Disaster Risk Reduction and Management (NCDRRM) which is under the Prime minister of Nepal (Rijal et al., 2020).

According to the Nepal government, during a period of 45 years (1971 to 2015), a total of 22,372 disaster events have been recorded. Hence, annually, Nepal is exposed to about 500 events (Nepal et al., 2018). After the major floods and landslide disaster of July 1993 in which 1336 people lost their lives and 85,451 families were affected. The Government of Nepal has been serious in the management of natural disasters in the country. Therefore, the government prepared National Action Plan on disaster management in 1996 which specified priority activities to be undertaken in the field of disaster management to be implemented by the concerned agencies (Tuladhar, 2012).

Since May 19th 2015, the Government of Nepal has taken firm steps toward transitioning from the relief phase to the recovery phase. Following the enactment of (NRA) Act on December 20th, the National Reconstruction Authority NRA was constituted on December 25th, 2015 with a mandate to manage, oversee and coordinate recovery and reconstruction work in the earthquake-affected districts (MoHA, 2017; UNDRR, 2019).

Nepal’s Constitution, for the first time, mentions Disaster Risk Management (DRM) under Article 51 and Schedules 5 to 9 and has assigned DRM as a concurrent responsibility of the three tiers of the governments, particularly of the local governments. Article 51 stipulates policies that the state shall pursue concerning DRM. For instance, the sub-article G which relates to “policies concerning protection, promotion and use of natural resources,” does mention that the state shall formulate policies related to the development of sustainable and reliable irrigation through the prevention of water-induced disasters and river management. On September 24th, 2017, the legislative parliament unanimously passed a new Disaster Risk Reduction and Management Act, 2017 (MoHA, 2017). In many respects, the Act is considered more progressive and comprehensive than the existing Natural Calamity Relief Act, 1982 since it also recognizes risk reduction as an important and integral part of risk management. The government of Nepal is recently developing the National Disaster Risk Reduction Policy (NDRR) and the Strategic Action Plan aligned with SFDRR: one that will replace the NSDRM, 2009. The new NDRR Policy and Strategic Action Plan will serve as a road map to guide the future course of action for DRM in Nepal till 2030. There is hope that these two policy documents will serve as a turning point for Nepal to be a disaster-resilient nation.

1.9. Motivation and research objectives

A few studies have been already done in these study areas but there is no detailed studies. have been done. The Seti River basin has attracted many scientists because of for the GLOF, land-use, tourism, and other aspects but no studies focused on household-level inundation survey as well as evacuation route identification. In Dolakha, UNDP and ICIMOD had calculated inundation values but they did not focus on the community-level detailed hazard map and evacuation-route identification. Besides that, anthropogenic activities such as unplanned settlement, encroachment of riverbanks, and unplanned construction are more serious issues in downstream communities in both riverside.

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.

The entire Himalayan region is very fragile and susceptible to multiple hazards. It is geologically unstable and highly prone to seismic events. Recently the climate variability and change processes are adding a new and hitherto unknown dimension to hazard, vulnerability, and risk scenarios in the mountain region. The total number of disasters and their frequency, intensity, and impact is increasing day by day in downstream communities. I choose these two river basins because both originated from the high Himalayas regions and have a high risk of GLOFs and landslide dam outburst flood (LDOFs).

1.10. Thesis structure

This study was designed to understand flood disasters and risk assessment of the Seti River basin and Tamakoshi River basin. Chapter 2 provides a detailed description of the data and methods used to achieve the aims of the research. Chapter 3 describes the results from: the Seti River basin for understanding the flood risk assessment and potential evacuation routes. A UAV (drone) survey, HEC-RAS modeling, inundation mapping, and socioeconomic surveys and their relationship are presented in the chapter. Chapter 4 describes the result of the Tamakoshi River basin in the same issues as Chapter

3. Chapter 5 compares the results with discussion of the two study areas, evacuation routes and evacuation time, and flood scenario of both river basins. Finally, conclusions are presented in Chapter 6.

Chapter 2 Methodology and Study area

2.1. Selection of Study area

2.1.1. Seti river basin, Pokhara

Pokhara (Figure 2.1) 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).

The flat morphology of the Pokhara plain is striking. The plain slopes gently to the south, with a general longitudinal gradient varying from 32‰ upstream to 9‰ downstream (Fort, 1987). The average annual precipitation in Pokhara is 3951 mm, with amounts exceeding 5000 mm north of the valley due to orographic amplification, which makes the south Annapurna front zone the area with the highest annual precipitation in the country(Fort et al., 2018). The Seti River is the major river flowing through the Pokhara. Many gorges and Canyons are created by the Seti River and its tributaries in and periphery of Pokhara as easily soluble calcareous materials are abundant there. Pokhara Valley has the intermontane fluvial basin spread around the midstream of the Seti River in the Lesser Himalaya (Gautam et al., 2000). It is filled with the quaternary age layered clastic deposits (gravel, silt, and clay), loaded from the Annapurna Mountain ranges, most likely by a series of Catastrophic debris flows (Yamanaka et al., 1982). The geology of Pokhara Valley can be categorized into seven formations; Begnas, Siswa, Tallakot, Ghachok, Phewa, Pokhara, and Rupakot formations (Yamanaka et al., 1982).

In the last few decades, Pokhara has been frequently exposed to multiple hazards such as floods (e.g., Seti flood in May 2012), sinkholes (e.g., several sinkholes in Armala, Pokhara in November 2013), land subsidence, landslides, fire, and earthquakes. It is believed that Pokhara itself was formed by the deposits from past catastrophic floods. As Pokhara is surrounded by beautiful Annapurna Mountain range sand hence, cascading effects because of hazards in the mountains can also adversely affect the Pokhara, for instance, the 5th May 2012 Seti Flood originated from the mountains. The fragile geology, unstable steep slopes, deep gorges, heavy rainfall, and dense settlement over weak geological structures are responsible for multiple hazards in Pokhara Valley (Rimal et al., 2015). Despite the 2012 flood event and several warnings by scientists for more yet bigger scale future floods in the Seti valley, the fluvial risk is may bigger and more disastrous by socioeconomic activities such as unplanned settlement, encroachment of riverbanks, haphazard construction, unplanned schools, drinking water, and hydropower projects in potential flood hazard areas in addition to the increased impacts of climate change on geological and hydro-metrological hazards (Gurung et al., 2021).

2.1.2. **Tamakoshi river basin, Dolakha**

Dolakha District (27° 28’ to 28° 0’ N & 85° 50’ to 86° 32’ E) 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) (Figure 2.1). 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).

Several elevated mountains and deep river valleys are spread throughout the district. Geologically, it moves up to the Higher Himalayan Range in the north and reaches the midlands in the south, with the major portion covered by the Higher Himalayan Range. Migmatites, Gneisses, Schists, and marbles are very common types of rocks in the upper region of the district while schists, gneisses, phyllites, and marbles are abundant in the region between 2000-5000m (Kandel et al., 2019).

Dolakha district is often hit by numerous natural hazards. It is typically adversely affected by Landslides, and in addition, the situation was exacerbated by the Gorkha (Mw) 7.8 and Dolakha Mw (7.3) earthquakes in 2015 (Schwanghart et al., 2016; Thapa et al., 2018; Qi et al., 2022). 1479 landslides were triggered by the 2015 earthquakes with total landslide area coverage of 7.89 km2 and a landslide volume of 0.06k m3 (Martha et al., 2017). However, other disasters such as floods, LDOFs (Uhlir, 1998), and soil erosions cannot be ignored (Thapa, 2020).

In this study, Gaurishankhar Rural Municipality with nine wards is considered. It is named after the holy mountain GauriShankhar. It has an area of 681.39km^2 and a population of 17,062 based on CBS 2011. This rural municipality is also the home of one of the largest glacial lakes, Tsho Rolpa Lake. Disasters in this rural municipality are common as this municipality comprises fragile geology, rivers, cryosphere, and centralized settlement overburdening the specific places (CBS, 2011). The settlement of

Gongar has the hydropower facilities for the Upper Tamakoshi Hydroelectric Project company. This is the near-complete 456 MW project, the largest hydropower project in Nepal, or the project that will generate a power output equivalent to two-thirds of Nepal’s current power generation. Therefore, maintaining and protecting the facilities will be important for the country of Nepal.

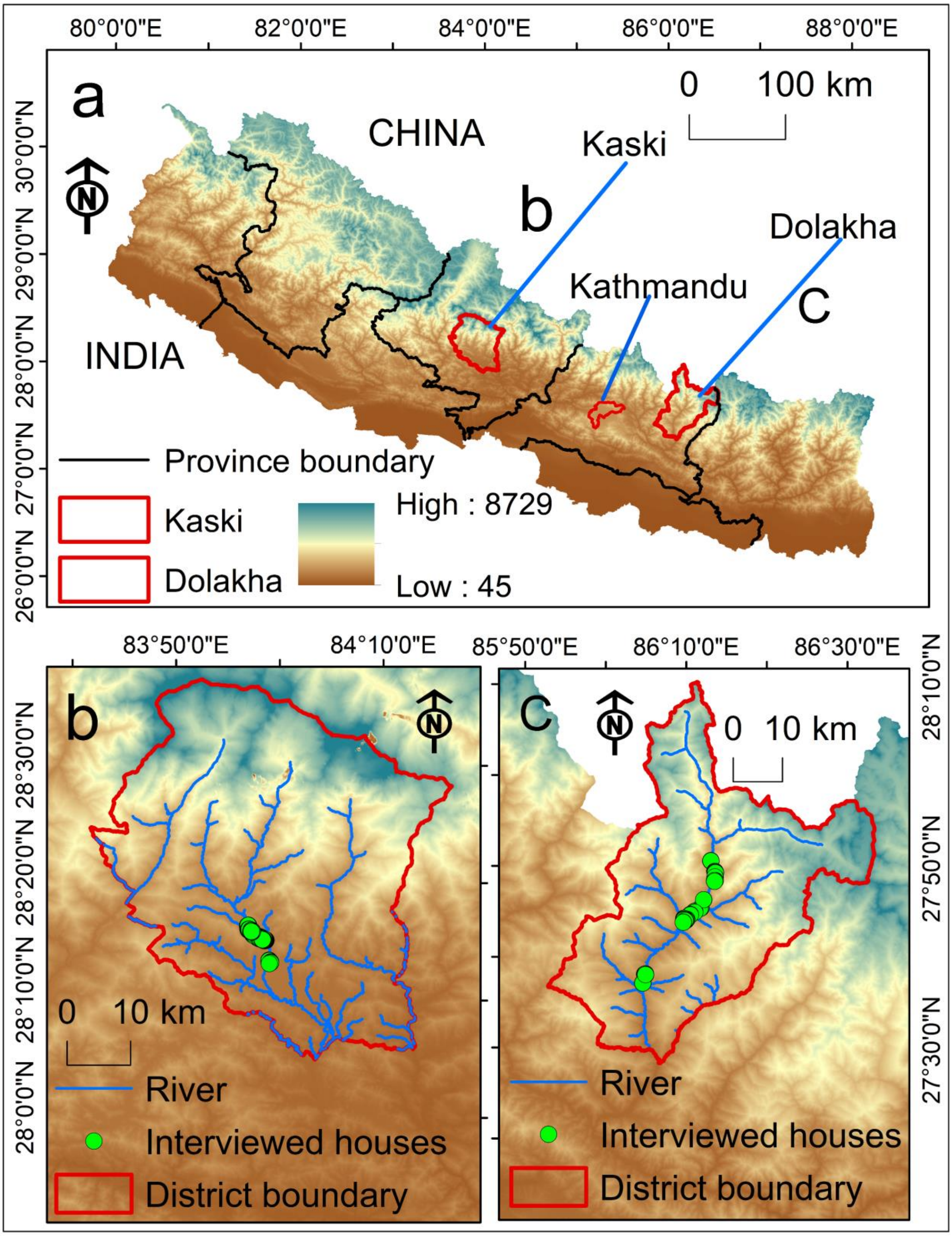

Figure 2.1 Study area: (a) Country map of Nepal; (b)Seti River basin, Kaski; (c) Tamakoshi River basin, Dolakha

2.2. 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 (Figure 2.2).

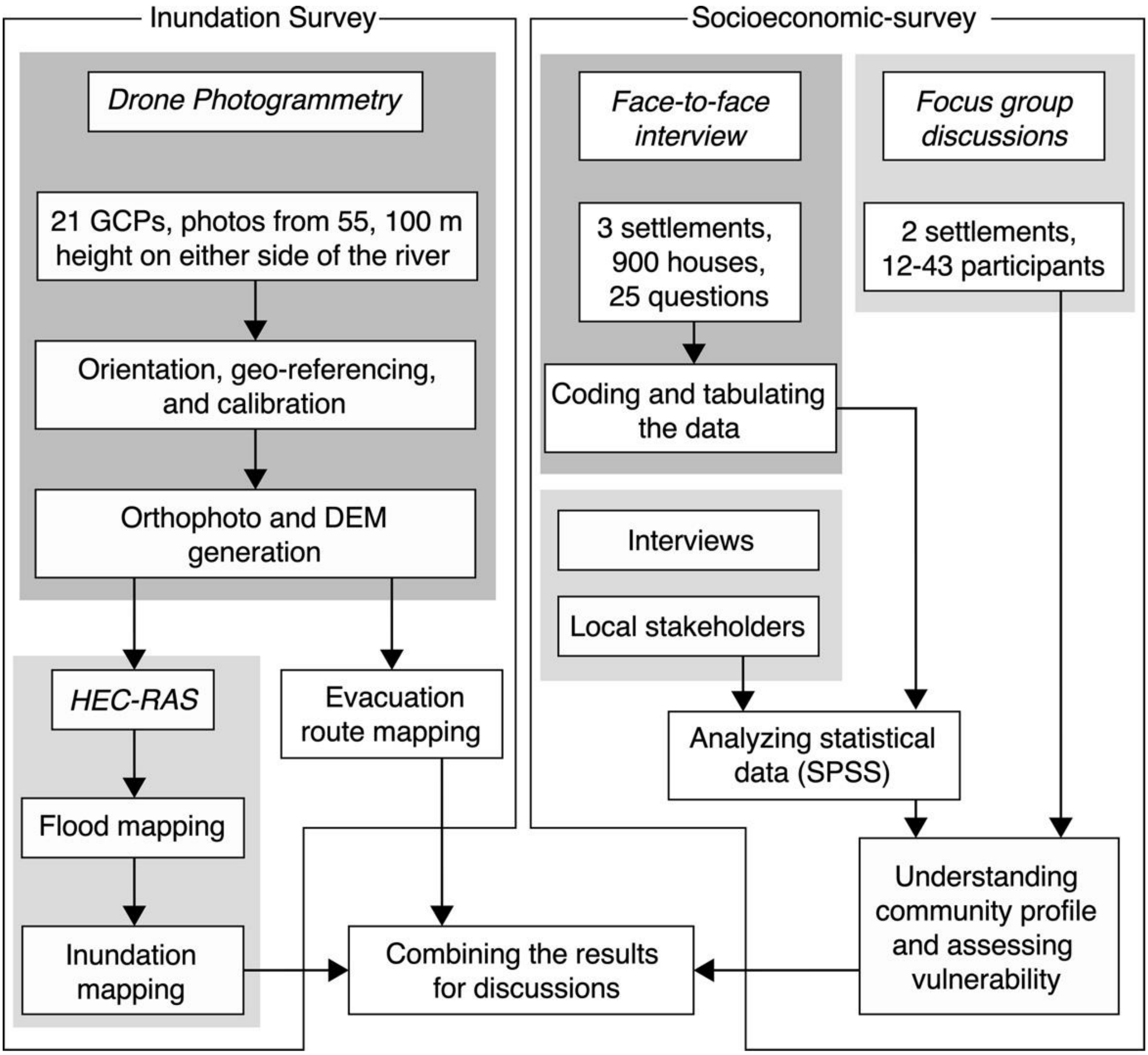

Figure 2.2 Conceptual flowchart of the methodology employed for Seti river basins.

I used the same two methods for the Tamakoshi river basin: (1) inundation mapping, and (2) Socioeconomic survey (Figure 2.3).

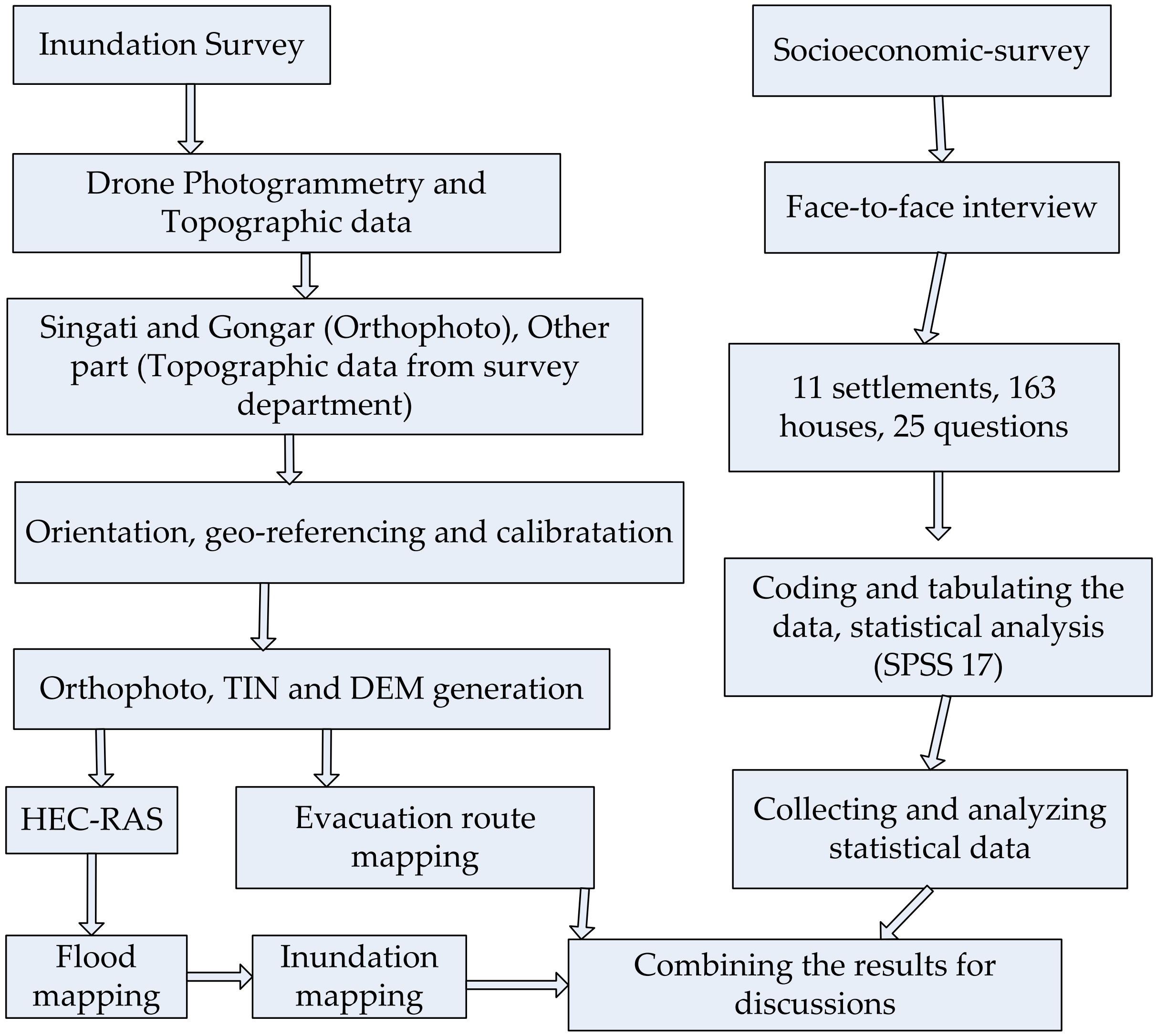

Figure 2.3 Methodological flow chart of Tamakoshi River basins

2.2.1. **Inundation Mapping**

2.2.1.1. **HEC-RAS Model**

Hydrologic Engineering Centers River Analysis System (HEC-RAS) software was developed by the United States Army Corps of Engineers (USACE). Geographic Information Systems (GIS) are successfully used to visualize the extent of flooding and also to analyze the flood maps to produce flood damage estimation maps and flood risk.

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. This study used Manning's Roughness Coefficient for different land use, which is as follows:

$Q=1/n\ AR^{2/3}\ S^{1/2}$………………………… (1)

where Q = discharge (m^3/s),

A = cross-section area (m^2),

R = hydraulic radius (m),

S = friction slope and

n = Manning's Roughness Coefficient (Chow et al., 2010).

The cross-section point filter was used in order 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 m3/s (Kathmandu University, 2012) for the Seti River. Similarly, I used peak discharge of 1940 m3/s for Tamakoshi River (taken from the rainfall data at Busti Station from 1970 to 2006 rainfall data).

The HEC-RAS model used to calculate the inundation area has a corresponding extension in ArcGIS (HEC-RAS *v*.4.1.0). Google Earth (GE) was used for the geographic coordinate system with the WGS84 datum. One of the main inputs for the HEC-RAS was a Triangulated Irregular Network (TIN), a type of DTM. 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 a 1-m contour interval to delineate watershed boundaries.

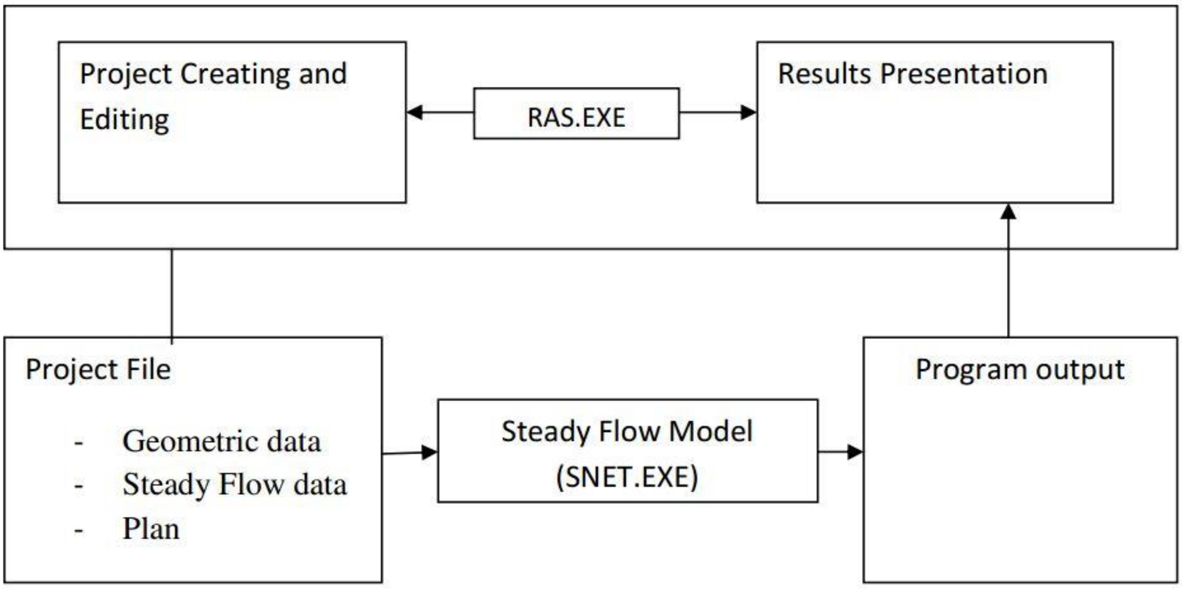

Figure 2.4 Schematic diagram showing HEC-RAS component (USAF, 2002)

2.2.1.2. **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·*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 (Figure 3.1). 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 100m. A total of 7 flights were flown in Singati and 5 flights were flown in Gongar. I used a detailed 5-meter contour for Singati and Gongar. 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 (Figures 4.2 and 4.4). 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 of the project area using ArcGIS (*v*.10.2). All topographic map components were in the standard format (land use map 1996 corrected in 2021) as provided by the Government of Nepal.

2.2.1.3. **Evacuation-Route Mapping**

2.2.1.3.1. Extracting an existing road network

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.

2.2.1.3.2. Suggesting a new route in Seti River basin

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.

2.2.1.3.3. Evacuation route mapping in Tamakoshi River basin

The evacuation route map 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.

2.3. 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 (Seti River basin).

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. Such a survey was necessary for Masinabagar and Laltinbazar, where many families had immigrated from different areas in recent years (Figure 3.1a). Per capita incomes were categorized based partially on a United Nations criterion (Kochhar, 2015)(Imai et al., 2016), 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. These members actively participated in the 2012 relief distribution program. A checklist was prepared to record the information gained through these interviews.

2.4. Future Flood Scenario (Return Period Calculation)

Water and Energy Commission (WECS) has published a regional hydrological analysis report in which the flood flow in any river of catchment area below 3000 m of elevation is given by:

$$Q2 = 1.8767 (A+1) ^{0.8783}$$

$$Q100 = 14.63 (A+1) ^{0.7342}$$

where suffixes 2 and 100 stand for the return period in number of years. The flood flows for any other return period T is then given by:

$$QT = \exp (\ln Q2 + S\alpha)$$

where S is the standard deviation of natural logarithms of annual floods and α stands for a standardized normal variant for return period T. S can be calculated as:

$$S = \ln (Q100/ Q2) /2.326$$

Flood return period was calculated based on this equation.

2.5. Topographic Map and Control Points

From Survey Department, Topographic maps of the project site, Sheet No. 2786-01D, 2786-05A, 2786-05B, and 2786-05C of scale 1:50,000 and 2884-13A, 2884-16B of scale 1:25,000 were collected. I could not obtain the control points of the site, so I use GPS to locate the interviewed households in each settlement.

2.6. Tools (Software) for Analysis

For the study, GIS 10.2 and HEC-RAS 6.1 was used to calculate water surface profiles and ArcGIS 9.3(demo version) were used for the GIS data processing. HEC-GeoRAS is an ArcView GIS extension especially designed to process geospatial data for use with Hydrological Engineering Center's River Analysis System (HEC-RAS). HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcView GIS using a graphical user interface (GUI). The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results. HEC-GeoRAS 6.1 for ArcGIS 10.2 was used to provide the interface between the systems. These software tools HEC-RAS 6.1 and HEC-GeoRAS were used in this research.

2.7. Calibration and Model Validation

The channel model was calibrated by adjusting the maximal ratio combining (MRC) until the differences between the simulated and observed water levels at channel stations were plotted (Hameed et al., 2013; Parhi, 2013; Imbenzi et al. 2015). The observed standard discharge data collected by the Department of Hydrology and Meteorology of Nepal (unpublished) from May 2011 were used as the input for the Seti River. The MRC was iteratively changed within the minimum and maximum values described in (Chow et al., 2010).

The water surface results in every cross-section from each model were compared with the observed water surface measurements. The MRC value that led to the least discrepancy between simulated and observed values was taken as the calibrated value for the channel (Figure 2.5).

The simulated high flood level was checked against the discharge volumes observed at peak flood levels during the 2012 event for model validation. The selected MRC values were 0.02 (adjusted) for over banks and 0.035 for the main channel (Chow et al., 2010). For inundation mapping, the flood level (peak discharge) was assumed to be the same as that observed on May 5, 2012, i.e., 1450 $m^3 \cdot s^{-1}$ (Kathmandu University, 2012). Notably, the measured MRC (n = 0.02) was identical to the modeled value derived by(Chow et al., 2010).

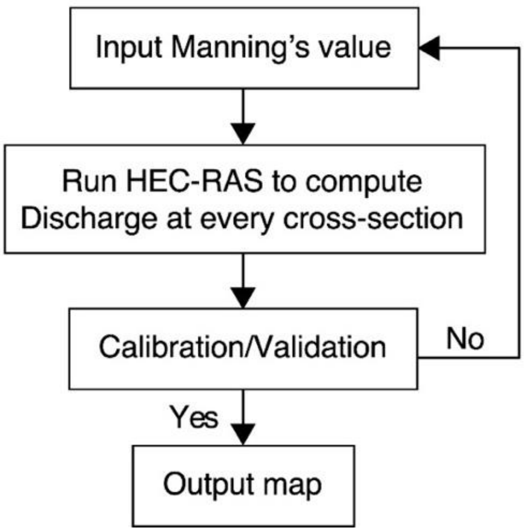

Figure 2.5 Conceptual Framework of HEC-RAS model calibration (Garrote et al., 2021).

As already mentioned, for the Tamakoshi river, I used the same discharge value of 1940 $m^3 \cdot s^{-1}$ (the highest maximum peak discharge recorded to the date on Busti station) as an input value and changed the Manning's Coefficient iteratively within the minimum and maximum values as mentioned in Chow and Maidment (Chow et al., 2010). For the validation of the model, I checked the simulated high flood level during high discharge value with the observed high flood level in 2021.

2.8. Evacuation route time calculation

The formula proposed by Satoh et al. (2006) as shown in Figure 2.6 and Eq. (1), which expresses the distance by the degree of inclination, is adopted in this study. Figure 2.6 shows the horizontal and slope distance and the possible resistance when a person moves on a slope. The actual diagonal slope distance L is expressed using the horizontal distance d and slope angle θ as:

$$L = \frac{d}{\cos\theta} \quad \text{.................. (1)}$$

According to Satoh et al. (2006), while walking on a slope, a resistance of $m\sin\theta$ occurs on the slope opposite to the travel direction for weight m. The total weight in the case of a slope is set to $m + m\sin\theta = m(1 + \sin\theta)$.

Based on this assumption, the pseudo-distance Lsim has been calculated as:

$$L_{sim} = \frac{d}{\cos\theta}(1 + \sin\theta) \quad \text{..................... (2)}$$

which shows the actual slope distance $d/\cos\theta$ multiplied by $(1+\sin\theta)$, representing the effect of the velocity change while moving on a slope. In this study, the pseudo-distance considering the slope was calculated as follows:

1. The road route data were subdivided into unit links, and the road distance (d) was calculated. The “unit links” refer to the links between the vertex and the vertex.
2. After calculating the road distance, convert the vertices of each unit road to points.
3. After finishing converting to the point, enter the corresponding elevation value (Z) for each point.
4. This study follows the pseudo-distance Lsim by slope obtained using the formula:

$L_{sim} \equiv (d\ /\cos\theta)(1 + \sin\theta)$ considering the speed reduction by (1+sinθ).

(slope = differencing vertical height/ horizontal distance*100)

5. This study used field data for the time taken simulation. The population was classified into four groups: under 15-year age group, 15–40-year age group, 40–65-year age group, and above 65-year age group. On August 14 -18, 2022 data were collected in 5 routes in Masinabagar sections a and b. Walking speed data was collected in seconds. Minimum 4 years to a maximum of 78 years old people participated to walk on a different slope. A total of 31 people residing in the areas were asked to walk along the designated routes to find out the walking speed on the actual five routes: 19 people on route 1, 21 people on route 2, total 20 people on route 3, total 20 people on route 4 and total 20 people on route 5 were asked to walk through each of the routes (Figure 2.7).

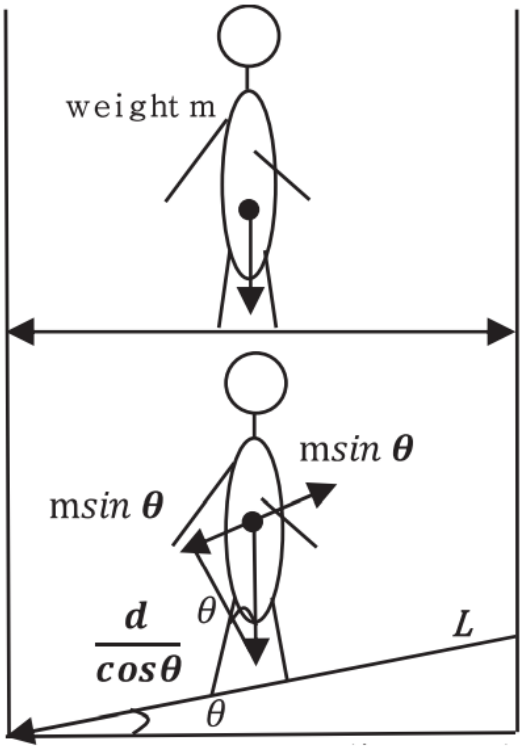

Figure 2.6 Calculation of inclined road distance (L) using the values of horizontal distance (d) (Satoh et al. 2006)

6. The walking speed of 60.49 m/s for <15 years age group, 52.30 m/s for 15-40 years age group, 78.90 m/s for 40-65 years age group, and 123.89 m/s for >65 years was used (see details in chapter 5).

7. After calculating the walking time based on the data collected from the five routes, I used a simple linear regression analysis for calculating the evacuation time for all proposed evacuation routes. **S**imple linear regression is a linear regression model with a single explanatory variable. That is, it concerns two-dimensional sample points with one independent variable and one dependent variable (conventionally, the *x* and *y* coordinates

in a cartesian coordinate system) and finds a linear function (a non-vertical straight line) that, as accurately as possible, predicts the dependent variable values as a function of the independent variable. The adjective *simple* refers to the fact that the outcome variable is related to a single predictor. This equation is expressed as:

$$y = \alpha + \beta x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

which describes a line with slope β and y-intercept α. In general, such a relationship may not hold exactly for the largely unobserved population of values of the independent and dependent variables; I call the unobserved deviations from the above equation the errors.

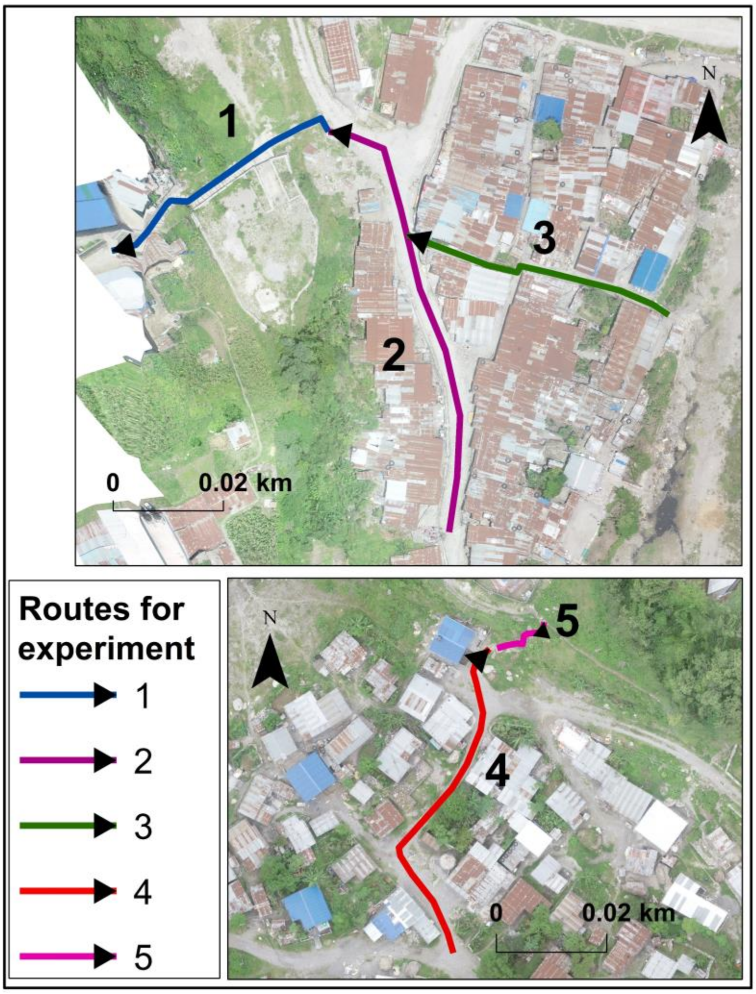

Figure 2.7 Location of the experiment routes to measure walking speed by age group.

2.9. Statistical Analysis

For the statistical analysis, I used the interquartile range (IQR). The IQR is a measurement of the variability of the median. More specifically, the IQR tells us the range of the middle half of the data. Another method I used for this study is the Kruskal–Willi's test. It is a nonparametric approach to one-way ANOVA. The procedure is used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. I used a chi-square test to compare observed results with expected results. A low value of chi-square implies that there is a high correlation between the two sets of data. 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.

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.

2.10. Limitation of the Study

It is possible that the model will not work properly in all sections. The centerline of the river could not be surveyed because of the discharge and fast-flowing river. The HEC-RAS model only assumes a fixed boundary of the river geometry and a one/two-dimensional steady flow pattern for this research. The assumption of one/two-dimensional flow may not be always a valid assumption. Manning's 'n' is taken from the table fixed on the observed river morphology.

But because of the stringency of the assumptions and the lack of evacuation preparations, it can be a significant improvement in the current situation. I can contribute to increasing the sustainability of the region from almost nothing. One of the limitations of this study is the lack of the ownership rate of mobile phones in communities with different social characteristics. In Pokhara, even though there are many poor people, many of them are employed by day laborers because Pokhara is the second-largest city in Nepal with more job opportunities. Therefore, there is a possibility that the ownership rate is high in Pokhara for the poor to obtain day laborer jobs through mobile phones. On the other hand, the ownership rate in rural Dolakha with smaller job opportunities was not examined in this study. The ratio of mobile phones should be increased. Regarding the development of evacuation schemes for low-income people using SNS, the data on mobile phone ownership in Nepal as a whole allows making an argument for the average population. However, the necessity of developing different schemes at the community or village scale is not fully discussed. Further research is needed in this regard.

Chapter 3 Result 1: Flood Risk and Management in Seti River basin (Pokhara) Kaski, District

3.1. Introduction

Climate change has increased the threat of global flooding disasters, as indicated by the rising frequency and greater spatial coverage during the last decade when compared to those observed in previous decades (Elalem et al., 2015). Global warming is generally expected to increase the magnitude and frequency of extreme rainfall events, thus potentially impacting riverine disasters (Dankers et al., 2008). Furthermore, increases in air temperature and heavy rainfall on a regional scale also influence flooding frequency and intensity (Field et al., 2014). Floods often cause enormous damage to lives, property, crops, and infrastructure, and the number of casualties by floods could increase in the future (Mirza, 2011; Hirabayashi et al., 2013; Towfiqul et al., 2021).

Monsoonal floods are a common hazard in Nepal, where glacier lake outburst floods (GLOFs) also threaten human safety and wellbeing (Mirza, 2011). GLOFs can cause catastrophic flooding in downstream areas, severely damaging property in addition to causing loss of life (Mohapatra et al., 2003). Melting glaciers contribute to the development of glacial lakes, which may in turn cause lake outbursts (Guhathakurta et al., 2011). Minimizing loss of life and property damage is crucial and requires a better understanding of glacial lake outbursts and their downstream effects (Halgamuge et al., 2017). However, studies on GLOF events, moraine dam failure, peak discharge measurement, and their downstream flooding are limited.

Unmanned aerial vehicles (UAVs) are a helpful tool for monitoring and investigating disasters since they can source data from otherwise inaccessible areas. Many recent studies are based on UAV applications for support and assessment of disaster management (Restas, 2015; Garrett et al., 2018; Restas, 2018; Langhammer et al., 2018; Kim et al., 2019; Barba et al., 2019; Hildmann et al., 2019; Backes et al., 2019). Furthermore, UAV platforms are nowadays considered valuable sources of data for inspection, surveillance, mapping, 3D modeling, and the creation of evacuation routes (Remondino et al., 2012; Maher et al., 2016; Langhammer et al., 2018). Most UAV applications in hydrological research are used for stream and riverscape flood mapping, all of which require continuous monitoring (Restas, 2015; Langhammer et al., 2018). In particular, UAVs can assist with monitoring the state of dams, disaster tracking (Ridolfi et al., 2017), provide evacuation guidance, and facilitate damage investigations, bank erosion and volcano observation, flood-hazard modeling, and industrial disasters (Xiong et al., 2016; Aljehani et al., 2016; Nagatani et al., 2018; Katayama et al., 2018; Langhammer et al., 2018; Kim et al., 2019; Backes et al., 2019). Accordingly, UAVs can generate an evacuation map over a relatively short period. However, limited research has been conducted on GLOFs and flash floods in the Himalayan region and downstream communities.

As unpreventable urban flood events have been increasing with the advancement of technology, flood-vulnerable areas can be identified through 1D/2D modeling so that losses of human life and property are minimized (Rangari et al., 2019; Rangari, et al., 2019). The Hydrologic Engineering Center River Analysis System (HEC-RAS) model was developed by the U.S. Army Corps of Engineers and has been widely employed in studies of risk assessment, hazard risk management, and emergency response guidelines in flood-affected areas (Tate et al., 2002; Pappenberger et al., 2005; Aggett et al., 2009; Sarhadi et al., 2012; Hameed et al., 2013; Quirogaa et al., 2016; Khattak et al., 2016; Demir et al., 2016; Patel et al., 2017; Kumar et al., 2017; Khalfallah et al., 2018; Kumar et al., 2020; Hutanu et al., 2020; Farooq et al., 2019). HEC-RAS creates one-dimensional (1D) and two-dimensional (2D) steady- and unsteady flow simulations (Sarhadi et al., 2012), and its joint use with GIS is essential to risk reduction programs (Khalfallah et al., 2018).

Flood impacts are further exacerbated by increasing urbanization (Campion et al., 2013; Mondino et al., 2020). This is especially prevalent in developing countries where populations, economic activities, and housing are often concentrated in less desirable flood-prone areas (Kumar et al., 2020). Various inaccuracies hamper public understanding; for instance, if a major flood disaster occurs once every in a particular period, no significant floods will occur for some time leading to a false sense of security surrounding newly built dams and other structures. Moreover, the low-risk awareness of residents living in flood-prone areas is usually considered one of the main causes of low preparedness, which in turn generates inadequate responses (Tingsanchali, 2012); thus, understanding disaster risk reduction, awareness, preparedness, and adaptation is a challenge (Miceli et al., 2008; Tingsanchali, 2012; Boero et al., 2015; Tuladhar et al., 2015).

Notably, a flash flood occurred on the Seti River in Pokhara, central Nepal, on May 5, 2012 as already mentioned. The flood killed 32 people, left 40 missing (presumed dead), and displaced community buildings and vital infrastructures, such as suspension bridges, electric poles, and potable water pipelines (Kargel et al., 2013). The discharge rate of the flood at a nearby dam site was estimated to be 1450 $m^3 \cdot s^{-1}$ (MoHA and DPNet-Nepal, 2015). Since then, many studies have examined the actual causal mechanisms of the flood, which have often been attributed to a fall of ~15 million m^3 of rock onto glacier ice at the slope bottom of the Annapurna IV peak (Petley, 2012). Other researchers have suggested that a rockfall blockage of the Seti River gorge occurred a few weeks before the disaster (Petley, 2012; Kathmandu University, 2012; Bhandary et al., 2012; Dwivedi, 2012; Kargel et al., 2013; Dwivedi, 2013; Hanisch et al.,2013; Kargel, 2014; Evans et al., 2014; MoHA and DPNet-Nepal, 2015) and that a rock/ice avalanche from the northern part of Annapurna IV (~7500 m) dislodged the previous rockfall dam when being swept into the reservoir; however, studies focused on downstream communities are absent.

Recently, some researchers have focused on either modeling or social approaches to disaster vulnerability. For example, social scientists have identified many ways in which people respond to rapid onset threats from earthquakes, flash floods, tornadoes, tsunamis, and volcanic eruptions(Lindell et al., 2015; Fraser et al., 2016; Lindell et al., 2019; Makinoshima et al., 2020). A community-based early alarming system would be more beneficial to be introduced because an effective response to the early warnings greatly reduces causalities and loss of life (Walch, 2018). Some researchers focused on tsunami-caused flash floods and investigate pre-impact hazard communication, immediate post-impact expectation, household evacuation, public risk perception, and behavioral intentions, (Apatu et al., 2016; Wei et al., 2017; Buylova et al., 2020).

However, thus far, the two have not been interconnected (Simonovic, 1999; Henk, 2001; Brouwer et al., 2004; Ghosh et al., 2012; Pardoe, 2012; Morss et al., 2016a). Researchers have examined socioeconomic issues using community-based early warning systems and adaptive capacity-building strategies (Smith et al., 2017). Other studies focused on social vulnerability, disaster risk reduction knowledge, preparedness, and adaptation and awareness programs for downstream communities (Rufat et al., 2015; Tuladhar et al., 2015; Mavhura et al., 2017; Jamrussri et al., 2018). Research has also focused on the policy-making process and challenges of implementation (Gentle et al., 2012; Jones et al., 2014). While several studies focus on dealing with natural disasters, modeling, and social aspects separately, no study has combined these three aspects.

3.2. Study Area

Pokhara (Figure 3.1) is located at an elevational range of 812 m to 1511 m. The Seti River originates from the southern flank of Annapurna Himal. It flows down to the Lesser Himalaya along the steep and narrow Pokhara Valley, which was formed by at least two giant debris-flow events in the past (Yamanaka et al., 1982; Fort, 1987).

The study area is in the northern part of Pokhara City (Pokhara Lekhnath Metropolis), categorized as a high flood risk zone. It is a marginal area close to the populated city center. Recently, the local government introduced a city planning act in Pokhara that strictly prohibited the construction of new houses within 10 m of the riverside; however, no plan exists for those already living in this area. Furthermore, there has been a rapid influx of migrants and the impoverished, thereby pushing legal boundaries to their limits in settlements such as Masinabagar, Laltinbazar, and KI-sing (Figure 3.1). Thus, vital urban planning and management policies are needed to prevent further damage. Accordingly, three methods have been employed in this study: (1) inundation-route mapping, (2) evacuation-route mapping, and (3) a socioeconomic survey (Figure 3.1), which will be detailed in the following section and will be discussed in the following section.

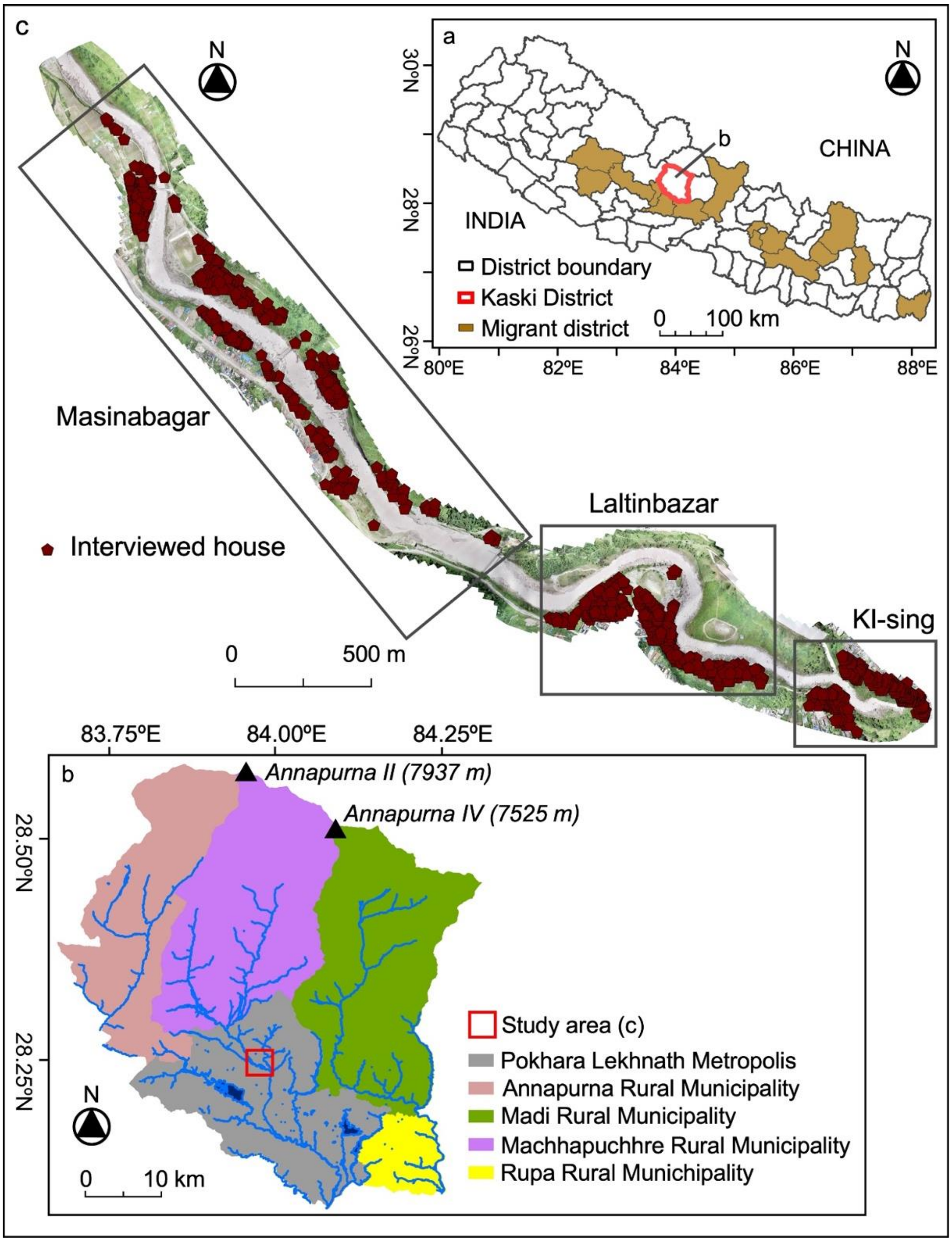

Figure 3.1 Location of the study area: (a) country of Nepal; (b) Kaski District; and (c) three areas of Masinabagar, Laltinbazar, and KI-sing. Boxed locations denote the areas shown in Figures 3.2, 3.3, and 3.4.

3.3. Results

3.3.1. Inundation Mapping

Flood-inundation and evacuation-route maps were prepared from Masinabagar to KI-sing. Figures 3.2 – 3.4 contain portions of the map for each settlement. 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.

Figure 3.2a shows that of the 466 buildings and non-residential structures, 268 are situated within the inundation area in Masinabagar, including one school, two churches, four crematoriums, 13 livestock farms, nine restaurants, and two warehouses. Of the 152 houses (including livestock farms), 95 are situated within the inundation zone. One primary school (Shramik, grades 1-5) is located near the suspension bridge in Masinabagar. The Shramik school is located entirely within the inundation zone. If a flood hazard were to occur during the day on weekdays, the 70 students would be at severe risk. Thus, the immediate relocation of this school is imperative.

In the left bank area shown in Figure 3.2b, the total number of households was 71 (total population 360), of which 33 houses and a few livestock farms are situated within the inundation zone. There are 59 total households (population 274) in the right bank area in Figure 3.2b, and all are situated within the inundation zone. Similarly, Figure 3.2c displays another vulnerable location, where out of the 46 houses, 22 are within the inundation zone (population 247). Lastly, Figure 3.2d shows a primary school located between the Yamdi Khola and Seti River named Bal Kalyan Basic, which educates 172 students. Five of the school’s buildings are within the inundation zone; thus, they should also be relocated as soon as possible.

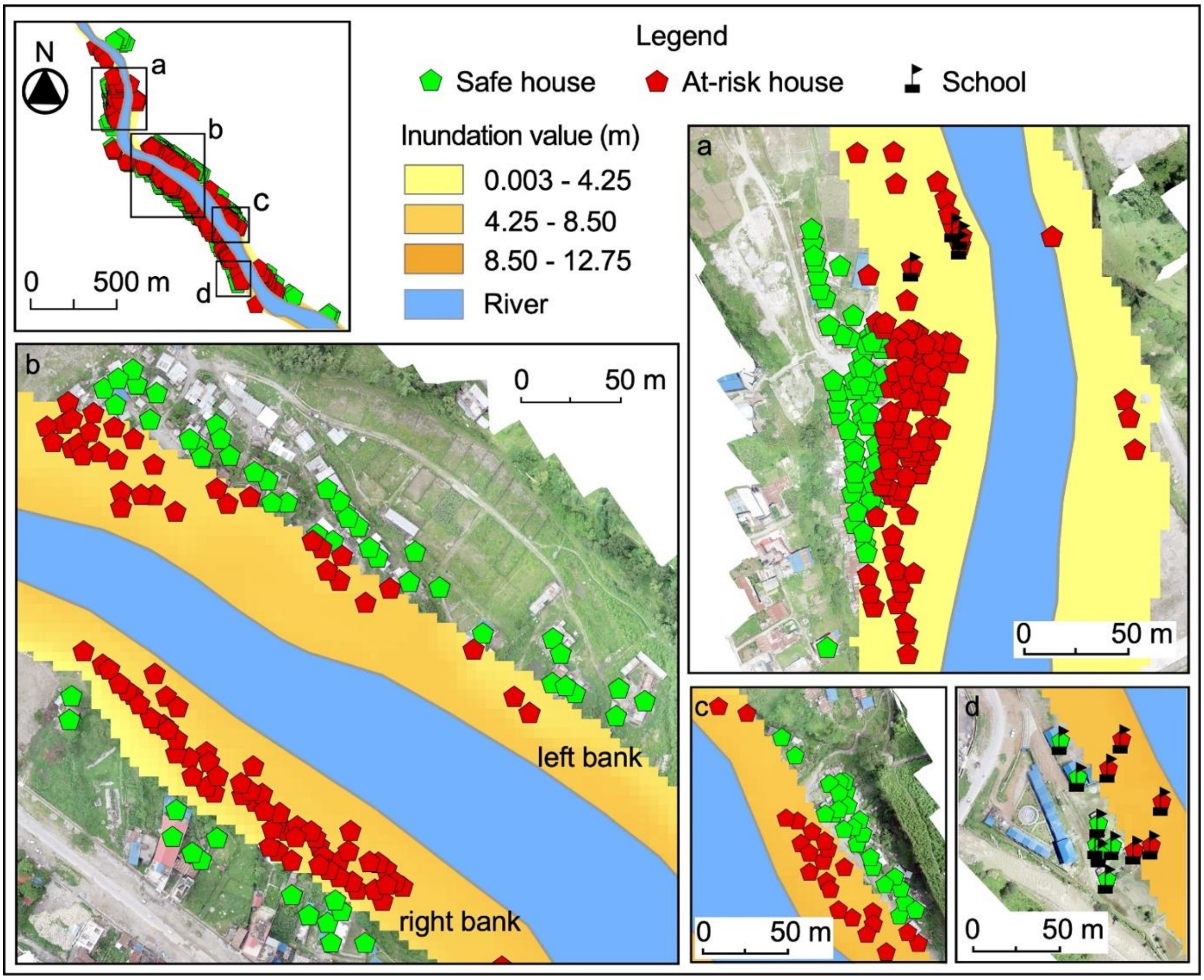

Figure 3.2 Inundation map in Masinabagar: (a) upper area; (b) central area; (c and d) lower areas. Locations of the interviewed households are shown as safe houses and at-risk houses.

Figure 3.3 shows the interviewed houses in Laltinbazar, where 232 of the 329 houses (population 1800) are located either within the floodplain or along slopes with low heights relative to the river water surface. Such topographic characteristics can lead to extensive flood damage and loss of life or property. In Figure 3.3a, 59 of the 87 houses are situated in the inundation zone, in addition to one lower secondary-level school (Ratna Basic, grades 1–8). The school has 103 students, and four of its five buildings are within the inundation zone. Of the 242 houses located within the site shown in figure 3.3b, 173 are situated in the inundation zone (1325 pop).

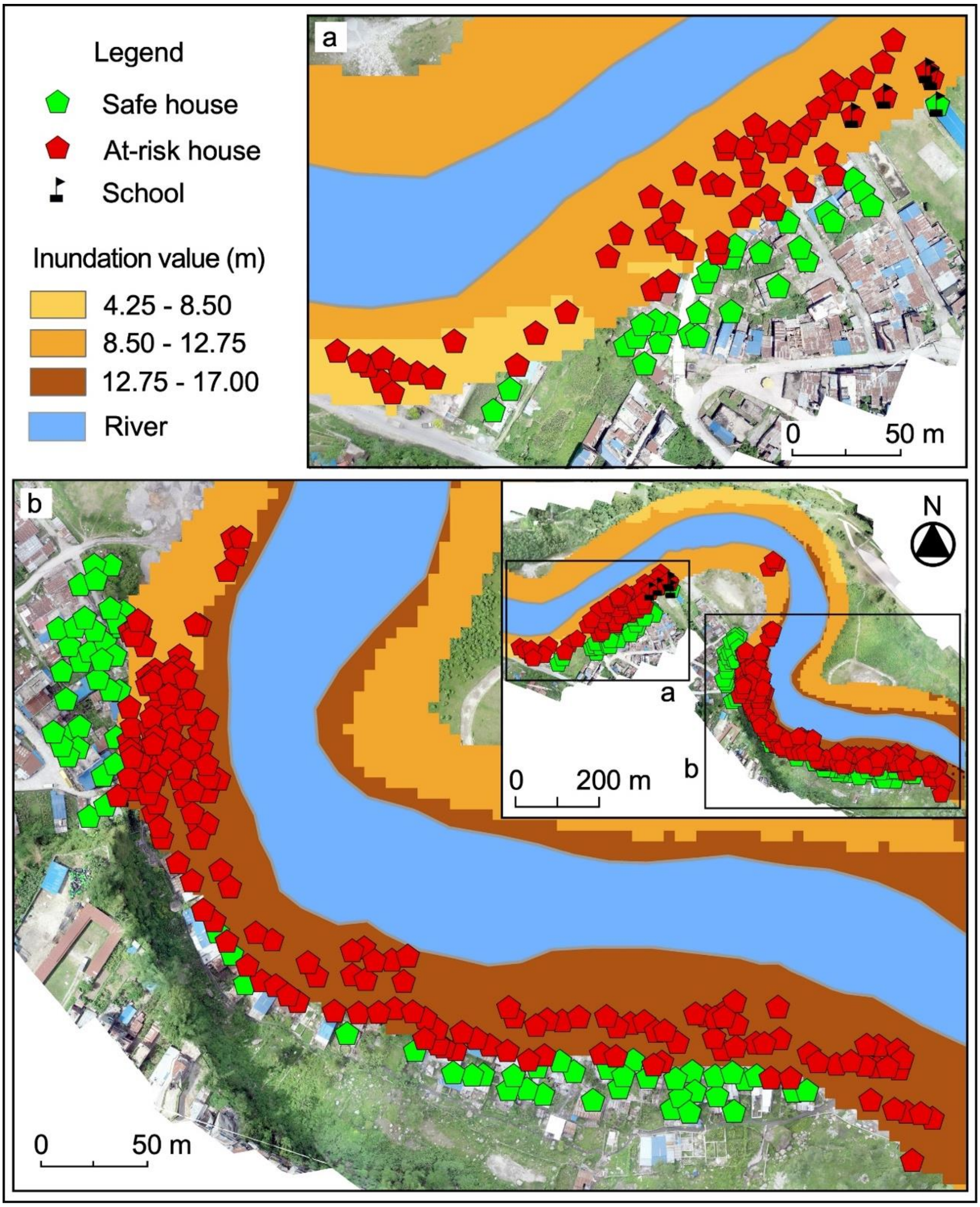

Figure 3.3 Inundation map in Laltinbazar: (a) western area; and (b) eastern area. Locations of the interviewed households are shown as safe houses and at-risk houses.

Of the 210 houses in KI-sing (population 786), 68 are situated within the inundation zone. A deep gorge starts immediately outside the city (right edge of Figure 3.4), and if a flood were to occur while the gorge was blocked, the expected area of water inundation would expand. Within the area depicted in the right bank in Figure 3.4, there are temples, houses, a community center, a research center, and a school. Of the 69 houses on this site, 45 are at risk of inundation. Of the 141 houses shown in the left bank in Figure 3.4, 23 are within the inundation zone.

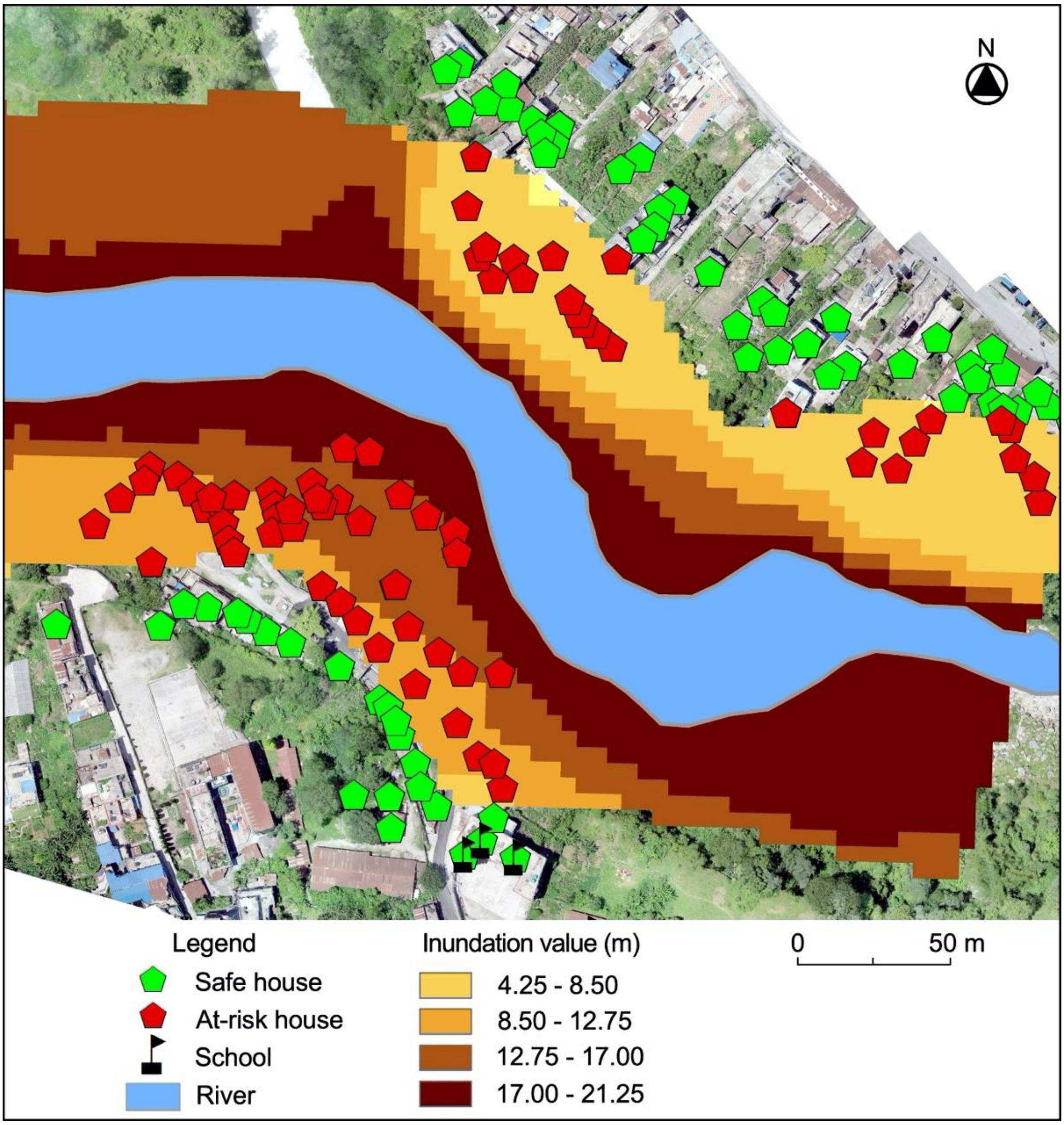

Figure 3.4 Inundation map in KI-sing. Locations of the interviewed households are shown as safe houses and at-risk houses.

Table 3.1 presents the flooding risk by building type for each location. 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.

Table 3.1 Safe and potentially inundated buildings by type.

Location Status	Masinabagar				Laltinbazar				KI-sing			
	Name	Total	%	Population	Name	Total	%	Population	Name	Total	%	Population
Safe	Household	167	84.3	1009	Household	96	99.0	560	Household	131	92.3	656
	School	7	3.5		School	1	1.0		School	4	2.8	
	Livestock farm	9	4.5						Community center	3	2.1	
	Restaurant	12	6.1						Temple	4	2.8	
	Guest house	3	1.5									
	Total	198	100.0		Total	97	100.0		Total	142	100.0	
Inundated	Household	229	85.4	1294	Household	225	97.0	1240	Households	32	47.1	130
	School	9	3.4		School	4	1.7		Community center	18	26.5	
	Livestock farm	13	4.9		Warehouse	3	1.3		Research center	3	4.4	
	Restaurant	9	3.4						Crematorium	4	5.9	
	Church	2	0.7						Temple	11	16.2	
	Crematorium	4	1.5									
	Warehouse	2	0.7									
	Total	268	100.0	2303	Total	232	100.0	1800	Total	68	100.0	786

Source: Field survey in 2019

3.3.2. **Evacuation Route**

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. Accordingly, this area requires appropriately planned and sufficiently broad evacuation routes. Our suggested evacuation route is for pedestrian use only. Both the existing and suggested routes can be used in emergencies as evacuation routes. Our suggested route is based on population, elevation differences, shortest distance, and total length (see Table A1). The safe destination is situated a little far from the settlement because research has suggested a place at an altitude at least 1 m higher than the altitudes of existing houses. Based on the research I consider a place higher than 1 m as safe for immediate and temporary shelter (Table A1).

3.3.2.1. **Masinabagar**

The area displayed in Figure 3.5a includes 148 houses and a total population of 712 residents, all of whom are dependent on a single existing evacuation route (route number 8), which leads to a single main path to higher (safer) ground (see Figures 3.6a and 3.6b and 3.6c). Presently, the paths are barely wide enough for two people at the same time (~1 m). The narrow main path (Figure 3.6a) has staircases, and hence it can get easily clogged with slower children and elderly people. Thus, the evacuation route would be severely inadequate in an emergency.

Therefore, I suggest that nine other routes be created for emergencies based on the population and distance from each house to an evacuation route (see Table A1). Both the existing route and the additional nine routes to be created can be used for emergencies.

The evacuation routes displayed in the left bank area in Figure 3.6b and Figure 3.6c serve a total population of 360 and are sectionally narrow and steep, making them insufficient for the simultaneous use of the residents. The group discussions identified that many people might be unable to evacuate in the future because of their limited knowledge of the impending threat and the challenging evacuation route itself. In this section, seven more potential evacuation routes (L1–L7) were identified, most of which can be connected with the existing routes.

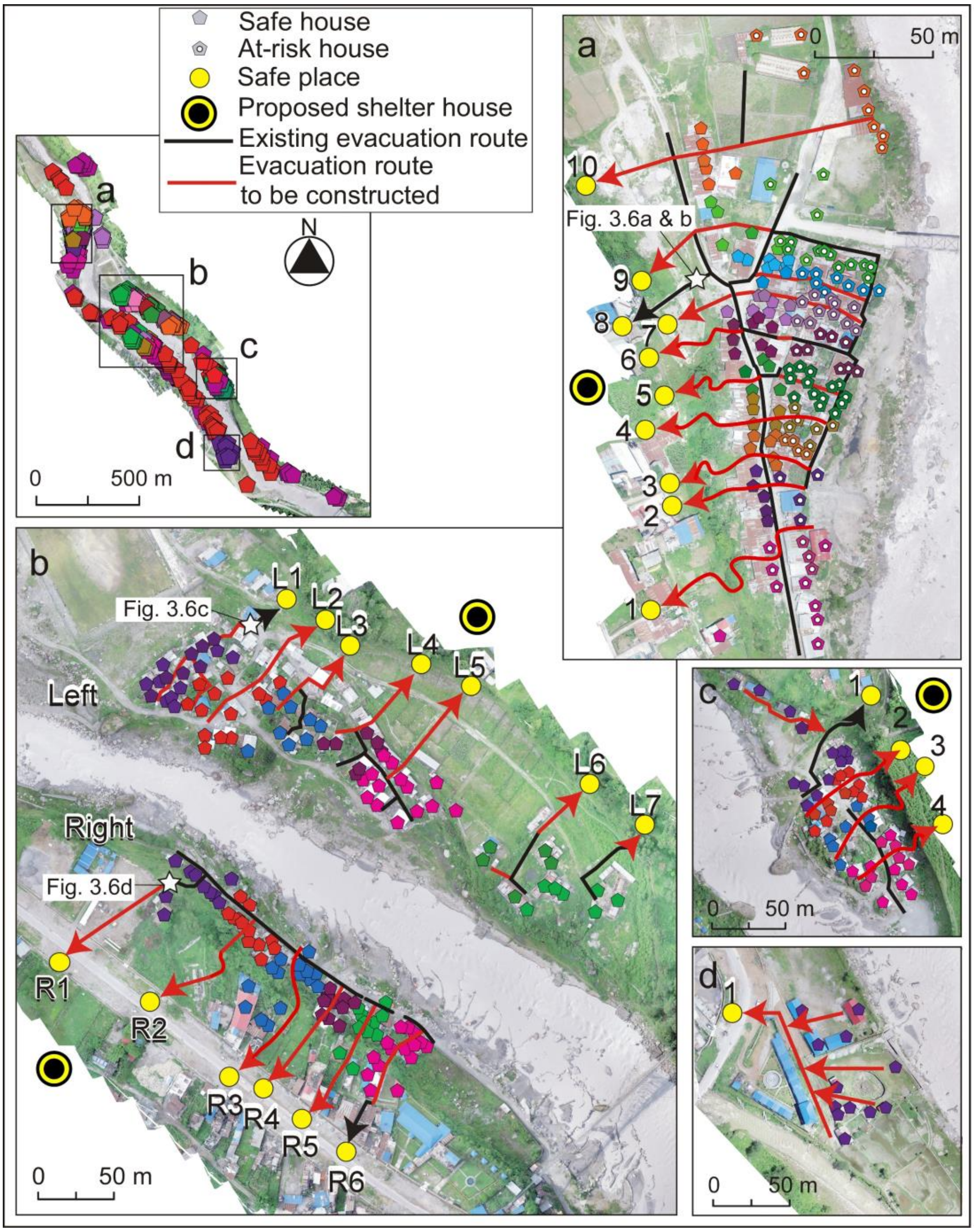

Figure 3.5 Evacuation-route maps in Masinabagar: (a) upper area; (b) central area; and (c and d) lower areas. The routes in black show the existing routes, and the routes in red color show the evacuation routes to be created. Houses depicted in the same colors present those depending on the same evacuation route. Houses with white dots in the center represent at-risk houses and without dots represent safe houses. The yellow color with a black dot represents proposed shelter house location. Note that some houses where the questionnaire survey was not conducted are also shown here.

The right bank area in Figure 3.5b (total population 372) is the most vulnerable of the entire area. There is only one extremely narrow (60–70 cm) and steep exit route (Figure 3.7c), permitting only one person to walk at a time. This route attains the river terrace (>18 m than the inundated residence zone) but needs to extend more to a safe place (R1). Five more evacuation routes are identified in this section.

Figure 3.6 Existing evacuation routes in Masinabagar (ad) and Laltinbazar (e). (b) is a close-up of (a). See Figures 3.5 and 3.7 for locations (Photos: B.T.).

Compared to routes at other sites (with a total population of 113), one is slightly better and broader (see Figure 3.5c). However, if residents cannot quickly receive flood information, lives may be lost because the only exit point (route 1 in Figure 3.5c) is far from the residence area. Therefore, three new evacuation routes should be created as soon as possible.

Similarly, Figure 3.5d displays a primary school where five people reside. In total, 172 students are present during the daytime. This location is between the Yamdi Khola and Seti River. This study has identified one location that is suitable for an evacuation route. There is no evacuation route currently available, and this should be addressed as soon as possible.

3.3.2.2. **Laltinbazar**

The area shown in Figure 3.7a has a total population of 456 households which is safe. As stated earlier, research suggests an altitude difference of more than 1 m is a safe place. This study suggests that nine new evacuation routes be created, three of which can be connected with the existing routes (routes 3, 6, and 8). Many houses along routes 4–9 are located in safe places. When evacuation is necessary, the residents in these safe places would also evacuate. Therefore, the width of the evacuation routes should be wide enough. The routes in black show the existing routes, and the routes in red show the proposed evacuation routes. Houses with the same colors present those depending on the same evacuation route. Houses with white dots in the center represent at-risk houses and without dots represent safe houses. Note that some houses where the questionnaire survey was not conducted are also shown here.

The area shown in Figure 3.7b has a total population of 1335. At present, there are only two routes stretching toward the higher elevation (routes 1 and 7). Route 1 is used only by 40 residents. On the other hand, route 7 is used by many residents. This route is a narrow (0.8–1.1 m wide) passage with a steep exit (Figure 3.6e). As only one person can pass at a time, this route is inadequate for the residents in the area. Therefore, research recommends seven other alternative routes (routes 2 to 9 excluding route 7) for emergency evacuations. There is no evacuation route in the right half of Figure 3.7b, where nine evacuation routes should be created.

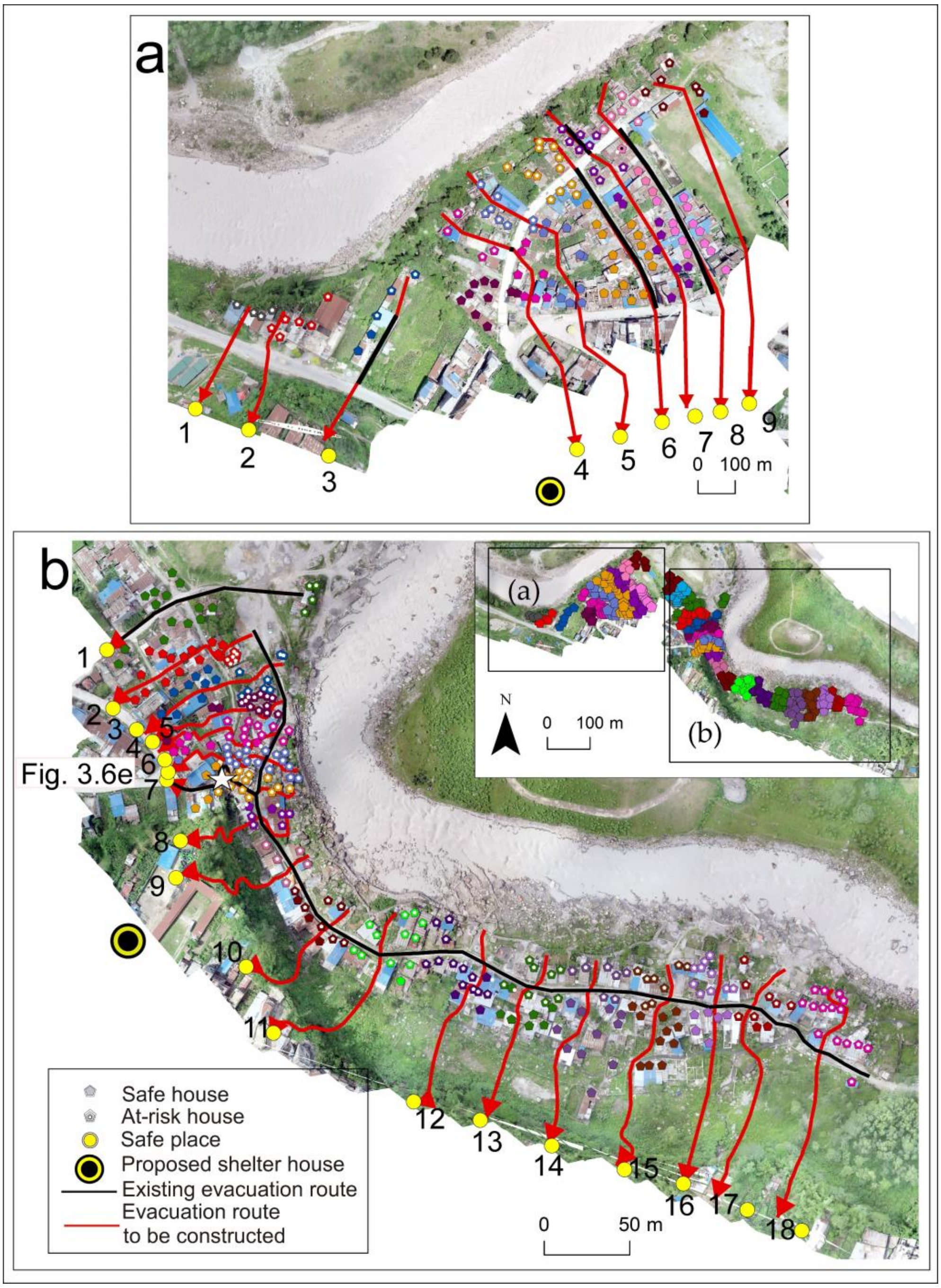

Figure 3.7 Evacuation-route maps in Laltinbazar: (a) western area and (b) eastern area. The routes in black show the existing routes, and the routes in red show the proposed evacuation routes. Houses with the same colors present those depending on the same evacuation route. Houses with white dots in the center represent at-risk houses and without dots represent safe houses. The yellow color with black dot represents proposed shelter house location. Note that some houses where the questionnaire survey was not conducted are also shown here.

3.3.2.3. **KI-sing**

The situation in the left bank area shown in Figure 3.8 (total population 690) is far better than elsewhere, as some routes to higher place exist; however, research suggest five new routes and four new sections to be connected with the existing routes for emergency evacuations. The evacuation route situation in the right bank area in Figure 10 is similar to most of the other areas above. Only one path to higher place (R1) is available for 96 residents. Therefore, study suggest three new routes for an emergency. The residents can use both the existing route and the suggested new routes as an evacuation route.

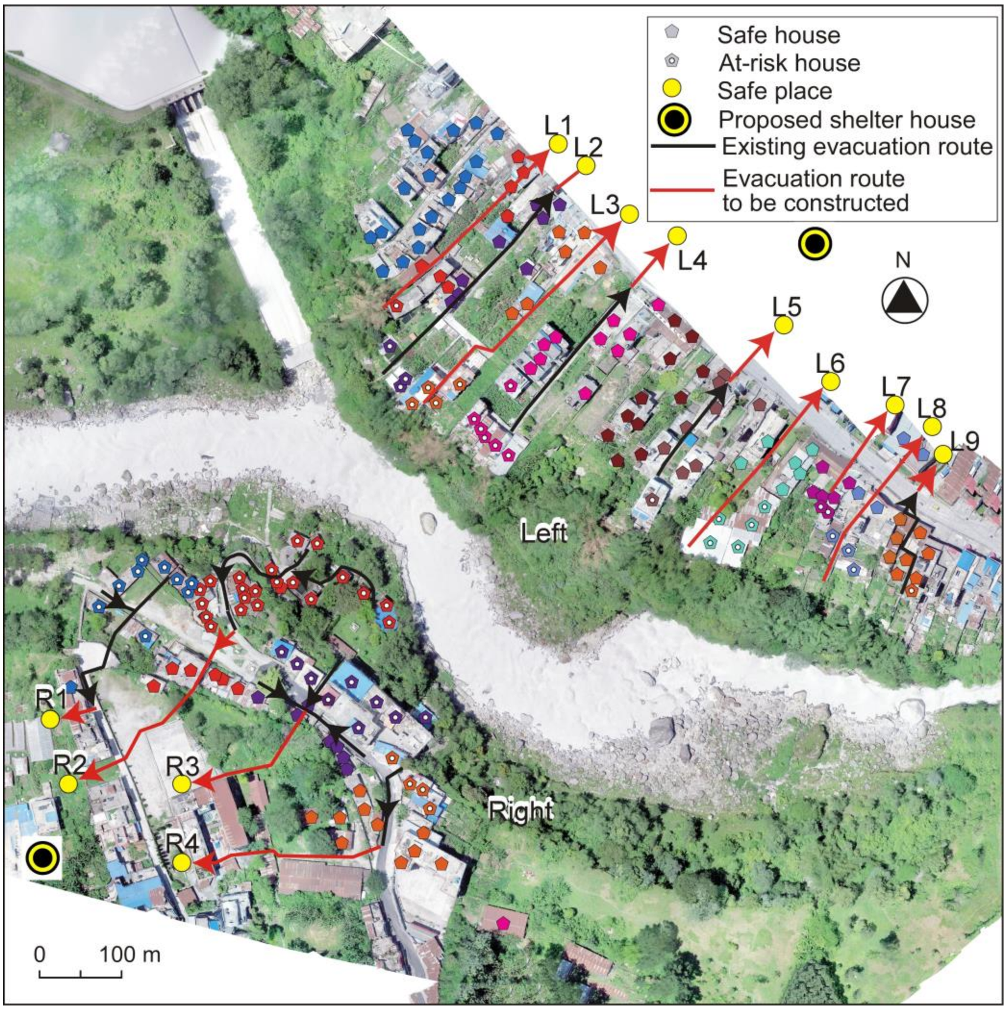

Figure 3.8 Evacuation-route map in KI-sing. The routes in black color show the existing routes, and the routes in red color show the suggested evacuation routes. Houses with the same colors present those depending on the same evacuation route. Houses with white dots in the center represent at-risk houses and without dots represent safe houses. The yellow color with black dot represents proposed shelter house location. Note that some houses where the questionnaire survey was not conducted are also shown here.

3.3.3. Cross-sectional profiles of emergency evacuation routes in the Seti River basin

A cross profile of the proposed emergency evacuation route shows the starting point of the route and the vertical or horizontal distance of the temporary safe place. Figure 3.9 showed the cross-sectional profiles of the evacuation routes of Masinabagar. The cross-cross-sectional profiles show the height of the houses where people start to evacuate, the height of safe places (destination), and the distance between the houses and the safe places. Red symbols represent the houses and yellow symbols represent the location of the safe places.

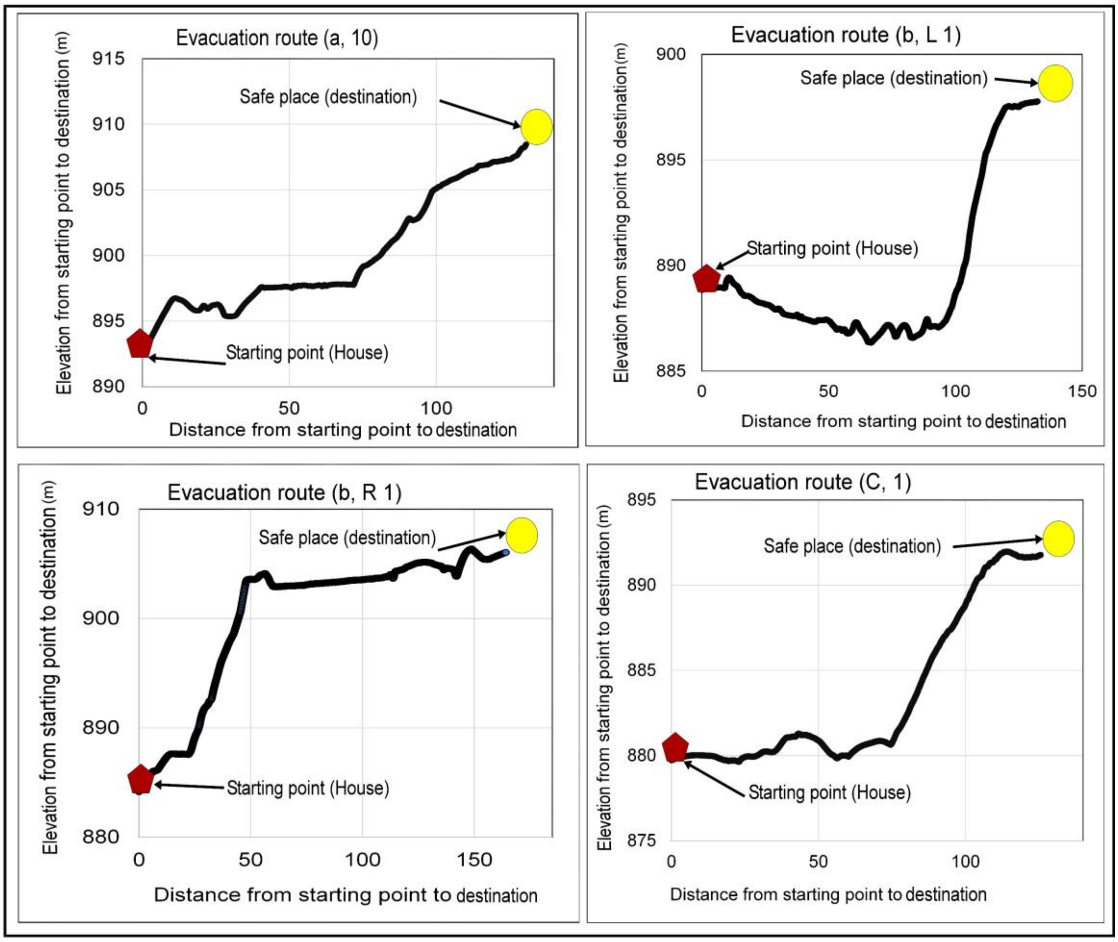

Figure 3.9 Examples of the proposed emergency evacuation routes (Routes a10, bL1, bR1, and C1) in Masinabagar. See Figure 3.5 for evacuation route number and location.

Figure 3.10 shows the cross-sectional profiles of the evacuation routes in the Laltinbazar section. Similarly, Figure 3.11 also shows the cross-sectional profiles of the evacuation routes in the KI-sing section.

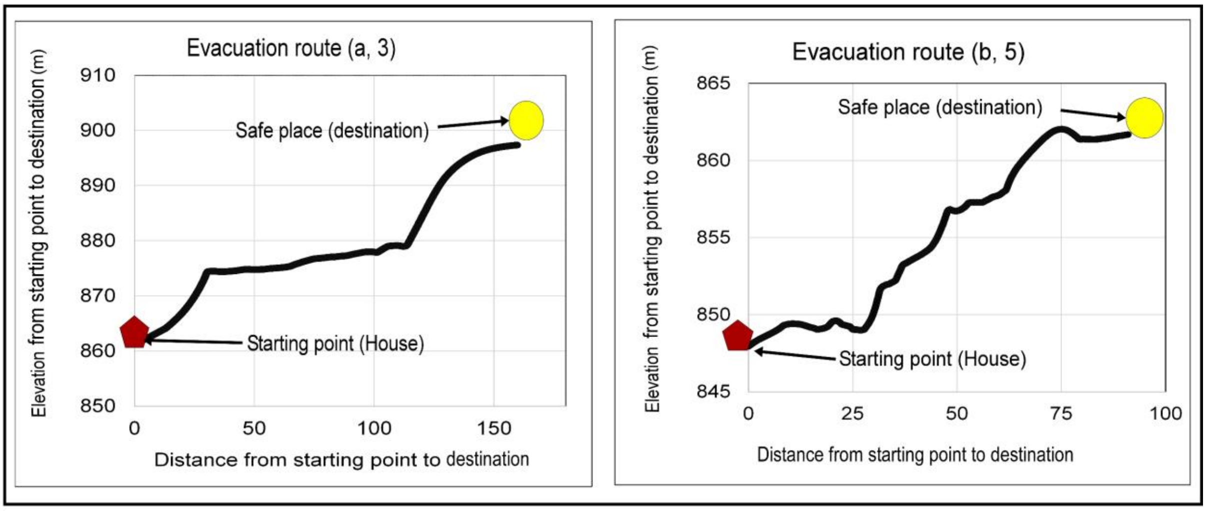

Figure 3.10 Examples of the proposed emergency evacuation routes (Route a3 and b5) in Laltinbazar. See Figure 3.6 for evacuation route number and location.

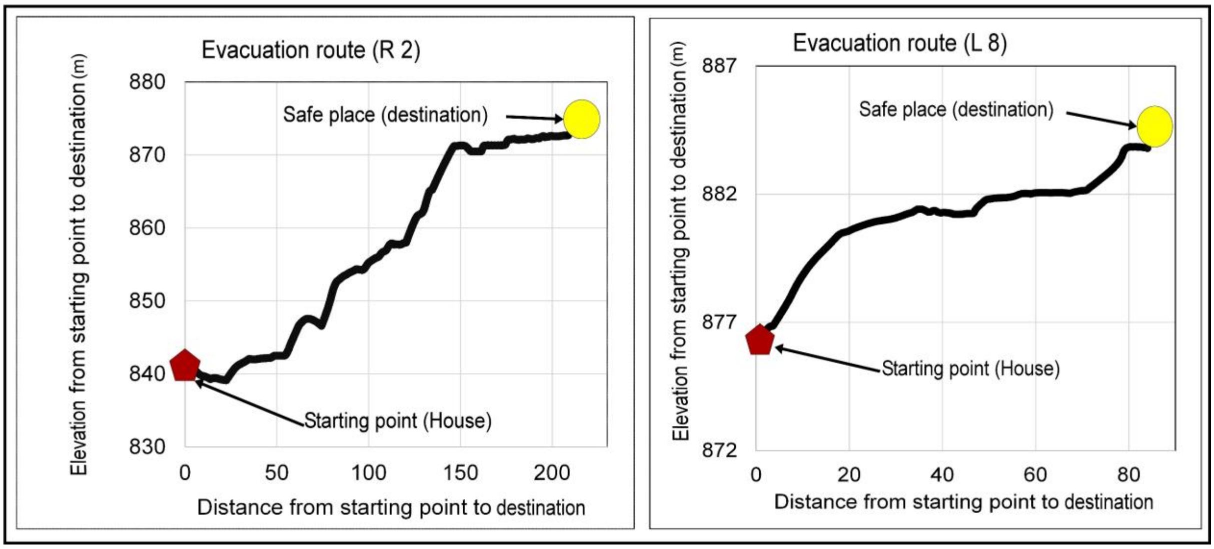

Figure 3.11 Example of the proposed emergency evacuation routes in KI-sing. Route R 2 (Right side) and L 8 (Left side). See figure 3.8 for evacuation route number and location.

3.3.4. **Socio-Economic Survey**

The percentages of households with annual incomes categorized as extremely poor were 71%, 74%, and 52% in Masinabagar, Laltinbazar, and KI-sing, respectively (Table 3.2). In total, 68% of people were in the extreme poverty class. In KI-sing, 3% of the residents belonged to the upper middle class. However, no residents from any settlement belonged to the high-income group.

Table 3.2 Classification based on annual income (USD·person^{1}) in the three settlements.

Household income (USD·yr^{1})	**Masinabagar**		**Laltinbazar**		**KI-sing**		**Total**	**%**
	Total	**%**	**Total**	**%**	**Total**	**%**		
Extremely poor	295	71.0	236	74.0	85	52.0	616	68.0
Low-income	93	22.0	78	24.0	36	22.0	207	23.0
Lower-middle income	28	7.0	7	2.0	37	23.0	72	8.0
Upper-middle income	-	-	-	-	5	3.0	5	1.0
High income	-	-	-	-	-	-	-	-
Total	416	100.0	321	100.0	163	100.0	900	100.0

Source: Field survey in 2019

Table 3.3 shows the number and percentage of heads of households engaged in different occupations. The labor industry was the most popular, accounting for 85.4% of the total employment of household heads, including 89.7% in Masinabagar, 96.0% in Laltinbazar, and 54.0% in KI-sing. Agriculture-based households varied from 0.0% in Laltinbazar to 0.2% in Masinabagar and 0.6% in KI-sing. Business-related occupations were 6.0% of the total in Masinabagar, 2.2% in Laltinbazar, and 23.3% in KI-sing. The service sector employed 1.4% of household heads in Masinabagar, 0.6% in Laltinbazar, and 6.1% in KI-sing. Recently, remittances have provided a sustainable form of income for 2.6% of households in Masinabagar, 1.2% in Laltinbazar, and 16.0% in KI-sing.

Table 3.3 Major occupations of the household heads.

Occupation	Masinabagar		Laltinbazar		KI-sing		Total	%
	Total	**%**	**Total**	**%**	**Total**	**%**		
Labor	373	89.7	308	96.0	88	54.0	769	85.4
Business	25	6.0	7	2.2	38	23.3	70	7.8
Remittance	11	2.6	4	1.2	26	16.0	41	4.6
Agriculture	1	0.2	0	0.0	1	0.6	2	0.2
Service	6	1.4	2	0.6	10	6.1	18	2.0
Total	416	100.0	321	100.0	163	100.0	900	100.0

Source: Field survey in 2019

The percentage of migrants varied greatly; Laltinbazar maintained the highest percentage (100.0%), which was followed by those of Masinabagar (96.4%) and KI-sing (62.6%) (Table 3.4). Altogether, 91.6% of the residents within the study area had migrated within the last 20 years. The majority of migrants came from nearby districts (Figure 3.1a) intending to survive off of the river's resources, and they were generally uneducated and unskilled laborers.

Table 3.4 Migration status of the study area's residents.

Migration Status	Masinabagar		Laltinbazar		KI-sing		Total	%
	Total	**%**	**Total**	**%**	**Total**	**%**		
Migrant	401	96.4	321	0.00	102	62.6	824	91.6
Non-migrant	15	3.6	0	0.00	61	37.4	76	8.4
Total household No.	416	100.0	321	0.00	163	100.0	900	100.0

Source: Field survey in 2019

3.4. Discussion

3.4.1. Inundation and Evacuation Routes

The inundation maps (Figures 3.5–3.8) revealed that many houses are situated near the riverbank and in the estimated inundation zone. The situation was similar in all three settlements (Table 3.5). In Masinabagar, Laltinbazar, and KI-sing, 268 (57.5%), 232 (70.5%), and 68 (32.4%) houses are located in the inundation zone. Notably, more houses fall under the at-risk category in Masinabagar and Laltinbazar.

Despite such high rates of at-risk houses in the three settlements, the current routes that can be used for evacuation are narrow, located on steep slopes, and their number was limited, as described earlier. Therefore, increasing the evacuation routes is strongly suggested as shown in Figures 3.5, 3.7, and 3.8. The population density of these areas is relatively high, and thus, adequate evacuation routes must be prioritized for the safety of these >2000 residents. These residents in the three settlements represent the nighttime population. However, none of the evacuation routes have streetlights, which makes evacuation extremely difficult at night. Installing streetlights on the routes is strongly suggested.

Regarding daytime evacuation, all three areas contained primary schools. In Masinabagar and Laltinbazar, the schools are entirely in the inundation zone. In KI-sing, many temples and community centers containing children and the elderly are located in the inundation zone. If a flood were to occur, the current evacuation routes are insufficient for these at-risk age groups to use. Thus, for all three areas, establishing adequate evacuation routes and relocating these schools, temples, and community centers must be prioritized among other short-term and long-term strategies, respectively.

Table 3.5 Safe and potentially inundated houses by settlement.

Location Status	Masinabagar		Laltinbazar		KI-sing		Total	%
	Total	%	Total	%	Total	%		
Safe	198	42.5	97	29.5	142	67.6	437	43.5
Inundated	268	57.5	232	70.5	68	32.4	568	56.5
Total	466	100.0	329	100.0	210	100.0	1005	100.0

Source: Field survey in 2019

3.4.2. **Socioeconomic Survey**

Based on the results of hydraulic modeling and socioeconomic survey, statistical relations between potentially inundated houses, safe houses, and residents' socioeconomic factors were examined via correlation coefficient analyses (Table 3.6). Results showed that highly impoverished and immigrant households were at the highest risk in terms of income and migration ($p<0.001$). Similarly, 455 laborers' houses were also significantly correlated with inundation risk ($p<0.001$).

Table 3.7 shows the relationship between per capita income and horizontal distance to the riverbank (medians and IQRs). In Masinabagar, extremely impoverished and low-income households existed closer to the river (medians = 31.8 and 29.6, respectively) compared to lower-middle-income family houses ($p<0.64$). In Laltinbazar, the lower-middle group was the nearest to the river. The low-income and extremely poor groups were the second and third closest to the river, respectively (although all three groups lived in houses significantly close to the river bank; $p<0.004$). The situation in KI-sing was similar ($p<0.001$). Thus, it was concluded that low-income family houses exist significantly closer to the river across the entire study area ($p<0.046$).

Table 3.6 Relationship between inundated/safe house locations and socioeconomic factors.

		Inundated	**Safe**	**χ^2 test**
Income	Extremely poor	362	254	p<0.001
	Low-income	111	96	
	Lower-middle income	17	55	
	Upper-middle income	3	2	
	High income	0	0	
Occupation	Labor	455	314	*p*<0.001
	Business	22	48	
	Remittance	13	28	
	Agriculture	0	2	
	Service	3	15	
Migration	Migrated	469	355	*p*<0.001
	Non- migrated	24	52	

Source: Field survey in 2019

Table 3.7 Annual household income and horizontal distance of houses to the riverbank.

Settlements	Income (USD·yr1)	Distance of house to the riverbank (m)			Kruskal Wallis test
		Median	IQR		
Masinabagar	Extremely poor	31.8	30.2	46.8	p<0.64
	Low-income	29.6	31.7	47.1	
	Lower-middle income	7.1	61.7	62.1	
	Upper middle income	---	---	---	
	High income	---	---	---	
Laltinbazar	Extremely poor	37.7	27.7	52	p<0.004
	Low-income	41.2	29.2	62.9	
	Lower-middle income	74.2	37.6	75.9	
	Upper middle income	---	---	---	
	High income	---	---	---	
KI-sing	Extremely poor	67.7	78.4	?56.9	p<0.001
	Low-income	51.7	69.1	?32.2	
	Lower-middle income	39.6	48	?27.6	
	Upper middle income	34.9	35.3	0.6	
	High income	---	---	---	
Total	Extremely poor	32.1	27	47.9	p<0.046
	Low-income	29.8	32	49.4	
	Lower-middle income	32.7	54.3	53.1	
	Upper middle income	34.9	35.3	0.6	
	High income	---	---	---	

Source: Field survey in 2019

Positive distances denote those to the right bank of the river and negative distances denote those to the left bank. IQR: Interquartile range with the distance of house to the first quartile mark Q1 (left column) and to the third quartile mark Q3 (right column).

The interview surveys and focus group discussion suggest that migrants came to Pokhara for a better future. However, owing to their relative lack of skills and money, they were forced into the less desirable riverside area, even though most knew that living in the area was illegal (public property). In Nepal, it is not permitted to build a house for personal use on public land. "Public land" is land allocated by the general public for paths, ponds, fountains, wells and their banks, grazing land, graveyards, public inns, temples, places for religious practice, memorials, courtyards, sewerage networks, market places, public entertainment, and sporting grounds (Acharya, 2008).

Table 3.8 shows the relationship between household income, migration status, and occupation of the people interviewed. In Masinabagar, 288 of the 295 highly impoverished families were migrants. In Laltinbazar, 236 families existed in extreme poverty, all of which were migrant laborers. In KI-sing, 63 of the 85 families were migrants in extreme poverty, and 71 were laborers. The residents of all five upper-middle-income families in KI-sing received remittances. In total, labor was the primary occupation of 592 extremely impoverished families. Moreover, of 616 families, 587 were migrants, and for 140 households, the major source of income was business. Correlation coefficients were computed among the three settlements based on income, migration status, and occupation (Table 3.8). The results suggested that 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 ($p<0.001$).

Table 3.8 Relationship between annual income, migration status, and occupation of the interviewed households of the study area.

Settlements	Income	Migration status		χ^2 test	Occupation					χ^2 test
		Local	Migrated		Labor	Business	Remittance	Agriculture	Service	
Masinabagar	Extremely poor	7	288	$p<0.001$	285	5	---	1	4	$p<0.001$
	Low income	2	91		87	2	2	---	2	
	Lower-middle income	6	22		1	18	9	---	---	
	Upper-middle income	---	---		---	---	---	---	---	
	High income	---	---		---	---	---	---	---	
Laltinbazar	Extremely poor	---	236	NA	236	---	---	---	---	$p<0.001$
	Low income	---	78		72	3	1	---	2	
	Lower-middle income	---	7		---	4	3	---	---	
	Upper-middle income	---	---		---	---	---	---	---	
	High income	---	---		---	---	---	---	---	
KI-sing	Extremely poor	22	63	$p<0.001$	71	5	5	1	3	$p<0.001$
	Low income	12	24		12	10	8	---	6	
	Lower-middle income	22	15		5	23	8	---	1	
	Upper-middle income	5	---		---	---	5	---	---	
	High income	---	---		---	---	---	---	---	
Total	Extremely poor	29	587	$p<0.001$	592	10	5	2	7	$p<0.001$
	Low income	14	193		171	15	11	---	10	
	Lower-middle income	28	44		6	45	20	---	1	
	Upper-middle income	5	---		---	---	5	---	---	
	High income	---	---		---	---	---	---	---	

Source: Field survey in 2015

Focus group discussions showed that very few people were aware of local disaster risks or could identify safe sites near their houses after the occurrence of the 2012 flood. Indeed, the majority of residents were still not aware of any safe sites near their settlements. In total, 70% of the inhabitants of Masinabagar, 85% in Laltinbazar, and 56% in KI-sing did not know about safe sites near their settlements. As a result of the exposure to radio and other awareness-raising programs, some people from Masinabagar (29%), Laltinbazar (45%), and KI-sing (43%) could identify safe destinations and quickly travel to these places if evacuation routes are constructed. This research identified evacuation routes, and i believe that such routes can save lives when a disaster happens. Evacuation planning is an essential aspect of today's growing initiative for early warning systems in the study area as well as in Nepal Himalaya. A long-term strategy must be established to increase evacuation preparedness during future flooding disasters (Smith et al., 2017; LIM et al., 2013).

3.5. Chapter conclusions

The inundation maps created in this study show that the Masinabagar, Laltinbazar, and KI-sing areas are highly susceptible to future flooding. 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.

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 ($p<0.001$).

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. Establishing adequate evacuation routes and shelter houses is the most pressing need. It is suggested that governmental agencies, NGOs, INGOs, and other related agencies prepare an adequate plan that targets the impoverished residents of the inundation zone, as they cannot afford safe lands for relocation. 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.

Chapter 4 Result 2: Flood Risk and Management in Tamakoshi river basin, Dolakha

4.1. Introduction

Over the last few decades, climate change and related events have greatly amplified risks to development across the globe. Climate change is projected to cause severe economic losses, which has the potential to affect the insurance sector and public compensation schemes considerably (Botzen et al., 2008). Climate change and global warming are generally expected to increase the frequency of extreme rainfall events, thus potentially impacting riverine disasters (Jhan et al., 2020; Dankers et al., 2008). Global warming is generally expected to increase the magnitude and frequency of extreme precipitation events, which may lead to more intense and frequent river flooding (Dankers et al., 2008). Increases in temperature and rainfall on a regional scale also influence flooding frequency and intensity (Field et al., 2014). Floods often cause severe damage to lives, property, crops, and infrastructure, and the number of casualties by floods could increase in the future (Hirabayashi et al., 2013; Mirza, 2011; Islam et al., 2021). The Intergovernmental Panel on Climate Change (IPCC) states that it is very likely that anthropogenic factors are responsible for the main part of the observed global warming since the mid-20th century. In particular, it has been acknowledged that greenhouse gases are a significant cause of global warming, even though other factors such as the natural variability of climate play a role as well (Botzen, 2008; IPCC, 2007).

The increased volume of rainfall caused by climate change during the past decades has intensified the flood problem in this part of the world. The population expected to be hardest hit by flood disasters is the poor people who lack adequate means to take protective measures and who also have very little capacity to cope with the loss of property and income (IPCC, 2001). In the context of Nepal, monsoonal floods played a major role, whereas glacier lake outburst floods (GLOFs) also threaten human safety and wellbeing (Mirza, 2011). GLOFs can cause catastrophic flooding in downstream areas, severely damaging property in addition to causing loss of life(Mohapatra, 2003). Melting glaciers contribute to the increase of glacial lakes, which may in turn cause lake outbursts.

In many incidents, people die due to a lack of information or knowledge such as the status of evacuation routes, pedestrians' traffic in the impacted area, and real-time alert systems. Using Unmanned Aerial Vehicles (UAVs) in this field of research is so beneficial for multiple reasons. For instance, UAVs have a high speed of covering areas, route safety, construction conditions, and pedestrians' movements aerially and without humans interfering in real-time (Maher & Inoue, 2016). Recently many studies are based on UAV applications for support and assessment of disaster management (Kim et al., 2019; Restas, 2015; Barba et al., 2019; Garrett et al., 2018; Langhammer et al., 2018; Hildmann et al., 2019; Backes et al., 2019; Restas, 2018).

Furthermore, UAV platforms are nowadays considered the most important sources of data for observing, mapping, 3D modeling, and the creation of evacuation routes (Langhammer et al., 2018; Maher et al., 2016; Remondino et al., 2012). Most UAV applications in hydrological research are used for stream and riverscape flood mapping, all of which require continuous monitoring (Restas, 2015; Langhammer et al., 2018). In particular, UAVs can assist with monitoring the state of dams, and disaster tracking. Accordingly, UAVs can generate an evacuation map over a relatively short period.

Flooding in urban areas is may be challenging because of the haphazard settlement and dense population. Prevention of such events is not possible but with the advancement of technology, flood-vulnerable areas can be identified through 2-D modeling of critical rainfall events (Rangari et al., 2019). As devastated urban flood events have been increasing with the advancement of technology, flood-vulnerable areas can be identified through hydrological modeling so that losses of human life and property (Rangari et al., 2019a; Rangari, et al., 2019b). The Hydrologic Engineering Center River Analysis System (HEC-RAS) model was developed by the U.S. Army Corps of Engineers and has been widely employed in studies of risk assessment, hazard risk management, and emergency response guidelines in flood-affected areas (Tate et al., 2002; Pappenberger et al., 2005; Aggett et al., 2009; Sarhadi et al., 2012; Hameed et al., 2013; Khattak et al., 2016; Demir, 2016; Quirogaa et al., 2016; Kumar et al., 2017; Patel et al., 2017; Khalfallah et al., 2018; Kumar et al., 2020; Hutanu et al., 2020). HEC-RAS creates one-dimensional (1D) and two-dimensional (2D) steady- and unsteady flow simulations (Sarhadi et al., 2012), and its joint use with GIS is essential to risk reduction programs (Khalfallah et al., 2018).

Vulnerability to hazards not only relies on the extent of natural hazards but also depends on the social and economic conditions of the communities (Khanal et al., 2015; Tasnuva et al., 2020). It highlights differences in the capacity to prepare for, respond to, and recover from disasters related to time, social groups, and demographic characteristics (Hummell et al., 2016). While social vulnerability has recently gained considerable attention in academic studies, many societies still lack awareness of how social differences within their population play a role in disaster impacts. It varies over space and time, and among and between social groups, largely due to differences in socioeconomic and demographic characteristics (Hummell et al., 2016).

Now researchers have focused on either physical or social approaches to disaster vulnerability. For example, social scientists have identified social issues and problems from earthquakes, flash floods, tornadoes, tsunamis, and volcanic eruptions (Lindell et al., 2015; Fraser et al., 2016; Lindell et al., 2019; Makinoshima et al., 2020). However, there is a vast gap and the two approaches have not been interconnected (Simonovic, 1999; Becker et al., 2001; Brouwer et al., 2004; Pardoe et al., 2012; Ghosh, 2012; Morss et al., 2016). Researchers have examined socioeconomic issues using a community-based approach (Smith et al., 2017). While many researches have been focusing on natural disasters, modeling, and social aspects separately, no study has combined these three aspects. This research identifies vulnerable houses, addresses social issues, and determines safe evacuation routes.

4.2. Study Area

Dolakha (Figure 4.1) District, with Charikot as its district headquarters, covers an area of 2,191 km^2 and has a population of 204,229 in 2001 and 186,557 in 2011. Dolakha District is a part of Bagmati Province. Dolakha District has located about 181 km from Capital Kathmandu. The district headquarters of Dolakha is located at $86^0$11’00’’ east longitude and $27^0$44’12’’ north latitude. Tamakoshi River is a transboundary river that originates from Tibetan Highlands. Gongar, Purano Jagat, Jagat, Manthali, Jamune, Suri Dobhan, Bhorle, Olitar, Singati, Dolakha is a northeast side, and Kattike and Tamakoshi settlements belong to the south-west of the Charikot (Figure 4.1c).

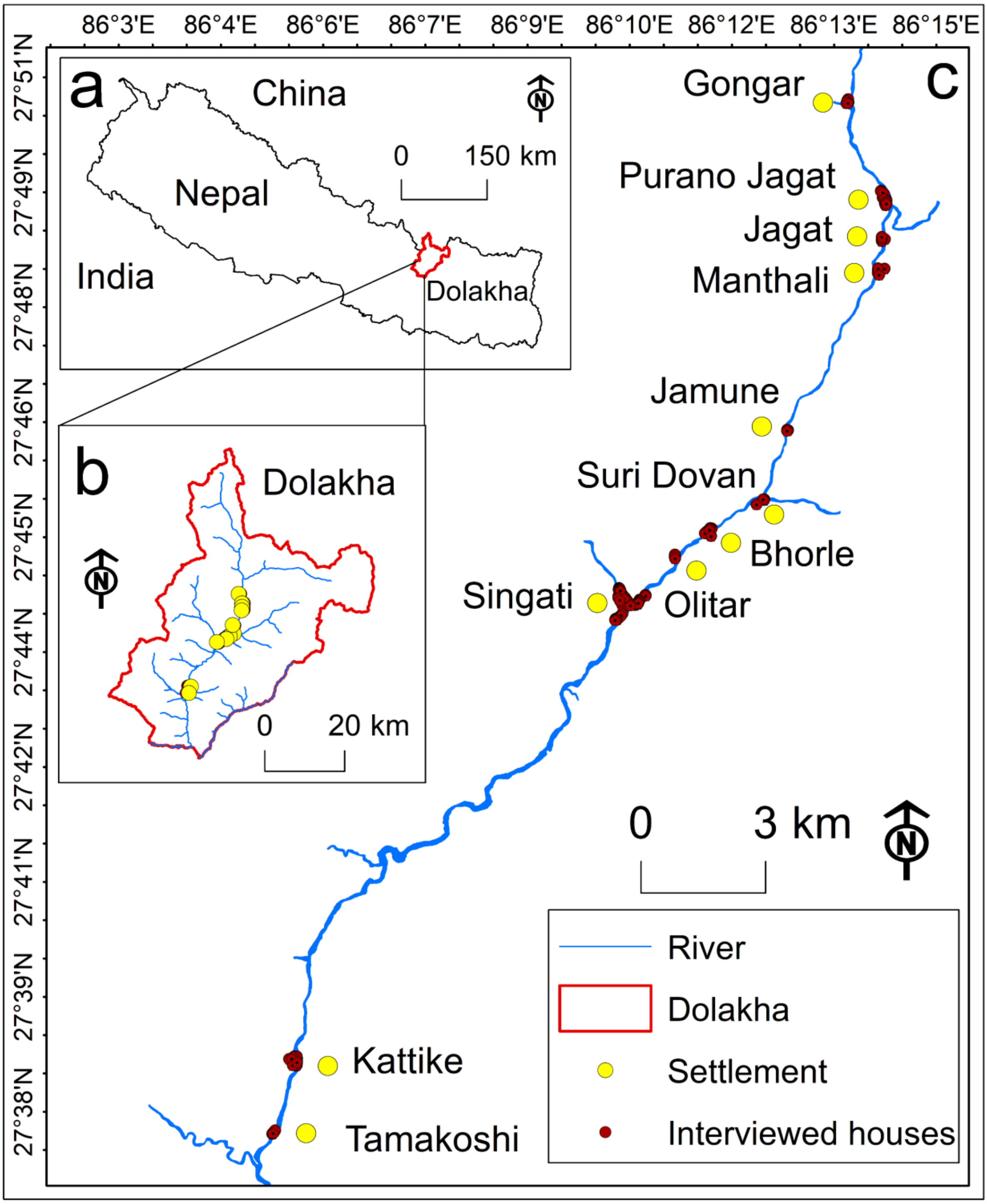

Figure 4.1 Location of the study area: (a) country of Nepal; (b) Dolakha district; (c) interviewed settlements. Locations shown in Figure c are shown in Figures 4.3-4.7.

4.3. Results

4.3.1. Inundation Mapping

Flood-inundation and evacuation-route maps were prepared from Gongar to Tamakoshi. Figures 4.3-4.7 contain portions of the map for each settlement. Figure 4.3 shows that out of the 87 buildings 3 buildings are situated within the inundation area. In Gongar, there is a police station (16 buildings), Tamakoshi hydropower's office (18 buildings), and 53 households (including 10 interviewed households) situated very near to the Tamakoshi River. Gongar is situated middle of the two rivers Gongar Khola and Tamakoshi rivers. This is the most dangerous area for the future flood. Therefore, thus, they should be relocated as soon as possible. The maximum inundation depth was calculated as 19.29 m in Gongar, 10 m in Jagat, 6 m in Bhorle, 10 m in Jamune, 38.69 m in Singati, 14 m in Kattike, and 19 m in Tamakoshi.

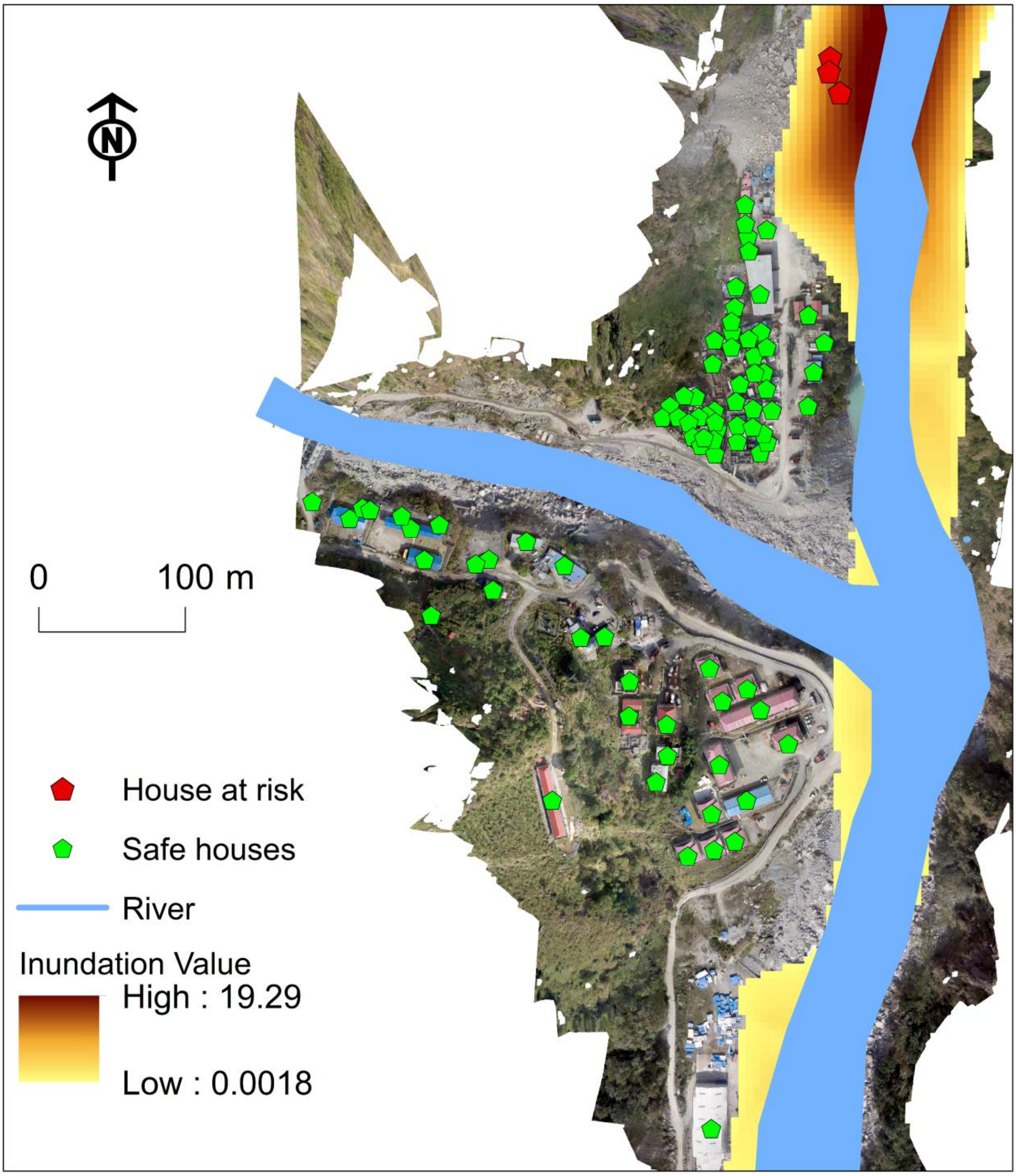

Figure 4.2 Inundation map in Gongar. Inundation map in Gongar. Locations of the houses, safe houses present in green color and, house at-risk present in red color.

Figure 4.3 shows the inundation map of the Purano Jagat (figure 4.3 a), Bhorle (figure 4.3 b), Manthali (figure 4.3 c), Olitar (figure 4.3 d), Jamune (figure 4.3 e), Suri Dovan (figure 4.3 f) and Jagat (figure 4.3 g). In Jamune 3 houses, Bhorle 1 and Jagat 1 houses are situated inside the inundation area. Other settlements look safe at this moment. However, all the interviewed houses are very near to the river so high-volume floods would be more dangerous for the future. The maximum inundation depth was calculated as 12 m in Purano Jagat, 9 in Manthali, 10 m in Olitar and 18 m in Suridovan.

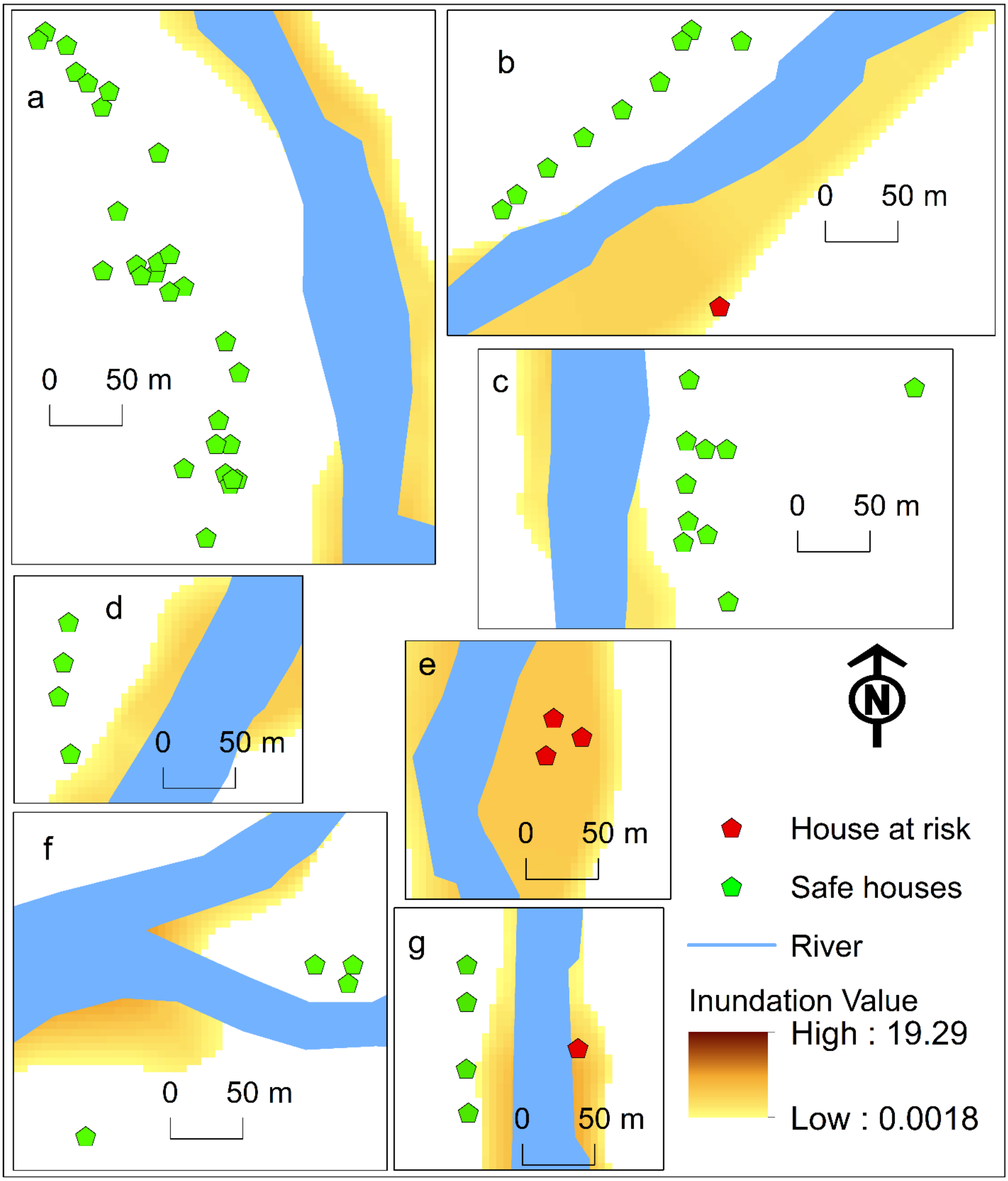

Figure 4.3 Inundation map: (a) Purano Jagat (b) Bhorle (c) Manthali (d) Olitar (e) Jamune (f) Suri Dhovan and (g) Jagat. Locations of the interviewed households are shown as safe houses and at-risk houses.

Figure 4.4 shows that in Singati out of 659 houses 220 houses are situated inside the inundation zone. In total 220 houses are situated within the flood plain or along with low relative heights to the river surface. This type of topographic situation can lead to extensive flood damage. I interviewed only 66 houses in this section.

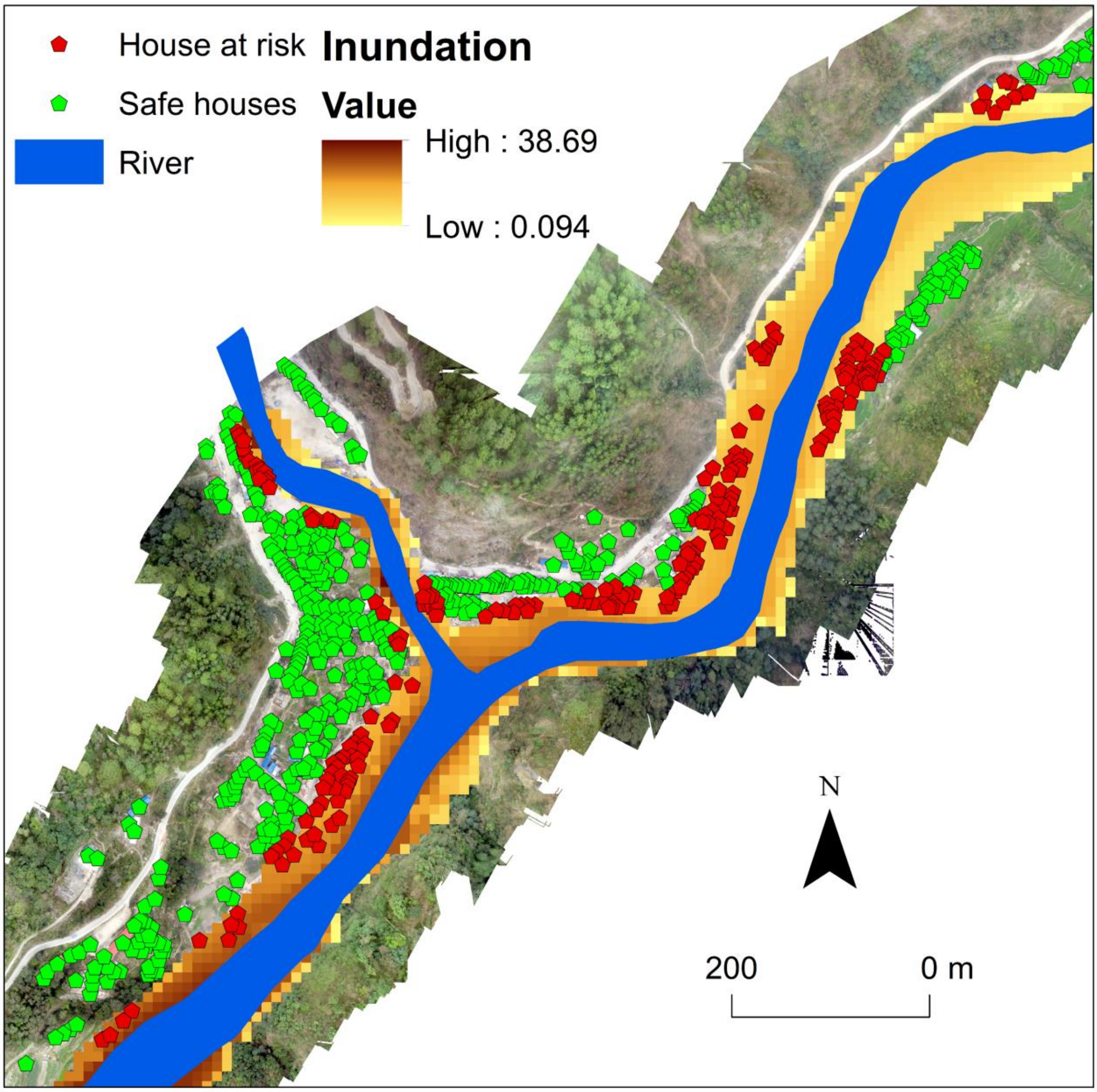

Figure 4.4 Inundation map in Singati. Locations of the houses are presented as safe in green color and at-risk houses are presented in red color.

Figure 4.5 shows the Inundation map of Kattike (Figure 4.5a) and Tamakoshi settlements (Figure 4.5b). Of the 17 houses in Kattike (population 61), 6 houses (population 23) are situated within the inundation zone. Other houses are also located very near to the inundation zone. In Tamakoshi all 6 houses (population 17) are situated inside the inundation zone.

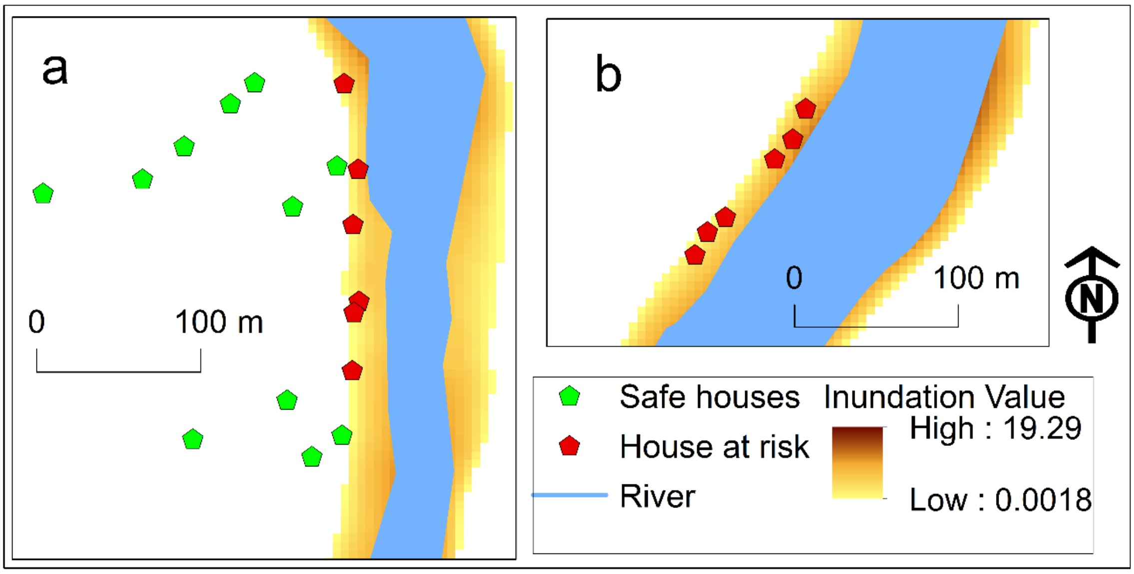

Figure 4.5 Inundation map: (a) Kattike and (b) Tamakoshi settlements. Locations of the interviewed households are shown as safe in green color and houses at-risk are shown as red color.

Table 4.1 present the flooding risk by houses in each settlement. In total 37 houses out of the 163 houses were situated inside the inundation zone. Of the total 560 interviewed population, 147 are situated inside the inundation zone.

Table 4.1 Safe and potentially inundated buildings and population.

Settlement	Households		Population		Inundation Depth (meter)
	Safe	Inundation	Safe	Inundation	m
Gongar	10	-	61	-	19.3
Purano Jagat	28	-	139	-	12
Jagat	4	1	19	6	10
Manthali	10	-	48	-	9
Suri Dobhan	4	-	21	-	18
Bhorle	9	1	39	4	6
Jamune	-	3	-	9	10
Olitar	4	-	18	-	10
Singati	46	20	177	88	38.7
Kattike	11	6	38	23	14
Tamakoshi	-	6	-	17	19
Total	126	37	560	147	

4.3.2. **Evacuation Routes**

UNDP and ICIMODE prepared flood hazard maps of the upper part of the basin but they did not focused on all the downstream settlements. There are no evacuation routes designated by the local or government side. This study, therefore, identified the existing pedestrian routes, which can be used as evacuation routes by the locals during the disaster.

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. Accordingly, this area needs more planned and wide evacuation routes. Our suggested evacuation route is for pedestrian use only. Both the existing and suggested routes can be used in emergencies as evacuation routes. Our suggested route is based on population, elevation differences, shortest distance, and total length. Because of the densely populated area, it is difficult to make a wider road for emergency vehicles. Therefore, this research suggests multiple pedestrian evacuation routes of the minimum distance, so that such routes can be easily used during the disaster by elderly people and children as well as poor people who do not own vehicles. The safe destination is situated a little far from the settlement because I have suggested a place at an altitude at least 1 m higher than the altitudes of existing houses. This study considers the place higher than 1 m and outside of the inundation area as safe for immediate and temporary shelter.

4.3.2.1. **Gongar**

The area displayed in Figure 4.6 includes 87 houses and a total population of approximately 400 residents and there is no existing evacuation route available.

Presently, the existing route is blocked by landslides and that route is not enough for two people at the same time (~1 m). The only suspension bridge is available right now to cross the Gongar Khola. In 2015 there was a flood and the main bridge was swept away (See figure 4.6). At the present, there is one suspension bridge to use for people and cattle. That flood cut off the link between the Gongar to Lamabagar. There is a Hydropower company's office and police station also situated very near to the river bed area.

This study suggests 9 new routes and a safe destination for the right side of the settlements (police and hydropower office cite) and one route for the left side of the settlements. The left side of the settlements is the most dangerous situation. Settlement is surrounded by two rivers in the south-east to south-west cite, the big landslide on the northeast side. So, research only suggests an evacuation route and a safe place on the northern side of the settlements. If the evacuation route is much wider for all the people it will save a life. Both the existing route and the additional nine routes to be created can be used for emergencies.

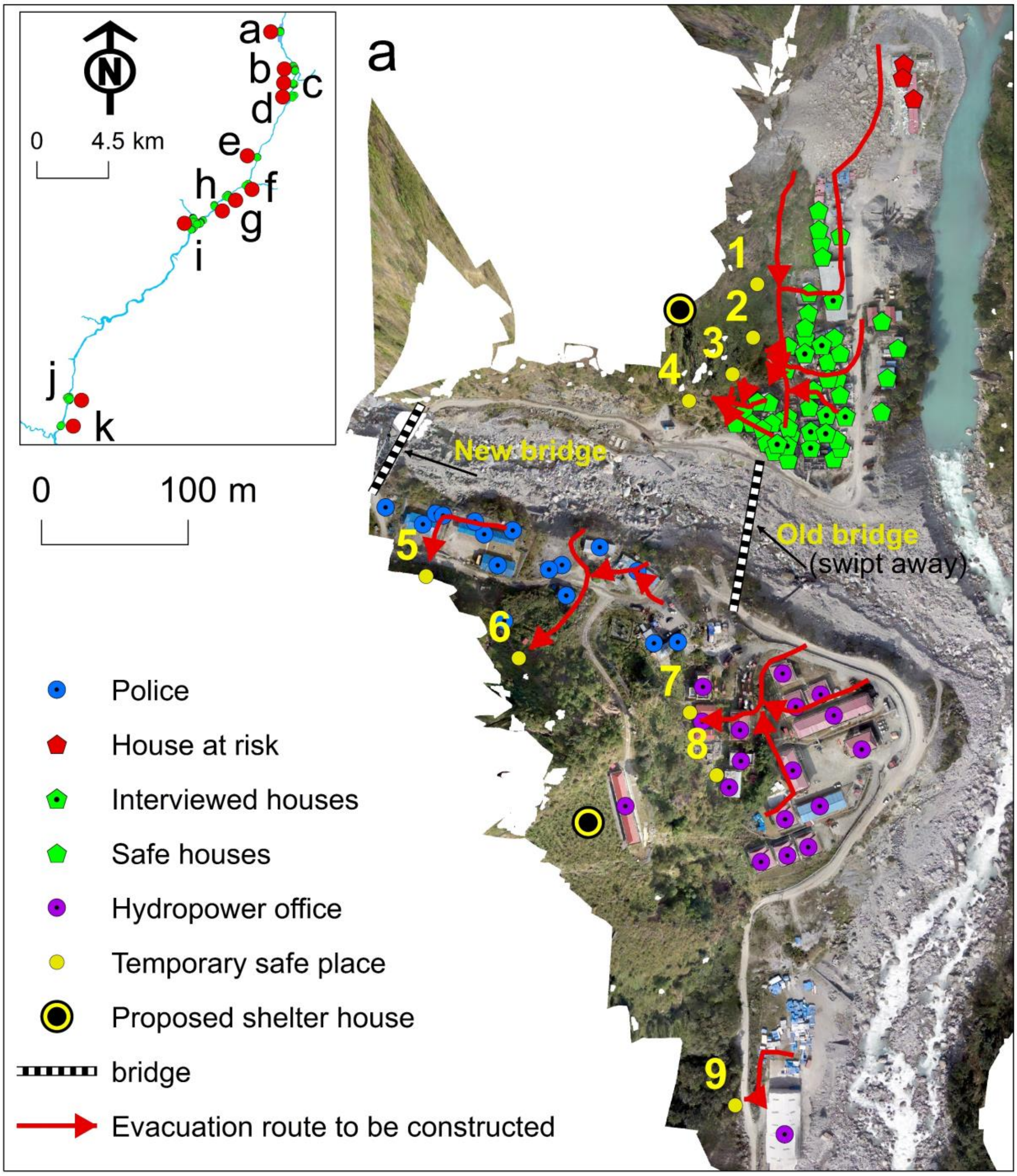

Figure 4.6 Evacuation-route maps in Gongar. The routes in red colour show the evacuation routes to be created. The yellow color with black dot represents the proposed shelter house location. Note that some houses where the questionnaire survey was not conducted are also shown here.

4.3.2.2. **Singati**

The area shown in Figure 4.7 has a total population of 265 (interviewed) of 177 is safe. In total 659 houses and 220 houses are situated in the inundation zone. So, this study suggests a new evacuation route in this area. Singati is the largest settlement among the potentially dangerous settlements. The settlement of Singati is also divided into two sections: the upper section (northern part) and a lower section (southern part) are divided by the Singati Khola, a tributary river running from the northwest to the southeast to reach the main river of the Tamakoshi River. Heavy landslides on the northern side and two rivers surrounded by east and west cite. This study suggests a safe place and evacuation route in figure 4.7. In total, this study suggests twenty-five new evacuation routes be created, and the suggested routes are connected with the existing routes. Few houses along with evacuation routes (green symbols houses) are located in safe places. When evacuation is necessary, the residents in these safe places would also evacuate. Existing routes are very steep, narrow, and not in good condition (Figure 4.8). Therefore, the width of the evacuation routes should be wide enough.

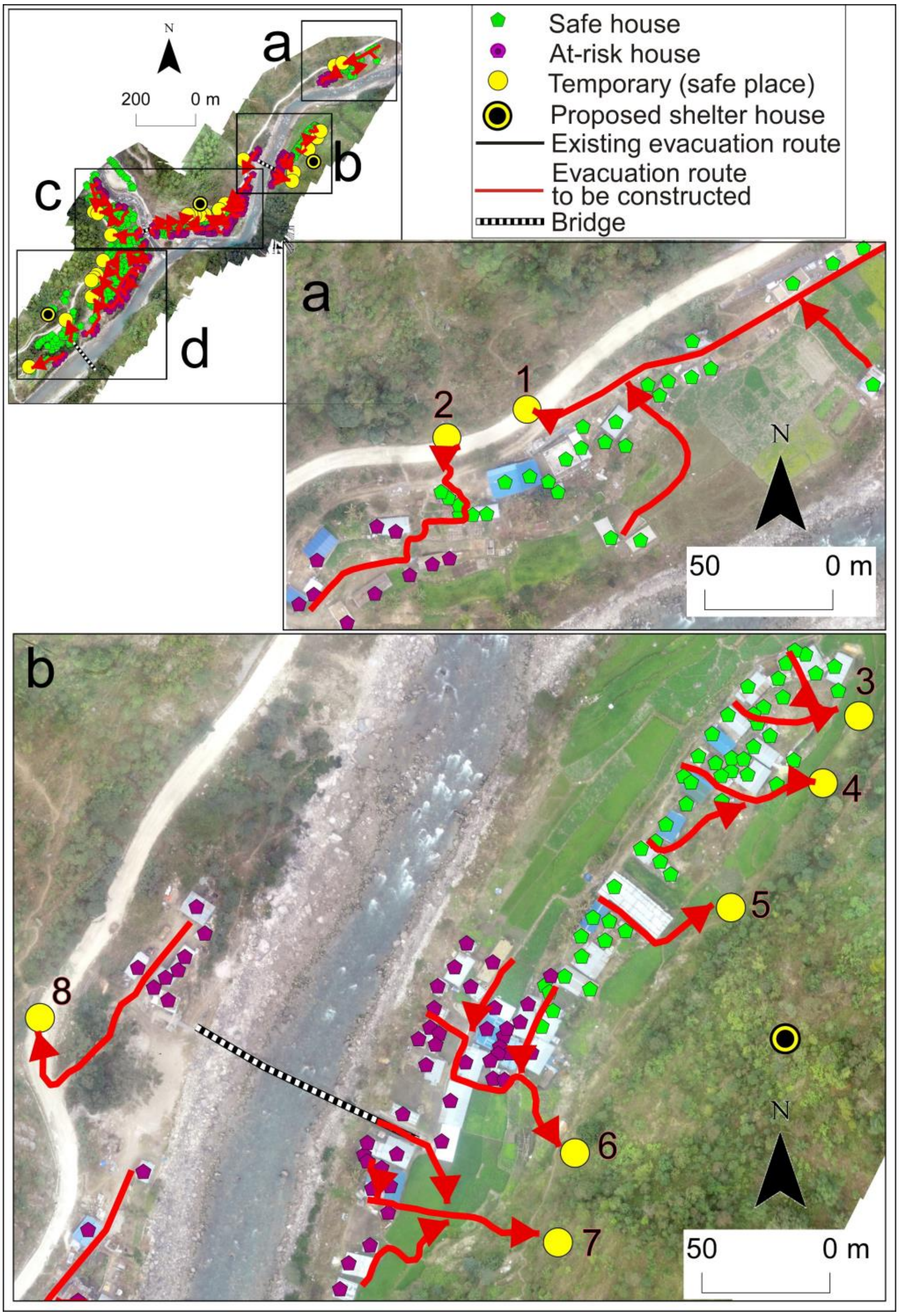

Figure 4.7 Evacuation-route maps in Singati (a and b). The routes in red color represent the proposed evacuation routes. Houses with green color represent the safe houses and dark pink represent at risk houses. The yellow color with black dot represents the proposed shelter house location.

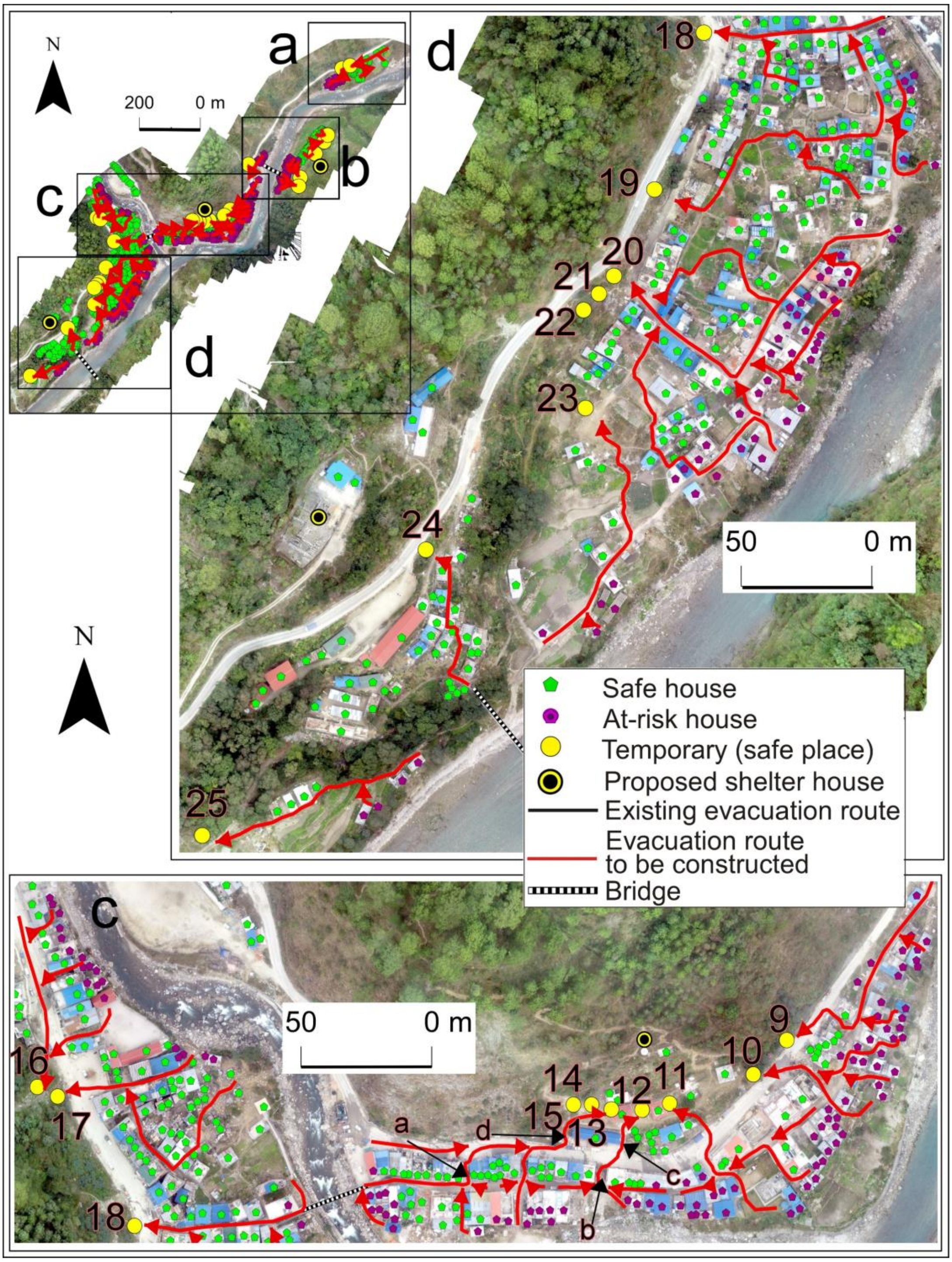

Figure 4.8 Evacuation-route maps in Singati (c and d). The routes in red color represent the proposed evacuation routes. Houses with green color represent the safe houses and dark pink represent at risk houses. The yellow color with black dot represents the proposed shelter house location.

Figure 4.9 Existing evacuation routes in Singati. a, b, c and d are close-up photos of the existing evacuation route. See Figures 4.8 for locations (photos: Bikram Parajuli)

4.3.2.3. **Jagat, Jamune, Bhorle, Kattike and Tamakoshi**

In Jagat one house (population 6) is situated inside the inundated zone so this study suggests one new route for emergency evacuations (Figure 4.10c). The evacuation route situation in Figure 4.10 e (Jamune) is more vulnerable compared to 4.10c. All three houses are situated inside the inundation zone (population 9). This research suggests one evacuation route for three houses. In Figure 4.10 h (Bhorle) one house is inside the inundation zone and I suggest one evacuation route (population 4).

In Kattike (Figure 4.10 J) six houses are in danger with 23 population. At the present only one path to a higher place is available and that path is bent toward the river. Therefore, the study suggests three new routes for emergency evacuation. The residents can use the existing route and the suggested routes for emergency evacuation. Figure 4.10 k (Tamakoshi) all the houses are in danger. The study suggests 2 evacuation routes for 17 people. Our suggested route is for pedestrian use only.

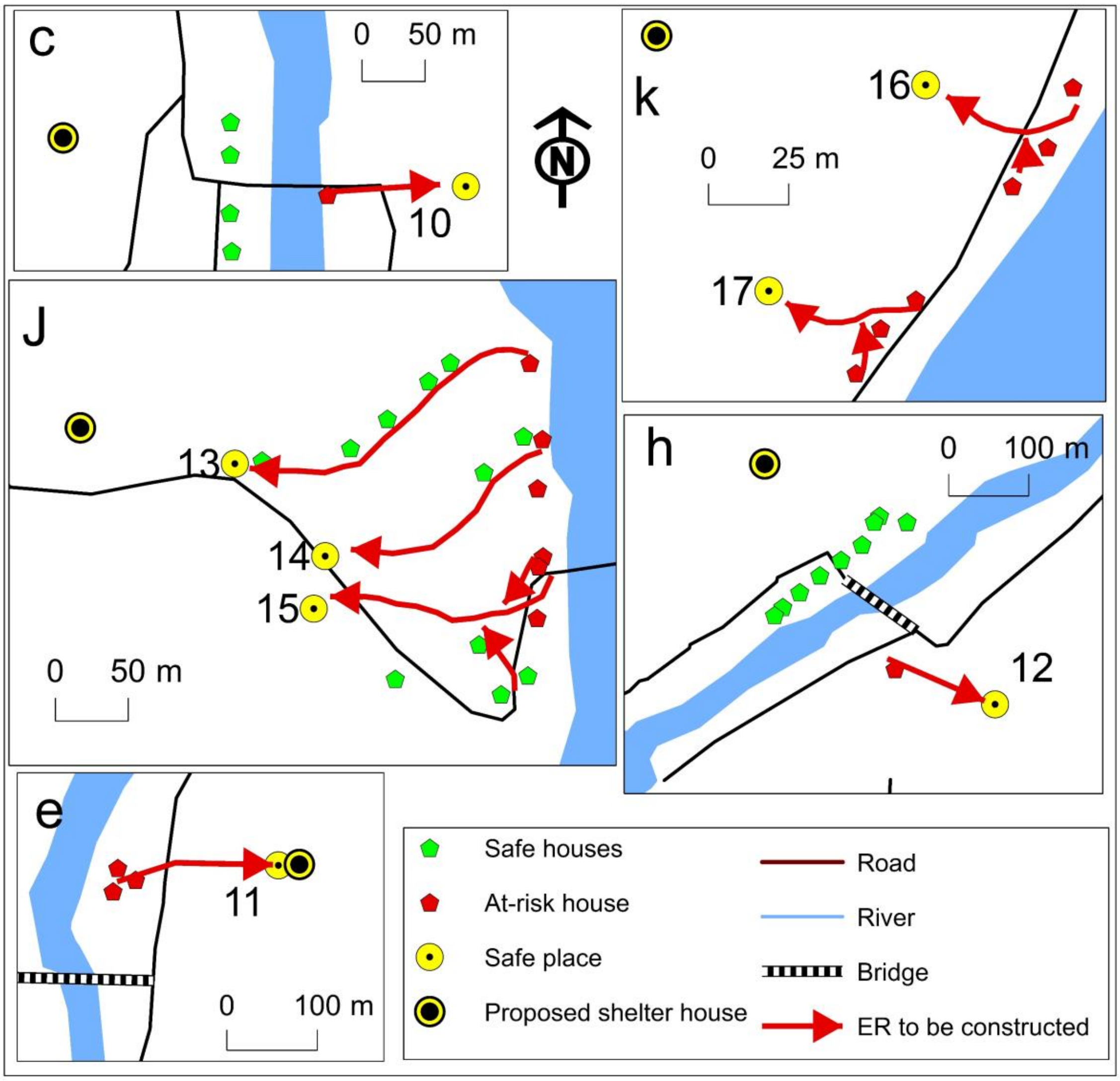

Figure 4.10 Evacuation-route maps in (c) Jagat, (e) Jamune, (h) Bhorle (J) Kattike, and (k) Tamakoshi. The routes in black color represent the existing routes, and the routes in red color represent the proposed evacuation routes. All houses shown are interviewed houses.

4.3.3. **Cross-sectional profiles of emergency evacuation routes in the Tamakoshi River basin (Singati)**

The cross-sectional profiles of the evacuation routes show the elevation from starting point (houses) to the safe place. Cross-sections of four evacuation routes were drawn by the 3D ortho-photograph of Singati. In the evacuation route of Singati, the relative height from households to the safe place (destination) ranges from 14 m to 70 m maximum. The total distance from a household to a safe place is a minimum of 53 m to a maximum of 450 m.

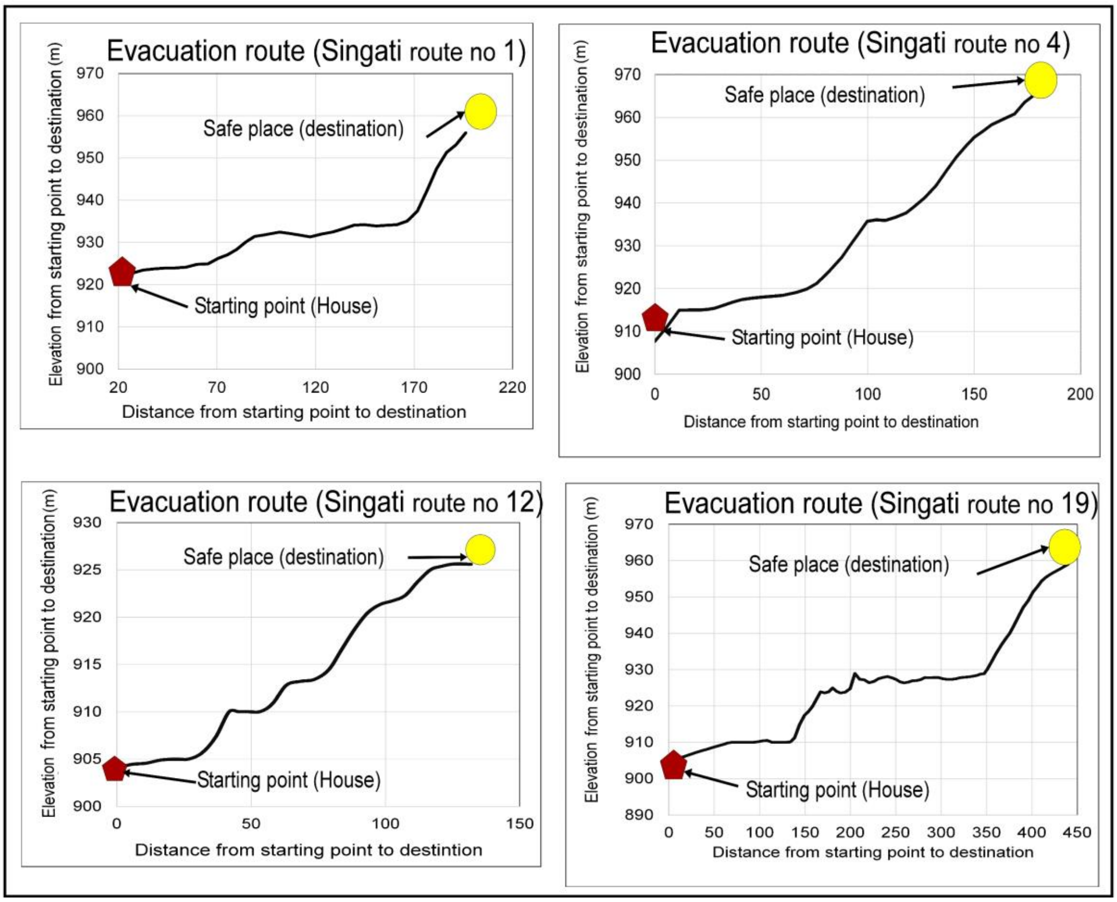

Figure 4.11 Examples of proposed emergency evacuation routes in Singati. Route 1, 4, 12 and 16. See Figure 4.7 and Figure 4.8 for evacuation route number and location.

4.3.4. **Socioeconomic Survey**

The percentages of households with annual incomes categorized as extremely poor were 46.01%, low income 28.83%, lower-middle 12.88%, and upper-middle 12.27%, in altogether 11 settlements (Table 4.2, Figure 4.12). However, no residents from any settlement belonged to the high-income group.

Table 4.2 Classification based on annual income (USD/person) in the eleven settlements.

Household income (USD·yr^{1})	Extreme poor	Low-income	Lower-middle	Upper middle	High income	Total
Gongar	8	0	1	1	0	10
Purano Jagat	18	7	1	2	0	28
Jagat	3	2	0	0	0	5
Manthali	8	0	0	2	0	10
Suri Dobhan	3	1	0	0	0	4
Bhorle	6	3	1	0	0	10
Jamune	3	0	0	0	0	3
Olitar	1	1	2	0	0	4
Singati	24	29	7	6	0	66
Kattike	0	4	6	7	0	17
Tamakoshi	1	0	3	2	0	6
Total	75	47	21	20	0	163
Total %	46.01	28.83	12.88	12.27	0.00	100.00

Source: Field survey in 2016.

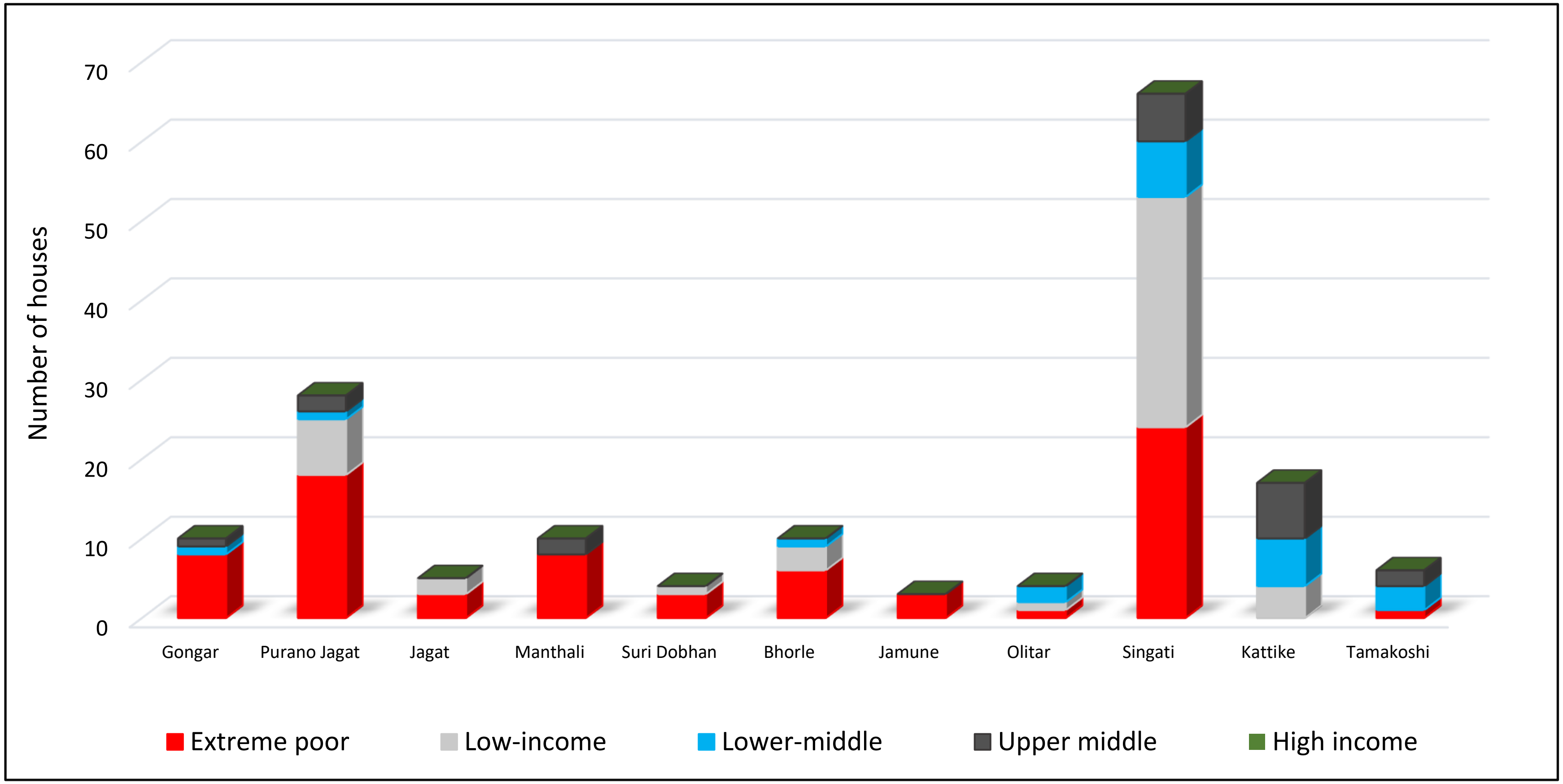

Figure 4.12 Classification based on annual income (USD/person) in the thirteen settlements.

Table 4.3 and Figure 4.13 shows the number and percentage of heads of households engaged in different occupations. The business (small vendor) industry was the most popular, accounting for 50.92% of the total employment of household heads altogether. The number of employees in different offices and small farms, the government office, and in small NGOs is 19.63%. Agriculture-based households varied from 15.95%. Recently remittance is another source of income out there. It has provided a sustainable form of income for 5.52% of households. Labor-related occupations were 4.29% of the total household in all areas. The Pension is another source of income for living. It contributes 3.68% of the household's income.

Table 4.3 Major occupations of the household heads.

Occupation	Agriculture	Business	Employee	Pension	Labor	Remittance	Total
Gongar	0	7	2	1	0	0	10
Purano Jagat	8	10	9	0	0	1	28
Jagat	2	3	0	0	0	0	5
Manthali	4	2	1	0	1	2	10
Suri Dobhan	0	4	0	0	0	0	4
Bhorle	4	6	0	0	0	0	10
Jamune	2	0	0	1	0	0	3
Olitar	1	0	3	0	0	0	4
Singati	3	42	7	4	4	6	66
Kattike	2	3	10	0	2	0	17
Tamakoshi	0	6	0	0	0	0	6
Total	26	83	32	6	7	9	163
Total %	15.95	50.92	19.63	3.68	4.29	5.52	100

Source: Field survey in 2016

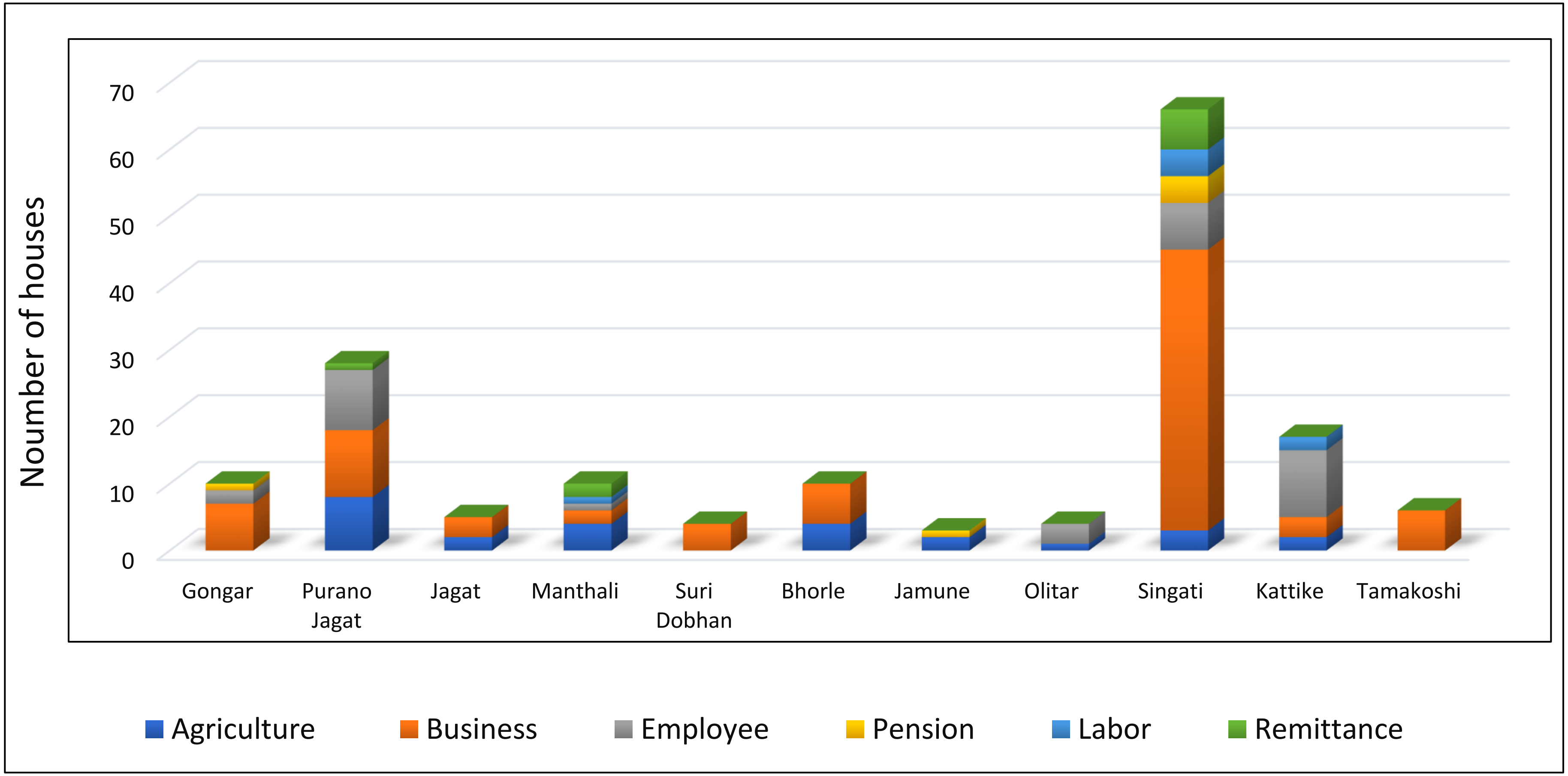

Figure 4.13 Major occupation of the household heads.

The percentage of immigration period within 20 years period varied greatly: Purano Jagat and Singati maintained the highest number 17 and 32 houses respectively (Table 4.4 and Figure 4.14). Altogether, 42.33% of the residents within the study area had migrated within the last 20 years. The majority of the population of the study area is local or non-migrated people (57.67%). The majority of migrants came from nearby districts intending to survive off of the river's resources, and they were generally uneducated and unskilled laborers.

Table 4.4 Migration status of the study area's residents.

Migration Status	Migrated	Non migrated	Total
Gongar	8	2	10
Purano Jagat	17	11	28
Jagat	1	4	5
Manthali	0	10	10
Suri Dobhan	2	2	4
Bhorle	2	8	10
Jamune	1	2	3
Olitar	2	2	4
Singati	32	34	66
Kattike	1	16	17
Tamakoshi	3	3	6
Total	69	94	163
Total %	42.33	57.67	100.00

Source: Field survey in 2016.

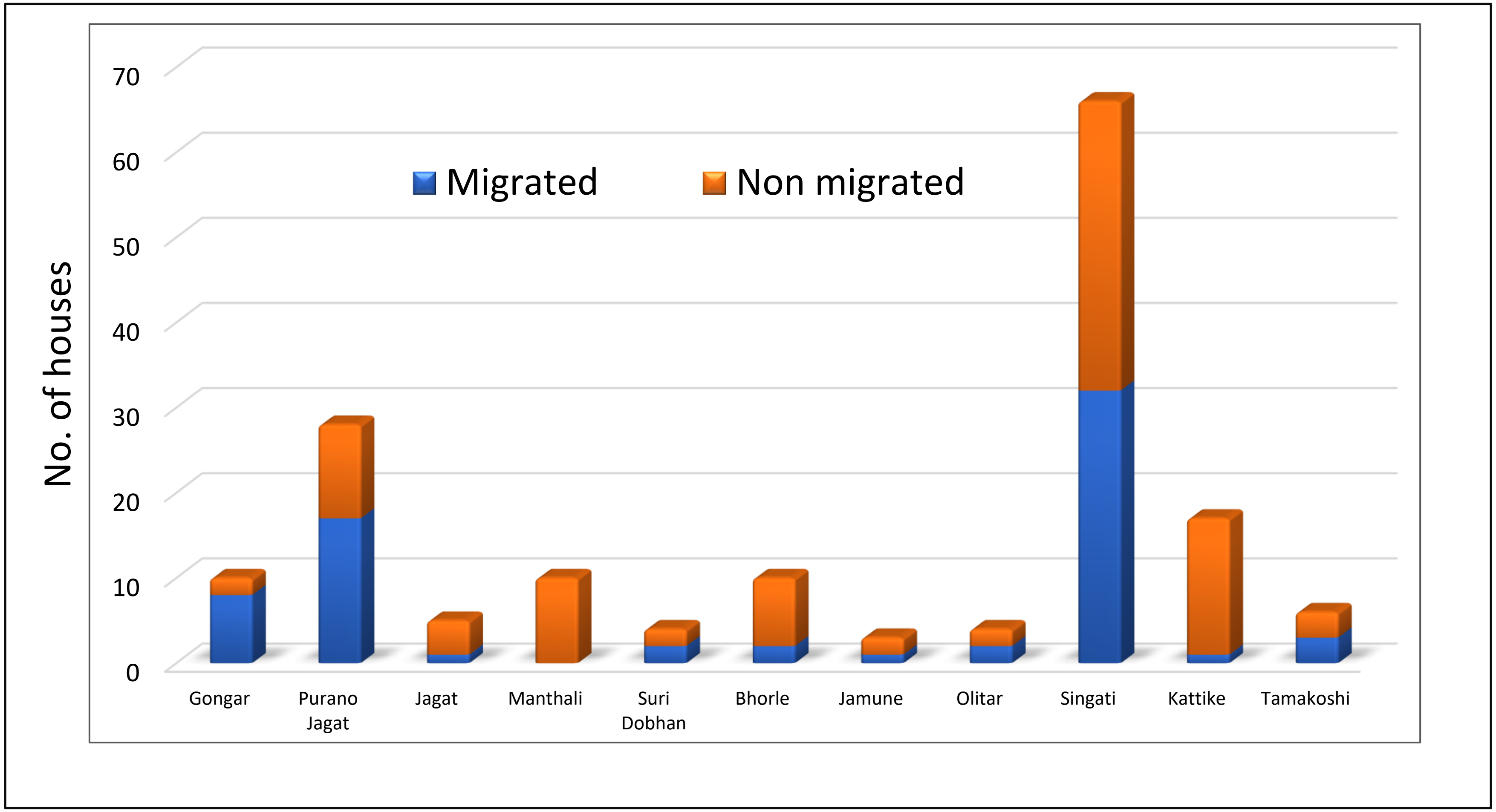

Figure 4.14 Migration status of the study area's residents.

Table 4.5 shows in total 38.65% of people are illiterate, 13.50% are literate and 11.04% of people got a primary level education. Only 13.50% of people finished lower secondary education. Similarly, 12.88% of people obtain secondary-level education. Altogether 4.91% of people got a higher secondary education. Similarly, 2.45% of people are graduates. lastly, only 3.07% of the people succeed to get a master's degree.

Table 4.5 Education status of the respondent.

Education status of respondent	Illiterate	Literate	Primary	Lower secondary	Secondary	Higher secondary	Bachelor	Master	Total
Gongar	3	-	4	2	1	-	-	-	10
Purano Jagat	15	7	1	2	2	1	-	-	28
Jagat	3	-	-	-	2	-	-	-	5
Manthali	7	-	3	-	-	-	-	-	10
Suri Dobhan	2	1	-	2	-	-	-	-	5
Bhorle	2	3	-	3	2	-	-	-	10
Jamune	3	-	-	-	-	-	-	-	3
Olitar	1	1	2	-	-	-	-	-	4
Singati	25	3	8	13	10	4	2	1	66
Kattike	0	5	-	-	2	3	2	4	16
Tamakoshi	2	2	-	-	2	-	-	-	6
Total	63	22	18	22	21	8	4	5	163
Total %	38.65	13.50	11.04	13.50	12.88	4.91	2.45	3.07	100.00

Source: Field survey in 2016.

4.4. Discussion

4.4.1. Inundation and Evacuation Routes

The inundation maps (Figures 4.2–4.5) revealed that many houses are situated near the riverbank and in the estimated inundation zone. The situation was similar in Gongar, Singati, Jagat, Bhorle, Jamune, Kattike, and Tamakoshi (Table 4.6). Nearer from the river in high risk for inundation. In Jagat 20%, Bhorle 10%, Singati 30.3%, Kattike 35.3% houses are located in the inundation zone. In Jamune and Tamakoshi 100% of houses are situated in the inundation zone. Notably, more houses fall under the at-risk category in Singati.

Despite such high rates of at-risk houses in the six settlements, the current routes that can be used for evacuation are narrow, located on steep slopes, and their number was limited, as described earlier. Therefore, increasing the evacuation routes is strongly suggested as shown in Figures 4.6, 4.7, 4.8, and 4.10. The population density of Singati and Gongar is relatively high, and thus, adequate evacuation routes must be prioritized for the safety of these 326 people (interviewed houses). However, there are many other houses (non-interviewed) and approximately >1000 people living inside the inundation zone. At present, none of the evacuation routes has streetlights, which makes evacuation extremely difficult at night. Installing streetlights on the routes is strongly suggested.

In Jamune and Tamakoshi houses are entirely in the inundation zone. If a flood were to occur, the current evacuation routes are insufficient for these at-risk age groups to use. Thus, for all six areas, establishing adequate evacuation routes and relocating schemes must be prioritized among other short-term and long-term strategies, respectively.

Table 4.6 Safe and potentially inundated houses by settlement.

Location	Safe	%	Inundation	%	Total	%
Gongar	10	100.0	-	-	10	6.1
Purano Jagat	28	100.0	-	-	28	17.2
Jagat	4	80.0	1	20.0	5	3.1
Manthali	10	100.0	-	-	10	6.1
Suri Dobhan	4	100.0	-	-	4	2.5
Bhorle	9	90.0	1	10.0	10	6.1
Jamune	-	0.0	3	100.0	3	1.8
Olitar	4	100.0	-	-	4	2.5
Singati	46	69.7	20	30.3	66	40.5
Kattike	11	64.7	6	35.3	17	10.4
Tamakoshi	-	-	6	100.0	6	3.7
Total	126		37		163	100.0

Source: Field survey in 2016

Table 4.7 shows the relationship between houses (interviewed and non-interviewed houses) and horizontal distance to the riverbank (medians and IQRs). In Singati, inundation households existed closer to the river and it is statically significant that near the river is riskier (*p*<0.001).

Table 4.7 Safe/Inundation houses and horizontal distance from the riverbank (interviewed houses) in Singati.

Singati (All house)	Houses	Median	IQR		Mann-Whitney Test
Inundation	37	18.95	14.29	31.62	p=0.001
Safe	126	47.19	33.44	78.94	

Source: Field survey in 2016

4.4.2. **Socioeconomic Survey**

Based on the results of the socio-economic survey (interview survey), statistical relations between education status and occupation factors were examined via correlation coefficient analyses (Table 4.8). Results showed that the majority of the population are illiterate and they choose agriculture by occupation. There are very few people who pursue a master's degree. Business, agriculture, and employee is the major occupation in this area. Occupation of labor, pension, and remittance are comparatively lesser than others. The correlation between education and occupation is significantly correlated ($p<0.002$).

Table 4.8 Relationship between education status and occupation.

Education status	Agriculture	Business	Employee	Pension	Labor	Remittance	Total	Chi-Square Test
Illiterate	18	29	5	4	3	4	63	
Literate	4	10	5	0	1	2	22	
Primary	2	8	4	1	0	3	18	
Lower Secondary	0	17	3	1	1	0	22	
Secondary	1	15	2	0	1	2	21	p=0.002
Higher Secondary	0	2	4	0	1	1	8	
Bachelor	1	1	2	0	0	0	4	
Master	0	0	5	0	0	0	5	
Total	26	82	30	6	7	12	163	

Source: Field survey in 2016

Table 4.9 shows the relationship between per capita income and education status. Income of illiterate people is less. Income is gradually increasing with the education status. Mostly low-income peoples are illiterate based on the interviewed survey. Educated people’s incomes are gradually higher. Surprisingly, some secondary-level people have a high level of income compared to highly educated people. Therefore, the correlation between education and income is significantly not correlated ($p<0.219$).

Table 4.9 Relationship between education status and income (yearly).

Education status	Number	Mean Yearly Income	Income Standard Deviation	ANOVA
Illiterate	63	402.83	499.06	p=0.219
Literate	22	728.62	1139.39	
Primary	18	507.93	454.80	
Lower Secondary	22	823.91	802.84	
Secondary	21	1687.24	4453.52	
Higher Secondary	8	865.00	343.14	
Bachelor	4	937.50	579.33	
Master	5	1220.00	614.00	
Total	163	741.59	1736.21	

Source: Field survey in 2016

Table 4.10 shows the relationship between household income status, and occupation of the people interviewed. In total 26 households' income belongs to agriculture and their income is low (430$ per year) compare to the business (mainly retail) category. In business (82) and employee (30) category shares the higher income. The share of pension is very low (180$/year). In total 7 households' major source of income was labor. Recently many people are working outside of the country so remittance shares 12 houses (880$/year). Correlation coefficients were computed among the two settlements based on income and occupation (Table 4.10). The correlation between occupation and income is statistically not significant ($p<0.839$).

Table 4.10 Relationship between occupation status and income (yearly).

Occupation	Number	Mean Yearly Income	Standard Deviation	ANNOVA
Agriculture	26	430.46	1059.41	p=0.839
Business	82	870.54	2326.92	
Employee	30	766.27	592.04	
Pension	6	180.67	127.01	
Labor	7	522.86	387.76	
Remittance	12	880.83	617.74	
Total	163	741.59	1736.21	

Source: Field survey in 2016

4.5. Chapter conclusions

The inundation maps created in this study show that the Gongar, Singati, Jagat, Bhorle, Jamune, Kattike, and Tamakoshi are highly susceptible to future flooding. In Gongar 3 houses (non-interviewed), 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. 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 ($p<0.839$).

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. Establishing adequate evacuation routes and shelter houses is the most pressing need. It is suggested that government agencies and other authorities prepare an adequate plan that targets the impoverished residents of the inundation zone, as they cannot afford safe lands for relocation.

Chapter 5 General discussion

5.1. Disaster and Social Parameters

Identification of evacuation routes plays an important role in emergency safety management for natural disasters (Bi et al., 2019). Evacuation route planning minimizes the time to evacuate the vulnerable population and it is very challenging for the authorities to prepare for a disaster with limited resources (Kim et al., 2007). Efficient tools are needed to identify routes and schedules to evacuate affected populations to safety in the event of natural disasters. Challenges arise during evacuations due to the spread of people over space and time and the multiple paths that can be taken to reach them; key assumptions such as stationary ranking of alternative routes and optimal substructure are violated in such situations (Shekhar et al., 2012). Techniques and models have been developed to simulate the evacuation of people living near the affected area, with the main objective of identifying the problems that can happen at the moment of evacuation (Campos et al., 2012). These problems can be increasing if there are no proper routes for evacuation and it contributes to increasing the time of evacuation and the number of injuries. Our suggested evacuation route allows the identification of the best possible independent evacuation routes from a potential disaster area to a temporary safe place. The applied methods of this research are based on shortest distance, straight route as much as possible and try to avoid intersection points among the different routes. However, avoiding intersections completely is impossible for the area where houses are so congested and existing routes are limited.

An evacuation alert is communicated to the population, who makes a decision to evacuate or not depending on their perception of danger (Stepanov et al., 2009).

5.1.1. Seti River Basin, Kaski District

In Kaski, (Table 5.1) 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 (Table 5.1). 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 ($p<0.504$).

Table 5.1 Relationship between safe/to be inundated to other factors in Masinabagar, Laltinbazar and KI-sing Pokhara, Kaski.

		Safe		To be inundated		Total		Chi-Square test
		n	%	n	%	n	%	
	n	407		493		900		
House type	Other	4	0.98	6	1.22	10	1.11	p<0.001
	Permanent	396	97.30	342	69.37	738	82.00	
	Semi-permanent	7	1.72	144	29.21	151	16.78	
	Temporary	-	0.00	1	0.20	1	0.11	
Disaster preparedness training	Government	10	2.46	5	1.01	15	1.67	p<0.001
	INGO	-	0.00	16	3.25	16	1.78	
	NGO	8	1.97	21	4.26	29	3.22	
	No idea	346	85.01	382	77.48	728	80.89	
	Others	43	10.57	69	14.00	112	12.44	
Knowledge of disaster preparedness training	No	302	74.20	95	19.27	397	44.11	p=0.001
	Yes	105	25.80	398	80.73	503	55.89	
Well prepared for disaster	No	302	74.20	95	19.27	397	44.11	p<0.001
	Yes	105	25.80	398	80.73	503	55.89	
disaster preparedness	No	144	35.38	85	17.24	229	25.44	p<0.001
	Yes	263	64.62	408	82.76	671	74.56	
72-hour supply kit	No	278	68.30	372	75.46	650	72.22	p=0.02
	Yes	129	31.70	121	24.54	250	27.78	
Safe site (near house)	No	300	73.71	121	24.54	421	46.78	p<0.001
	Yes	107	26.29	372	75.46	479	53.22	
Evacuate Safe site (practice/regular drill)	No	402	98.77	490	99.39	892	99.11	p=479
	Yes	5	1.23	3	0.61	8	0.89	
knowledge about Hazard Map	No	407	100.00	491	99.59	898	99.78	p=0.504
	Yes	-	0.00	2	0.41	2	0.22	

Source: Field survey 2019

Table 5.2 highlighted that almost 80 % of extremely poor, 82.13% of low income, 87.50% lower-middle, and 100 % upper-middle households were found to have no idea about disaster preparedness of any kind. The government of Nepal was the major entity responsible to disseminate the information about the disaster followed by NGOs and INGO. only 1.67 % of the household received information regarding disaster preparedness from the government of Nepal while a combined 5% of the household received it from NGOs and INGO. A total of 490 extremely poor households have not received any disaster training. Therefore almost 80% of extreme don't have any idea regarding preparedness. 37.66% are extremely poor, 37.68% low income, 52.78% lower-middle, and surprisingly 100% upper middle people don't have any knowledge of disaster preparedness training. Therefore, the correlation between income group and disaster preparedness is not statistically significant (p<0.406). Regarding the knowledge of disaster preparedness training, 384 (62.34) extremely poor families know about it. Similarly, 129 (62.32%) low-income families, and 34 (47.22%) families have an understanding of preparedness training although they didn't get any (P=0.003). however, 100% of the upper-middle family doesn't know about it.

Statistically, correlated data show that 59.25% are extremely poor, 57.97% are low-income and 25% of the lower-middle-income families are well prepared for the flood disaster. Although 40.75% are extremely poor, 42.03% are low-income and 75% of the lower-middle-income families have not prepared for any disasters (p<0.001).

After the 2012 flash flood, some NGOs and INGO have distributed relief material including a 72-hour emergency kit. Therefore, 72.24 % are extremely poor, 71.50% are low-income and 72.22% of the lower-middle-income families carry a basic emergency kit. In the context of knowing a safe site near the house, 43.02 % are extremely poor, 44.93% are low-income and 80.56% of the lower-middle-income families are not aware of it (p<0.001).

For the proper evacuation regular drill is the key component but in the research area 99.19% are extremely poor, 98.55% are low income and 100% of the lower-middle-income families had never practiced. Similarly, 99.68% of extremely poor, 100% low income, and 100% of lower-middle-income families have no idea about the hazard map.

Table 5.2 Relationship between income level to other parameters in Masinabagar, Laltinbazar, and KI-sing Pokhara, Kaski.

		Extreme poor		Low income		Lower-middle		Upper middle		High income	Total		Chi-Square test
		n	%	n	%	n	%	n	%	n			
	n		616	207			72	5		-	900		
House type	Other	8	1.30	2	0.97	-	0.00	-	0.00	-	10	1.11	p=0.025
	Permanent	493	80.03	168	81.16	72	100.00	5	100.00	-	738	82.00	
	Semi-permanent	114	18.51	37	17.87	-	0.00	-	0.00	-	151	16.78	
	Temporary	1	0.16	-	0.00	-	0.00	-	0.00	-	1	0.11	
Disaster preparedness training from	Government	11	1.79	3	1.45	1	1.39	-	0.00	-	15	1.67	p=0.406
	INGO	16	2.60	-	0.00	-	0.00	-	0.00	-	16	1.78	
	NGO	20	3.25	9	4.35	-	0.00	-	0.00	-	29	3.22	
	No idea	490	79.55	170	82.13	63	87.50	5	100.00	-	728	80.89	
	Others	79	12.82	25	12.08	8	11.11	-	0.00	-	112	12.44	
knowledge of disaster preparedness training	No	232	37.66	78	37.68	38	52.78	5	100.00	-	353	39.22	p=0.003
	Yes	384	62.34	129	62.32	34	47.22	-	0.00	-	547	60.78	
Well prepared for disaster	No	251	40.75	87	42.03	54	75.00	5	100.00	-	397	44.11	p<0.001
	Yes	365	59.25	120	57.97	18	25.00	-	0.00	-	503	55.89	
72-hour supply kit	No	445	72.24	148	71.50	52	72.22	5	100.00	-	650	72.22	p=0.015
	Yes	171	27.76	59	28.50	20	27.78	-	0.00	-	250	27.78	
Safe-site (near the house)	No	265	43.02	93	44.93	58	80.56	5	100.00	-	421	46.78	p<0.001
	Yes	351	56.98	114	55.07	14	19.44		0.00	-	479	53.22	
Evacuate Safe site (practice/regular drill)	No	611	99.19	204	98.55	72	100.00		100.00	-	892	99.11	p=0.689
	Yes	5	0.81	3	1.45	-	0.00		0.00	-	8	0.89	
Knowledge of Hazard Map	No	614	99.68	207	100.00	72	100.00		100.00	-	898	99.78	p=0.820
	Yes	2	0.32	-	0.00	-	0.00		0.00	-	2	0.22	

Source: Field survey 2019

Table 5.3 present the correlation of education factors to other disaster parameters. It shows that almost 85 % of illiterate, 67% of literate, 46% primary level, 86% lower secondary level, 76% secondary level, 52% higher secondary level, and 56% bachelor level's house is permanent type. For some reason, they don't follow the government rule and illegally encroach the public property to build permanent to semi-permanent houses (p<0.001).

The majority of the illiterate people (549 families) did not get any preparedness training. Few literates and educated people receive preparedness training from NGOs. Although some of them understand the preparedness training because of the TV and radio. Preparedness for the disaster in the illiterate group has less compared to high educated group (p<0.001).

Similarly, 71% illiterate, 56% literate, 85% primary level, 63% lower secondary, 85% secondary level, 61% higher secondary level, and 78% bachelor level education group don't have any access to emergency supply kit (p<0.001).

Illiterate to literate almost all groups think they know the safe place outside of the house (p<0.001). In total, 187 households didn't have livestock, 30 families lost their livestock, and 66 households marked their livestock as safe. The Chi-square test shows a value less than 0.001 meaning the livestock and income of the households are highly correlated and the result is significant. Similarly, 227 households had no idea about disaster preparedness training while 35, 5, and 7 households had gone through government, INGO, and NGO disaster preparedness training respectively. Additionally, 9 households had taken disaster preparedness training from other different agencies. The chi-square test shows that the value is equivalent to 0.001 depicting disaster preparedness training correlates with income. Lastly, knowledge about the safe site also shows significance with a chi-square value of 0.001. Altogether 149 households had no idea knowledge about safe sites while 134 were aware of safe sites.

Human loss does not seem to be correlated with income as the Chi-square test displays a value of more than 0.005. Eight people died, 15 people were injured and 260 people were marked safe. Similarly, readiness doesn’t show significance with income as the chi-square test results in 0.035. Only 31 households were found to be ready whereas 252 families were not ready. Similarly, supply kit, evacuation, and discussion are also not correlated with income. Twenty-eight households were supplied with the kit and had discussions whereas 255 were empty-handed and went through no discussion. Seven families were evacuated while 276 were left unattended. Moreover, the meeting point outside doesn’t show any correlation as the value is higher than 0.005. Forty-six households had meeting points outside and 276 did not have the meeting points outside. Surprisingly, only 3 households had an idea about the hazard map out of 283 people. Education status didn't play any impactful role in getting information about hazard map knowledge.

Table 5.3 Relationship between education factor to other parameters in Masinabagar, Laltinbazar, and KI-sing Pokhara, Kaski.

		Illiterate		Literate		Primary		Lower Secondary		Secondary		Higher Secondary		Bachelor		Masters	Total		Chi-Square test
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	n	%	
	n	671		9		13		57		118		23		9		0	900		
House type	Other	8	1.19	0	0.00	0	0.00	0	0.00	2	1.69	0	0.00	0	0.00	0	10	1.11	p=0.001
	Permanent	570	84.95	6	66.67	6	46.15	49	85.96	90	76.27	12	52.17	5	55.56	0	738	82.00	
	Semi-permanent	92	13.71	3	33.33	7	53.85	8	14.04	26	22.03	11	47.83	4	44.44	0	151	16.78	
	Temporary	1	0.15	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	1	0.11	
Disaster preparedness training from	Government	10	1.49	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	11.11	0	11	1.22	p=0.518
	INGO	12	1.79	0	0.00	1	7.69	2	3.51	3	2.54	1	4.35	0	0.00	0	19	2.11	
	NGO	22	3.28	1	11.11	0	0.00	3	5.26	1	0.85	1	4.35	0	0.00	0	28	3.11	
	No idea	549	81.82	6	66.67	1	7.69	46	80.70	1	0.85	16	69.57	7	77.78	0	626	69.56	
	Others	78	11.62	2	22.22	9	69.23	6	10.53	95	80.51	5	21.74	1	11.11	0	196	21.78	
Knowledge about disaster preparedness training	No	288	42.92	2	22.22	2	15.38	15	26.32	18	15.25	5	21.74	4	44.44	0	334	37.11	p=0.009
	Yes	383	57.08	7	77.78	10	76.92	42	73.68	82	69.49	18	78.26	5	55.56	0	547	60.78	
Discuss preparedness	No	166	24.74	1	11.11	3	23.08	11	19.30	36	30.51	5	21.74	7	77.78	0	229	25.44	p=0.009
	Yes	505	75.26	8	88.89	10	76.92	46	80.70	82	69.49	18	78.26	2	22.22	0	671	74.56	
72-hour supply kit	No	477	71.09	5	55.56	11	84.62	36	63.16	100	84.75	14	60.87	7	77.78	0	650	72.22	p<0.001
	Yes	194	28.91	4	44.44	2	15.38	21	36.84	18	15.25	9	39.13	2	22.22	0	250	27.78	
Safe site (near the house)	No	479	71.39	8	88.89	10	76.92	40	70.18	93	78.81	20	86.96	7	77.78	0	657	73.00	p=0.342
	Yes	192	28.61	1	11.11	3	23.08	17	29.82	25	21.19	3	13.04	2	22.22	0	243	27.00	
Evacuate Safe site (practice/regular drill)	No	425	63.34	4	44.44	8	61.54	29	50.88	78	66.10	12	52.17	7	77.78	0	563	62.56	p=0.290
	Yes	246	36.66	5	55.56	5	38.46	28	49.12	40	33.90	11	47.83	2	22.22	0	337	37.44	
Knowledge about hazard Map	No	669	99.70	9	100.00	13	100.00	57	100.00	118	100.00	23	100.00	9	100.00	0	898	99.78	p=0.995
	Yes	2	0.30	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	2	0.22	

Source: Field survey 2019

5.1.2. **Tamakoshi River basin, Dolakha**

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 (Table 5.4.).

Table 5.4 Awareness level of evacuation and safe site in Dolakha.

Evacuate to safe site	Yes	No	Total
Gongar	-	10	10
Purano Jagat		28	28
Jagat	1	4	5
Manthali		10	10
Suri dobhan		4	4
Bhorle		10	10
Jamune		3	3
Olitar		4	4
Singati	2	64	66
Kattike	3	14	17
Tamakoshi		6	6
Total	6	157	163
Total %	3.7	96.3	100

Source: Field survey in 2016

Table 5.5 shows that 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 ($p<0.170$).

Table 5.5 Relationship between education to livestock farming in Dolakha (11 settlements).

Education	Livestock				Chi Square test
	No livestock	Loss	Safe	Total	
Illiterate	28	7	28	63	
Literate	14	4	4	22	
Primary	9	4	5	18	
Lower Secondary	17	1	4	22	
Secondary	12	1	8	21	p=0.170
Higher Secondary	3	1	4	8	
Bachelor	2	0	2	4	
Master	2	2	1	5	
Total	87	20	56	163	

Source: Field survey in 2016

In the earthquake, 2015 hit Dolakha, 96.94 % of the total population of the district was marked to be safe indicating the extent of the human loss was minimal after the earthquake. Around 1.6% of the population were injured while 2 % of the population lost their life. Out of 14 deaths, Kattike rural municipality suffered the most with 5 deaths, Singati had 3 deaths, Purano Jagat, Jagat, and Bhorle with 1 death each while no deaths were recorded for the Manthali, Suri Dobhan, Jamune and Olitar rural municipalities. Singati accounted for the most cases of injuries (9) (Table 5.6).

Table 5.6 Human loss, injuries, and safe after the 2015 earthquake in Dolakha.

Human Loss / Injury	Death	Injured	Safe	Total
Gongar	-	2	59	61
Purano Jagat	1	-	138	139
Jagat	1	-	24	25
Manthali	-	1	47	48
Suri dobhan	-	1	20	21
Bhorle	1	-	43	44
Jamune	-	1	7	8
Olitar	-	-	18	18
Singati	3	9	253	265
Kattike	5	-	56	61
Tamakoshi	-	-	17	17
Total	11	14	682	707
Total %	1.6	2.0	96.5	100.0

Source: Field survey in 2016

In total (Table 5.7), 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.

Also, table 5.7 highlighted that almost 37 of the extremely poor, 27 of low income, 13 of lower-middle, and 10 of upper-middle households have no livestock. Extremely poor 12, low-income 2, lower-middle 4, and upper-middle 2 families lost their livestock during the earthquake 2015 (p<0.328). The extremely poor people the majority group was found to have no idea about disaster preparedness of any kind.

The government of Nepal was the major entity responsible to disseminate information about the disaster followed by NGOs and INGO. Only 35 of the household received information regarding disaster preparedness from the government of Nepal while a combined 6 of the household received it from NGOs and INGO. In total 113 households didn't get any preparedness training. 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.

Table 5.7 Relationship between Income status to other social factors in the Tamakoshi River basin (11 settlements).

		Extreme poor	Low-income	Lower-middle 1026-3995	Upper middle 3996-12375	High income >12375	Total	Chi-Square test
	Number	75	49	21	18	0		
Livestock	No livestock	37	27	13	10	0	87	p=0.328
	Loss	12	2	4	2	0	20	
	Safe	26	20	4	6	0	56	
Disaster preparedness training from	Government	16	15	3	1	0	35	p<0.001
	INGO	0	0	0	2	0	2	
	NGO	2	2	0	0	0	4	
	No idea	57	30	15	11	0	113	
	Others	0	2	3	4	0	9	
Well prepared for disaster	Yes	12	12	3	3	0	30	p=0.621
	No	63	37	18	15	0	133	
72 hr. supply kit	Yes	9	10	2	2	0	23	p=0.498
	No	66	39	19	16	0	140	
Meeting point outside the home	Yes	22	12	4	5	0	43	p=0.795
	No	53	37	17	13	0	120	
Evacuate (regular drill)	Yes	0	4	0	2	0	6	p=0.026
	No	75	45	21	16	0	157	
The safe site near the house	Yes	2	6	7	8	0	23	p<0.001
	No	73	43	14	10	0	140	
knowledge of Hazard Map	Yes	0	1	1	0	0	2	p=0.309
	No	75	49	21	18	0	163	

Source: Field survey in 2016

The temporary shelters were found to be effective for 12.27% of total households but were ineffective for 47.24% of the households. A total of 0.61% of the household did not require any temporary shelter while those provided for 39.88% of the household was not sufficient to accommodate the entire family. Purano Jagat accounts for the highest number of effective households. Singati had in total of 63 households with ineffective and insufficient temporary shelter.

The earthquake had a major impact on the integrity of the structures of the household. 26.98% of the total household were marked with red stickers indicating significant damage to the structure and unsuitable for living. A total of 2.33% of the household were marked with yellow stickers and 24.19% with green stickers. Yellow stickers meant the household needs reinforcement to make it suitable for living while green stickers indicated no further reinforcement was needed. A total of 46.51 % of the total household were not monitored. Out of the total monitored household, Singati, Kattike, and Tamakoshi rural municipalities had a greater number of households with yellow stickers.

Meanwhile, 29.93 % of the total households were deprived of any food support due to the devasting aftermath of the earthquake while 53.37 % of the total households received support for three to six months. A total of 12.27% of the household received support for six to nine months and 9.20 % for more than a year. A mere 1.23% of the household had a surplus of food

A total of 77.91% of the households of the district were destroyed by the earthquake while 21.47% were partly destroyed. Only 0.61% of the household remained intact after the earthquake. Singati rural municipality had the major share of destroyed households. Most of the rural municipalities suffered damage due to earthquakes.

More than 69.33% of the households were found to have no idea about disaster preparedness of any kind. The government of Nepal was the major entity responsible to disseminate information about the disaster followed by NGOs and INGO. A total of 21.47% of the household received information regarding disaster preparedness from the government of Nepal while a combined 3.68% of the household received it from NGOs and INGO. A total of 5.52% of the household got the information from other sources. Singati had the most households (34) without any information regarding disaster preparedness.

Similarly, 16.56% of the household lost their livestock due to the earthquake while 77.30 % of the household had no loss of livestock. A total of 6.13 % of the household had no livestock. Singati rural municipality had the most loss of livestock with 14 houses losing its livestock. Singati also had a major share of safe livestock. A total of 81.60% of the households were not prepared for the disaster that might occur in the future while the remaining 18.40% were prepared for it. Singati and Purano Jagat for the most unprepared rural municipality.

Therefore, 83.44 % of the total surveyed households had no discussion regarding the preparedness for disasters that might occur in the future but the remaining 16.56% had it discussed. Singati had most of the houses having no discussion regarding the disaster. On average 85.89% of the households were not able to receive 72 hours supply kit after the disaster while 14.11% of the household were fortunate enough to get the kit. Singati had most of the houses not receiving the kit after the disaster.

Residents of 96.3% of the houses were not evacuated to a safe site after the incident while the remaining 3.7% were evacuated to the safe site. Singati and Purano Jagat, Gongar, Bhorle, Tamakoshi, and Manthali had the major proportion of the houses not being evacuated to the safe site. More than 98.77% of the houses had no idea about the hazard map while a mere 1.23% had some sort of idea about the map. Singati and Kattike each had one house having an idea about the hazard map while combined 161 houses had no idea.

Of the 14.11% the total household had access to a safe site while 85.89% of the household had no access to a safe site. Kattike had 14 households having access to safe sites whereas Singati had 64 households with no access to safe sites. In total 26.38% of the household had an outside meeting point for an emergency while 73.62% of the household had no outside meeting point during an emergency. Singati had the highest number of households having no outside meeting point for emergency followed by Purano Jagat and Kattike.

Similarly, 4.91% of the households did not receive any kind of compensation from the government and NGO/INGO. A total 10.43% of the houses received compensation of more than 30000 while 39.26% of the houses received compensation between 15000-30000 and 45.40% of houses received compensation of less than 15000. Singati had 52 houses receiving compensation of less than 15000 rupees.

This research identified evacuation routes, and I believe that such routes can save lives when a disaster happens. Evacuation planning is an essential aspect of today's growing initiative for early warning systems in the study area as well as in Nepal Himalaya. A long-term strategy must be established to increase evacuation preparedness during future flooding disasters (Paul J. Smith et al., 2017; LIM et al., 2013).

5.1.3. Proposed Evacuation System

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.

Evacuation planning is an essential part of any disaster response strategy in vulnerable areas (Campos et al., 2012). Initially, flooding risk awareness must be addressed, in addition to the actions required for safety. Local authorities and government agencies should provide the public with proper preparedness and prevention training. Residents must be aware and well trained, including evacuation drill practice, for disaster preparedness. Abarquez and Murshed (2004) stated that preparedness is the ability of the community to avoid the negative impacts of an impending hazard (Abarquez et al., 2004). In the following sub-sections, I have discussed the proposed flooding risk alleviation system in the study area (Figure 5.1).

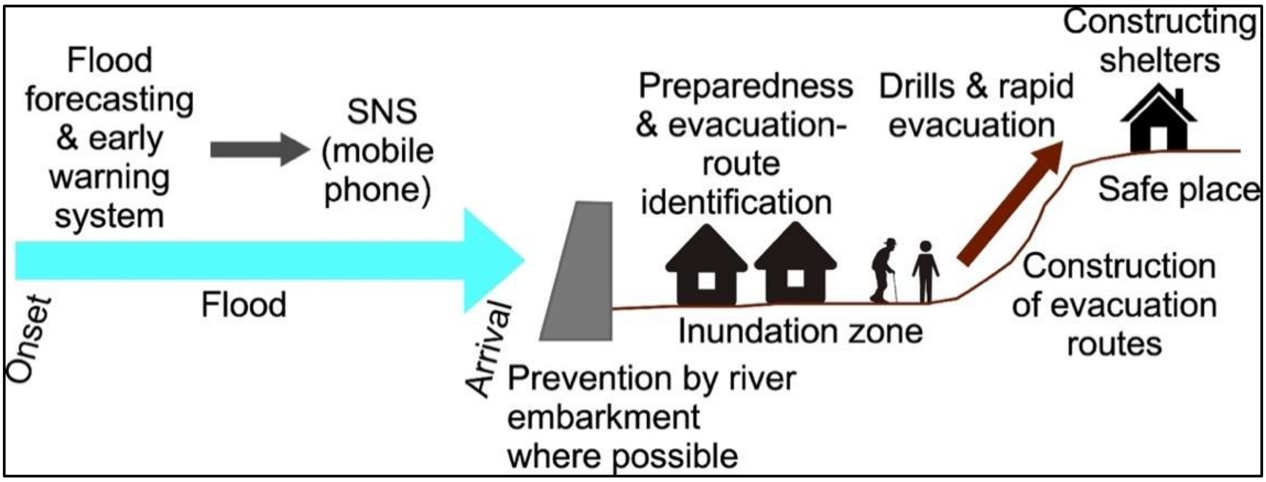

Figure 5.1 Proposed immediate flooding risk alleviation system in the study area.

Proper planning for evacuations is an important part of keeping communities safe from the harm caused by disasters. For that purpose, proper evacuation strategies are essential. Planning for evacuations should occur early and involve local governments and communities. Evacuation planning should factor in key issues such as evacuation routes, shelter facilities, messaging to communities, and risks to safe evacuation. Evacuation plans should be regularly reviewed, where necessary, to ensure that they address all relevant issues. Therefore, this study proposed two categorize plans, i.e., short-term (immediate or maximum 5 years) plan and long-term evacuation (more than 5 years to maximum 10 years) plan for the local government and people (Cabinet Office, 2020).

Both short-term and long-term risk management strategies are equally important (Prenger-Berninghoff et al., 2014). Short-term strategies mean the strategies should implement immediately. A long-term plan considers a strategy to be a broader, more goal- or vision-based agenda, although long-term plan also needs to implement as soon as possible. Short-term and long-term perspectives should be managed within an integrated risk management framework that accounts for both temporary management strategies and permanent preventive measures to reduce the impact of flood hazard processes (Fuchs et al., 2013).

Emergency management or civil protection helps to strengthen a community's capacity to be better prepared for flood hazards and to better respond in case of a disaster strikes. Addressing the short-term perspective also serves long-term planning goals and can, therefore, implement long-term prevention measures. A purposefully applied risk mitigation strategy requires coordination of short-term and long-term mitigation measures and thus effective coordination of emergency management and spatial planning (Prenger-Berninghoff et al., 2013).

In the following sections, I discuss (a) short-term strategies (within 5-year period) for local people and government and (b) long-term strategies (5-to 10-year period) for local government.

5.1.3.1. Short-Term Strategies for Local People

5.1.3.1.1. Emergency plan and regular rehearsal drills

Evacuation planning is an integral part of emergency plans, particularly for regions vulnerable to disasters (Yusoff et al., 2008; Campos et al., 2012). Evacuation is a complex process consisting of several consecutive phases (Campos et al., 2012). The evacuation decision during a flood primarily represents the household’s choice to evacuate or remain in the risk area (Lim et al., 2019). Although superficial, this may appear a simple decision, in practice, it involves a complex set of behavioral and external factors at a particularly critical time. Thus, when flood (especially flash floods) occur, people must make quick decisions to protect themselves and their families, which is most often achieved in a rapid evacuation to a safe place.

Shelters at safe places provide immediate and short-term stay for the victims, help them recover from trauma of a disaster, and provide a base to start the process of rehabilitation (Bashawri et al., 2014; Wagemann, 2017).

5.1.3.1.2. Identifying evacuation routes, preparing for emergency evacuation, and essential kits

Low-risk awareness among the residents living in flood-prone areas is usually considered one of the leading causes of low preparedness, which generates an inadequate response to disasters (Scolobig et al., 2012). This step of spreading awareness should be implemented well before the onset of floods, and locals must be educated about preparedness. Focus group discussions and interview surveys suggested that knowledge of preparedness was nearly zero in the study area. Authorized persons should provide background information regarding risk mitigation and evacuation techniques to help minimize disasters (Marchi et al., 2012).

Timely identification of a safe evacuation route is essential for successful evacuation. The proposed evacuation maps (Figures 3.6, 3.8, 3.9, 4.8, 4.9, and 4.11) help identify building-specific evacuation routes available within the study area to ensure that people reach the nearest safe destination. It is vital to have broad and alternative routes in case of roadblocks. Prior knowledge of the most appropriate evacuation route can help increase the efficiency of evacuation. Authorities in charge of determining safe places or temporary/permanent shelter locations must aid in minimizing the total evacuation time by aiding evacuees to reach their choice of destination via the corresponding route, as pointed out by (Kongsomsaksakul et al., 2005). Injuries can happen during disasters. Therefore, it is important to prepare a basic first-aid kit with items such as sterile gloves, gauze, soap, burn ointment, bandages in a variety of sizes, pain relievers, scissors, and tweezers.

5.1.3.2. **Short-Term Strategies for Local Government**

5.1.3.2.1. Installation of weather and hydrological stations

Nepal is considered one of the most disaster-prone countries in the world. Moreover, apart from flooding, other natural hazards such as earthquakes and landslides pose a recurrent risk to large sections of the population (Smith et al., 2017).

At present, there is one weather station available between Masinabagar and Laltinbazar, which was damaged by the 2012 flood. If water levels rise and flood hazards occur, Masinabagar will be inundated even before getting information. Similarly, in the Tamakoshi river basin, there is no weather station installed. Similarly, large earthquakes in April and May 2015 have loosened the deposits on steep slopes in the Tamakoshi Watershed and the deposits composed of the moraines damming the large volume of lake water of Tsho Rolpa (Khanal, 2015), one of the potentially dangerous glacial lakes in Nepal. These loosened deposits can slide or burst due to monsoon rain as well as further earthquakes in the future.

The installation of a weather station in a proper place near the settlements is required. In addition, a hydrological station for the monitoring water level of the river is needed at an appropriate location. These will be helpful to get scientific data and for early warning as well. Also, careful planning is needed to select the location for establishing weather stations.

5.1.3.2.2. Flood forecasting and early warning system

An early warning system is vital for disaster risk reduction and it is important to allow sufficient time for evacuation (Alias et al., 2020). In particular, timely warnings, communication, and decision-making are critical (Morss et al., 2015). An effective community-based early warning system must use local resources and capacities to prepare effectively and respond to flooding events (Smith et al., 2017). In the study area, installing a low-cost warning system for sustainable use is recommended, and it should be connected to the residents' mobile phones so that they can act quickly. It is essential to understand how people perceive flash flood risks and what influences their response to warning information (Morss et al., 2016b).

People must also understand the importance of flash flood forecasts and early alerts. Accordingly, local authorities should design and establish an upriver weather station with an interconnected early warning system as soon as possible. Appropriate hydrological forecasts can also be used to predict future water levels (Smith et al., 2014). The underlying spontaneity of extreme flooding risks creates an extremely dynamic challenge (Morss et al., 2015). Appropriate, accurate, and timely communication and an early warning system are essential for saving lives.

5.1.3.2.3. Transmission of early warning

Flood warning broadcasts from various information sources are very important for individuals to make evacuation decisions (Busato et al., 2016). Once a flood risk has been detected, the early warning system will provide the first information. However, this may not be enough in some cases. In crisis communication, trust in the source of information is crucial; therefore, disaster broadcasts, such as TV and radio, and their messages should be trusted by the community (Murphy et al., 2014). Recently, a social networking service (SNS) has been thought to be a more effective method of communication. In many developing countries, SNS has become the most important means of communication for flood warnings. Using SNS through a mobile phone would be the most effective and quick way for the people in the study area.

The Nepal Government has already introduced advanced early alarm systems, e.g., in the area of Imja and Tsho Rolpa Glacial lakes for future GLOF events. However, a simple and cost-effective way should be adopted to transmit information. 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, study suggest 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.

In Nepal, mobile coverage and internet connection are available even in remote areas. In 2016, approximately 92% of the population in Nepal had access to a 2G mobile-phone network at the minimum (Statista, 2021). The World Bank publishes mobile-phone subscription data. Based on that, there were 139.4 mobile-phone handsets available in Nepal in 2018 per 100 people (The World Bank, 2021). The research area is an adjoining part of Pokhara city. There is 100% mobile-phone network coverage. Based on the social survey, 98% of the people had a mobile phone handset.

Results of the field survey show that 98.6%, 98.8%, and 99.o % of the 15- to 64-year-olds have mobile-phone handsets in Masinabagar, Laltinbazar, and KI-sing, respectively (Table 5.8). Altogether 98.68 % of 15- to 64-year-old people have a mobile phone. Therefore, an early warning system through mobile phones would be the best solution. Children at school can get assistance from teachers, and their parents can inform them at night. In Masinabagar, Laltinbazar, and KI-sing, all students go to the local community school. Only about one-fourth of the elderly people (> 64 years old) have direct access to early warning through a mobile phone. They are most likely to get assistance from their family members at home, especially at night. However, they need assistance from the community when they are alone during the daytime or live alone.

Having a mobile phone is a necessity rather than a luxury even among the poor in recent days. In Gandaki province (Kaski district lies in Gandaki province), 97.6% of the people in rural areas and 97.7% in city areas have access to mobile phones. The prepaid billing system and the low-priced mobile phone headsets (less than USD 10) are also major factors that have increased its user base.

There is no postpaid system in Nepal. Most mobile companies offer free SIM (Subscriber Identity/Identification Module) cards, low-cost internet data packages, and low-cost voice mail services. The official Nepal Telecom (official service provider) offers the SIM card for NRS 90 (USD 0.80), which comes with NRS 50 (USD 0.45) credit. In total, 88.3% of the poorest people have mobile phones (NPC & CBS 2018;CBS, 2018, 2019, 2020). 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.

Table 5.8 Mobile phone availability by age group in the three settlements.

Settlements	Population	Age group			
		< 15 years old	15-64 years old	> 64 years old	Total
Masinabagar	Total population	843	1368	92	2303
	Population with mobile phone	0	1349	22	1371
	Population without mobile phone	843	19	70	932
	Percentage of population with mobile phone	0.00	98.61	23.91	59.53
Laltinbazar	Total population	688	999	113	1800
	Population with mobile phone	0	987	31	1018
	Population without mobile phone	688	12	82	782
	Percentage of population with mobile phone	0.00	98.80	27.43	56.56
KI-sing	Total population	267	442	77	786
	Population with mobile phone	0	436	18	454
	Population without mobile phone	267	6	59	332
	Percentage of population with mobile phone	0.00	99.00	23.00	58
Total	Total population	1798	2809	282	4889
	Population with mobile phone	0	2772	71	2843
	Population without mobile phone	1798	37	211	2046
	Percentage of population with mobile phone	0.00	98.68	25.18	58.15

Source: Field survey in 2021

Nepal Telecom (NTC) operated new GSM towers in the rural and very remote areas of Dolakha on December 5, 2017. Recently, NTC has been expanding the GSM network in remote areas, to meet mobile coverage in all parts. The company has recently installed a new GSM BTS base station tower in Dadakharka of Dolakha District. It covers Melung Village, Dadakharka, Chinne, Fadke, Sarnthali, GhalDada, Bhedfu of Dolakha and Fulasi, Daduwa, Hariya Chinne of Ramechhap. The mobile tower there benefits more than 4 thousand customers in the area. Customers can not only make a call through their GSM mobile-phone but also can use some internet data on their mobile-phone. Therefore, this study suggests a mobile phone base alarming system for both areas.

5.1.3.2.4. Making safer and wider evacuation routes

Evacuation is one of the important preparedness measures in disaster management, and it requires careful modeling and planning (Lim et al., 2016, Shekhar et al., 2012). For safe evacuations, a proper evacuation route is needed. Evacuation route recommendation plays an important role in emergency safety management, especially for natural disasters (Bi et al., 2019). The evacuation route should be the shortest, and routes to different shelters cannot present intersection points either in order to allow continuous traffic flow and reduce potential accidents (Jamrussri et al., 2018). At present, there is a very narrow, extremely bent, and congested route available (Figures 3.6, 3.8, 3.9, 4.8, 4.9, and 4.11). In the future, evacuation routes should be designed based not only on the shortest traveling distance, but also on the existing population, geomorphological structure, and wider and easy-to-use roads.

5.1.3.2.5. Flood prevention using river embankment

Managing and monitoring natural and artificial river levees are crucial to reducing hydrological risks (Busato et al., 2016). In addition to these processes that enable quick evacuation, installing a river embankment is one of the important strategies to prevent and reduce flood risk. It would not be realistic to install the embankment at every place in terms of budget. However, if a river embankment is installed where the population is concentrated, it would lead to a longer evacuation time.

5.1.3.3. Long-Term Strategies

Evacuations must be planned for safe execution, and those plans should be resourced (anticipating all the resources required to complete a project), implemented, and reviewed. Local governments have an important role in evacuation planning, and they need to consider local capacity and capability to manage the evacuation process. This includes preparing a long-term disaster plan, shelter house, and relocation sites.

5.1.3.3.1. Long-term disaster preparedness plan and policies

Flood disaster plans in developing countries are mostly reactive, responding to prevailing disaster situations (emergency response and recovery) (Tingsanchali, 2012). The reactive response should be changed to a proactive response to increase management effectiveness and reduce loss of life and properties. This study suggests that the plan should address installing weather stations in the settlements.

Government and law-making agencies must establish new disaster plans for the downstream communities. The local authority should make long-term sustainable plans for vulnerable settlements such as Masinabagar, Laltinbazar, and KI-sing. The authority should also implement strict rules and regulations to avoid investment in the construction of buildings and other infrastructure in areas prone to inundation. Landuse guidelines and codes are also essential. The settlement of Gongar has the police station and hydropower facilities. Of the Upper Tamakoshi Hydroelectric Project company. This is the near-complete 456 MW project, the largest hydropower project in Nepal, and the project that will generate a power output equivalent to two-thirds of Nepal's current power generation. Therefore, maintaining and protecting the facilities are important not only for Singati but also for the country of Nepal.

5.1.3.3.2. Prohibition of construction of new buildings

Riverside communities often face situations that require creative short and long-term housing plans. Effectively moving survivors into post-disaster housing is a critical step toward long-term recovery. However, most parts of the country do not have disaster housing plans. While some housing programs were federally introduced not at the national level planning for disaster, housing should occur at all levels of government before a disaster strike. Recently, the local government introduced a city planning act in Pokhara that strictly prohibited the construction of new houses within 10 m of the riverside. However, a lack of enforcement means that these processes have not yet completely stopped. Furthermore, no planning exists for those already living in the riverside area. However, there is no plan exist for the Tamakoshi river basin.

5.1.3.3.3. Shelter

When flooding occurs, people should be evacuated safely to designated shelters along the optimal routes to minimize serious damages to lives and properties (Park et al., 2020). An adequate shelter has a significant impact on human survival in the initial stage of a disaster, and that requires more than just a roof for a space to be habitable (Lim et al., 2019). Temporary houses or transitional shelters are the most important when no other alternatives are available. Shelters provide immediate and short-term stay for the victims, help them recover from the trauma of a disaster and provide a base to start the process of rehabilitation (Bashawri et al., 2014; Wagemann, 2017). Making a shelter and meeting its needs in the pre-and post-disaster stages remain a major challenge for the government. A shelter location may be required for periods that extend for several months or even years after a disaster, but local authorities should prioritize this factor when planning and designing shelters. The government can categorize shelter types, such as emergency, temporary, or permanent shelters (Lim et al., 2019). The government should ensure that emergency shelters are accessible and far away from vulnerable slopes, and allow large numbers of people (Liu et al., 2011). Therefore, the emergency shelters should have adequate space, basic living requirements, and be located in safe areas (Jamrussri et al., 2018). Moreover, there are no shelter houses present in the considered locations, and the local government should consider the design of shelter houses for the future.

Providing adequate shelters is one of the most intractable problems in international humanitarian response (Davis, 2011). Tents are too costly and do not last long enough. Rebuilding houses take years, even when land issues are not major obstacles (Davis, 2011).

Increasing quality while reducing the time and costs of progressing disaster-affected populations from emergency shelter to permanent housing is key for improving post-disaster resilience (Lines et al., 2022). Another major issue is in a post-disaster context. The higher the level of resources being invested in temporary housing measures, the less is available for permanent reconstruction (Zhang et al., 2014). Costly houses are not suitable for all post-disaster people especially if they are poor. Therefore, locally available materials used for temporary housing projects are required. Disaster relief temporary housing policy needs to be developed in all rural areas with affected communities, with those experiencing disasters in the past. This will greatly benefit future disaster survivors.

5.1.3.3.4. Structure, material, and fire safety

Plastic sheeting can be good but most often is low quality and falls apart immediately (Sanderson et al., 2014). So, the shelter building must be structurally sound to protect residents from the elements and not pose any threat to the health and safety of the residents. There must be at least one working smoke detector in each occupied unit of the shelter. Where possible, smoke detectors must be located near sleeping areas. The fire alarm system must be designed for hearing-impaired residents. All public areas of the shelter must have at least one working smoke detector. There must also be a second means of exiting the building in the event of a fire or another emergency.

The critical importance of promoting housing designs and building technologies that are not only safe but also culturally appropriate, affordable, comfortable, and sustainable is recognized by the handbook for housing reconstruction recently published by the World Bank (Jha et al., 2010).

5.1.3.3.5. Space and security

Except where the shelter is intended for day use or long term, the shelter must provide each person in the shelter with an acceptable place to sleep and security for themselves and their belongings. Disaster shelters are considered vital for personal safety, climate protection, security, and resistance to disease and ill health. Such shelters are commonly used until a displaced group of people can be re-housed in either their rehabilitated original dwellings or new permanent accommodations (Bashawri et al., 2014).

5.1.3.3.6. Air quality, water supply, sanitary facilities and hygiene

Each room or space within the shelter must have a natural or mechanical means of ventilation. The interior air must be free of pollutants at a level that might threaten or harm the health of residents. The shelter's water supply must be free of contamination. When an emergency or temporary shelter is not provided with basic facilities it can cause many health problems, including acute respiratory infections, cholera epidemics, gastroenteritis, and measles, particularly among young children (Van Rooyen & Leaning, 2005).

Each person in the shelter must have access to sanitary facilities that are in proper operating condition. The shelter must be maintained in a sanitary condition. Personal and environmental hygiene is required to protect people’s health. Water, sanitation, and hygiene infrastructure and facilities have to be adequate in the shelter house (Bashawri et al., 2014).

5.1.3.3.7. Food and electricity

In the shelter house, survivors’ nutrition should be considered, such as their ability to store, prepare, and cook food (Bashawri et al., 2014). Food preparation areas, if any, must contain suitable space and equipment to store, prepare, and serve food in a safe and sanitary manner. There must be sufficient electrical sources to permit the safe use of electrical appliances in the shelter.

5.1.3.3.8. Relocation

Relocation implies permanently moving to a new location. Relocation is a process that introduces a newly built area for the displaced community (Sridarran et al., 2018). Population resettlement is a complex process that can create serious social, economic, and cultural problems for the people involved if it is not implemented properly (Bang et al., 2012).

As per our findings, the population in this area is very poor, and therefore, the relocation plan should be free of cost. To help the resettled households adapt to the new environments, the local government should make development plans, which should include various job opportunities (Chen et al., 2008). Therefore, the local government should make a long-term plan for those vulnerable settlements. This research identified many houses, schools, office buildings, and livestock farms that are within high-risk areas (Figures 3.3, 3.4, 3.5, 4.3, 4.4 and 4.5 and 4.6). Therefore, the local government should take action to relocate these to safe places as soon as possible.

5.1.3.4. Slope and taken time calculation of each evacuation route

During a flood disaster, people need to evacuate themselves as soon as possible. Various complex factors can influence evacuation time. Evacuation time (ET) is affected by various factors such as slope, distance, and physical status. The walking speed during evacuation depends on the physical ability of the individual and the conditions of the evacuation route (Bae & Kobayashi, 2021). This research suggests that the purposed evacuation route can serve as the basis for the conceptual framework and help local government in decision-making for future planning. In the following section, this research presents the time taken during evacuation by age group.

The population was classified into four age groups: under 15-year-old, 15–40-year-old, 40–65-year-old, and above 65-year-old (Figure 2.7, Table 5.9). In total 31 residents were invited to walk on the five experimental routes. The result found that walking speed is decreased by increasing age. Walking speed decreases on the uphill slope speed, whereas it increases on flat or down slope.

Table 5.10 shows the 40-60 years age people and >65 age people needed a long time to finish all five routes. As shown in Table 5.10 the evacuation time for the elderly group (>65) was 2.28 m/s, adult group (15-40) was 1.09 m/s, middle-aged group (40-65) was 1.95 m/s and children group (<15) was 1.22 m/s.

Table 5.9 Walking speed collected form field by age group.

Route	Age	Time (s)	Height (ft)	Weight (kg)	Route	Age	Time (s)	Height (ft)	Weight (kg)
1	56	141	5	56	2	27	55	5.4	65
	22	94	5.4	50		8	75	3.11	16
	10	53	4	25		14	59	5	42
	15	77	5.4	50		38	61	5	56
	43	85	5.7	82		22	55	5.4	50
	7	103	4	26		72	84	5	45
	4	112	3.6	18		18	58	5	42
	5	106	3.8	21		7	78	4	26
	16	59	5.2	53		4	79	3.6	18
	9	72	4.2	29		5	83	3.8	21
	18	61	5.6	58		16	56	5.2	53
	69	132	5.3	51		9	76	4.2	29
	73	145	5.2	56		18	54	5.6	58
	78	168	5.3	49		69	92	5.3	51
	32	54	5.5	64		73	96	5.2	56
	48	51	5.2	52		78	107	5.3	49
	42	46	5.1	62		32	59	5.5	64
	4	84	3.3	18		48	62	5.2	52
	4	86	3.5	21		42	60	5.1	62
3	17	59	5.2	53		4	84	3.3	18
	8	64	3.11	16		4	86	3.5	21
	18	61	5.5	56	4	38	65	5	56
	38	58	5	56		8	63	3.11	16
	22	50	5.4	50		30	62	5	62
	14	56	5	42		22	66	5.4	50
	7	75	4	26		14	62	5	42
	4	83	3.6	18		29	61	5.6	65
	5	79	3.8	21		7	85	4	26
	16	56	5.2	53		4	95	3.6	18
	9	61	4.2	29		5	105	3.8	21
	18	57	5.6	58		16	58	5.2	53
	69	88	5.3	51		9	59	4.2	29
	73	92	5.2	56		18	52	5.6	58
	78	98	5.3	49		69	105	5.3	51
	32	59	5.5	64		73	112	5.2	56
	48	64	5.2	52		78	118	5.3	49
	42	62	5.1	62		32	54	5.5	64
	4	84	3.3	18		48	57	5.2	52
	4	86	3.5	21		42	56	5.1	62
						4	84	3.3	18
						4	86	3.5	21
5	30	35	5	62	5	9	59	4.2	29
	29	29	5.6	65		18	30	5.6	58
	38	32	5	56		69	62	5.3	51
	14	30	5	42		73	65	5.2	56
	8	48	3.11	16		78	68	5.3	49
	22	30	5.4	50		32	30	5.5	64
	7	52	4	26		48	60	5.2	52
	4	58	3.6	18		42	58	5.1	62
	5	55	3.8	21		4	84	3.3	18
	16	28	5.2	53		4	86	3.5	21

Source: Field survey in 2022.

Table 5.10 Relationship between slope degree and taken time for walking by age group. (Time in second)

Slope (degree)	Time taken (second)				R^2
	0-15 age group	15-40 age group	40-65 age group	>65 age group	
<5	45.7	37.6	64.1	109.1	**0.59**
5 to 10	47.3	39.2	65.7	110.7	
10 to 15	50.5	42.3	68.9	113.8	
15-20	54.7	46.5	73.1	118.1	
20-25	57.1	48.9	75.5	120.5	
25-30	60.9	52.7	79.3	124.3	
30-35	65.4	57.2	83.8	128.8	
35-40	70.3	62.1	88.7	133.7	
40-45	73.1	64.9	91.5	136.5	
>45	79.9	71.8	98.3	143.3	
Average time (second)	**60.49**	**52.30**	**78.90**	**123.89**	
Average speed (m/s)	**1.22**	**1.09**	**1.95**	**2.28**	

Source: Field survey in 2022.

5.1.3.5. **Seti river basin**

5.1.3.5.1. Masinabagar

Table 5.11 shows the calculated walking time under the slope criteria based on age group. It shows the proposed evacuation route and existing evacuation route and its completion time based on age group. Figure 5.2 shows the relationship between age group and walking speed. Elderly people and 40-65 years old people take a longer time to compare to children and adults (<40 years old).

In this section, route number 3 required the shortest time taken and route number 8 required the longest time. Interestingly route number 8 is the only existing route although it is steep and longest.

Table 5.11 Evacuation completion time calculated in each segment based on age group in section a, Mainabagar.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)				Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Masinabagar, Section a	1	898.5	910.4	27.8	4.4	43.6	35.4	62.0	107.0	7	893.9	895.6	16.4	44.2	75.5	67.3	93.9	138.9
		897.1	909.6	13.7	21.5	52.0	43.8	70.4	115.4		895.6	898.2	7.8	10.2	37.7	29.5	56.1	101.1
		898.5	908.1	26.0	15.1	52.9	44.7	71.3	116.3		898.2	903.8	28.4	8.1	47.5	39.3	65.9	110.9
		903.0	906.9	11.3	39.2	67.7	59.5	86.1	131.1		892.2	893.6	22.6	8.4	44.4	36.2	62.8	107.8
		912.8	916.4	6.8	38.4	64.4	56.2	82.8	127.8		893.6	897.2	17.8	6.6	40.0	31.8	58.4	103.4
	2	895.9	899.9	21.1	23.0	57.7	49.5	76.1	121.1		897.2	903.3	8.0	50.9	77.0	68.8	95.4	140.4
		903.9	911.2	23.4	15.9	52.2	44.0	70.6	115.6	8	903.3	911.0	18.8	18.8	52.3	44.2	70.7	115.7
		903.8	911.1	7.5	54.6	80.3	72.1	98.7	143.7		892.0	893.8	14.6	14.6	45.9	37.7	64.3	109.3
		911.0	918.4	7.5	25.2	52.0	43.8	70.4	115.4		893.8	893.3	16.5	0.4	33.3	25.1	51.7	96.7
	3	909.1	918.3	13.1	54.0	82.9	74.7	101.3	146.3		893.3	897.3	19.9	5.8	40.4	32.2	58.8	103.8
		896.7	910.2	22.0	4.6	40.5	32.3	58.9	103.9		897.3	902.4	25.1	7.7	45.2	37.0	63.6	108.6
		893.6	898.5	23.2	17.0	53.1	44.9	71.5	116.5		902.4	909.1	12.4	44.6	73.5	65.3	91.9	136.9
		915.1	916.3	12.1	26.0	55.4	47.2	73.8	118.8		891.7	892.7	17.4	36.7	68.8	60.6	87.2	132.2
	4	894.8	895.4	16.0	20.3	52.1	43.9	70.5	115.5	9	892.7	896.7	35.6	11.2	54.7	46.5	73.1	118.1
		895.4	899.0	14.9	12.5	44.0	35.8	62.4	107.4		910.2	917.6	17.9	2.2	35.8	27.6	54.2	99.2
		899.0	903.0	10.0	5.0	34.0	25.8	52.4	97.4		889.9	893.6	24.2	5.7	42.8	34.6	61.2	106.2
		906.9	908.2	27.8	14.4	53.3	45.1	71.7	116.7		898.5	907.5	12.3	34.2	63.4	55.2	81.8	126.8
		892.8	894.9	8.3	55.4	81.5	73.3	99.9	144.9		907.5	917.6	20.3	34.2	68.0	59.8	86.4	131.4
		894.9	894.9	5.8	52.3	77.1	68.9	95.5	140.5	10	889.8	892.7	20.9	18.4	53.2	45.0	71.6	116.6
	5	894.9	896.0	9.2	28.2	55.9	47.7	74.3	119.3		892.7	896.7	26.1	2.2	40.6	32.4	59.0	104.0
		896.0	897.9	30.0	4.6	45.1	36.9	63.5	108.5		896.7	906.9	42.9	8.4	56.2	48.0	74.6	119.6
		897.9	906.5	25.8	14.0	51.7	43.5	70.1	115.1		906.9	915.1	20.2	20.0	54.2	46.1	72.6	117.6
		906.5	912.8	9.2	55.4	82.1	73.9	100.5	145.5		894.1	894.5	14.1	9.4	40.6	32.4	59.0	104.0
		891.8	892.6	7.4	53.4	79.2	71.0	97.6	142.6									
	6	892.6	894.9	16.6	44.3	75.6	67.4	94.0	139.0									
		894.9	896.8	26.8	8.9	47.4	39.2	65.8	110.8									
		896.8	897.9	29.0	5.6	45.5	37.3	63.9	108.9									
		897.9	903.9	9.2	28.1	55.8	47.6	74.2	119.2									
		891.6	893.9	8.3	52.8	79.0	70.8	97.4	142.4									

Source: Field survey in 2022.

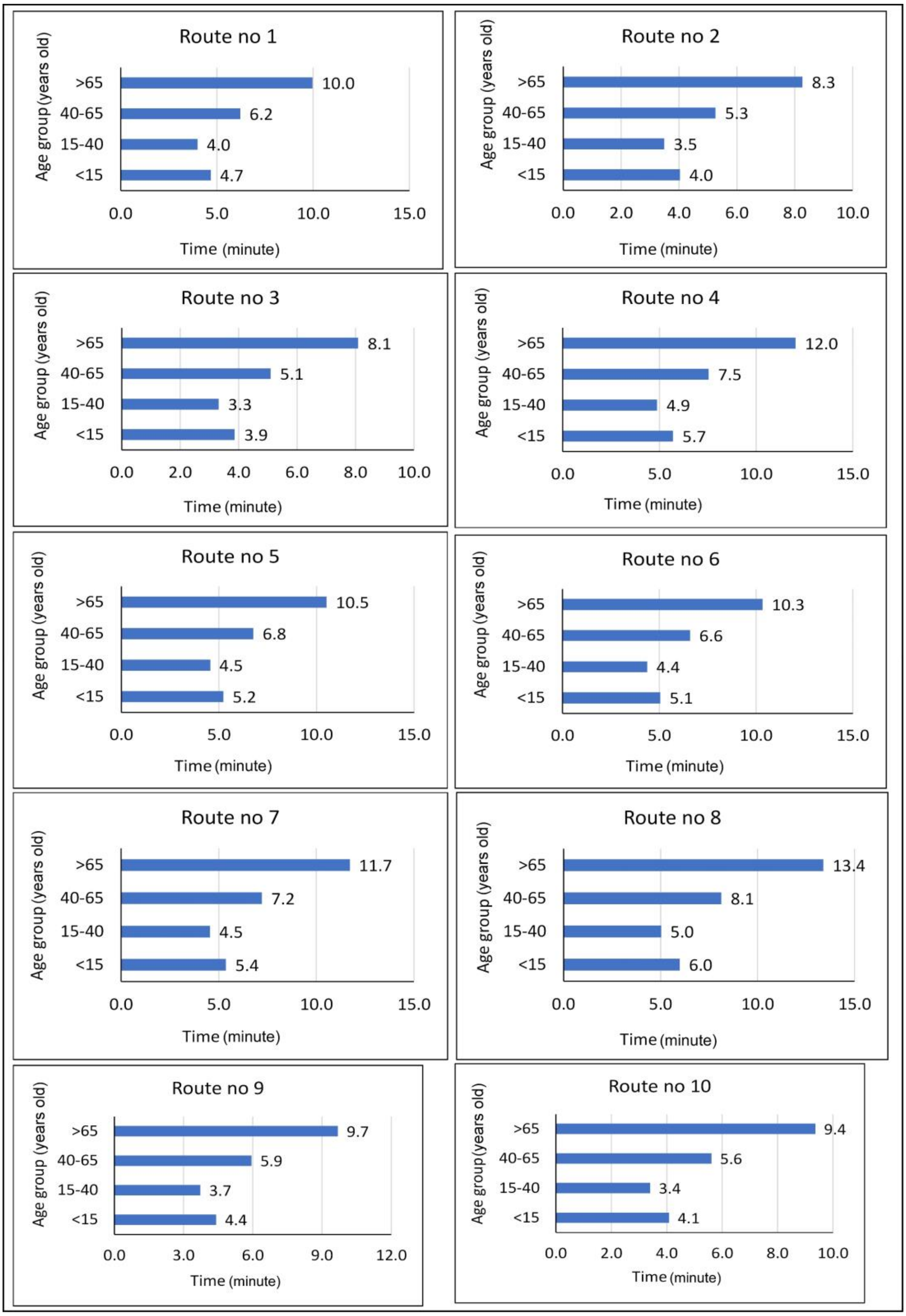

Figure 5.2 Relationship between age group and walking speed (crossing time) in Masinabagar section a, routes 1-10. Note: Time is presented in minutes. (See Figure 3.5 for location)

Table 5.12 shows the evacuation times for seven evacuation routes based on slope and age group. Figure 5.3 shows the relationship between walking speed and age group. Based on the results in this section, route number 6 requires the shortest time needed taken and route number 1 requires the longest time needed. Route number 1 is the only existing route, which is the longest time needed route among all routes.

Table 5.12 Evacuation completion time calculated in each segment based on age group in section b (left side) Mainabagar.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Masinabagar, Section b (left side)	1	889.0	898.0	17.1	48.5	79.9	71.8	98.3	143.3
		887.6	893.2	28.7	4.2	44.0	35.8	62.4	107.4
		886.4	893.5	34.7	3.8	47.0	38.8	65.4	110.4
		886.4	889.4	15.7	2.8	35.1	26.9	53.5	98.5
		892.7	891.6	17.3	2.9	36.1	27.9	54.5	99.5
		890.8	892.2	11.0	16.7	45.8	37.6	64.2	109.2
	2	887.4	895.7	22.7	13.4	49.4	41.2	67.8	112.8
		889.0	887.8	30.3	2.5	43.3	35.1	61.7	106.7
		887.8	886.5	35.4	0.1	43.9	35.7	62.3	107.3
		886.5	886.9	20.9	32.7	66.9	58.7	85.3	130.3
	3	886.9	887.4	16.7	53.8	84.8	76.6	103.2	148.2
		895.7	897.5	32.2	1.4	43.3	35.1	61.7	106.7
		887.1	886.3	10.6	6.0	35.2	27.0	53.6	98.6
		886.3	886.4	14.4	24.4	55.1	46.9	73.5	118.5
	4	889.4	895.2	28.9	24.6	63.7	55.5	82.1	127.1
		886.6	886.1	18.4	8.8	42.5	34.3	60.9	105.9
		886.1	885.5	12.1	11.5	41.3	33.2	59.7	104.7
		885.5	889.0	23.7	0.3	37.3	29.1	55.7	100.7
	5	886.6	885.0	26.3	21.2	58.9	50.7	77.3	122.3
		885.0	886.4	19.7	15.8	49.9	41.7	68.3	113.3
		893.5	893.4	24.9	0.2	37.9	29.7	56.3	101.3
	6	884.5	887.6	43.7	2.6	51.1	42.9	69.5	114.5
		893.2	893.3	18.7	0.2	34.3	26.2	52.8	97.7
		892.6	892.7	19.9	8.8	43.3	35.1	61.7	106.7
	7	891.6	893.3	37.4	3.7	48.5	40.3	66.9	111.9
		890.8	890.8	16.3	0.4	33.2	25.0	51.6	96.6
		892.2	902.6	14.9	36.9	67.5	59.3	85.9	130.9

Source: Field survey in 2022.

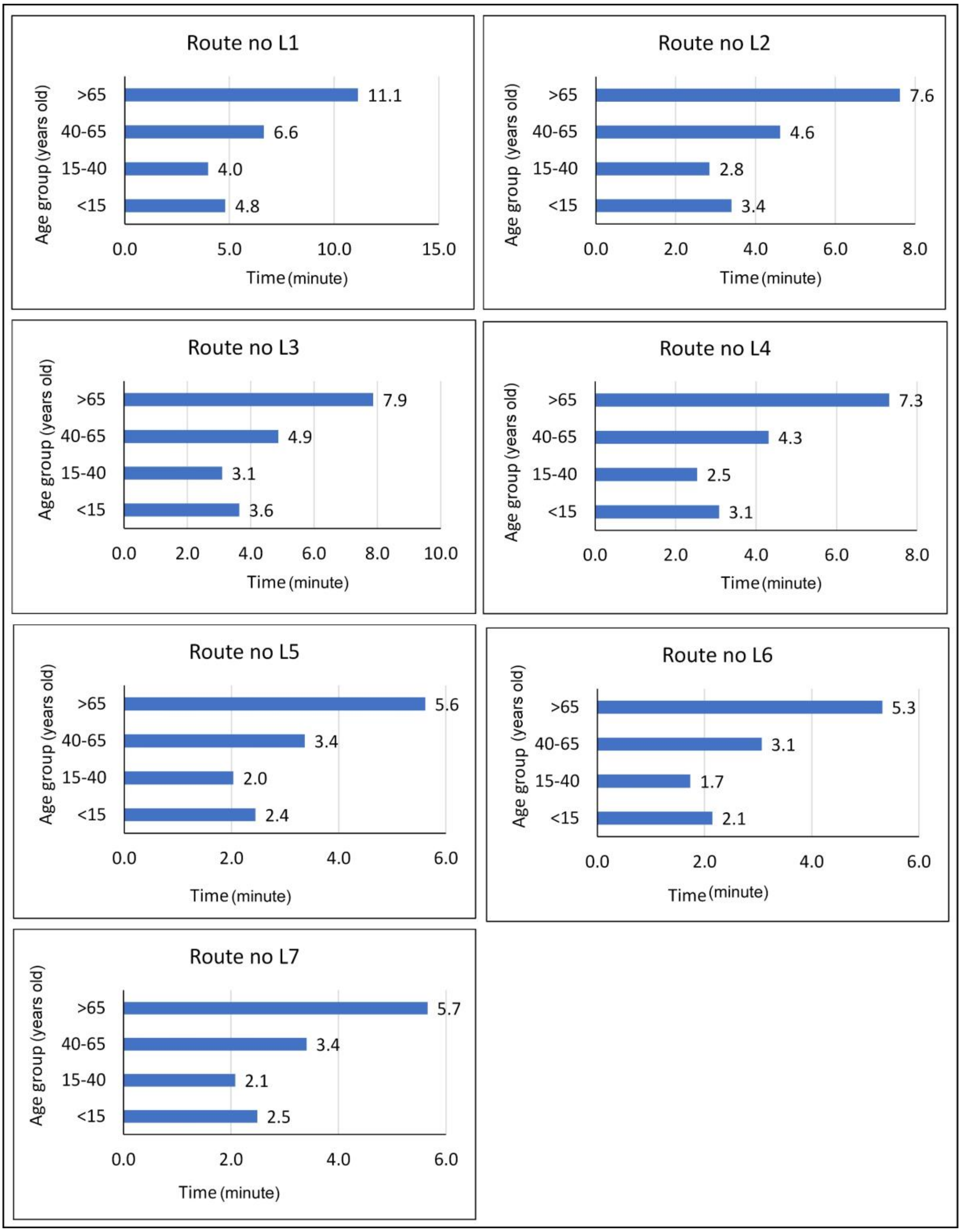

Figure 5.3 Relationship between age group and walking speed (crossing time) in Masinabagar section b (left side), routes 1-7. Note: Time is presented in minutes. (See Figure 3.5 for location).

Table 5.13 shows the total six evacuation routes and crossing times based on slope and age group. It shows the proposed evacuation route and existing evacuation route. Similarly, Figure 5.4 shows the relationship between age group and walking speed. Based on the results in this section route number 4 is the shortest time taken and route no 2 is the longest time taken routes. Route no one is the only existing route where all the people depend on route among the all.

Table 5.13 Evacuation completion time calculation in each segment based on age group in Mainabagar section b (right side).

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Masinabagar, Section b (Right side)	1	902.8	904.7	80.1	1.9	71.3	63.2	89.7	134.7
		902.9	904.5	10.3	38.1	66.1	57.9	84.5	129.5
		901.6	901.3	7.1	44.5	70.4	62.2	88.8	133.8
		896.9	901.2	7.6	43.4	69.6	61.4	88.0	133.0
		896.3	900.6	14.6	15.4	46.6	38.4	65.0	110.0
		900.0	899.8	17.9	5.9	39.4	31.2	57.8	102.8
	2	887.4	891.4	36.7	5.3	49.6	41.5	68.0	113.0
		891.4	897.4	14.6	29.6	60.4	52.2	78.8	123.8
		897.4	900.7	15.8	32.2	63.5	55.3	81.9	126.9
		900.7	902.9	5.4	34.1	59.3	51.1	77.7	122.7
		904.5	905.5	12.0	17.6	47.3	39.1	65.7	110.7
		885.8	890.2	15.9	0.5	32.9	24.8	51.3	96.3
		890.2	899.5	23.0	3.4	39.9	31.7	58.3	103.3
	3	899.5	901.4	28.8	1.2	41.1	32.9	59.5	104.5
		901.4	903.5	11.9	26.2	55.5	47.3	73.9	118.9
		903.5	903.6	12.1	29.1	58.4	50.3	76.8	121.8
		903.6	902.8	11.2	30.3	59.0	50.8	77.4	122.4
		884.1	887.2	19.9	23.3	57.3	49.1	75.7	120.7
		887.2	890.7	27.7	3.0	42.2	34.0	60.6	105.6
	4	890.7	897.8	49.5	8.8	60.4	52.2	78.8	123.8
		897.8	902.5	32.6	21.3	62.7	54.5	81.1	126.1
		902.5	901.6	8.9	28.0	55.5	47.3	73.9	118.9
		882.9	889.8	32.9	1.1	43.4	35.2	61.8	106.8
	5	889.8	896.9	53.5	7.9	61.9	53.7	80.3	125.3
		901.2	901.6	23.8	22.8	59.0	50.8	77.4	122.4
		882.4	887.8	11.8	49.9	78.3	70.1	96.7	141.7
		887.8	896.3	35.6	1.2	45.0	36.8	63.4	108.4
	6	900.6	900.1	27.2	0.6	39.6	31.4	58.0	103.0
		881.7	891.3	29.7	32.2	71.5	63.3	89.9	134.9
		891.3	897.6	8.9	37.9	65.0	56.8	83.4	128.4
		897.6	900.6	33.8	8.8	51.4	43.2	69.8	114.8
		900.6	900.0	24.2	2.4	39.7	31.5	58.1	103.1

Source: Field survey in 2022.

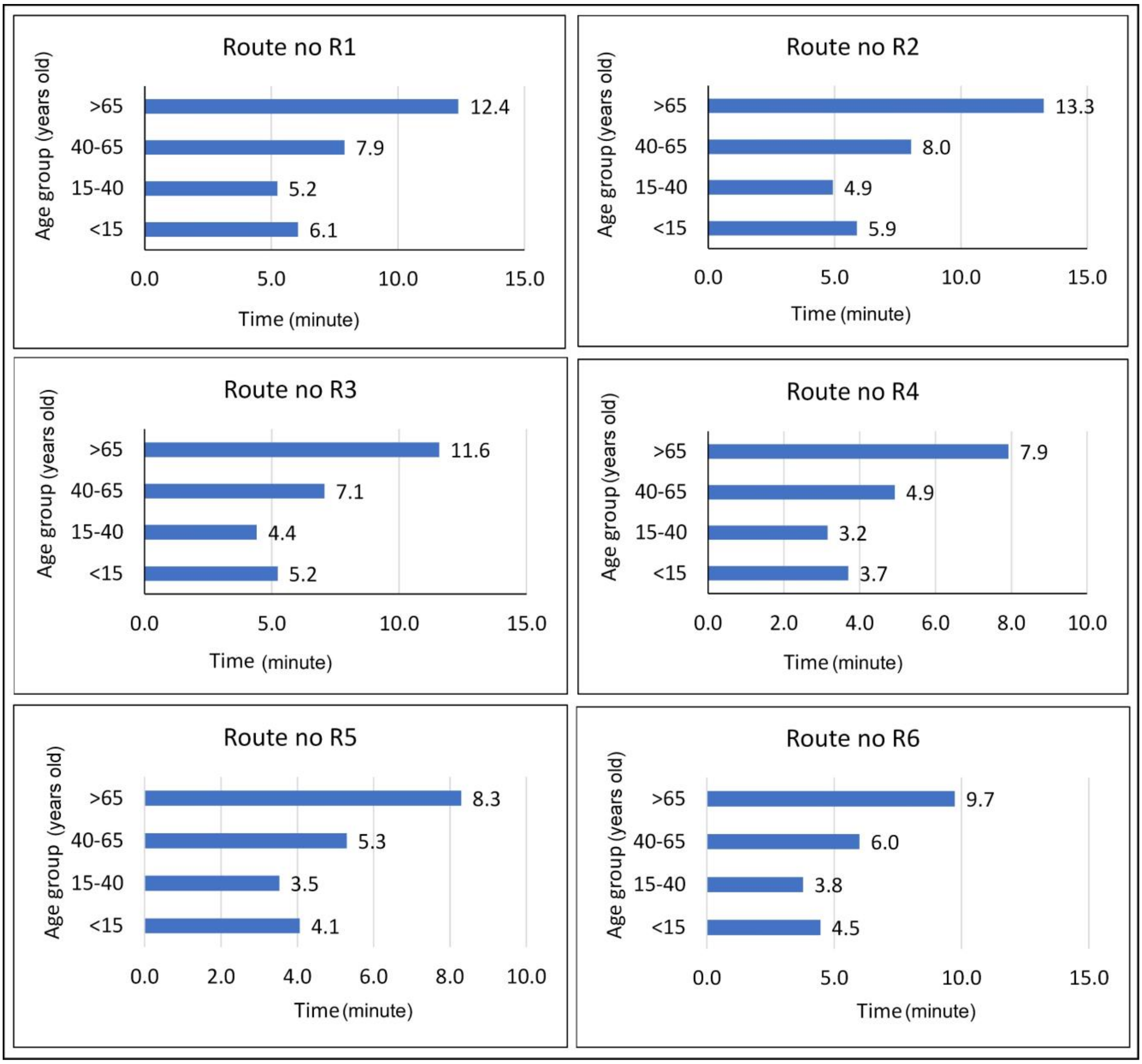

Figure 5.4 Relationship between age group and walking speed in section b (right side), routes 1-6 Masinabagar. Note: Time is presented in minutes. (See Figure 3.5 for location)

Table 5.14 shows four evacuation routes in section c and one route in section d. Figure 5.5 and Figure 5.6 shows the relationship between walking speed and age group. Route number 1 is the shortest and route number 2 is the longest route. Route number 1 is the only existing route for both areas. In section d, most users of the route are children became primary school is located at the end point of the routes.

Table 5.14 Evacuation completion time calculated in each segment based on age group in sections C and D, Mainabagar.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Masinabagar, Section C	1	887.0	891.0	14.6	27.2	58.0	49.8	76.4	121.4
		887.1	882.3	54.3	0.2	54.8	46.6	73.2	118.2
		888.1	900.0	19.4	13.1	47.1	39.0	65.5	110.5
		882.3	893.4	19.9	23.1	57.0	48.8	75.4	120.4
		879.8	879.9	10.3	7.7	36.7	28.5	55.1	100.1
	2	879.9	882.5	12.3	34.6	63.8	55.7	82.2	127.2
		882.5	887.0	15.1	3.6	35.6	27.4	54.0	99.0
		891.0	891.8	18.3	24.6	57.7	49.5	76.1	121.1
		877.7	878.1	23.5	15.6	52.0	43.8	70.4	115.4
		878.1	877.8	12.6	41.6	70.8	62.6	89.2	134.2
		877.8	878.2	10.8	18.6	47.6	39.4	66.0	111.0
	3	878.2	881.1	15.3	19.0	50.5	42.3	68.9	113.9
		881.1	888.1	18.8	2.1	36.2	28.0	54.6	99.6
		876.5	877.1	14.4	1.5	33.1	24.9	51.5	96.5
		877.1	878.3	14.3	2.8	34.3	26.1	52.7	97.7
		878.3	879.2	17.9	16.2	49.3	41.1	67.7	112.7
		879.2	881.0	10.7	44.1	72.0	63.8	90.4	135.4
	4	881.0	882.3	10.1	17.2	45.8	37.6	64.2	109.2
		877.2	878.1	32.3	1.8	43.7	35.5	62.1	107.1
		878.1	878.2	12.9	9.8	40.2	32.0	58.6	103.6
		878.2	881.1	8.6	9.9	37.9	29.7	56.3	101.3
		881.1	887.1	4.4	40.2	64.7	56.5	83.1	128.1
		882.3	900.0	5.9	22.6	48.6	40.4	67.0	112.0
Masinabagar, Section D	1	876.1	883.7	120.4	6.3	98.9	90.7	117.3	162.3
		875.6	876.4	59.4	1.3	58.9	50.7	77.3	122.2

Source: Field survey in 2022.

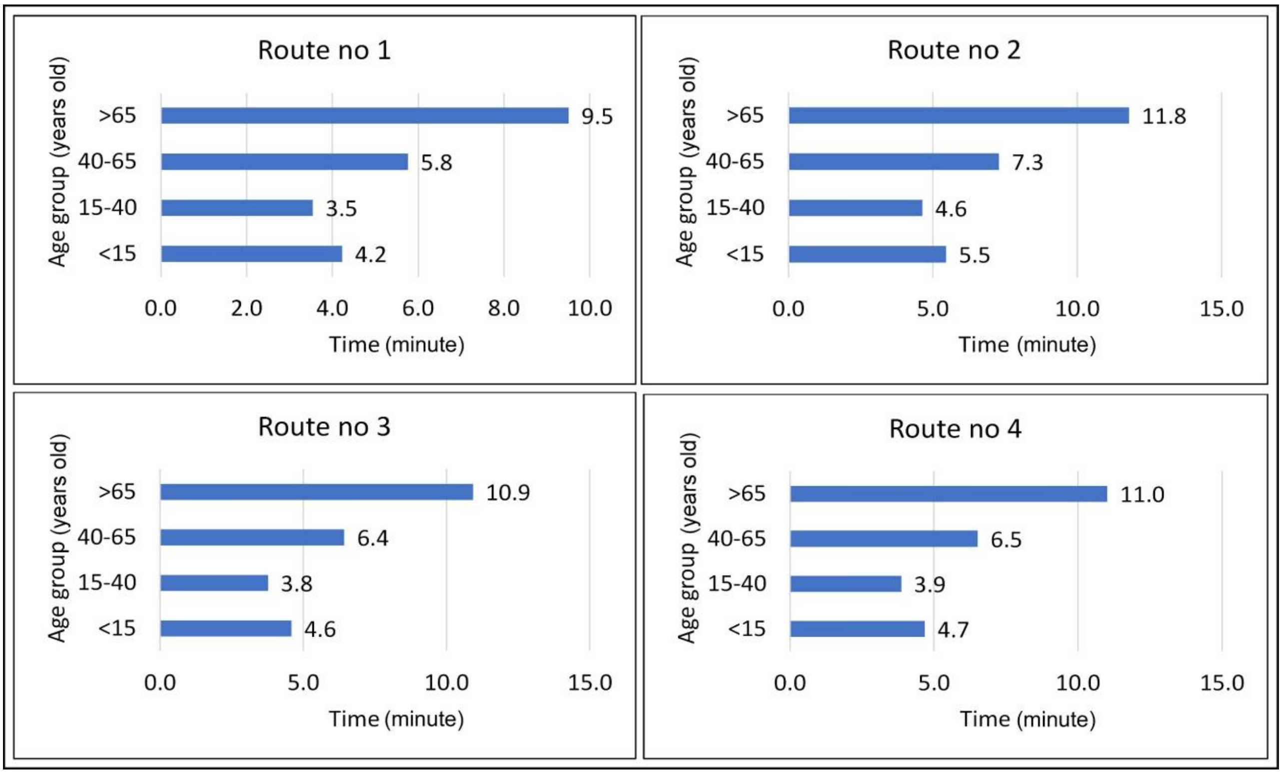

Figure 5.6 Relationship between age group and walking speed in section c, routes 1-4, Masinabagar. Note: Time is presented in minutes. (See Figure 3.5 for location).

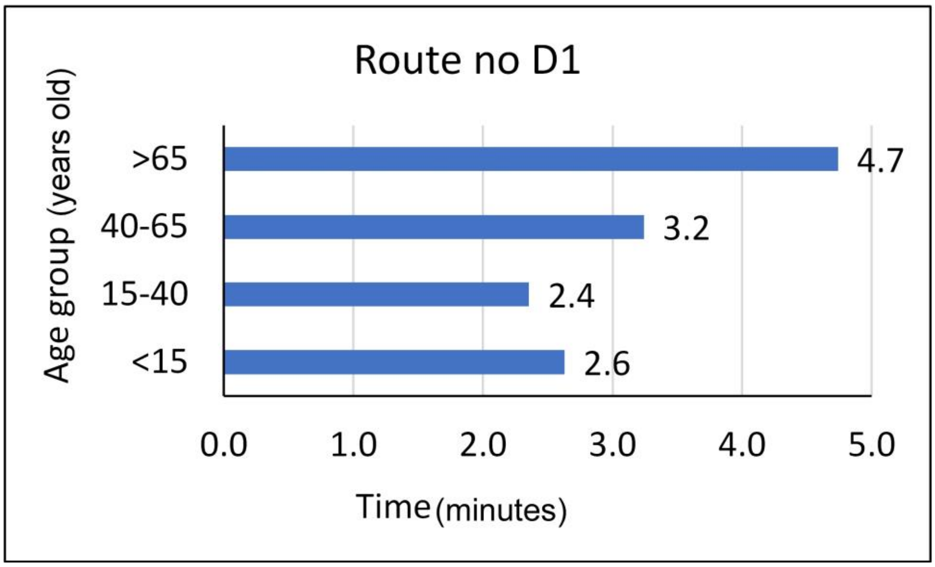

Figure 5.5 Relationship between age group and walking speed in section d (primary school). 1-4, Masinabagar. Note: Time is presented in minutes. (See Figure 3.5 for location).

5.1.3.5.2. Laltinbazar

Table 5.15 shows the evacuation time for the proposed nine routes of section a, Laltinbazar. Figure 5.7 shows the relationship between age group and walking speed on routes one to nine. Based on the results route 8 is the longest and route 3 is the shortest one.

Table 5.15 Evacuation completion time calculation in each segment based on age group in Laltinbazar section a.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Laltinbazar, Section a	1	874.9	879.1	21.7	29.4	64.2	56.0	82.6	127.6
		864.0	867.3	19.8	36.9	70.4	62.2	88.8	133.8
		862.9	865.1	21.6	15.5	50.7	42.5	69.1	114.1
	2	883.2	889.5	25.7	34.6	71.5	63.3	89.9	134.9
		866.0	867.4	21.6	23.4	58.4	50.2	76.8	121.8
		864.1	867.5	23.9	27.6	63.8	55.6	82.2	127.2
	3	865.0	864.0	54.8	7.7	62.3	54.2	80.7	125.7
		864.0	862.9	23.8	9.8	46.5	38.3	64.9	109.9
		862.2	860.5	30.2	30.8	70.4	62.2	88.8	133.8
	4	886.5	895.4	48.4	6.8	57.8	49.6	76.2	121.2
		872.5	879.8	16.7	36.9	68.5	60.3	86.9	131.9
		879.8	883.2	30.0	4.3	44.8	36.6	63.2	108.2
		874.8	879.9	17.5	0.5	34.0	25.8	52.4	97.4
		879.9	886.5	27.7	3.6	42.8	34.6	61.2	106.2
		872.6	874.9	35.5	0.9	44.7	36.5	63.1	108.1
	5	879.1	898.1	95.0	1.5	79.5	71.3	97.9	142.9
		860.6	866.8	22.5	23.0	58.5	50.3	76.9	121.9
		866.8	865.5	42.4	1.1	48.8	40.6	67.2	112.2
		865.5	865.4	39.4	3.8	49.8	41.6	68.2	113.2
	6	865.4	864.4	61.7	5.5	64.2	56.0	82.6	127.6
		864.4	864.0	12.0	12.4	42.3	34.1	60.7	105.7
		858.9	864.1	18.9	22.6	56.0	47.8	74.4	119.4
		864.1	864.5	72.4	1.7	66.6	58.5	85.1	130.0
		864.5	866.0	28.9	0.3	40.3	32.1	58.7	103.7
	7	859.6	861.1	106.0	1.0	85.4	77.2	103.8	148.8
		861.1	865.4	16.7	29.6	61.5	53.3	79.9	124.9
		865.4	864.2	19.6	9.9	44.2	36.1	62.7	107.6
		864.2	864.1	60.5	4.4	62.4	54.2	80.8	125.8
	8	858.2	863.1	59.7	3.7	61.3	53.1	79.7	124.7
		863.1	865.0	97.0	1.1	80.3	72.2	98.7	143.7
		864.0	866.6	18.1	23.2	56.2	48.0	74.6	119.6
		859.5	863.7	33.3	0.9	43.5	35.3	61.9	106.9
		863.7	864.0	66.6	3.3	64.9	56.7	83.3	128.3
	9	862.9	865.1	101.3	1.7	83.3	75.1	101.7	146.7
		862.6	862.2	19.2	2.2	36.6	28.4	55.0	99.9
		860.5	864.8	88.6	4.8	79.1	70.9	97.5	142.5

Source: Field survey in 2022.

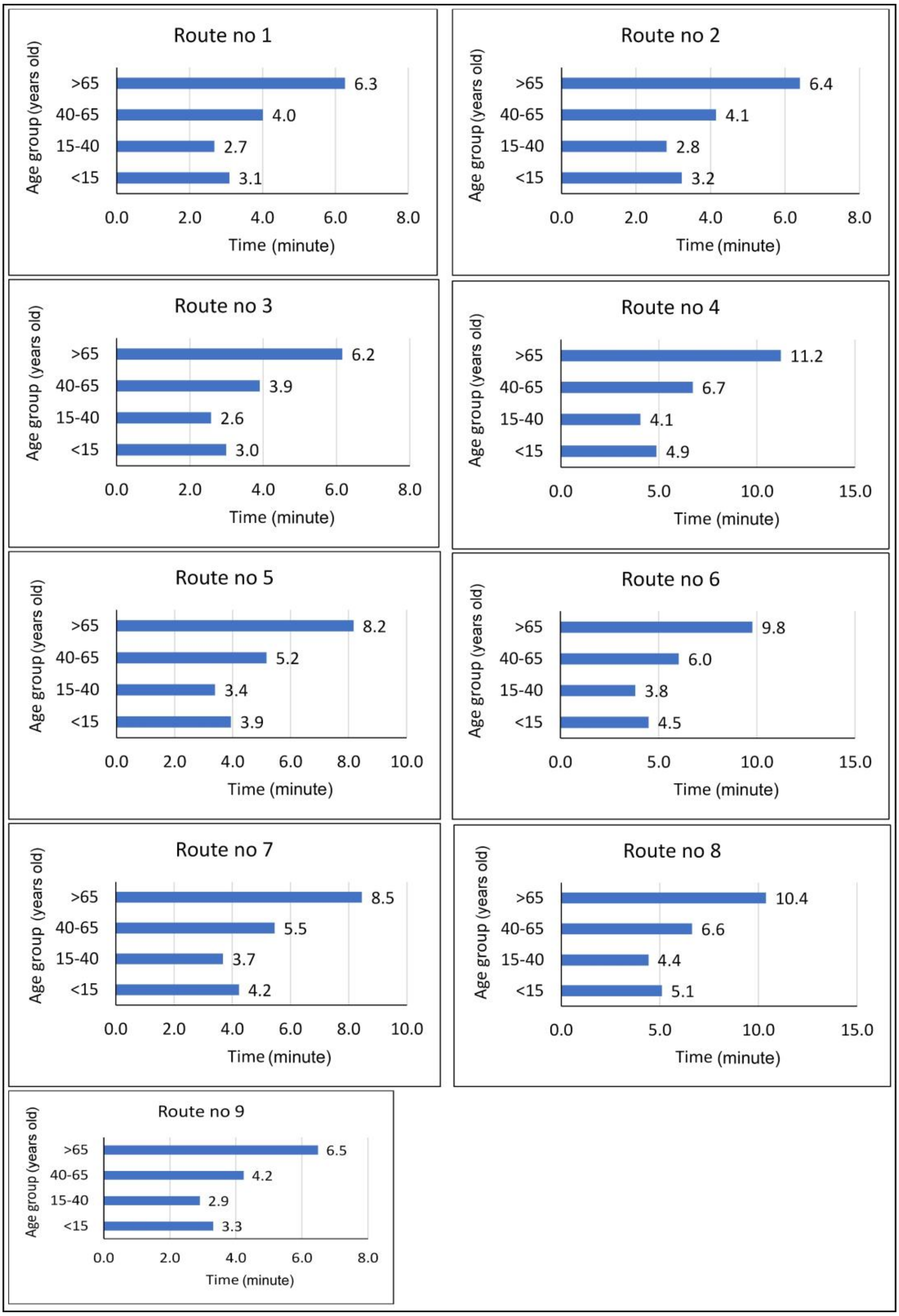

Figure 5.7 Relationship between age group and walking speed (crossing time) in section a, routes 1-9, Laltinbazar. Note: Times presented in minutes. (See Figure 3.7 for location)

Table 5.16 shows the evacuation time for the proposed 18 routes of section b, Laltinbazar. Figure 5.8 shows the relationship between walking speed and age group on routes 1 to 18.

In this section, routes 1 and 7 are existing. Route 7 is a lengthy and narrow route for evacuation. Based on the results, routes 8 (16.2 m) and 7 (15.0 m) are the routes that required the longest evacuation time. Therefore, another alternative evacuation route is an urgent need to cut down the pressure of this route.

Table 5.16 Evacuation completion time calculated in each segment based on age group in section b, Laltinbazar.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second) Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second) Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Laltinbazar, Section b	1	844.6	855.2	49.2	7.0	58.4	50.2	76.8	121.8	9	851.9	854.2	14.5	39.9	70.2	62.0	88.6	133.6
		857.9	861.3	46.2	2.7	52.6	44.4	71.0	116.0		854.2	857.1	30.0	3.9	44.4	36.2	62.8	107.8
		860.8	861.5	29.8	6.6	46.9	38.7	65.3	110.3		857.1	860.8	16.1	14.2	46.3	38.1	64.7	109.7
	2	855.8	858.9	36.4	8.4	52.4	44.2	70.8	115.8		850.7	848.5	11.8	28.1	57.2	49.1	75.6	120.6
		857.1	857.8	25.8	3.1	41.2	33.0	59.6	104.6		848.5	848.6	14.9	47.7	77.9	69.7	96.3	141.3
		856.7	860.1	11.2	1.5	31.2	23.1	49.6	94.6		848.6	849.6	8.6	0.4	28.7	20.5	47.1	92.1
		859.4	861.2	10.0	6.7	35.6	27.4	54.0	99.0	10	849.6	853.4	18.2	52.4	84.4	76.2	102.8	147.8
		858.6	861.4	19.2	7.7	41.8	33.6	60.2	105.2		853.4	857.5	34.3	3.1	46.1	37.9	64.5	109.5
	3	865.7	875.1	25.5	2.7	40.7	32.5	59.1	104.1		857.5	857.8	17.1	19.8	52.3	44.1	70.7	115.7
		872.9	880.7	22.4	3.2	39.3	31.2	57.7	102.7		857.8	865.7	11.1	36.1	64.6	56.4	83.0	128.0
		861.8	871.4	21.1	11.3	46.4	38.3	64.8	109.8		849.2	848.0	6.9	24.8	51.3	43.1	69.7	114.7
		859.6	876.1	24.9	13.3	50.5	42.3	68.9	113.9	11	848.0	850.3	15.1	19.7	51.0	42.9	69.5	114.4
	4	845.2	852.5	17.6	19.3	52.1	44.0	70.6	115.5		850.3	861.9	20.5	4.4	39.5	31.3	57.9	102.9
		847.2	845.9	14.4	18.5	49.5	41.3	67.9	112.9		861.9	872.9	29.6	3.0	43.3	35.1	61.7	106.7
		844.2	848.6	19.1	1.6	35.9	27.7	54.3	99.3		880.7	880.7	33.5	34.5	75.9	67.7	94.3	139.3
		843.0	848.6	24.3	11.2	48.1	39.9	66.5	111.5		848.6	847.6	11.9	18.4	47.9	39.7	66.3	111.3
		843.3	858.8	14.8	7.3	38.9	30.7	57.3	102.3		847.6	850.9	14.3	18.7	49.7	41.5	68.1	113.1
	5	842.0	861.4	18.8	9.6	43.5	35.3	61.9	106.9	12	850.9	861.8	37.8	19.1	63.6	55.4	82.0	127.0
		854.7	855.9	26.2	11.4	49.4	41.3	67.8	112.8		871.4	880.0	35.1	5.0	48.4	40.2	66.8	111.8
		855.9	857.9	20.5	7.4	42.3	34.1	60.7	105.7		847.6	846.7	29.7	10.8	50.9	42.7	69.3	114.3
		854.9	855.7	19.1	18.1	51.9	43.7	70.3	115.2		846.7	845.8	17.6	16.8	49.7	41.5	68.1	113.1
		855.7	855.8	13.9	9.2	40.2	32.0	58.6	103.6	13	845.8	857.4	43.1	3.1	51.1	42.9	69.5	114.5
	6	860.4	861.0	26.5	10.6	48.8	40.6	67.2	112.2		857.4	859.6	27.7	2.8	42.0	33.8	60.4	105.4
		858.9	860.4	20.2	2.2	37.2	29.0	55.6	100.6		876.1	878.8	35.3	19.2	62.2	54.0	80.6	125.6
		854.0	854.7	9.8	31.2	59.1	50.9	77.5	122.5	14	846.7	848.4	46.2	9.6	59.3	51.1	77.7	122.7
		854.7	857.1	25.9	15.5	53.3	45.1	71.7	116.6		848.4	845.2	20.4	0.8	35.9	27.7	54.3	99.3
		857.8	861.1	13.8	16.7	47.4	39.2	65.8	110.8		852.5	855.4	34.7	4.7	47.9	39.7	66.3	111.3
	7	851.6	854.2	26.2	2.8	41.1	33.0	59.5	104.5		846.5	847.2	15.2	25.5	56.7	48.5	75.1	120.1
		854.2	853.9	14.4	5.3	36.7	28.6	55.1	100.1	15	845.9	852.7	44.4	12.5	61.0	52.8	79.4	124.4
		853.9	856.7	15.3	3.1	35.2	27.0	53.6	98.6		846.0	845.8	21.6	2.7	38.4	30.3	56.8	101.8
		860.1	861.1	8.6	9.7	37.6	29.4	56.0	101.0		845.8	844.2	45.2	5.0	54.2	46.0	72.6	117.6
		850.2	853.2	6.6	31.3	57.3	49.2	75.7	120.7		848.6	852.5	12.3	13.0	43.0	34.8	61.4	106.4
		853.2	854.7	8.1	29.1	56.1	47.9	74.5	119.5		844.7	845.3	13.8	27.1	57.4	49.2	75.8	120.8
		854.7	858.1	11.8	24.7	54.0	45.8	72.4	117.4	16	845.3	843.0	41.8	25.5	72.1	63.9	90.5	135.5
		858.1	859.4	8.0	46.1	72.4	64.2	90.8	135.8		852.3	853.9	29.8	1.6	42.1	33.9	60.5	105.5
	8	848.7	849.2	18.5	50.9	83.1	74.9	101.5	146.5		848.6	852.3	49.4	0.5	52.3	44.1	70.7	115.7
		849.2	852.2	14.7	14.7	46.0	37.8	64.4	109.4		843.8	844.3	15.4	31.3	62.4	54.2	80.8	125.8
		852.2	856.3	6.7	0.8	28.0	19.8	46.4	91.4	17	844.3	844.6	78.0	19.9	87.5	79.3	105.9	150.9
		856.3	858.6	31.9	3.2	44.8	36.6	63.2	108.2		855.2	860.1	52.5	0.2	53.8	45.6	72.2	117.2
		850.2	849.4	7.3	51.1	76.8	68.6	95.2	140.2		843.2	843.3	23.7	39.5	75.1	66.9	93.5	138.5
		849.4	848.9	5.1	52.7	77.1	68.9	95.5	140.5	18	858.8	876.2	75.9	25.6	91.8	83.6	110.2	155.1
		848.9	849.8	5.3	6.3	32.5	24.3	50.9	95.9		842.6	842.0	39.7	1.4	47.6	39.4	66.0	111.0
		849.8	851.9	8.9	48.0	74.8	66.6	93.2	138.2		861.4	877.1	36.1	43.6	86.2	78.0	104.6	149.6

Source: Field survey in 2022.

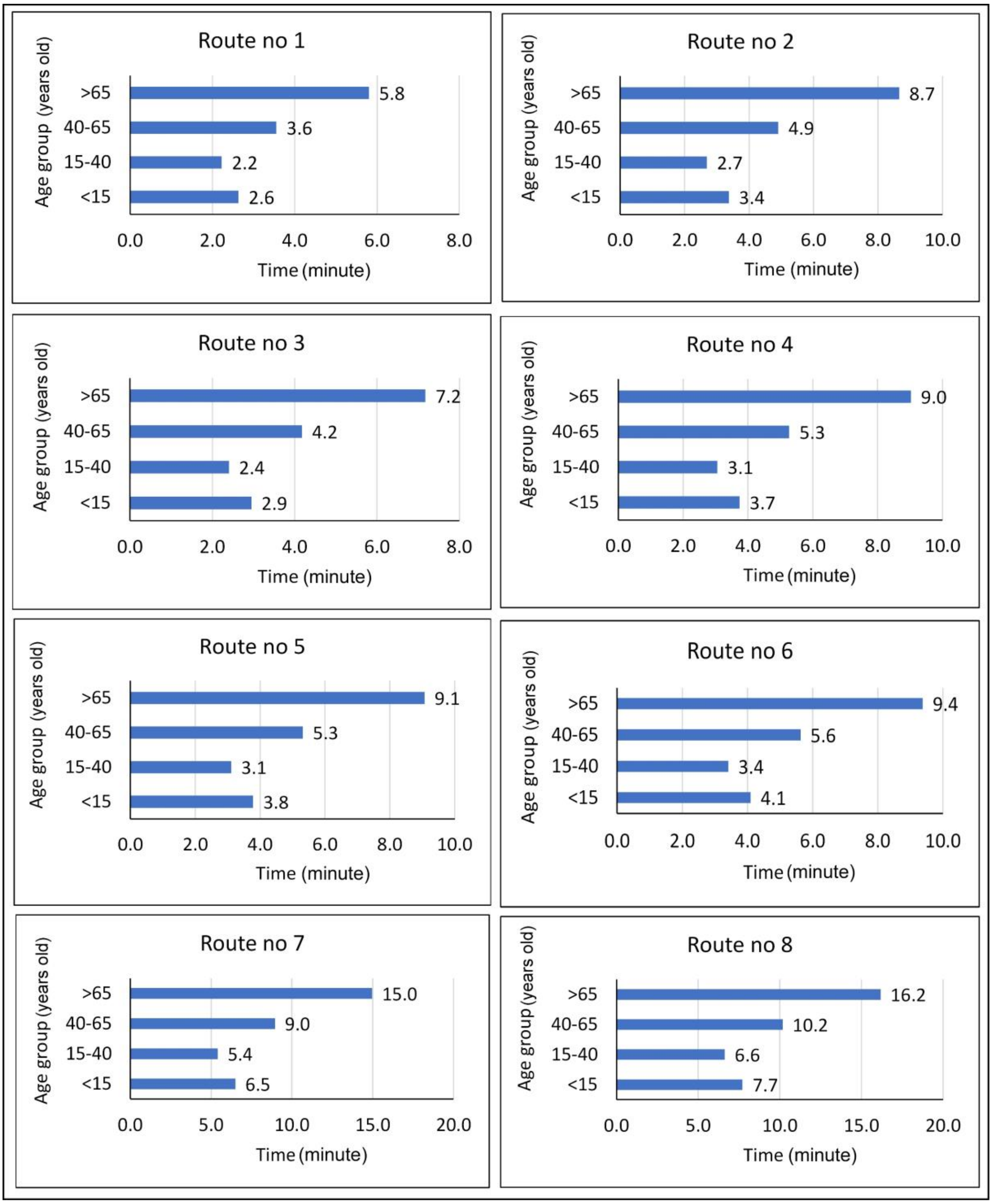

Figure 5.8 Relationship between age group and walking speed in section b, routes 9-18, Laltinbazar. Note: Time presented in minutes. (See figure 3.7 for location).

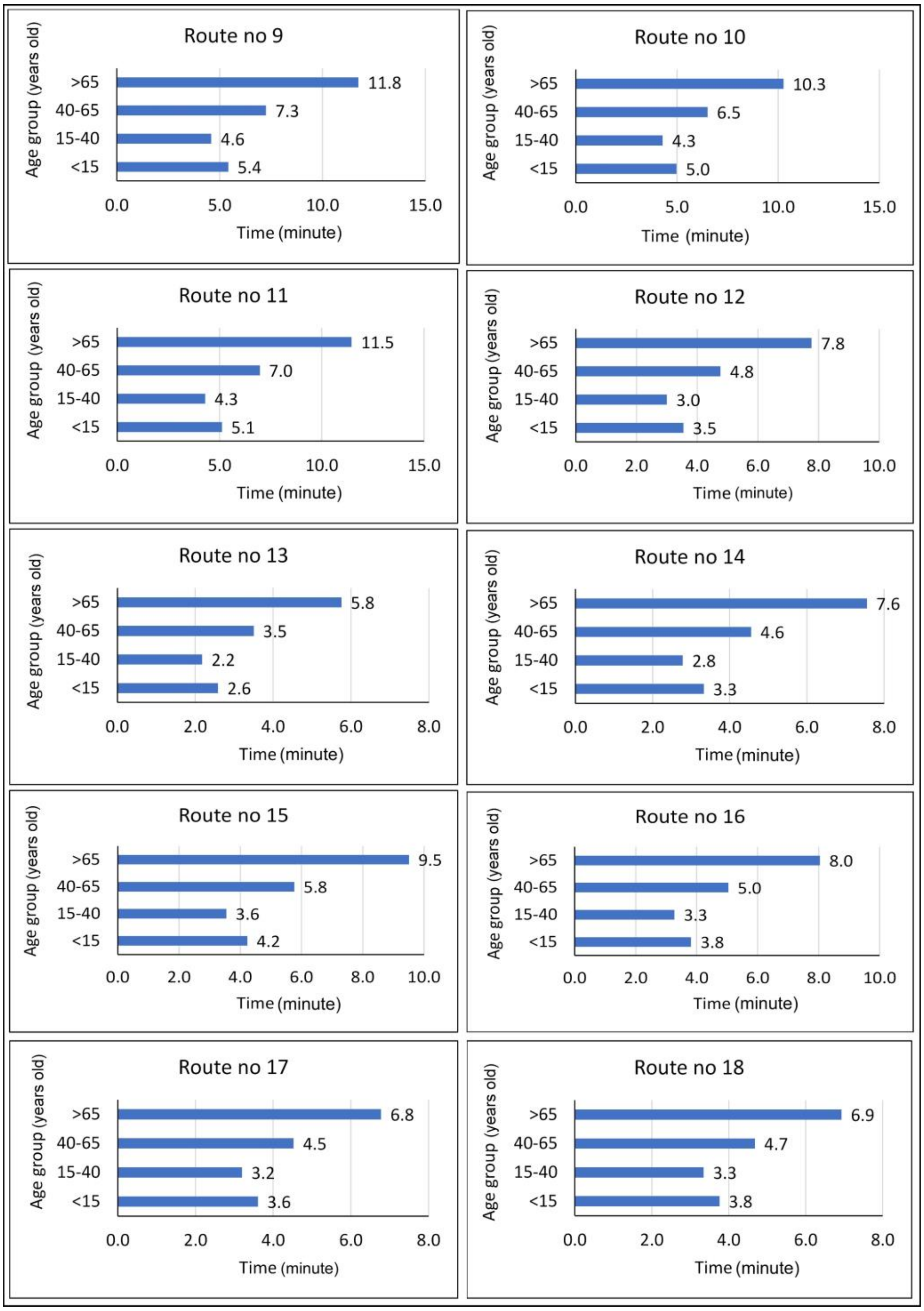

Figure 5.8 (continued).

5.1.3.5.3. KI-Sing

The right bank side of the part belongs to the temple and religious centers. Therefore, elderly people mostly visit this area. The left bank side is an adjoining part of Pokhara city itself with high population density. Table 5.17 shows the evacuation time calculated in both sections (right bank side and left side). Similarly, Figure 5.9 represents the evacuation routes (a total of 9 evacuation route) in the left bank side. Route number 4 is the longest and route number 7 needs less time foe evacuation. Figure 5.10 shows the right side of the KI-Sing section. There are a total of 4 evacuation routes proposed. Route number 2 needs the longest time for evacuation and route number 1 needs shorter time for evacuation.

Table 5.17 Evacuation completion time calculated in each segment based on age group in KI-Sing (left side and right side).

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
KI-Sing (Left side)	1	882.6	883.1	52.8	0.6	56.0	47.8	74.4	119.4
		882.4	883.8	42.3	2.9	48.6	40.4	67.0	111.9
	2	882.3	881.9	83.6	0.7	72.1	63.9	90.5	135.5
		878.5	881.8	33.8	7.4	58.2	50.1	76.6	121.6
	3	880.7	881.4	47.9	2.4	53.8	45.6	72.2	117.2
		881.1	881.0	34.4	0.2	54.7	46.5	73.1	118.1
		875.3	880.5	33.7	15.5	43.4	35.2	61.8	106.8
	4	881.8	884.1	49.7	21.5	72.7	64.5	91.1	136.1
		879.9	881.0	16.3	2.3	33.0	24.8	51.4	96.4
		881.0	881.4	48.2	0.8	51.2	43.0	69.6	114.6
	5	877.2	882.6	52.5	16.0	54.3	46.1	72.7	117.7
		878.5	882.6	28.9	11.9	45.8	37.6	64.2	109.2
	6	882.6	882.4	43.9	0.6	55.8	47.6	74.2	119.2
		881.9	881.9	43.3	0.2	49.6	41.4	68.0	113.0
	7	881.9	881.8	26.7	0.1	41.0	32.8	59.4	104.4
		880.5	882.3	17.6	6.0	35.8	27.6	54.2	99.2
	8	881.8	882.4	44.2	1.3	49.0	40.8	67.4	112.4
		881.1	880.7	24.4	2.4	55.1	46.9	73.5	118.5
	9	876.6	881.1	34.0	18.3	57.9	49.7	76.3	121.3
		880.5	881.1	28.7	2.1	42.0	33.8	60.4	105.4
KI-Sing (Right side)	1	869.7	872.6	33.0	5.2	77.6	69.4	96.0	141.0
		859.9	871.9	28.4	36.6	53.1	44.9	71.5	116.5
		868.9	869.9	14.6	5.1	33.7	25.6	52.2	97.1
	2	870.4	872.1	55.9	5.1	60.6	52.4	79.0	124.0
		855.9	859.9	23.6	13.9	41.0	32.8	59.4	104.4
		871.9	872.2	28.5	2.1	49.3	41.1	67.7	112.7
		840.5	839.5	25.9	4.2	49.0	40.8	67.4	112.4
		839.5	842.3	29.8	9.9	74.6	66.5	93.0	138.0
		842.3	845.2	39.4	11.1	80.3	72.1	98.7	143.7
	3	845.2	855.7	19.5	35.4	39.5	31.3	57.9	102.9
		855.7	869.7	32.6	35.5	90.3	82.1	108.7	153.7
		843.1	859.4	26.7	49.9	73.1	64.9	91.5	136.5
		859.4	868.9	18.8	35.6	37.4	29.2	55.8	100.8
	4	869.9	870.5	33.7	3.3	47.7	39.5	66.1	111.1
		848.6	863.1	24.4	32.6	68.8	60.7	87.2	132.2
		863.1	870.3	48.8	14.6	65.6	57.4	84.0	129.0
		870.3	870.4	36.9	0.4	45.0	36.8	63.4	108.4
		872.1	870.8	26.2	5.2	43.5	35.3	61.9	106.9

Source: Field survey in 2022.

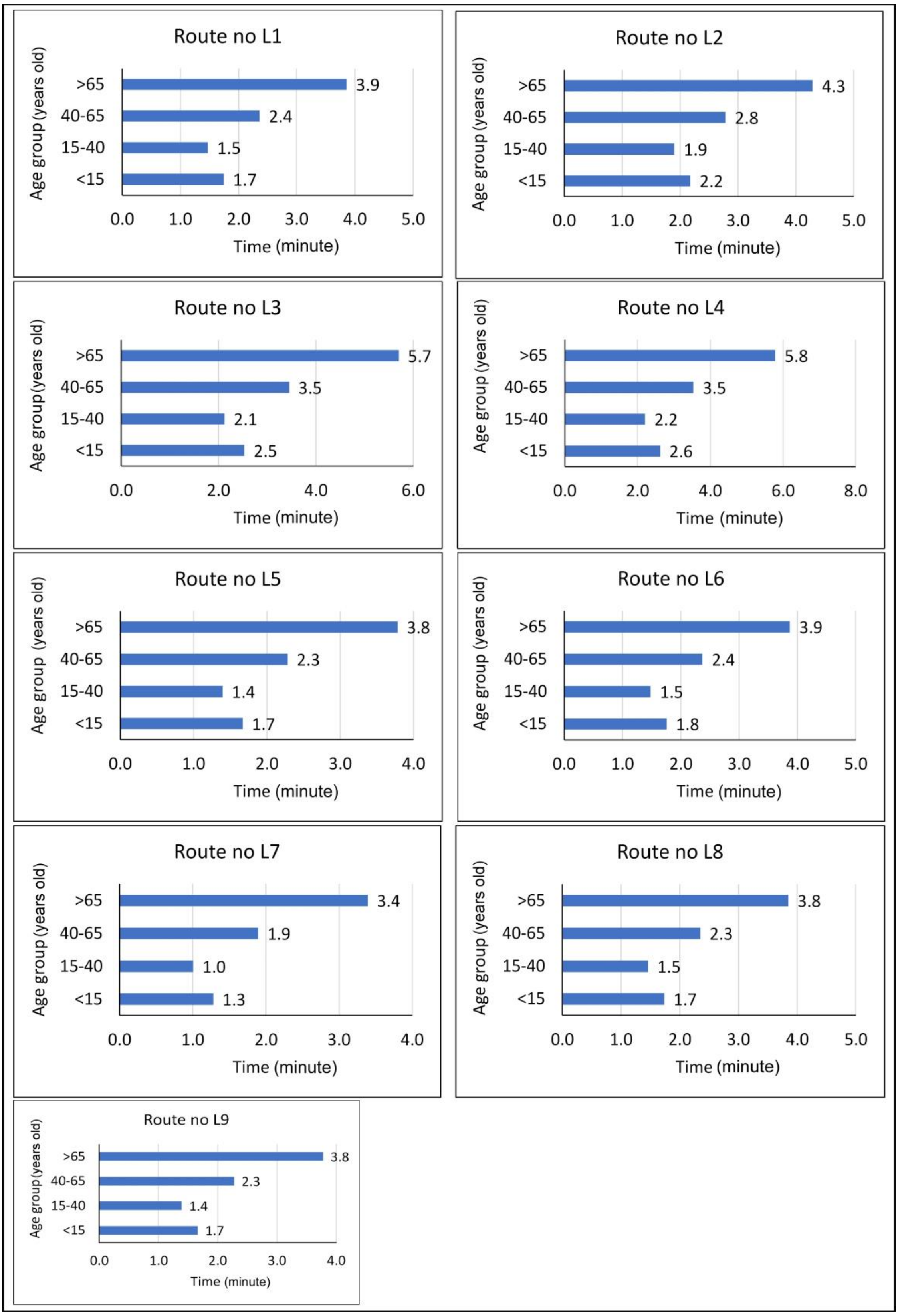

Figure 5.9 Relationship between age group and walking speed in, routes 1-9, KI-Sing (Left side). Note: Time is presented in minutes. (See Figure 3.8 for location).

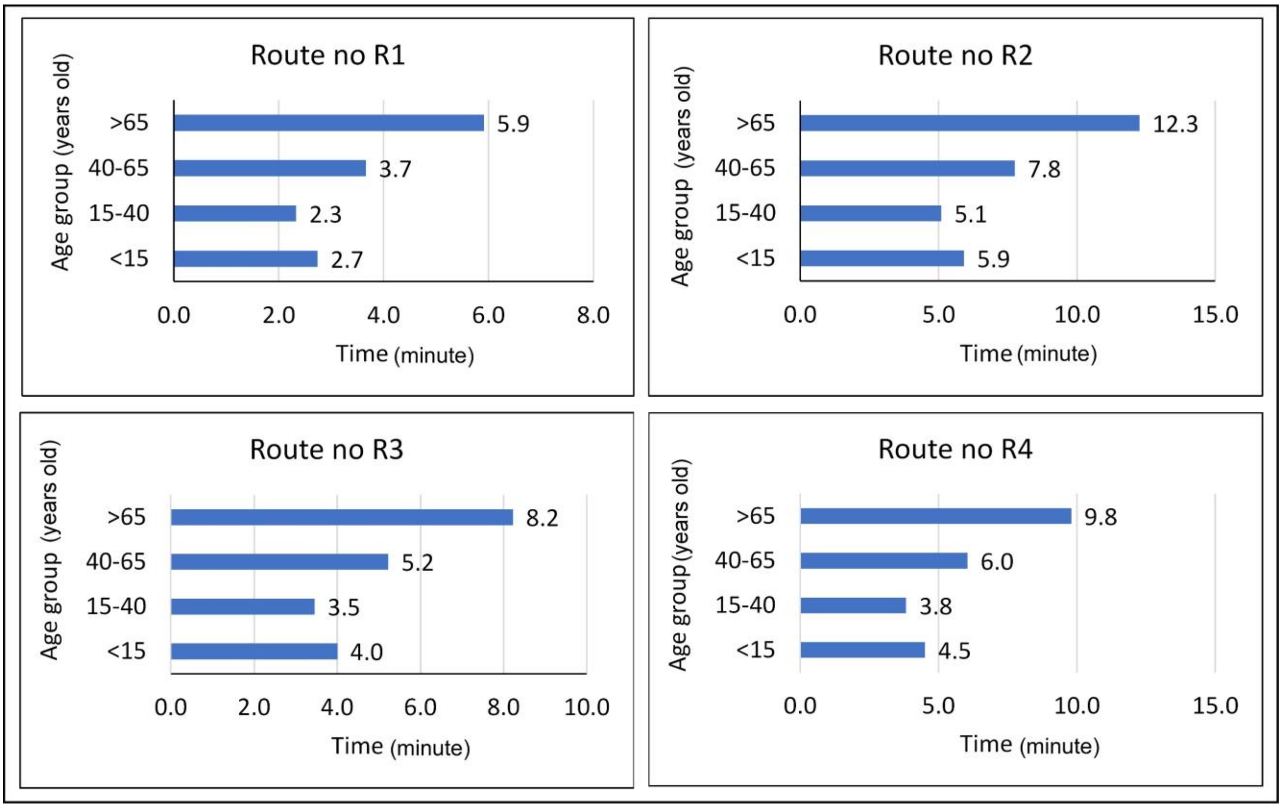

Figure 5.10 Relationship between age group and walking speed in routes 1-4, KI-Sing (Right side). Note: Time is presented in minutes. (See Figure 3.8 for location)

5.1.3.6. **Tamakoshi river basin**

5.1.3.6.1. Singati

A total of 25 emergency evacuation routes are proposed. Table 5.18 shows the evacuation time calculated in Singati. Figure 5.11 represent the result of evacuation routes 1 to 25. Among them, route number 7 requires the longest evacuation time and route number 15 requires the shortest time needed for evacuation in this section.

Table 5.18 Evacuation completion time calculated in each segment based on age group in Singati.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
Singati	1	924.3	924.6	37.1	0.9	45.6	37.4	64	83	13	913.4	915.0	26.3	6.1	44.4	36.2	62.8	81.8
		924.6	928.0	17.3	19.7	52.3	44.1	70.7	89.7		903.8	905.0	24.7	5.1	42.5	34.3	60.9	79.9
		919.4	920.7	27.7	4.7	43.8	35.6	62.2	81.2		920.9	924.5	32.1	11.2	52.7	44.5	71.1	90.1
		915.0	918.1	30.1	10.3	50.6	42.5	69	88		905.0	905.0	10.8	0	29.6	21.4	48	67
		911.9	917.4	34.5	15.8	58.5	50.3	76.9	95.9		905.0	905.0	9.8	0	29	20.8	47.4	66.4
		913.2	915.0	26.7	6.9	45.3	37.1	63.7	82.7	14	921.6	923.1	40.4	3.8	50.3	42.1	68.7	87.7
		910.5	911.8	57.6	2.3	58.8	50.6	77.2	96.2		918.9	921.8	37.1	7.8	52.3	44.1	70.7	89.7
	2	910.0	917.5	35.8	20.9	64.2	56	82.6	101.6		921.8	923.0	8.9	13.3	41.3	33.1	59.7	78.7
		910.0	916.8	35.7	19.1	62.4	54.2	80.8	99.8		923.0	924.6	20.7	7.8	42.8	34.6	61.2	80.2
		905.7	905.0	61.3	1.2	59.8	51.6	78.2	97.2		928.0	931.6	17.1	20.8	53.3	45.1	71.7	90.7
		915.0	912.1	52.4	5.5	58.9	50.7	77.3	96.3	15	923.1	928.1	27	18.5	56.7	48.6	75.1	94.1
		913.7	915.0	57.2	2.2	58.5	50.3	76.9	95.9	16	923.7	924.6	20.3	4.6	39.5	31.3	57.9	76.9
	3	910.0	910.0	38.9	0	45.8	37.6	64.2	83.2		920.0	922.5	22.3	11	46.8	38.6	65.2	84.2
		902.3	904.9	58	4.4	61	52.8	79.4	98.4		915.0	915.7	14.7	4.8	36.5	28.3	54.9	73.9
	4	902.0	905.3	38.6	8.6	53.9	45.7	72.3	91.3		915.7	917.0	13.6	9.3	40.1	32	58.5	77.5
		899.3	902.7	40.1	8.5	54.7	46.5	73.1	92.1		917.0	919.4	22.7	10.7	46.8	38.6	65.2	84.2
		897.1	900.0	14.9	19.4	50.6	42.4	69	88	17	911.0	915.1	18.1	22.6	55.6	47.4	74	93
	5	910.0	910.0	34.4	0	43.2	35	61.6	80.6		918.1	925.5	26.3	28.1	65.6	57.4	84	103
		909.4	910.0	49.4	1.2	52.9	44.7	71.3	90.3		916.2	917.8	19.6	8.3	42.7	34.5	61.1	80.1
Singati	6	911.8	914.0	39.9	5.7	51.8	43.7	70.2	89.2		917.4	919.1	19.5	8.8	43.1	34.9	61.5	80.5
		908.1	910.0	42	4.5	51.9	43.7	70.3	89.3		912.8	911.9	33.9	2.8	45.6	37.4	64	83
		909.8	910.0	57.7	0.4	57	48.8	75.4	94.4	18	908.1	910.1	69.6	2.8	66.2	58	84.6	103.6
		909.0	914.2	33.4	15.6	57.7	49.5	76.1	95.1		910.1	912.5	38	6.4	51.4	43.2	69.8	88.8
		915.0	916.2	22.6	5.2	41.4	33.2	59.8	78.8		912.5	916.1	19.2	18.7	52.4	44.3	70.9	89.9
		915.0	915.0	26.8	0	38.8	30.6	57.2	76.2		914.2	915.0	26.7	2.9	41.5	33.3	59.9	78.9
	7	911.4	911.1	62.3	0.6	59.8	51.6	78.2	97.2	19	907.9	913.2	30.3	17.4	57.6	49.4	76	95
		908.5	910.0	30.6	5	45.8	37.6	64.2	83.2		915.0	915.0	22.5	0	36.3	28.2	54.7	73.7
		906.7	910.0	47.1	7.1	57.4	49.2	75.8	94.8		911.8	917.8	41.7	14.3	61.2	53	79.6	98.6
		905.4	905.0	54.1	0.8	55.3	47.1	73.7	92.7		904.9	910.0	34.1	14.9	57.4	49.2	75.8	94.8
		910.0	910.0	48.9	0	51.5	43.3	69.9	88.9		904.0	905.7	31.2	5.5	46.7	38.5	65.1	84.1
		910.0	925.0	44.5	33.7	81.5	73.3	99.9	118.9		905.7	910.0	34.2	12.5	55.2	47	73.6	92.6
		915.0	910.0	46	10.9	60.3	52.1	78.7	97.7		905.0	910.0	53.3	9.4	63.1	54.9	81.5	100.5
	8	909.8	907.3	34.1	7.4	50.2	42	68.6	87.6	20	912.1	919.7	47.5	16	66.2	58	84.6	103.6
		910.0	910.2	23.2	1	37.7	29.5	56.1	75.1		908.2	915.0	33.9	20.2	62.4	54.2	80.8	99.8
		914.2	914.3	31.5	0.6	42.1	33.9	60.5	79.5		905.8	908.1	39	5.9	51.5	43.3	69.9	88.9
	9	916.1	915.0	24.1	4.6	41.7	33.5	60.1	79.1		910.0	910.0	39.6	0	46.2	38	64.6	83.6
		908.3	910.0	17.4	9.8	42.9	34.7	61.3	80.3		905.0	913.7	56.6	15.4	70.8	62.6	89.2	108.2
		908.7	914.0	25.9	20.3	57.9	49.7	76.3	95.3	21	910.0	910.0	47.8	0	50.9	42.7	69.3	88.3
		908.7	912.2	28.7	12.2	51.7	43.5	70.1	89.1		910.0	910.0	43	0	48.1	39.9	66.5	85.5
		915.1	917.5	19.6	12.3	46.5	38.3	64.9	83.9		910.0	910.0	32	0	41.8	33.6	60.2	79.2
		920.0	919.4	30.2	2	42.6	34.4	61	80		907.0	910.0	37.7	7.9	52.7	44.5	71.1	90.1
	10	919.9	920.0	23	0.5	37.2	29	55.6	74.6		910.0	910.0	30.3	0	40.8	32.6	59.2	78.2
		920.3	923.4	35.6	8.5	52.1	43.9	70.5	89.5	22	905.5	907.0	77.9	1.9	70.1	61.9	88.5	107.5
		920.2	923.7	26.7	12.9	51.2	43	69.6	88.6		905.7	910.0	61.8	6.9	65.7	57.5	84.1	103.1
		920.6	922.9	21.5	10.9	46.3	38.1	64.7	83.7		901.5	904.5	31	9.7	50.6	42.4	69	88
		915.0	915.0	14.1	0	31.5	23.3	49.9	68.9		904.5	902.3	44	4.9	53.4	45.2	71.8	90.8
		903.4	905.7	26.3	8.7	46.8	38.6	65.2	84.2	23	904.9	908.2	45.7	7.2	56.6	48.4	75	94
	11	900.5	900.9	48.7	0.7	52.1	43.9	70.5	89.5		901.5	904.3	60.5	4.5	62.6	54.4	81	100
		896.9	900.1	12.3	26.7	56.2	48	74.6	93.6		925.0	923.4	43.6	3.6	52	43.8	70.4	89.4
		905.4	907.2	36.9	4.9	49.3	41.2	67.7	86.7		904.4	908.2	29.8	12.8	52.8	44.6	71.2	90.2
		904.3	905.0	12.4	5.6	35.9	27.7	54.3	73.3	24	924.6	925.0	36.5	1.1	45.5	37.3	63.9	82.9
		903.9	907.5	22	16.4	51.9	43.7	70.3	89.3		928.2	932.8	25.2	18.4	55.7	47.5	74.1	93.1
	12	905.0	905.0	27.9	0	39.4	31.2	57.8	76.8	25	925.0	928.2	41.7	7.6	54.7	46.5	73.1	92.1
		920.4	922.5	36.5	5.7	49.9	41.7	68.3	87.3		906.2	905.7	41	1.1	48	39.8	66.4	85.4
		910.0	911.3	21.8	5.8	41.5	33.3	59.9	78.9		900.9	901.5	41.8	1.7	49	40.9	67.4	86.4
		908.9	914.8	28.8	20.5	59.7	51.5	78.1	97.1		899.5	899.3	28.3	0.8	40.4	32.2	58.8	77.8
											902.7	904.4	28	6	45.2	37	63.6	82.6

Source: Field survey in 2022.

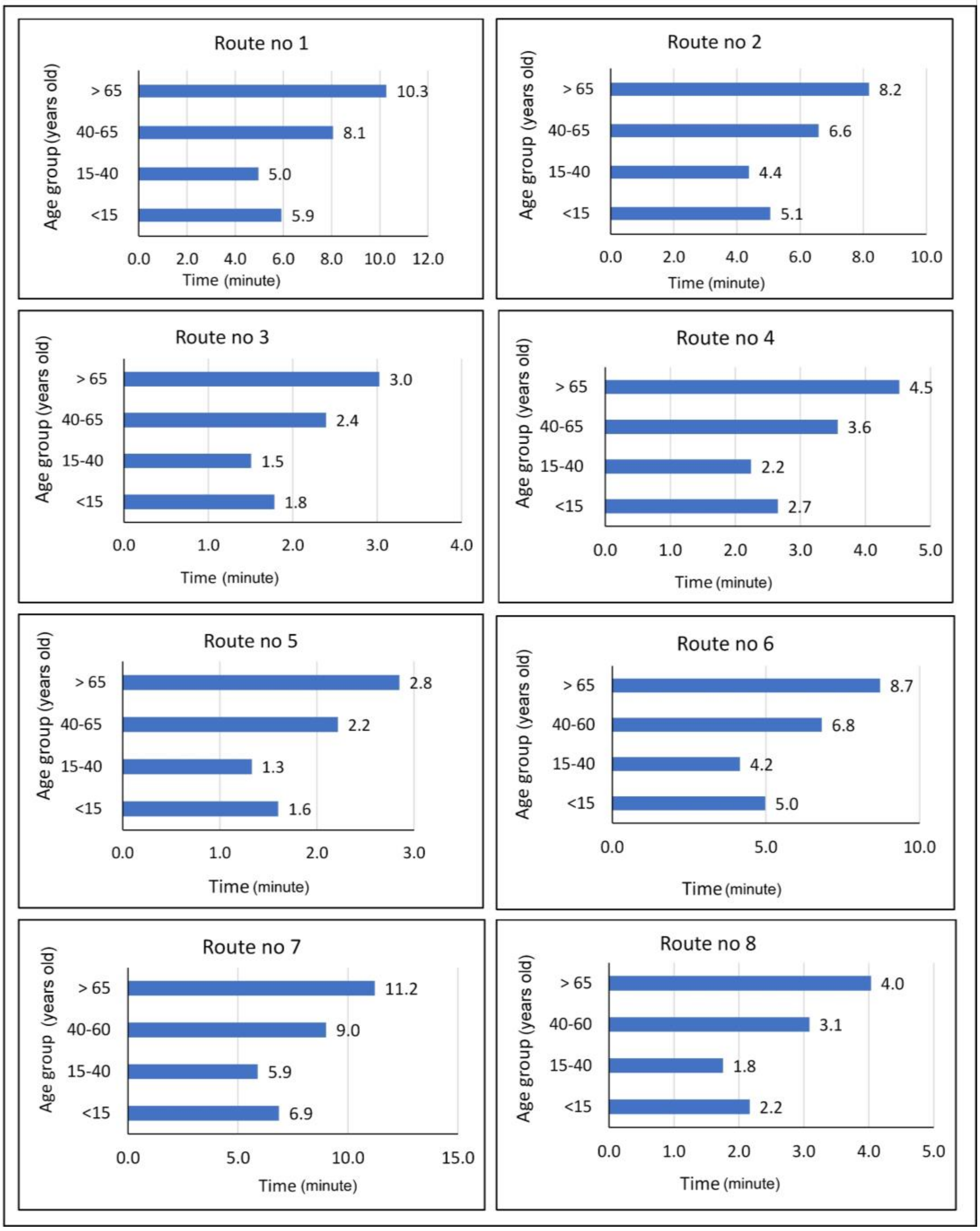

Figure 5.11 Relationship between age group and walking speed in routes 1-25, Singati. Note: Time is presented in minutes. (See Figure 4.7 for location).

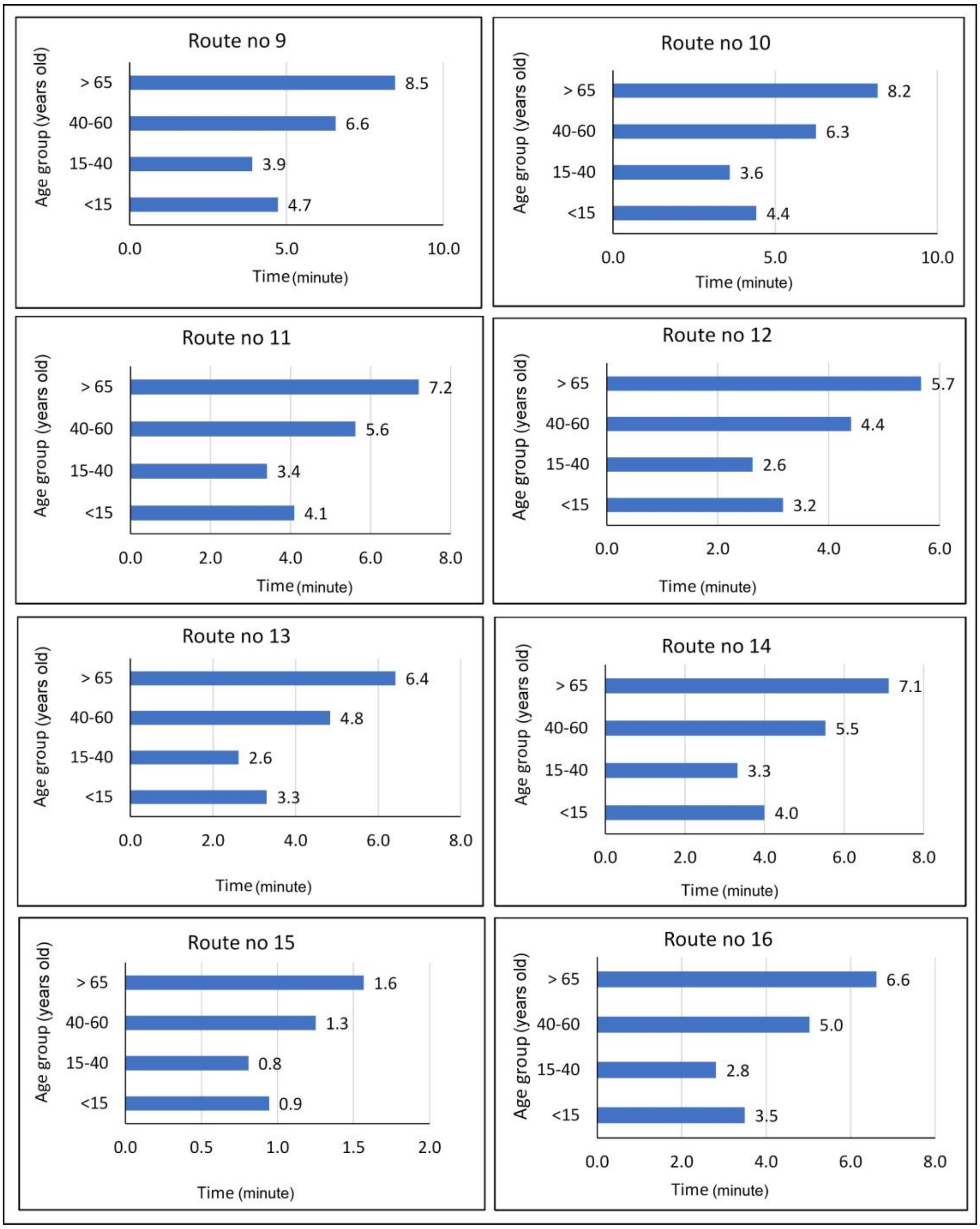

Figure 5.11 (Continued).

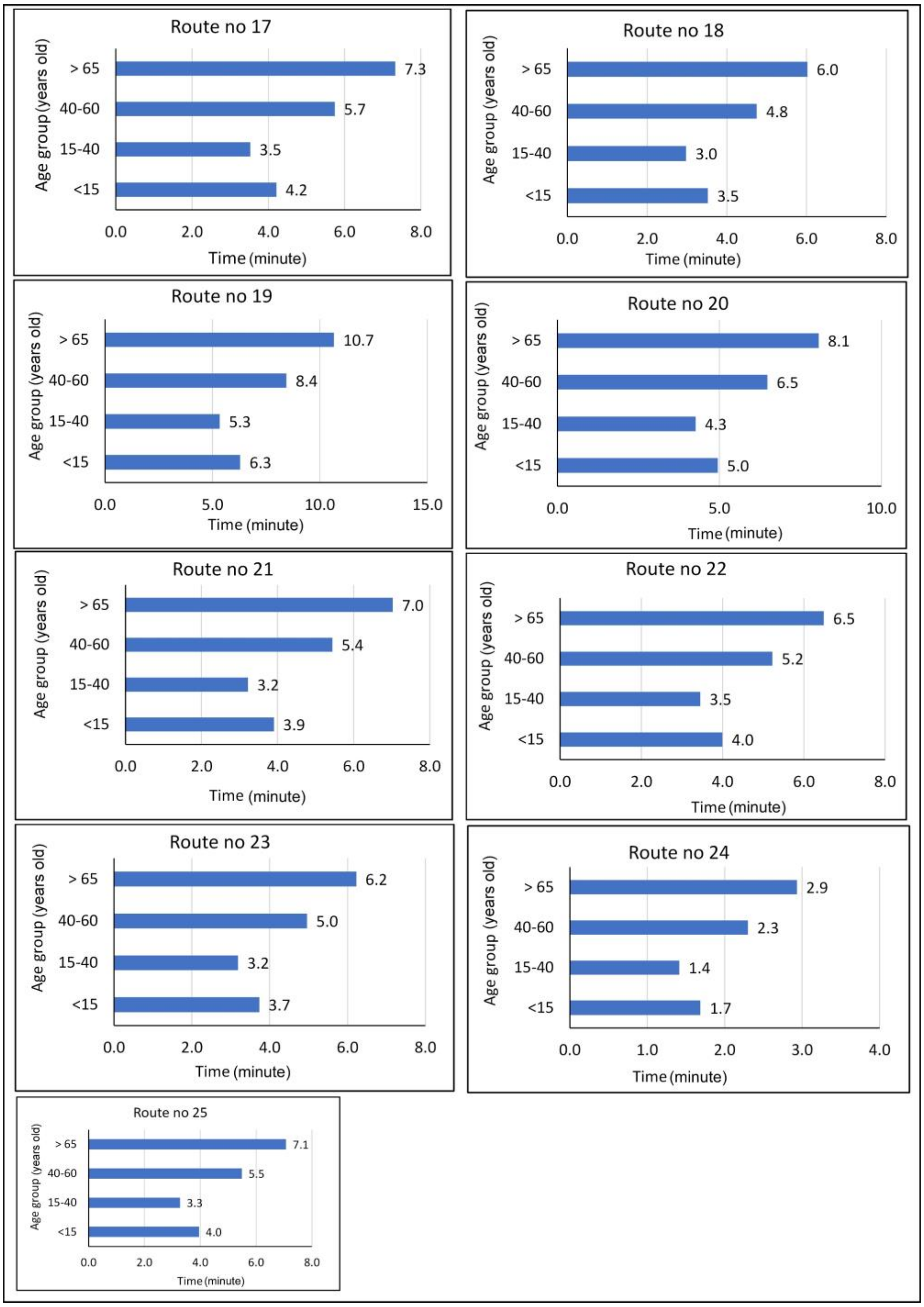

Figure 5.11 (Continued).

5.1.3.6.2. Gongar, Jagat, Jamune, Bhorle, Kattike and Tamakoshi

Table 5.19 shows the evacuation time for the of six settlements. Routes 1 to 9 Gongar, route 10 for Jagat, 11 for Jamune, 12 for Bhorle, 13-15 for Kattike, and 16 and 17 for Tamakoshi based on age group. Similarly, Table 5.20 shows the maximum evatuation time based on elderly people in each segment.

Figure 5.12 shows the relationship between walking speed and age group. Gongar: route 5 is the shortest and route 1 is the longest.

Table 5.19 Evacuation completion time calculation in each segment based on age group in Gongar, Jagat, Jamune, Bhorle, Kattike and Tamakoshi.

Section Name	Route no	Start elevation	End elevation	Segment length (m)	Slope (degree)	Time (second)			
						Age group 1 (<15)	Age group 2 (15 - 40)	Age Group 3 (40 - 65)	Age Group 4 (>65)
		1293.0	1282.0	274.3	35.1	210.6	202.4	229.0	274.0
	1	1282.0	1282.0	81.9	0.0	100.0	91.8	118.4	163.4
	2	1375.0	1458.0	96.2	30.3	115.4	107.2	133.8	178.8
		1406.0	1431.0	52.5	30.5	91.3	83.1	109.7	154.7
	3	1375.0	1450.0	41.3	37.9	85.4	77.2	103.8	148.8
		1282.0	1375.0	18.9	39.1	68.1	59.9	86.5	131.5
		1286.0	1450.0	8.9	39.7	28.5	20.3	46.9	91.9
		1286.0	1298.0	41.1	29.2	75.2	67.0	93.6	138.6
Gongar	4	1282.0	1282.0	42.5	0.0	47.8	39.6	66.2	111.2
	5	1263.0	1280.0	75.8	22.4	88.7	80.5	107.1	152.1
		1258.0	1268.0	105.0	9.5	93.0	84.8	111.4	156.4
		1258.0	1260.0	41.2	4.9	51.8	43.6	70.2	115.2
	6	1255.0	1260.0	31.6	15.8	56.8	48.6	75.2	120.2
	7	1358.0	1421.0	103.4	49.9	131.1	122.9	149.5	194.5
		1389.0	1428.0	119.4	32.7	123.6	115.4	142.0	187.0
	8	1329.0	1407.0	49.6	26.2	80.4	72.2	98.8	143.8
	9	1353.0	1400.0	61.8	42.5	84.2	76.0	102.6	147.6
Jagat	10	1220.0	1287.0	89.5	38.2	115.9	107.7	134.3	179.3
Jamune	11	1080.0	1200.0	175.4	50.5	161.3	153.1	179.7	224.7
Bhorle	12	850.0	961.0	132.5	42.0	148.5	140.3	166.9	211.9
	13	876.0	972.0	221.8	36.5	191.7	183.5	210.1	255.1
	14	979.0	858.0	158.7	42.5	150.0	141.8	168.4	213.4
Kattike		997.0	932.0	166.9	28.6	160.5	152.3	178.9	223.9
	15	955.0	959.0	50.5	10.4	80.1	71.9	98.5	143.5
		939.0	966.0	38.5	47.2	55.6	47.4	74.0	119.0
		958.0	958.0	47.2	0.0	96.1	87.9	114.5	159.5
Tamakoshi	16	941.0	976.0	11.6	42.6	30.0	21.8	48.4	93.4
		941.0	941.0	44.5	0.0	90.1	81.9	108.5	153.5
	17	1284.0	1429.0	15.0	29.5	32.0	23.8	50.4	95.4

Source: Field survey in 2022.

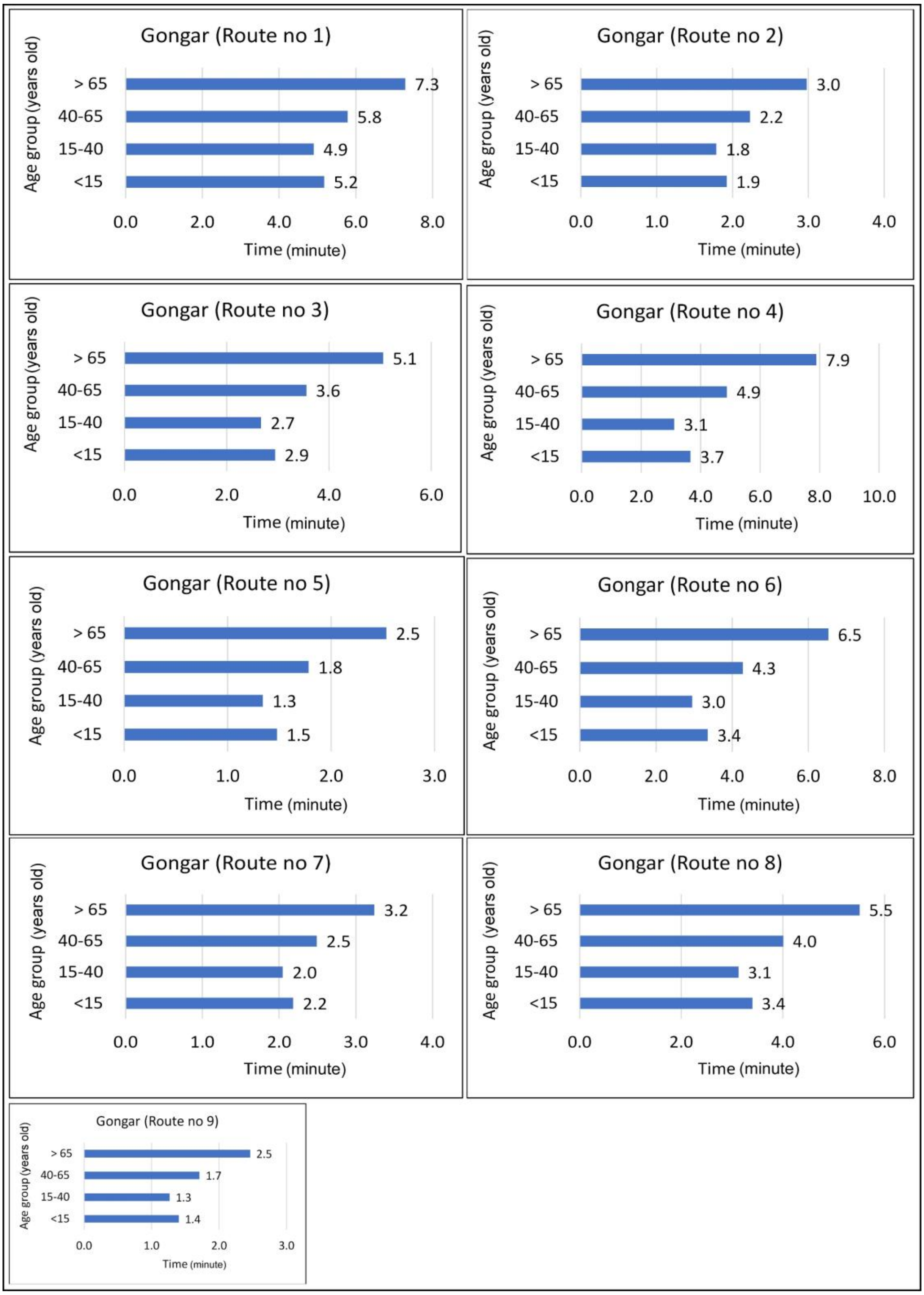

Figure 5.12 Relationship between age group and walking speed in routes 1-17, Gongar. Note: Time is presented in minutes. (See Figure 4.6 for location)

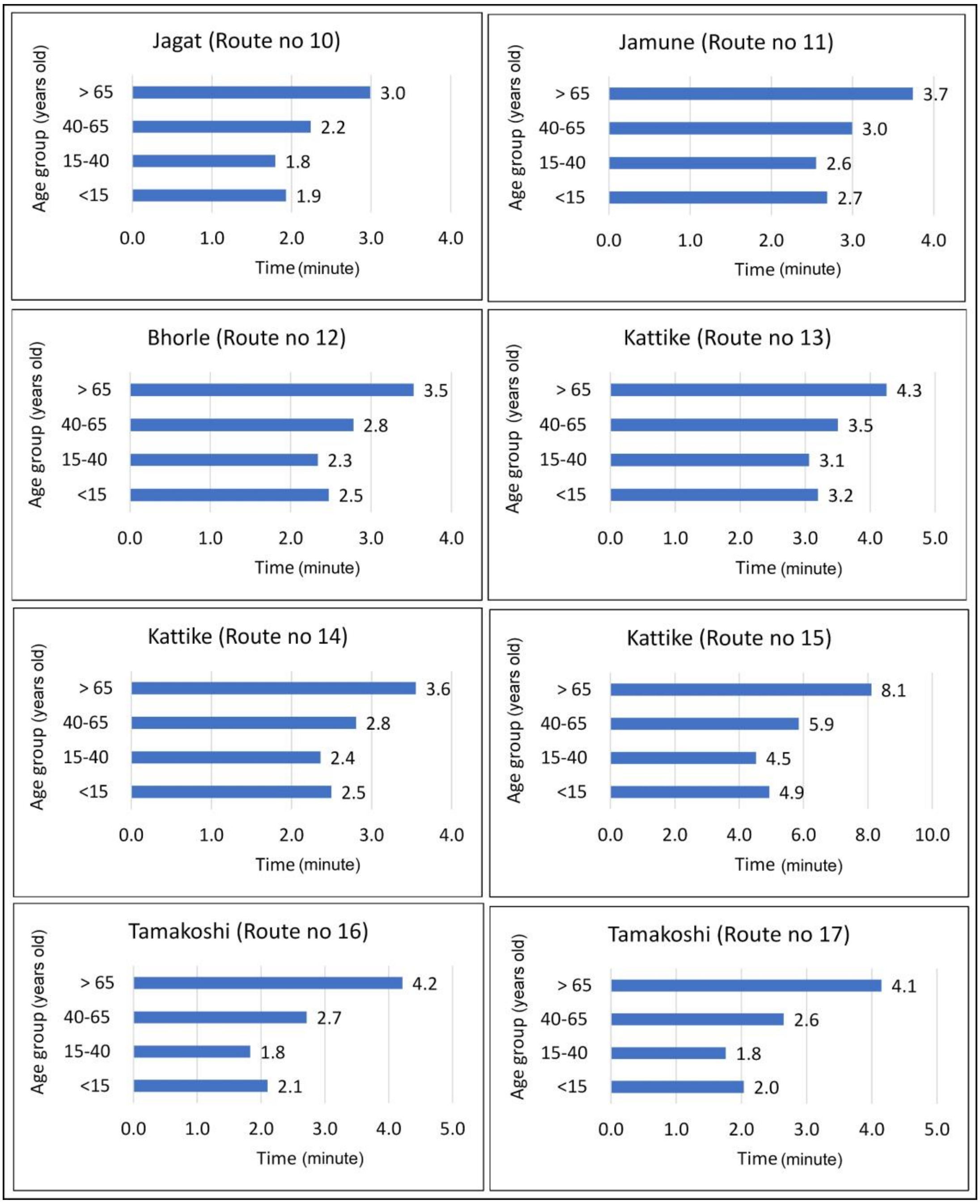

Figure 5.12 (Continued)

Table 5.20 Maximum evatuation time based on elderly people in each segment

Settlements	Total evacuation time (minute)		
	<10 minute	<15 minute	<20 minute
Masinabagar	16	12	-
Laltinbazar	20	6	1
KI-Sing	12	1	-
Singati	22	3	-
Gongar	9	-	-
Jagat	1	-	-
Jamune	1	-	-
Bhorle	1	-	-
Kattike	3	-	-
Tamakoshi	2	-	-

Source: Field survey in 2022.

5.1.4. The need of evacuation system by social networking service (SNS)

The percentage of mobile-phone possession was found to be high with about two handsets in every household (Table 5.8). This means that evacuation warnings are transmitted to most working-age residents in most families (especially to the night population). However, it was found that many of the children and the elderly do not have mobile-phone, indicating that it is essential to create a system (training sessions and evacuation drills), in which families of working age can pass on evacuation information to their children and the elderly, and evacuate together. It can be suggested that the development of evacuation schemes using SNS should be focused on family-based evacuation especially for night evacuation.

For the daytime population, it is assumed that the working-age population are separated from children and the elderly. All children with a certain income in their family go to school and can be expected to be guided to evacuate by their teachers. Therefore, it is important to practice evacuation drills at the school level as well. If the elderly are physically fit, they are likely to be working day jobs with working-age people in the lower-income groups, or the elderly in the higher-income groups are likely to have some level of telephone ownership. Therefore, daytime evacuation drills are so important. For this reason, it would be preferable to carry out daytime evacuation drills by occupation and by the workplace in order to succeed the evacuation system by SNS.

5.1.5. Result of lack of awareness and preparedness in Singati from the 2015 to 2022

Figure 5.13 showed that the newly built houses are mainly located along the riverside area. The majority of those new houses are situated already in the inundation zone. In total 101 new houses were built in this area of Singati between 2015 and 2022, despite the fact that Singati already faced an earthquake disaster and had a huge property loss.

There are lack of awareness of disaster preparedness among the residents and lack of policies, and regulation from the government side. 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.

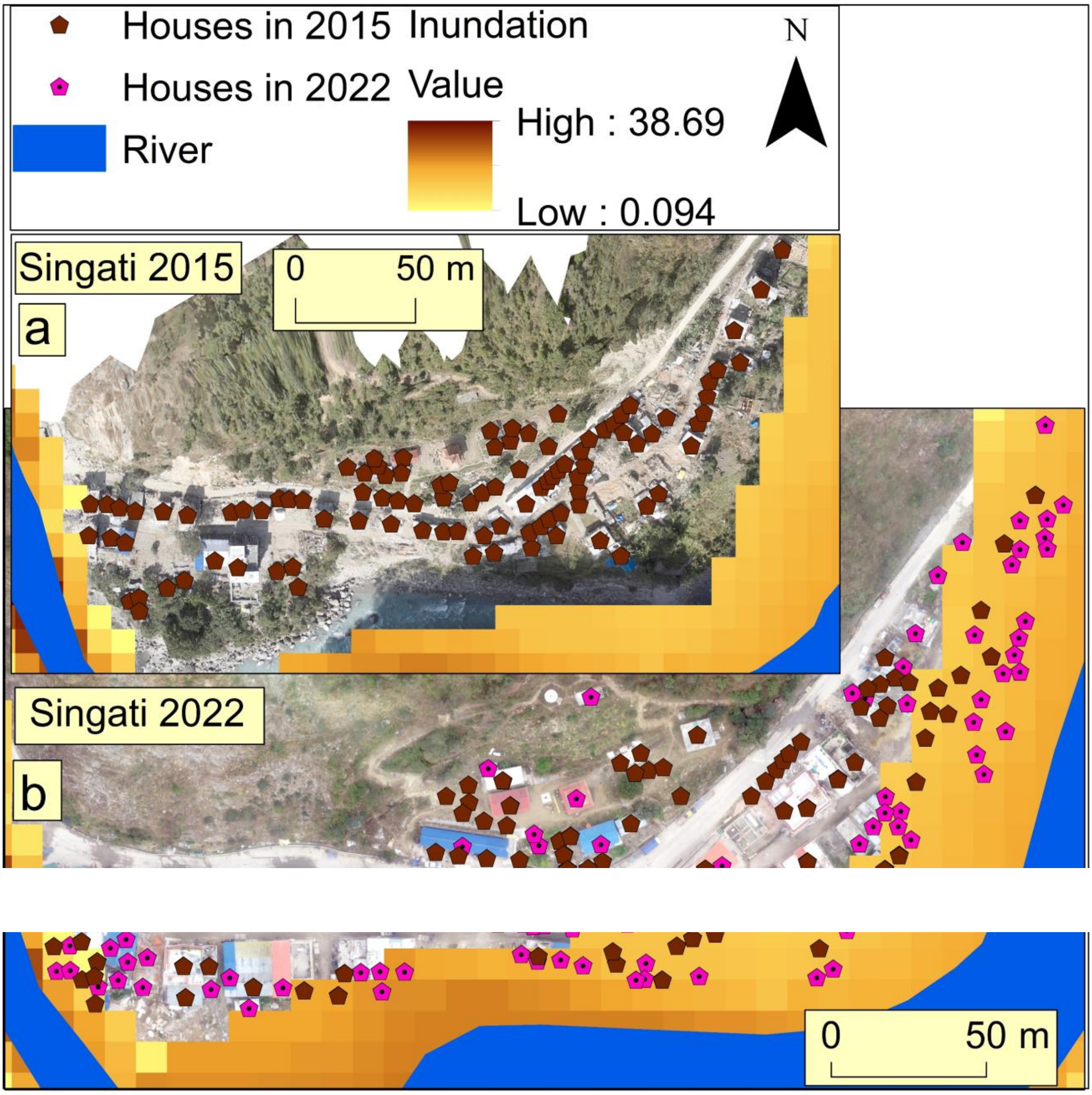

Figure 5.13 Changes of houses in Singati between 2015 to 2022. Dark brown color represents the houses that existed in 2015 (orthophoto was prepared based on the UAV photographs taken after the earthquake). Pink color represents the newly built houses after 2015. Note that some houses where the questionnaire survey was not conducted are also shown here.

5.1.6. **Return Period Calculation of Flood**

This study assumed that the flood level for the inundation mapping was 1450 m^3/s as described earlier. When the peak discharge that this study used for the Seti River is considered, its return period is expected to be 50 years (Tables 5.21 and 5.22).

The Water and Energy Commission Secretariat (WECS) in Nepal (WECS, 1990) published a report on the regional hydrological analysis, which gives the following equation:

$Q_2 = 1.8767 (A<3000 + 1)$ ^0.8783

$Q_{100} = 14.639 (A<3000 + 1)$ ^0.7342

where A<3000 is the area of the catchment below 3000 m elevation in km^2, Q_2 and Q_{100} are discharge of 2-year and 100-year return period floods, respectively. Flood discharge for any other return period T is then given by:

$QT = \exp (\ln Q_2 + S_\alpha)$

where S is the standard deviation of natural logarithms of annual floods and α stands for a standardized normal variant for return period T.

S can be calculated as:

$S = \ln (Q_{100}/ Q_2) /2.326$

Table 5.21 Calculated results of discharge in 500-year return period in Seti River (WECS 1990 Method)

Total catchment area			600.00 km^2
Catchment area below 3000 m	A		360.00 km^2
Two-year flood	Q_2	$1.8767(A+1)^{0.8783}$	517.70 m^3/s
Hundred-year flood	Q_{100}	$14.63\ (A+1)^{0.7342}$	1605.07 m^3/s
Standard deviation of natural log	σ	$(Q_{100}/Q_2)/2.326$	0.4865
Fifty-year flood			1406 m^3/s

Table 5.22 Flood Return Period Calculation

Return periods (Years)	Flood discharge (m^3/s)
2	517.70
5	779.78
10	965.89
20	1152.44
50	1406.14
100	1605.07
200	1812.64
500	2099.50
1000	2327.58
5000	2897.18
10000	3160.77

The catchment areas of the Tamakoshi River basin and all the settlements are demarcated on the Digital Elevation Model (DEM) of the research area. The Tamakoshi River has been gauged since 1970 at the Busti Station (Station No. 647), just downstream of the confluence of Tamkoshi and Singati Rivers. The peak discharges for various return periods are estimated based on the instantaneous maximum discharge records at the Busti Station for the stretch of Tamakoshi between Suri Dovan and Singati. The annual maximum daily rainfall values of the relevant station are collected and 24 hours maximum rainfalls for various returns periods are calculated.

Table 5.23 Water and Energy Commission Secretariat Method (WECS 1990 Method)

Total catchment area			1471.00 sqkm
Catchment area below 3000m	A		698.00 sqkm
Two-year flood	Q2	$1.8767(A+1)^{0.8783}$	1137.02 m^3/s
Hundred-year flood	Q100	$14.63\ (A+1)^{0.7342}$	3098.29 m^3/s
Standard deviation of natural log	σ	(Q100/Q2)/2.326	0.4310
Ten years flood			1975.688 m^3/s

Table 5.24 Flood Return Period Calculation

Return periods (Years)	Flood discharge (m^3/s)
2	1137.02
5	1634.422
10	1975.688
20	2310.258
50	2755.576
100	3098.291
200	3450.757
500	3930.423
1000	4306.446
5000	5228.111
10000	5647.393

The return period for the Tamakoshi river is expected to be 10 years (Table 5.23 and Table 5.24). Table 5.25 shows the flood return period calculation of each settlement. Similarly, the observed annual instantaneous maximum discharge of Tamakoshi River at the Busti Station and estimated peak discharges of various return periods of all settlements.

Table 5.25 Flood Return Period Calculation of each settlement

	Total Catchment (km^2)	Catchment Area <3000 m (km^2)	Flood return period years (m3/s)						Max depth of water (m)
			2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	
Total Area	1471	698	1137	1634	1976	2310	2756	3098	38.69
Gongar	673	94	573	857	1059	1260	1533	1746	19.29
Purano jagat, Jagat and mantali	749	155	629	936	1153	1369	1661	1888	10.00
Jamune	786	191	656	974	1198	1421	1722	1956	10.00
Suri dobhan, bhorle and Olitar	1039	356	838	1227	1497	1764	2123	2401	6.00
Singati	1262	510	994	1440	1748	2051	2456	2769	38.69
Kattike and Tamakoshi	1471	710	1137	1634	1976	2310	2756	3098	K 14, T 19.29

5.1.7. Significance of the Combined Approach: Modeling, Mapping, and Socio-Economic Context and Response

Nepal has experienced numerous GLOFs and other water-related disasters in recent years. Thus far, most correlated disaster studies have focused on modeling, while others have adopted a sociological approach. However, these studies have tended to be conducted separately. The present study showed the relationship between the locations of individual buildings and houses, with or without flood-hazard dangers, and the socioeconomic status of these residents. Based on these findings, it was concluded that the buildings within the inundation risk zone must be relocated; however, this requires the financial support of governmental agencies, NGOs, INGOs, and other related agencies, as the at-risk residents belong to lower-income categories. Furthermore, this study identified and suggested detailed evacuation routes and a safe evacuation system, which only became possible with the combined approach applied here.

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. These were de-lived from the combined approach, which can be adapted in other parts of the Himalayan countries.

5.1.8. Flood disaster and HEC-RAS

Among all kinds of natural hazards of the world flood is probably most devastating, wide spread and frequent. A river flooding is a recurrent natural phenomenon in the humid tropics and subtropical climates (Sanyal, 2004). Climate variability and global climatic change have brought tremendous impact on the high mountainous glacial environment. The Himalayan glaciers are shrinking, retreating, and lowering their surface and they cause consequently lakes formed at the glacier snouts or on the glaciers expanding rapidly in most cases (Bajracharye, 2010). Thus, the GLOF and high-intensity rainfall for a shorter time period produces high peak runoff from altered/urbanized catchment (Rangari, Sridhar, et al., 2018, 2019).

In recent times, severe foods in urban areas are occurring more frequently owing to uncontrolled urbanization and climate change and they will continue to grow in upcoming years. Prevention of such events is not possible but food-vulnerable areas can be identified through 2-D modeling of critical rainfall events with advancement of technology (Rangari, et al., 2019). HEC-RAS along with geographic information system (GIS) has become the key tool for flood monitoring in recent years as described earlier. Development in this field has evolved from optical to radar remote sensing, which has provided all-weather capability compared to optical sensors for the purpose of flood mapping. Extracting flood hazard settings in highly vulnerable areas by using GIS and hydraulic models such as HEC-RAS is common nowadays. In this framework, the 1D/2D hydraulic models, which were generated based on

Digital Elevation Model (DEM) and processed within Geographical Information Systems (GIS), can improve accuracy of large-scale flood hazard maps (Hutanu et al., 2020; Aggett & Wilson, 2009; Ben Khalfallah & Saidi, 2018; Demir & Kisi, 2016; Quirogaa et al., 2016; Sarhadi et al., 2012; Kumar et al., 2020; Khattak et al., 2016; Patel et al., 2017; Tate et al., 2002).

Gurung et al., (2021), examined the flood disaster in the Seti River basin and emphasized the use of the HEC-RAS model and socioeconomic impact assessment. However, their study mainly focused on hydro-geomorphological mapping, analysis of land-use and land-cover change, and hydrological analysis including HEC-RAS modeling and historical archives. As the current study emphasized, they suggest the necessity of early warning system and public awareness education in order to mitigate and manage the future impact of fluvial hazards along the Seti valley.

UNDP, (2010) studied the hazard, vulnerability, and risk assessment in three communities of Dolakha (Tamakoshi river basin) using HEC-RAS. Their research focused on landslide susceptibility, inundation modeling, and socioeconomic aspect. However, they had not used high-resolution DEM for inundation neither they suggested any evacuation measures. All the previous studies, however, are limited to analyzing the flood frequency and their research is not focused on evacuation routes and measures. Therefore, the current study successfully filled the research gap and identified vulnerable houses, and calculated the flood depth. Furthermore, based on 2D HEC-RAS hydraulic modeling and orthophoto derivate DEM with 1-m spatial resolution it described the detailed evacuation routes (Figure 3.5-3.8 and Figure 4.6-4.10).

5.1.9. **Evacuation time, slope, and age group**

Finding a safe place for a disaster emergency in steep and riverside areas with is a challenging task. Vertical evacuation to high-story buildings rising above the expected inundation depth is one of the most suitable alternatives (Yoshitsugu et al., 2020). This approach may be adequate in the areas where the long evacuation time is required (e.g. route 1 in Masinabagar of Figure 5.4). Therefore, achieving safe evacuation is the main goal of selecting an evacuation route, although constructing high-story buildings cost large amount of money. General path-finding methods determine a single shortest route to one endpoint; however, finding the shortest route alone is insufficient for selecting evacuation routes (Yoshitsugu et al., 2020). All settlements in the study area have a dense population with many steep and narrow slopes. As a result, it is important to prepare multiple evacuation sites and routes in case the existing routes are over crowed during the disasters.

5.1.10. **Early warning and evacuation using SNS approach**

Evacuation is the primary protective action utilized in large-scale disasters such as hurricanes, floods, tsunamis, volcanic eruptions, releases of hazardous or nuclear materials, and high-rise building fires and explosions (Sorensen & Sorensen, 2007). Recently many studies are focused on the adoption of warning systems. Smith et al. (2014) described the testing of probabilistic adaptive real-time flood forecasting models. Liu et al. (2011) emphasized the need of establishing an early warning system for the disaster-prone area. Maharjan et al. (2021) and Dewan (2015b) emphasized the importance of early warning via informal risk communication from upstream communities. Dewan (2015b) further stated that there is a need to establish early warning systems in the watershed with strong involvement from upstream and downstream communities, supported by local and national government entities.

Similarly, few studies are focused on community-based flood early-warning systems as well as low-cost sensing technology (Pandeya et al., 2021). This study, focused on mobile phone-based SSN alarming system. This study showed 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 (Table 5.8). Altogether 98.68 % of the 15- to 64-year-old people have a mobile phone. Similarly, in Dolakha, NTC has been expanding and installed a new GSM BTS base station tower in Dadakharka of Dolakha district. It covers all part of the district. The mobile tower there benefits more than 4 thousand customers in the area. Customers can not only make a call through their GSM mobile but also can use some internet data on their mobile. Therefore, this study can suggest a mobile phone base alarming system for both areas. An early warning system through mobile phones would be the best solution in the areas as well as other parts of Nepal.

This result is supported by Alias et al. (2020), which also prefers low-cost early alarming systems for the local people. Nepal Government already introduced high tech alarming systems in other parts of the country such as Imja lake. However, those high-tech system is not applicable to rural area where most of the people are living in scattered settlement. Therefore, early warning is out of the coverage for those types of people.

5.1.11. Limitations of the study and future prospective

This study emphasized the use of HEC-RAS with help of UAV photogrammetry. The great advantage of UAV systems is the ability to quickly deliver high temporal and spatial resolution image information and to allow a rapid response in several critical situations where immediate access to 3D geoinformation is crucial (Remondino et al., 2011).

The HEC-RAS model only assumes a fixed boundary of the river geometry and a steady flow pattern for this research. The assumption of 1D/2D-dimensional flow may not be always valid. Manning's 'n' is taken from the table fixed on the observed river morphology. Walking time data are another limitation of this study. Only five routes were examined because of the time limitation. This study used a simple linear regression model for the rest of the calculations. A regression model is a standardly established model for this type of work, although measuring all routes one by one will give a more accurate result.

Another limitation of this study is that it did not consider shelter-house location and land ownership. This research only figured out the safe location based on the relative height and distance from the river. Landownership and budget are not considered.

Chapter 6 Conclusions and recommendation

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 route and route to be created can be used for emergencies. Therefore, in Masinabagar 27 routes are to be created. Similarly, 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 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 Kaski, Pokhara, people's knowledge about evacuation safe sites is 53.22% ($p<0.001$). In total 46.78% of the people are unaware of the evacuation process. 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%). Correlation between disaster preparedness training and safe/inundated houses is statically correlated (p<0.001). Even 44.11% of the people have not any knowledge about such kind of training (p<0.001). They never participate or practice any drill. Almost 100% of people are unaware of the hazard map (p<0.504).

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.

In the Tamakoshi river basin, the evacuation route height from households to a safe place (destination) is a minimum of 14 meters to 280 meters maximum. Similarly, the total distance from a household to a safe place is a minimum of 53 meters to a maximum of 276 meters. 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: under 15-years old, 15–40-years old, 40–65-years old, and above 65-years old groups. The result found that walking speed is decreased by increasing age. 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 percent were upper-middle people 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 50.9%. The number of employees in different offices and small farms, government offices, and in small NGOs is 19.6%. Agriculture-based households varied from 15.9% percent. Remittance provided a sustainable form of income for 5.5% of households. Labor-related occupations were 4.2% and pension contributes 3.7% of the household's income.

Mostly the non-migrated people are living in this area (57.7%). Altogether, 42.3% 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 ($p<0.002$). 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 ($p<0.839$).

In Dolakha people's knowledge about evacuation is only 3.7% and a total of 96.3% of the people are unaware of the evacuation process. Similarly, 113 households had no idea about disaster preparedness training. 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 about knowledge about safe sites while 23 were aware of safe sites. In the entire study area out of 163 households, only 6 households had minimum knowledge about the regular drill. Therefore, only three families are aware of the hazard map.

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. People should be made aware of the increasing risk of water-induced disasters. It is suggested that governmental agencies, NGOs, INGOs, and other related agencies prepare an adequate plan that targets the impoverished residents of the inundation zone, as they cannot afford safe lands for relocation. The inundation maps clearly show that in the past 7 years, people started building new houses inside the inundation zone, which should be stopped and controlled.

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.

Reference

Dahal. K. R., & Hasegawa. S, & A. (2020). Representative rainfall thresholds for landslides in the Nepal Himalaya. *Geomorphology*, *26*(3–4), 36–42. https://doi.org/10.1029/2011GL049940

Abarquez, I., & Murshed, Z. (2004). *Community-based disaster risk management: Field practitioners' handbook*. 150. http://info.worldbank.org/etools/ docs/library/230352/ Session-3/Reading 3 - ADPC Handbook.pdf

Acharya, A., & Kayastha, R. B. (2018). Mass and energy balance estimation of Yala Glacier (2011-2017), Langtang Valley, Nepal. *Water (Switzerland)*, *11*(1). https://doi.org/10.3390/w11010006

Acharya, T. D., Mainali, S. C., Yang, I. T., & Lee, D. H. (2016). Analysis of jure landslide dam, Sindhupalchowk using GIS and Remote Sensing. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *41*(July), 201–203. https://doi.org/10.5194/isprsarchives-XLI-B6-201-2016

Adapt-Nepal_UNDP(2010)Singati Area. (n.d.).

Aggett, G. R., & Wilson, J. P. (2009). Creating and coupling a high-resolution DTM with a 1-D hydraulic model in a GIS for scenario-based assessment of avulsion hazard in a gravel-bed river. *Geomorphology*, *113*(1–2), 21–34. https://doi.org/10.1016/j.geomorph.2009.06.034

Aksha, S. K., Juran, L., Resler, L. M., & Zhang, Y. (2019). An analysis of social vulnerability to natural hazards in Nepal using a modified social vulnerability index. *International Journal of Disaster Risk Science*, *10*(1), 103–116. https://doi.org/10.1007/s13753-018-0192-7

Alias, N. E., Salim, N. A., Taib, S. M., Mohd Yusof, M. B., Saari, R., Adli Ramli, M. W., Othman, I. K., Annammala, K. V., Yusof, H. M., Ismail, N., Yuzir, A., & Blenkinsop, S. (2020). Community responses on effective flood dissemination warnings—A case study of the December 2014 Kelantan Flood, Malaysia. *Journal of Flood Risk Management*, *13*(S1), 1–13. https://doi.org/10.1111/jfr3.12552

Aljehani, M., & Inoue, M. (2016). Multi-UAV tracking and scanning systems in M2M communication for disaster response. *2016 IEEE 5th Global Conference on Consumer Electronics, GCCE 2016*, 2–3. https://doi.org/10.1109/GCCE.2016.7800524

Alves, F., Cruz, S., Ribeiro, A., Silva, A. B., Martins, J., & Cunha, I. (2020). Walkability index for elderly health: A proposal. *Sustainability (Switzerland)*, *12*(18). https://doi.org/10.3390/SU12187360

Ancey, C. (2001). *13 Snow Avalanches* (pp. 319–338). Springer-Verlag Berlin Heidelberg.

Apatu, E. J. I., Gregg, C. E., Wood, N. J., & Wang, L. (2016). Household evacuation characteristics in American Samoa during the 2009 Samoa Islands tsunami. *Disasters*, *40*(4), 779–798. https://doi.org/10.1111/disa.12170

Backes, D., Schumann, G., Teferele, F. N., & Boehm, J. (2019). Towards a high-resolution drone-based 3D mapping dataset to optimise flood hazard modelling. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(2/W13), 181–187. https://doi.org/10.5194/isprs-archives-XLII-2-W13-181-2019

Bae, C. Y., & Kobayashi, K. (2021). Analysis of evacuation time for vulnerable individuals during inundation of lowland areas. *Journal of Disaster Research*, *16*(5), 866–873. https://doi.org/10.20965/jdr.2021.p0866

Bajracharya, S. R., Maharjan, S. B., Shrestha, F., Sherpa, T. C., Wagle, N., & Shrestha, A. B. (2020). Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi , Gandaki , and Karnali river basins of Nepal , the Tibet Autonomous Region of China , and India. Research Report. ICIMOD and UNDP.

Bang, H. N., & Few, R. (2012). Social risks and challenges in post-disaster resettlement: The case of Lake Nyos, Cameroon. *Journal of Risk Research*, *15*(9), 1141–1157. https://doi.org/10.1080/13669877.2012.705315

Baniya, M. B., Asaeda, T., K.C., S., & Jayashanka, S. M. D. H. (2019). Hydraulic parameters for sediment transport and prediction of suspended sediment for Kali Gandaki river basin, Himalaya, Nepal. *Water*, *11*, 1–18. https://doi.org/doi:10.3390/w11061229

Barba, S., Barbarella, M., Di Benedetto, A., Fiani, M., Gujski, L., & Limongiello, M. (2019). Accuracy assessment of 3D photogrammetric models from an unmanned aerial vehicle. *Drones*, *3*(4), 79. https://doi.org/10.3390/drones3040079

Bashawri, A., Garrity, S., & Moodley, K. (2014). An overview of the design of disaster relief shelters. *Procedia Economics and Finance*, *18*(September), 924–931. https://doi.org/10.1016/s2212-5671(14)01019-3

Ben Khalfallah, C., & Saidi, S. (2018). Spatiotemporal floodplain mapping and prediction using HEC-RAS - GIS tools: Case of the Mejerda river, Tunisia. *Journal of African Earth Sciences*, *142*, 44–51. https://doi.org/10.1016/j.jafrearsci.2018.03.004

Bhambri, R., Mehta, M., Dobhal, D. P., Gupta, A. K., Pratap, B., Kesarwani, K., & Verma, A. (2015). Devastation in the Kedarnath (Mandakini) Valley, Garhwal Himalaya, during 16–17 June 2013: a remote sensing and ground-based assessment. *Natural Hazards*, *3*. https://doi.org/10.1007/s11069-015-2033-y

Bhandary, N. P., Dahal, R. K., & Okamura, M. (2012). Preliminary understanding of the Seti River Debris-Flood in Pokhara , Nepal , on May 5th , 2012: A report based on a Quick Field Visit Program. *ISSMGE Bulletin*, *6*(4), 8–18.

Bi, C., Pan, G., Yang, L., Lin, C. C., Hou, M., & Huang, Y. (2019). Evacuation route recommendation using auto-encoder and Markov decision process. *Applied Soft Computing Journal*, *84*, 105741. https://doi.org/10.1016/j.asoc.2019.105741

Boero, R., Bianchini, L., & Pasqualini, D. (2015). Vulnerability and adaptation to severe weather events in the American southwest. *Weather and Climate Extremes*, *8*, 12–25. https://doi.org/10.1016/j.wace.2015.04.002

Bonilauri, E. M., Harris, A. J. L., Morin, J., Ripepe, M., Mangione, D., Lacanna, G., Ciolli, S., Cusolito, M., & Deguy, P. (2021). Tsunami evacuation times and routes to safe zones: a GIS-based approach to tsunami evacuation planning on the island of Stromboli, Italy. *Journal of Applied Volcanology*, *10*(1), 1–20. https://doi.org/10.1186/s13617-021-00104-9

Botzen, W. J. W., & Van Den Bergh, J. C. J. M. (2008). Insurance against climate change and flooding in the Netherlands: Present, future, and comparison with other countries. *Risk Analysis*, *28*(2), 413–426. https://doi.org/10.1111/j.1539-6924.2008.01035.x

Bricker, J. D., Schwanghart, W., Adhikari, B. R., Moriguchi, S., Roeber, V., & Giri, S. (2017). Performance of models for flash flood warning and hazard assessment: The 2015 Kali Gandaki landslide dam breach in Nepal. *Mountain Research and Development*, *37*(1), 5–15. https://doi.org/10.1659/MRD-JOURNAL-D-16-00043.1

Brouwer, R., & Van Ek, R. (2004). Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological Economics*, *50*(1–2), 1–21. https://doi.org/10.1016/j.ecolecon.2004.01.020

Bubeck, P., & Thieken, A. H. (2018). What helps people recover from floods? Insights from a survey among flood-affected residents in Germany. *Regional Environmental Change*, *18*(1), 287–296. https://doi.org/10.1007/s10113-017-1200-y

Busato, L., Boaga, J., Peruzzo, L., Himi, M., Cola, S., Bersan, S., & Cassiani, G. (2016). Combined geophysical surveys for the characterization of a reconstructed river embankment. *Engineering Geology*, *211*, 74–84. https://doi.org/10.1016/j.enggeo.2016.06.023

Buylova, A., Chen, C., Cramer, L. A., Wang, H., & Cox, D. T. (2020). Household risk perceptions and evacuation intentions in earthquake and tsunami in a Cascadia Subduction Zone. *International Journal of Disaster Risk Reduction*, *44*, 101442. https://doi.org/10.1016/j.ijdrr.2019.101442

Byers, A. C., Chand, M. B., Lala, J., Shrestha, M., Byers, E. A., & Watanabe, T. (2020). Reconstructing the history of glacial lake outburst floods (GLOF) in the kanchenjunga conservation area, east Nepal: An interdisciplinary approach. *Sustainability (Switzerland)*, *12*(13), 1–24. https://doi.org/10.3390/su12135407

C., P.-R. E., & Pardoe, J. (2012). Who loses if flood risk is reduced: Should we be concerned? *Royal Geographical Society (AREA)*, *44*(2), 152–159. https://doi.org/10.1111/j.1475-4762.2012.01085.x

Cabinet Office. (2020). *Disaster management in Japan [White paper]*.

Campion, B. B., & Venzke, J. F. (2013). Rainfall variability, floods and adaptations of the urban poor to flooding in Kumasi, Ghana. *Natural Hazards*, *65*(3), 1895–1911.

https://doi.org/10.1007/s11069-012-0452-6

Campos, V., Bandeira, R., & Bandeira, A. (2012). A method for evacuation route planning in disaster situations. *Procedia - Social and Behavioral Sciences*, *54*, 503–512. https://doi.org/10.1016/j.sbspro.2012.09.768

Cenderelli, D. A., & Wohl, E. E. (2001). Peak discharge estimates of glacial-lake outburst floods and "normal" climatic floods in the Mount Everest region, Nepal. *Geomorphology*, *40*(1–2), 57–90. https://doi.org/10.1016/S0169-555X(01)00037-X

Central Bureau of Statistics (CBS). (2019a). *Environmetntal Statistics of Nepal 2019*. https://www.nepalindata.com/resource/environment-statistics-2019/?fbclid=IwAR0UvWRfkhpgsg1I4_pe3F_f1xi35-ox9P6yIUxnX_l486SMK5LoH6GvquM

Central Bureau of Statistics (CBS), N. (2019b). *Statistical Year Book 2019* (Issue 47). https://cbs.gov.np/wp-content/upLoads/2021/01/Statistical-Year-Book-of-Nepal-2019.pdf

Central Bureau of Statistics (CBS), N. (2020). *Nepal Multiple Indicator Cluster Survey 2019,Survey Findings Report.*

Chen, H., Zhao, J., Liang, Q., Maharjan, S. B., & Joshi, S. P. (2022). Assessing the potential impact of glacial lake outburst floods on individual objects using a high-performance hydrodynamic model and open-source data. *Science of the Total Environment*, *806*, 151289. https://doi.org/10.1016/j.scitotenv.2021.151289

Chen, Y., Tan, Y., & Yong Luo. (2008). Post-disaster resettlement and livelihood vulnerability in rural China. *Disaster Prevention and Management: An International Journal*, *26*(1), 65–78. https://doi.org/https://doi.org/10.1108/DPM-07-2016-0130

Chow V.T, Maidment D.R., M. L. W. (2010). *Applied Hydrology*. Tata McGraw Hill Education Pvt Ltd.

Christensen, J. H., Kanikicharla, K. K., Aldrian, E., An, S. Il, Albuquerque Cavalcanti, I. F., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J. K., Kitoh, A., Kossin, J., Lau, N. C., Renwick, J., Stephenson, D. B., Xie, S. P., Zhou, T., Abraham, L., Ambrizzi, T., … Zou, L. (2013). Climate phenomena and their relevance for future regional climate change. *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, *9781107057*, 1217–1308. https://doi.org/10.1017/CBO9781107415324.028

Christian F. Uhlir (1998). Landslide-dammed lakes: a case study of lamabagar and Chaunrikharka landslide deposits, Dolakha and Solukhumbhu district, eastern Nepal. *Journal of Nepal Geological Socity*, *18*, 329–334.

Dankers, R., & Feyen, L. (2008). Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations. *Journal of Geophysical Research Atmospheres*, *113*(19), 1–17. https://doi.org/10.1029/2007JD009719

Davis, I. (2011). What have we learned from 40 years' experience of disaster shelter? *Environmental Hazards*, *10*(3), 193–212. https://doi.org/10.1080/17477891.2011.597499

de Loyola Hummell, B. M., Cutter, S. L., & Emrich, C. T. (2016). Social vulnerability to natural hazards in Brazil. *International Journal of Disaster Risk Science*, *7*(2), 111–122. https://doi.org/10.1007/s13753-016-0090-9

De Marchi, B., & Scolobig, A. (2012). The views of experts and residents on social vulnerability to flash floods in an Alpine region of Italy. *Disasters*, *36*(2), 316–337. https://doi.org/10.1111/j.1467-7717.2011.01252.x

Delalay, M., Ziegler, A. D., Shrestha, M. S., Wasson, R. J., Sudmeier-Rieux, K., McAdoo, B. G., & Kochhar, I. (2018). Towards improved flood disaster governance in Nepal: A case study in Sindhupalchok District. *International Journal of Disaster Risk Reduction*, *31*, 354–366. https://doi.org/10.1016/j.ijdrr.2018.05.025

Demir, V., & Kisi, O. (2016). Flood hazard mapping by using geographic information system and hydraulic model: Mert River, Samsun, Turkey. *Advances in Meteorology*, 1–9. https://doi.org/10.1155/2016/4891015

Department of Water Induced Disaster Prevention, DWIDP, N. (2013). *Disaster review 2012*.

Devkota, R. P., Cockfield, G., & Maraseni, T. N. (2014). Perceived community-based flood adaptation strategies under climate change in Nepal. *International Journal of Global Warming*, *6*(1), 113–124. https://doi.org/10.1504/IJGW.2014.058758

Dewan, T. H. (2015a). Societal impacts and vulnerability to floods in Bangladesh and Nepal. *Weather and Climate Extremes*, *7*, 36–42. https://doi.org/10.1016/j.wace.2014.11.001

Dewan, T. H. (2015b). Societal impacts and vulnerability to floods in Bangladesh and Nepal. *Weather and Climate Extremes*, *7*, 36–42. https://doi.org/10.1016/j.wace.2014.11.001

Dewolf, A. H., Ivanenko, Y., Zelik, K. E., Lacquaniti, F., & Willems, P. A. (2018). Kinematic patterns while walking on a slope at different speeds. *Journal of Applied Physiology*, *125*(2), 642–653. https://doi.org/10.1152/japplphysiol.01020.2017

Dinanath, B., Sanchita, N., Peter, H., Bimal, R., & Phil, M. (2020). *Disaster risk reduction and management in Nepal : Delineation of roles and responsibilities* (Issue May). https://www.preventionweb.net/files/72985_delineationofresponsibilityfordisas[1].pdf

Du, S., Cheng, X., Huang, Q., Chen, R., Ward, P., & Aerts, J. C. J. H. (2019). Brief communication: Rethinking the 1998 China floods to prepare for a nonstationary future. *Natural Hazards and Earth System Sciences*, *19*(3), 715–719. https://doi.org/10.5194/nhess-19-715-2019

Dwivedi Shreekamal. (2013). Cause and mechanism of the Seti Flood of 5th may 2012, Western Nepal. *Journal If Nepal Geological Socity*, *46*, 11–18.

Eckstein, D., Hutfils, M.-L., & Winges, M. (2019). Global climate risk index 2019, Who suffers most from extreme weather events? weather-related loss events in 2017 and 1998 to 2017. In *Greenwatch*. Germanwatch e.V.

https://germanwatch.org/sites/germanwatch.org/files/Global Climate Risk Index 2019_2.pdf%0Ahttps://germanwatch.org/en/7677

Elalem, S., & Pal, I. (2015). Mapping the vulnerability hotspots over Hindu-Kush Himalaya region to flooding disasters. *Weather and Climate Extremes*, *8*, 46–58. https://doi.org/10.1016/j.wace.2014.12.001

Evans, S. G., & Delaney, K. B. (2014). Catastrophic mass flows in the mountain glacial environment. In *Snow and Ice-Related Hazards, Risks, and Disasters* (Issue September). https://doi.org/10.1016/B978-0-12-394849-6.00016-0

Farooq, M., Shafique, M., & Khattak, M. S. (2019). Flood hazard assessment and mapping of River Swat using HEC-RAS 2D model and high-resolution 12-m TanDEM-X DEM (WorldDEM). *Natural Hazards*, *97*(2), 477–492. https://doi.org/10.1007/s11069-019-03638-9

Ferreira, S., Hamilton, K., & Vincent, J. R. (2011). Nature, socioeconomics and adaptation to natural disasters: New evidence from floods. *SSRN ELibrary*, *June*. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1876300

Field B. Christopher, Barros R. Vicente, Mach J. Katharine, M. D. M. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In *Cambridge University Press, Cambridge*. https://doi.org/10.1016/j.renene.2009.11.012

Field, C. B., Barros, V., Stocker, T. F., Dahe, Q., Jon Dokken, D., Ebi, K. L., Mastrandrea, M. D., Mach, K. J., Plattner, G. K., Allen, S. K., Tignor, M., & Midgley, P. M. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the intergovernmental panel on climate change. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*, *9781107025*(September), 1–582. https://doi.org/10.1017/CBO9781139177245

Forrest, S., Trell, E.-M., & Woltjer, J. (2018). Flood groups in England. *Governing for Resilience in Vulnerable Places*, *November*, 92–115. https://doi.org/10.4324/9781315103761-7

Fort, M. (1987). Sporadic morphogenesis in a continental subdcution setting: An example from the Annapurna Range, Nepal Himalaya. *Z. Geomorph. N.F., Suppl.Bd.*, 9–36.

Fort, M., Adhikari, B. R., & Rimal, B. (2018). Pokhara (central Nepal): A dramatic yet geomorphologically active environment versus a dynamic, rapidly developing city. In *Urban Geomorphology: Landforms and Processes in Cities*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-811951-8.00012-6

Fraser, S. A., Doyle, E. E. H., Wright, K. C., Potter, S. H., McClure, J., Johnston, D. M., Leonard, G. S., Coomer, M. A., Becker, J. S., & Johal, S. (2016). Tsunami response behaviour during and following two local-source earthquakes in Wellington, New Zealand. *International Journal of Disaster Risk Reduction*, *16*, 123–133. https://doi.org/10.1016/j.ijdrr.2016.02.008

Fuchs, S., Keiler, M., Sokratov, S., & Shnyparkov, A. (2013). Spatiotemporal dynamics: The need for an innovative approach in mountain hazard risk management. *Natural Hazards*, *68*(3), 1217–1241. https://doi.org/10.1007/s11069-012-0508-7

Fujita, K., Sakai, A., Takenaka, S., Nuimura, T., Surazakov, A. B., Sawagaki, T., & Yamanokuchi, T. (2013). Potential flood volume of Himalayan glacial lakes. *Natural Hazards and Earth System Sciences*, *13*(7), 1827–1839. https://doi.org/10.5194/nhess-13-1827-2013

Garrett, B., & Anderson, K. (2018). Drone methodologies: Taking flight in human and physical geography. *Transactions of the Institute of British Geographers*, *43*(3), 341–359. https://doi.org/10.1111/tran.12232

Garrote, J., González-Jiménez, M., Guardiola-Albert, C., & Díez-Herrero, A. (2021). The manning's roughness coefficient calibration method to improve flood hazard analysis in the absence of river bathymetric data: Application to the urban historical zamora city centre in spain. *Applied Sciences (Switzerland)*, *11*(19). https://doi.org/10.3390/app11199267

Gautam, D., & Dong, Y. (2018). Multi-hazard vulnerability of structures and lifelines due to the 2015 Gorkha earthquake and 2017 central Nepal flash flood. *Journal of Building Engineering*, *17*, 196–201. https://doi.org/10.1016/j.jobe.2018.02.016

Gautam, P., Raj Pant, S., & Ando, H. (2000). Mapping of subsurface karst structure with gamma ray and electrical resistivity profiles: A case study from Pokhara valley, central Nepal. *Journal of Applied Geophysics*, *45*(2), 97–110. https://doi.org/10.1016/S0926-9851(00)00022-7

Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science and Policy*, *21*, 24–34. https://doi.org/10.1016/j.envsci.2012.03.007

Ghosh, S., & Dutta, S. (2012). Impact of climate change on flood characteristics in Brahmaputra basin using a macro-scale distributed hydrological model. *Journal of Earth System Science*, *121*(3), 637–657. https://doi.org/10.1007/s12040-012-0181-y

Government of Nepal, National Planning comission, Central Bureau of Statistics, Kathmandu, N. (2018). *Statistical Pocket Book Nepal 2018*. www.cbs.gov.np

Guha-Sapir, D., Hoyois, P., & Below, R. (2014). Annual disaster statistical review 2014: The numbers and trends. In *Centre for Research on the Epidemiology of Disasters (CRED)*. http://www.cred.be/sites/default/files/ADSR_2010.pdf

Guha-Sapir, D., Hoyois, P., & Below, R. (2015). Annual Disaster Statistical Review 2015. The numbers and trends centre for research on the epidemiology of disasters (CRED). In

Centre for Research on the Epidemiology of Disasters (CRED).

Guhathakurta, P., Sreejith, O. P., & Menon, P. A. (2011). Impact of climate change on extreme rainfall events and flood risk in India. *Journal of Earth System Science*, *120*(3), 359–373. https://doi.org/10.1007/s12040-011-0082-5

Guo, C. wen, Huang, Y. dan, Yao, L. kan, & Alradi, H. (2017). Size and spatial distribution of landslides induced by the 2015 Gorkha earthquake in the Bhote Koshi river watershed. *Journal of Mountain Science*, *14*(10), 1938–1950. https://doi.org/10.1007/s11629-016-4140-y

Gurung, N., Fort, M., Bell, R., Arnaud-Fassetta, G., & Maharjan, N. R. (2021). Hydro-torrential hazard vs. anthropogenic activities along the Seti valley, Kaski, Nepal: Assessment and recommendations from a risk perspective. *Journal of Nepal Geological Society*, *62*, 58–87. https://doi.org/10.3126/jngs.v62i0.38695

Halgamuge, M. N., & Nirmalathas, A. (2017). Analysis of large flood events: Based on flood data during 1985–2016 in Australia and India. *International Journal of Disaster Risk Reduction*, *24*, 1–11. https://doi.org/10.1016/j.ijdrr.2017.05.011

Hambrey, M. J., Quincey, D. J., Glasser, N. F., Reynolds, J. M., Richardson, S. J., & Clemmens, S. (2008). Sedimentological, geomorphological and dynamic context of debris-mantled glaciers, Mount Everest (Sagarmatha) region, Nepal. *Quaternary Science Reviews*, *27*(25–26), 2361–2389. https://doi.org/10.1016/j.quascirev.2008.08.010

Hanisch J, Koirala A, B. N. . (2013). The Pokhara May 5th flood sisaster in Nepal - a last warning sign sent by nature? *Journal Iof Nepal Geological Socity*, *46*, 1–10.

Henk Becker A. (2001). Social impact assessment. *European Journal of Operational Research*, *128*, 311–321. http://www.scopus.com/inward/record.url?eid=2-s2.0-0022826769&partnerID=40&md5=46c5928275e07ab389fc1bb123ea7e40

Higuchi, K., & Higuchi, K. (1977). *Effect of Nocturnal Rikha Precipitation Glacier , on the Hidden Mass Nepal * of the Samba*. 43–49.

Hildmann, H., & Kovacs, E. (2019). Review: Using unmanned aerial vehicles (UAVs) as mobile sensing platforms (MSPs) for disaster response, civil security and public safety. *Drones*, *3*(3), 59. https://doi.org/10.3390/drones3030059

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., & Kanae, S. (2013). Global flood risk under climate change. *Nature Climate Change*, *3*(9), 816–821. https://doi.org/10.1038/nclimate1911

Hirokawa, R., Kubo, D., Suzuki, S., Meguro, J. I., & Suzuki, T. (2007). A small UAV for immediate hazard map generation. *Collection of Technical Papers - 2007 AIAA InfoTech at Aerospace Conference*, *1*(May), 153–158. https://doi.org/10.2514/6.2007-2725

Hoeksema, R. J. (2007). Three stages in the history of land reclamation in the Netherlands. *Irrigation and Drainage*, *56*(SUPPL. 1), 113–126. https://doi.org/10.1002/ird.340

Hutanu, E., Mihu-Pintilie, A., Urzica, A., Paveluc, L. E., Stoleriu, C. C., & Grozavu, A. (2020).

Using 1D HEC-RAS modeling and LiDAR data to improve flood hazard maps accuracy: A case study from Jijia floodplain (NE Romania). *Water (Switzerland)*, *12*(6), 1–21. https://doi.org/10.3390/w12061624

Imai, K. S., Gaiha, R., & Bresciani, F. (2016). *Dynamics of rural transformation and poverty in rural asia and the pacific*.

Imbenzi J. Serede1, Benedict M. Mutua, James M. Raude. (2015). Calibration of channel roughness coefficient for Thiba main canal reach in Mwea irrigation scheme, Kenya. *Hydrology*, *3*(6), 55. https://doi.org/10.11648/j.hyd.20150306.11

Intergovernmental Panel on Climate Change (IPCC) (2001). Climate change 2001: The scientific basis. In *University Press, Cambridge*. https://doi.org/10.1016/S1058-2746(02)86826-4

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate change 2007: Impacts, adaptation and vulnerability edited. In *Cambridge University Press*. https://doi.org/10.1016/B978-008044910-4.00250-9

Jamrussri, S., & Toda, Y. (2018). Available flood evacuation time for high-risk areas in the middle reach of Chao Phraya River basin. *Water (Switzerland)*, *10*(12), 1–23. https://doi.org/10.3390/w10121871

Jha, A. K., Barenstein, J. D., Phelps, P. M., Pittet, D., & Sena, S. (2010). Safer homes, stronger communities : A handbook for reconstructing after natural disasters. In *World Bank*. https://openknowledge.worldbank.org/handle/10986/2409

Jhan, H. T., Ballinger, R., Jaleel, A., & Ting, K. H. (2020). Development and application of a socioeconomic vulnerability indicator framework (SVIF) for local climate change adaptation in Taiwan. *Sustainability (Switzerland)*, *12*(4). https://doi.org/10.3390/su12041585

Jones, S., Oven, K., Manyena, B., & Aryal, K. (2014). Governance struggles and policy processes in disaster risk reduction: A case study from Nepal. *Geoforum*, *57*, 78–90. https://doi.org/10.1016/j.geoforum.2014.07.011

Jonkman, S. N. (2005). Global perspectives on loss of human life caused by floods. *Natural Hazards*, *34*(2), 151–175. https://doi.org/10.1007/s11069-004-8891-3

Juarez-Lucas, A. M., Kibler, K. M., Sayama, T., & Ohara, M. (2019). Flood risk-benefit assessment to support management of flood-prone lands. *Journal of Flood Risk Management*, *12*(3). https://doi.org/10.1111/jfr3.12476

Julius, L. M., Brach, J. S., Wert, D. M., & VanSwearingen, J. M. (2012). Perceived effort of walking: Relationship with gait, physical function and activity, fear of falling, and confidence in walking in older adults with mobility limitations. *Physical Therapy*, *92*(10), 1268–1277. https://doi.org/10.2522/ptj.20110326

Jurg Schweizer, Perry Bartelt, A. van H. (2015). *Snow avalanches*. http://dx.doi.org/10.1016/B978-0-12-394849-6.00012-3

Kadhim Hameed, L., & Tawfeek Ali, S. (2013a). Estimating of manning's roughness coefficient for Hilla river through calibration using HEC-RAS model. *Jordan Journal of Civil Engineering*, *7*(1), 44–53.

Kadhim Hameed, L., & Tawfeek Ali, S. (2013b). Estimating of manning's roughness coefficient for Hilla river through calibration using HEC-RAS model. *Jordan Journal of Civil Engineering*, *7*(1), 44–53.

Kandel, B., Timilsina, M., & Acharya, I. P. (2019). Earthquake induced landslide susceptibility assessment of Dolakha District using logistic regression model. *KECConference2019, Kantipur Engineering College , Dhapakhel Lalitpur*, 1–6.

Kargel J., Poudel L, Leonard G, Regmi D, Joshi S, Poudel K, Thapa B, Watanabe T, F. M. (2013). Causes and human impacts of the Seti River (Nepal) disaster of 2012. *Glacial Flodding and Disaster Risk Management*, 0–9.

Kargel, J. (2014). *One Scientist's Search for the Causes of the Deadly Seti River Flash Flood*. NASA. https://earthobservatory.nasa.gov/blogs/fromthefield/2014/01/24/setiriverclues/comment-page-1/

Kargel, J. S., Leonard, G. J., Shugar, D. H., Haritashya, U. K., Bevington, A., Fielding, E. J., Fujita, K., Miles, G. M., & S., and E. (2015). Geomorphic and tectonic controls of geohazards induced by the 2015 Gorkha Earthquake , Nepal. *SIAS Faculty Publications., June*, 1–13. https://www.sciencedirect.com/science/article/pii/S0169555X04001114?casa_token=vLhQF-_PacEAAAAA:D9SV5k_FTSNxiUmWQh3b7H-58NJ5jD90OsTE_FZxQUuMHjm_UHW7LrliecuP7vwR7ldmvmmfvg

Katayama, K., Takahashi, H., Yokota, N., Sugiyasu, K., & Kinoshita, T. (2018). Cooperation scheme of Multi-UAVs for evacuation guidance support. *2018 IEEE 7th Global Conference on Consumer Electronics, GCCE 2018*, 79–80. https://doi.org/10.1109/GCCE.2018.8574602

Kathmandu University (2012). *Flood inundation mapping – seti river* (Issue 07306).

Kattel, D. B., & Yao, T. (2018). Temperature–topographic elevation relationship for high mountain terrain: an example from the southeastern Tibetan Plateau. *International Journal of Climatology*, *38*, e901–e920. https://doi.org/10.1002/joc.5418

Kattelmann, R. (2003). Glacial lake outburst floods in the Nepal Himalaya: A manageable hazard? *Natural Hazards*, *28*(1), 145–154. https://doi.org/10.1023/A:1021130101283

Kazuhisa, C., Tomomi, Y., Akiko, S., & Ram, P. G. (1997). Hydrodynamic effects on the basin expansion of Tsho Rolpa Giacier Lake in the Nepal Himalaya. *Bulletin Of Glacier Research*, *15*, 59–69.

Khanal, N. R., Hu, J. M., & Mool, P. (2015). Glacial lake outburst flood risk in the Poiqu/Bhote Koshi/Sun Koshi river basin in the Central Himalayas. *Mountain Research and*

Development, *35*(4), 351–364. https://doi.org/10.1659/MRD-JOURNAL-D-15-00009

Khanal, N. R., Mool, P. K., Shrestha, A. B., Rasul, G., Ghimire, P. K., Shrestha, R. B., & Joshi, S. P. (2015). A comprehensive approach and methods for glacial lake outburst flood risk assessment, with examples from Nepal and the transboundary area. *International Journal of Water Resources Development*, *31*(2), 219–237. https://doi.org/10.1080/07900627.2014.994116

Khattak, M. S., Anwar, F., Saeed, T. U., Sharif, M., Sheraz, K., & Ahmed, A. (2016). Floodplain Mapping Using HEC-RAS and ArcGIS: A Case Study of Kabul River. *Arabian Journal for Science and Engineering*, *41*(4), 1375–1390. https://doi.org/10.1007/s13369-015-1915-3

Kim, S., George, B., & Shekhar, S. (2007). Evacuation route planning: Scalable heuristics. *Proceedings of the 15th International Symposium on Advances in Geographic Information Systems*, 146–153. https://doi.org/10.1145/1341012.1341039

Kim, S. S., Kim, T. H., & Sim, J. S. (2019). Applicability assessment of uav mapping for disaster damage investigation in Korea. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(3/W8), 209–214. https://doi.org/10.5194/isprs-archives-XLII-3-W8-209-2019

Kimura, N., Kiri, H., & Kitagawa, I. (2018). The impact of multiple typhoons on severe floods in the mid-latitude region (Hokkaido). *Water (Switzerland)*, *10*(7). https://doi.org/10.3390/w10070843

Klijn, F., Asselman, N., & Wagenaar, D. (2018). Room for rivers: Risk reduction by enhancing the flood conveyance capacity of The Netherlands' large rivers. *Geosciences (Switzerland)*, *8*(6). https://doi.org/10.3390/geosciences8060224

Kongsomsaksakul, S., Yang, C., & Chen, A. (2005). Shelter location-allocation model for flood evacuation planning. *Journal of the Eastern Asia Society for Transportation Studies*, *6*(1981), 4237–4252.

Kovář, P., Pelikán, M., Heřmanovská, D., & Vrana, I. (2014). How to reach a compromise solution on technical and non-structural flood control measures. *Soil and Water Research*, *9*(4), 143–152. https://doi.org/10.17221/27/2014-swr

Kumar, N., Kumar, M., Sherring, A., Suryavanshi, S., Ahmad, A., & Lal, D. (2020). Applicability of HEC-RAS 2D and GFMS for flood extent mapping: a case study of Sangam area, Prayagraj, India. *Modeling Earth Systems and Environment*, *6*(1), 397–405. https://doi.org/10.1007/s40808-019-00687-8

Kumar, N., Lal, D., Sherring, A., & Issac, R. K. (2017). Applicability of HEC-RAS & GFMS tool for 1D water surface elevation/flood modeling of the river: A case study of river Yamuna at Allahabad (Sangam), India. *Modeling Earth Systems and Environment*, *3*(4), 1463–1475. https://doi.org/10.1007/s40808-017-0390-0

Langhammer, J., & Vacková, T. (2018). Detection and mapping of the geomorphic effects of flooding using UAV photogrammetry. *Pure and Applied Geophysics*, *175*(9), 3223–3245. https://doi.org/10.1007/s00024-018-1874-1

Lashford, C., Rubinato, M., Cai, Y., Hou, J., Abolfathi, S., Coupe, S., Charlesworth, S., & Tait, S. (2019). SuDS & sponge cities: A comparative analysis of the implementation of pluvial flood management in the UK and China. *Sustainability (Switzerland)*, *11*(1), 1–14. https://doi.org/10.3390/su11010213

Lei, T., Wang, J., Li, X., Wang, W., Shao, C., & Liu, B. (2022). *Flood Disaster Monitoring and Emergency Assessment Based on Multi-Source Remote Sensing Observations*. 1–16.

Li, C., Cheng, X., Li, N., Du, X., Yu, Q., & Kan, G. (2016). A framework for flood risk analysis and benefit assessment of flood control measures in Urban Areas. *International Journal of Environmental Research and Public Health*, *13*(8). https://doi.org/10.3390/ijerph13080787

Lim, J., Lim, M., & Piantankulchi M. (2013). A Review of Recent Studies on Flood Evacuation Planning. *Journal of the Eastern Asia Society for Transportation Studies*, *10*, 147–162. https://doi.org/10.11175/easts.10.147

Lim, M. B. B., Lim, H. R., & Piantanakulchai, M. (2019). Flood evacuation decision modeling for high risk urban area in the Philippines. *Asia Pacific Management Review*, *24*(2), 106–113. https://doi.org/10.1016/j.apmrv.2019.01.001

Lim, M. B. B., Lim, H. R., Piantanakulchai, M., & Uy, F. A. (2016). A household-level flood evacuation decision model in Quezon City, Philippines. *Natural Hazards*, *80*(3), 1539–1561. https://doi.org/10.1007/s11069-015-2038-6

Lindell, M. K., Arlikatti, S., & Huang, S. K. (2019). Immediate behavioral response to the June 17, 2013 flash floods in Uttarakhand, North India. *International Journal of Disaster Risk Reduction*, *34*, 129–146. https://doi.org/10.1016/j.ijdrr.2018.11.011

Lindell, M. K., Prater, C. S., Gregg, C. E., Apatu, E. J. I., Huang, S. K., & Wu, H. C. (2015). Households' immediate Responses to the 2009 American Samoa Earthquake and Tsunami. *International Journal of Disaster Risk Reduction*, *12*, 328–340. https://doi.org/10.1016/j.ijdrr.2015.03.003

Lines, R., Faure Walker, J. P., & Yore, R. (2022). Progression through emergency and temporary shelter, transitional housing and permanent housing: A longitudinal case study from the 2018 Lombok earthquake, Indonesia. *International Journal of Disaster Risk Reduction*, *75*(April), 102959. https://doi.org/10.1016/j.ijdrr.2022.102959

Liu, M., Chen, N., Zhang, Y., & Deng, M. (2020). Glacial lake inventory and lake outburst flood/debris flow hazard assessment after the gorkha earthquake in the Bhote Koshi Basin. *Water (Switzerland)*, *12*(2). https://doi.org/10.3390/w12020464

Liu, Q., Ruan, X., & Shi, P. (2011). Selection of emergency shelter sites for seismic disasters in mountainous regions: Lessons from the 2008 Wenchuan Ms 8.0 Earthquake, China. *Journal of Asian Earth Sciences*, *40*(4), 926–934.

https://doi.org/10.1016/j.jseaes.2010.07.014

Luo, P., He, B., Takara, K., Xiong, Y. E., Nover, D., Duan, W., & Fukushi, K. (2015). Historical assessment of Chinese and Japanese flood management policies and implications for managing future floods. *Environmental Science and Policy*, *48*, 265–277. https://doi.org/10.1016/j.envsci.2014.12.015

Maharjan, S. B., Steiner, J. F., Shrestha, A. B., Maharjan, A., Nepal, S., Shrestha, M. S., Bajracharya, B., Rasul, G., Shrestha, M., Jackson, M., & Gupta, N. (2021). *The Melamchi flood disaster: Cascading hazard and the need for multihazard risk management*. *August*, 1–21. https://lib.icimod.org/record/35284

Maher, A., & Inoue, M. (2016). Generating Evacuation Routes By Using Drone System and Image Analysis To Track Pedestrian and Scan the Area After. *Conference: The 10th SEATUC*.

Makinoshima, F., Imamura, F., & Oishi, Y. (2020). Tsunami evacuation processes based on human behaviour in past earthquakes and tsunamis: A literature review. *Progress in Disaster Science*, *7*, 100113. https://doi.org/10.1016/j.pdisas.2020.100113

Malecha, M. L., Brand, A. D., & Berke, P. R. (2018). Spatially evaluating a network of plans and flood vulnerability using a Plan Integration for Resilience Scorecard: A case study in Feijenoord District, Rotterdam, the Netherlands. *Land Use Policy*, *78*(May 2017), 147–157. https://doi.org/10.1016/j.landusepol.2018.06.029

Martha, T. R., Roy, P., Mazumdar, R., Govindharaj, K. B., & Kumar, K. V. (2017). Spatial characteristics of landslides triggered by the 2015 Mw 7.8 (Gorkha) and Mw 7.3 (Dolakha) earthquakes in Nepal. *Landslides*, *14*(2), 697–704. https://doi.org/10.1007/s10346-016-0763-x

Martinez, M., Bakheet, R., & Akib, S. (2020). Innovative Techniques in the Context of Actions for Flood Risk Management: A Review. *Eng*, *2*(1), 1–11. https://doi.org/10.3390/eng2010001

Mas, E., Adriano, B., & Koshimura, S. (2013). An integrated simulation of tsunami hazard and human evacuation in La Punta, Peru. *Journal of Disaster Research*, *8*(2), 285–295. https://doi.org/10.20965/jdr.2013.p0285

Maskey, S., Kayastha, R. B., & Kayastha, R. (2020). Glacial Lakes Outburst Floods (GLOFs) modelling of Thulagi and Lower Barun Glacial Lakes of Nepalese Himalaya. *Progress in Disaster Science*, *7*, 100106. https://doi.org/10.1016/j.pdisas.2020.100106

Mavhura, E., Manyena, B., & Collins, A. E. (2017). An approach for measuring social vulnerability in context: The case of flood hazards in Muzarabani district, Zimbabwe. *Geoforum*, *86*(September), 103–117. https://doi.org/10.1016/j.geoforum.2017.09.008

Miceli, R., Sotgiu, I., & Settanni, M. (2008). Disaster preparedness and perception of flood risk: A study in an alpine valley in Italy. *Journal of Environmental Psychology*, *28*(2), 164–173. https://doi.org/10.1016/j.jenvp.2007.10.006

Mirza, M. M. Q. (2011). Climate change, flooding in South Asia and implications. *Regional Environmental Change*, *11*(SUPPL. 1), 95–107. https://doi.org/10.1007/s10113-010-0184-7

MoHA. (2017). *Nepal disaster report 2017* (*Issue December*).

MoHA. (2019). *Nepal Disaster Report 2019*. In Ministry of Home Affairs,Kathmandu Nepal.

MoHA and DPNet-Nepal. (2015). *Nepal disaster report 2015*. https://doi.org/10.1017/CBO9781107415324.004

MoHA, & DPNet. (2009). *Ministry of Home and Nepal Disaster Preparedness Network-Nepal Nepal Disaster Report 2009: The hazardscape and vulnerability*. https://archnet.org/publications/8867

Mondino, E., Scolobig, A., Borga, M., Albrecht, F., Mård, J., Weyrich, P., & Di Baldassarre, G. (2020). Exploring changes in hydrogeological risk awareness and preparedness over time: a case study in northeastern Italy. *Hydrological Sciences Journal*, *65*(7), 1049–1059. https://doi.org/10.1080/02626667.2020.1729361

Mool, P. K., Maskey, P. R., Koirala, A., Joshi, S. P., Wu, L., Shrestha, A. B., Eriksson, M., Gurung, B., Pokharel, B., Khanal, N. R., Panthi, S., Adhikari, T., Kayastha, R. B., Ghimire, P., Thapa, R., Shrestha, B., Shrestha, S., & Shrestha, R. B. (2011). Glacial lakes and glacial lake outburst floods in Nepal. In *Icimod*. https://doi.org/978 92 9115 193 6

Morss, R. E., Demuth, J. L., Bostrom, A., Lazo, J. K., & Lazrus, H. (2015). Flash flood risks and warning decisions: A mental models study of forecasters, public officials, and media broadcasters in boulder, Colorado. *Risk Analysis*, *35*(11), 2009–2028. https://doi.org/10.1111/risa.12403

Morss, R. E., Mulder, K. J., Lazo, J. K., & Demuth, J. L. (2016a). How do people perceive, understand, and anticipate responding to flash flood risks and warnings? Results from a public survey in Boulder, Colorado, USA. *Journal of Hydrology*, *541*, 649–664. https://doi.org/10.1016/j.jhydrol.2015.11.047

Morss, R. E., Mulder, K. J., Lazo, J. K., & Demuth, J. L. (2016b). How do people perceive, understand, and anticipate responding to flash flood risks and warnings? Results from a public survey in Boulder, Colorado, USA. In *Journal of Hydrology* (Vol. 541). https://doi.org/10.1016/j.jhydrol.2015.11.047

Mohapatra P.K & Sing R.D (2003). Flood management in India. *Natural Hazards*, *28*(3), 131–143. https://doi.org/10.1177/0019556120120109

Murrau, R., & Pinna, F. (2014). PEDESTRIAN BEHAVIOUR IN URBAN AREA-Roberto Murrau, Francesco Pinna. *International Conference on Traffic and Transport Engineering-Belgrade*.

Nagatani, K., Yajima, R., Kiribayashi, S., Izu, T., Kanai, H., Kanasaki, H., Minagawa, J., & Moriyama, Y. (2018). *Field Report: UAV-Based Volcano Observation System for Debris Flow Evacuation Alarm*. 163–175. https://doi.org/10.1007/978-3-319-67361-5_11

Nayava, J. L. (1974). Heavy monsoon rainfall in Nepal. *Weather*, *29*, 443–450. https://doi.org/10.1002/j.1477-8696.1974.tb03299.x

Nepal, G. & National Planning Commission Secretariat Central Bureau of Statistics Kathmandu, Nepal (2011). National population and housing census 2011 (National Report). In *Government of Nepal National Planning Commission Secretariat Central Bureau of Statistics Kathmandu, Nepal* (Vol. 01).

Nepal, P., Khanal, N. R., & Sharma, P. P. B. (2018). Policies and institutions for disaster risk management in Nepal: A review. *Geographical Journal of Nepal*, *11*, 1–24. https://doi.org/10.3126/gjn.v11i0.19546

Nguyen, C. D., Ubukata, F., Nguyen, Q. T., & Vo, H. H. (2021). Long-Term Improvement in Precautions for Flood Risk Mitigation: A Case Study in the Low-Lying Area of Central Vietnam. *International Journal of Disaster Risk Science*, *12*(2), 250–266. https://doi.org/10.1007/s13753-020-00326-2

Oi, H., Higaki, D., Yagi, H., Usuki, N., & Yoshino, K. (2014). Report of the investigation of the flood disaster that occurred on May 5, 2012 along the Seti River in Nepal. *International Journal of Erosion Control Engineering*, *7*(4), 111–117. https://doi.org/10.13101/ijece.7.111

Pandey, C. L. (2018). Making communities disaster resilient: Challenges and prospects for community engagement in Nepal. *Disaster Prevention and Management: An International Journal*, *28*(1), 106–118. https://doi.org/10.1108/DPM-05-2018-0156

Pandeya, B., Uprety, M., Paul, J. D., Sharma, R. R., Dugar, S., & Buytaert, W. (2021). Mitigating flood risk using low-cost sensors and citizen science: A proof-of-concept study from western Nepal. *Journal of Flood Risk Management*, *14*(1), 1–13. https://doi.org/10.1111/jfr3.12675

Pappenberger, F., Beven, K., Horritt, M., & Blazkova, S. (2005). Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations. *Journal of Hydrology*, *302*(1–4), 46–69. https://doi.org/10.1016/j.jhydrol.2004.06.036

Parhi, P. K. (2013). HEC-RAS Model for Mannnig's Roughness: A Case Study. *Open Journal of Modern Hydrology*, *03*(03), 97–101. https://doi.org/10.4236/ojmh.2013.33013

Park, S., Lee, G., & Kim, J. O. (2020). Flood evacuation mapping using a time-distance cartogram. *ISPRS International Journal of Geo-Information*, *9*(4). https://doi.org/10.3390/ijgi9040207

Patel, D. P., Ramirez, J. A., Srivastava, P. K., Bray, M., & Han, D. (2017). Assessment of flood inundation mapping of Surat city by coupled 1D/2D hydrodynamic modeling: a case application of the new HEC-RAS 5. *Natural Hazards*, *89*(1), 93–130. https://doi.org/10.1007/s11069-017-2956-6

Pathak, S., Panta, H. K., Bhandari, T., & Paudel, K. P. (2020). Flood vulnerability and its influencing factors. *Natural Hazards*, *104*(3), 2175–2196. https://doi.org/10.1007/s11069-020-04267-3

Paudel, P. P., Omura, H., Kubota, T., & Morita, K. (2003). Landslide damage and disaster management system in Nepal. *Disaster Prevention and Management: An International Journal*, *12*(5), 413–419. https://doi.org/10.1108/09653560310507235

Peacock, W. G., Dash, N., Zhang, Y., & Van Zandt, S. (2018). Post-Disaster Sheltering, Temporary Housing and Permanent Housing Recovery. *Handbooks of Sociology and Social Research*, 569–594. https://doi.org/10.1007/978-3-319-63254-4_27

Petley D, S. C. (2012). *Understanding the Seti River landslide in Nepal*.

Prenger-Berninghoff, K., Cortes, V. J., Sprague, T., Aye, Z. C., Greiving, S., Glowacki, W., & Sterlacchini, S. (2014). The connection between long-term and short-term risk management strategies for flood and landslide hazards: Examples from land-use planning and emergency management in four European case studies. *Natural Hazards and Earth System Sciences*, *14*(12), 3261–3278. https://doi.org/10.5194/nhess-14-3261-2014

Prenger-Berninghoff, Kathrin, Cortes, V. J., Aye, C., & Sprague, T. (2013). Coordination of short-term and long-term mitigation measures of hydro-meteorological risks: the importance of establishing a link between emergency management and spatial planning. *Natural Hazards Earth System Sciences*, *15*(April), 1085–1107.

Qi, Y., Wu, L., Ding, Y., & Mao, W. (2022). Microwave brightness temperature anomalies associated with the 2015 Mw 7.8 Gorkha and Mw 7.3 Dolakha earthquakes in Nepal. *IEEE Transactions on Geoscience and Remote Sensing*, *60*. https://doi.org/10.1109/TGRS.2020.3036079

Quirogaa, V. M., Kurea, S., Udoa, K., & Manoa, A. (2016). Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: Application of the new HEC-RAS version 5. *Ribagua*, *3*(1), 25–33. https://doi.org/10.1016/j.riba.2015.12.001

R. Bajracharya, S. (2010). Glacial Lake Outburst Flood Disaster Risk Reduction Activities in Nepal. *International Journal of Erosion Control Engineering*, *3*(1), 92–101. https://doi.org/10.13101/ijece.3.92

Rai, R. K., van den Homberg, M. J. C., Ghimire, G. P., & McQuistan, C. (2020). Cost-benefit analysis of flood early warning system in the Karnali River Basin of Nepal. *International Journal of Disaster Risk Reduction*, *47*(August 2019), 101534. https://doi.org/10.1016/j.ijdrr.2020.101534

Rakesh K. (2015). *A global middle class is more promise than reality From 2001 to 2011, nearly 700 million step out of poverty, but most only barely*. Springer. http://www.pewglobal.org/2015/07/08/a-global-middle-class-is-more-promise-than-reality/

Ram, B, A. (2008). Government and public land management in Nepal. *FIG/FAO/CNG*

International Seminar on State and Public Sector Land Management Verona, Italy, 1–7. https://www.fig.net/resources/proceedings/2008/verona_fao_2008_comm7/papers/10_sept/5_4_acharya.pdf

Rana, B., Shrestha, A. B., Reynolds, J. M., Aryal, R., Pokhrel, A. P., & Budhathoki, K. P. (2000). Hazard assessment of the Tsho Roipa glacier lake and ongoing remediation measures. In *Journal of Nepal Geological Society* (Vol. 22). https://doi.org/10.3126/jngs.v22i0.32432

Rangari, V. A., Sridhar, V., Umamahesh, N. V., & Patel, A. K. (2018). Floodplain mapping and management of urban catchment using HEC-RAS: A case study of hyderabad city. *Journal of The Institution of Engineers (India): Series A*, *100*(1), 49–63. https://doi.org/10.1007/s40030-018-0345-0

Rangari, V. A., Umamahesh, N. V., & Bhatt, C. M. (2019). Assessment of inundation risk in urban floods using HEC RAS 2D. *Modeling Earth Systems and Environment*, *5*(4), 1839–1851. https://doi.org/10.1007/s40808-019-00641-8

Regmi, D., Kargel, J., Paudel, L. P., Poudel, K. R., Leonard, G., & Bhabana, T. (2012). Investigation of the Seti River disaster (May 5 , 2012) and assessment of past and future mountain hazards facing Pokhara , Nepal and upstream communities. *Himalaya-Karakoram-Tiber Workshop (HKT)*, *27*, 38–39.

Remondino, F., Barazzetti, L., Nex, F., Scaioni, M., & Sarazzi, D. (2012). Uav Photogrammetry for Mapping and 3D Modeling – Current Status and Future Perspectives. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XXXVIII-1/*(June 2014), 25–31. https://doi.org/10.5194/isprsarchives-xxxviii-1-c22-25-2011

Restas, A. (2015). Drone applications for supporting disaster management. *World Journal of Engineering and Technology*, *03*(03), 316–321. https://doi.org/10.4236/wjet.2015.33c047

Restas, A. (2018). Water related disaster management supported by drone applications. *World Journal of Engineering and Technology*, *06*(02), 116–126. https://doi.org/10.4236/wjet.2018.62b010

Reynolds, J. M. (1999). Glacial hazard assessment at Tsho Rolpa, Rolwaling, central Nepal. *Quarterly Journal of Engineering Geology*, *32*(3), 209–214. https://doi.org/10.1144/GSL.QJEG.1999.032.P3.01

Richardson, S. D., & Reynolds, J. M. (2000). An overview of glacial hazards in the Himalayas. *Quaternary International*, *65–66*, 31–47. https://doi.org/10.1016/S1040-6182(99)00035-X

Ridolfi, E., Buffi, G., Venturi, S., & Manciola, P. (2017). Accuracy analysis of a dam model from drone surveys. *Sensors (Switzerland)*, *17*(8). https://doi.org/10.3390/s17081777

Rijal, S., Adhikari, S., & Shrestha, A. (2020). Guiding documents for disaster risk reduction and management in health care system of Nepal. *Journal of the Nepal Medical Association*, *58*(230), 831–833. https://doi.org/10.31729/jnma.5041

Rimal, B., Baral, H., Stork, N. E., Paudyal, K., & Rijal, S. (2015). Growing city and rapid land use transition: Assessing multiple hazards and risks in the Pokhara Valley, Nepal. *Land*, *4*(4), 957–978. https://doi.org/10.3390/land4040957

Rimal, B., Zhang, L., Keshtkar, H., Sun, X., & Rijal, S. (2018). Quantifying the spatiotemporal pattern of urban expansion and hazard and risk area identification in the Kaski District of Nepal. *Land*, *7*(1). https://doi.org/10.3390/land7010037

Romo-Murphy, E., & Vos, M. (2014). The role of broadcast media in disaster preparedness education: Lessons learned in the scientific literature 2002–2012. *Media Asia*, *41*(1), 71–85. https://doi.org/10.1080/01296612.2014.11690001

Rosbjerg, D., Blöschl, G., Burn, D., Castellarin, A., Croke, B., Baldassare, G., Iacobellis, V., Kjeldsen, T., Kuczera, G., Merz, R., Montanari, A., Morris, D., Ouarda, T., Ren, L., Rogger, M., Salinas, J. L., Toth, E., & Viglione, A. (2013). Prediction of floods in ungauged basins. *Runoff Prediction in Ungauged Basins: Synthesis Across Processes, Places and Scales*, 189–226.

Rufat, S., Tate, E., Burton, C. G., & Maroof, A. S. (2015). Social vulnerability to floods: Review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction*, *14*, 470–486. https://doi.org/10.1016/j.ijdrr.2015.09.013

Sanderson, D., Sharma, A., Kennedy, J., & Burnell, J. (2014). Principles, practice and lessons from haiti for urban post-disaster shelter recovery programs. *Asian Journal of Environment and Disaster Management (AJEDM) - Focusing on Pro-Active Risk Reduction in Asia*, *06*(02), 131–151. https://doi.org/10.3850/s1793924014000362

Sanyal, J. (2004). Application of remote sensing in flood management with special reference to monsoon Asia: A review. *Natural Hazards*, *33*, 283–301.

Sarhadi, A., Soltani, S., & Modarres, R. (2012). Probabilistic flood inundation mapping of ungauged rivers: Linking GIS techniques and frequency analysis. *Journal of Hydrology*, *458–459*, 68–86. https://doi.org/10.1016/j.jhydrol.2012.06.039

Satoh, E., & Yoshikawa, T. (2005). *Accessibility to Community Facilities Considering Topographical Features and Changes in Physical Strength by the Age of Residents Accessibility to Community Facilities Considering Topographical Features and Changes in Physical Strength by the Age of Resid*. *October*.

Schanze, J., Zeman, E., & Marsalek, J. (2006). Flood Risk Management: Hazards, Vulnerability and Mitigation Measures. *Earth and Environmental Sciences*, *67*. https://doi.org/10.1007/978-1-4020-4598-1

Schimpl, M., Moore, C., Lederer, C., Neuhaus, A., Sambrook, J., Danesh, J., Ouwehand, W., & Daumer, M. (2011). Association between walking speed and age in healthy, free-living individuals using mobile accelerometry-a cross-sectional study. *PLoS ONE*, *6*(8). https://doi.org/10.1371/journal.pone.0023299

Schwanghart, W., Bernhardt, A., Stolle, A., Hoelzmann, P., Adhikari, B. R., Andermann, C., Tofelde, S., Merchel, S., Rugel, G., Fort, M., & Korup, O. (2016). Repeated catastrophic valley infill following medieval earthquakes in the Nepal Himalaya. In *Science* (Vol. 351, Issue 6269). https://doi.org/10.1126/science.aac9865

Scolobig, A., De Marchi, B., & Borga, M. (2012). The missing link between flood risk awareness and preparedness: Findings from case studies in an Alpine Region. *Natural Hazards*, *63*(2), 499–520. https://doi.org/10.1007/s11069-012-0161-1

Sharma, K., Saraf, A. K., Das, J., Baral, S. S., Borgohain, S., & Singh, G. (2018). Mapping and Change Detection Study of Nepal-2015 Earthquake Induced Landslides. *Journal of the Indian Society of Remote Sensing*, *46*(4), 605–615. https://doi.org/10.1007/s12524-017-0720-8

Shekhar, S., Yang, K. S., Gunturi, V. M. V., Manikonda, L., Oliver, D., Zhou, X., George, B., Kim, S., Wolff, J. M. R., & Lu, Q. (2012). Experiences with evacuation route planning algorithms. *International Journal of Geographical Information Science*, *26*(12), 2253–2265. https://doi.org/10.1080/13658816.2012.719624

Shreekamal, D. (2012). *Report submitted by the committee formed to find out the cause of the Seti Flood of 5th May 2012 to the Chief Secretary, Government of Nepal*.

Shrestha, A. B., Shah, S. H., & Karim, R. (2008a). Resource Manual on Flash Flood Risk Management. *Icimod*, 103.

Shrestha, A. B., Shah, S. H., & Karim, R. (2008b). Resource manual on flash flood risk management module 1: Community-based management. *International Centre for Integrated Mountain Development (ICIMOD)*, 60 pages. http://www.preventionweb.net/files/9298_flashfloodriskmanagement1.pdf

Shrestha, M. (2008). Impacts of floods in South Asia. *Journal of South Asia Disaster Studies*, *1*(1), 85–106.

Shrestha, M. S., Gurung, M. B., Khadgi, V. R., Wagle, N., Banarjee, S., Sherchan, U., Parajuli, B., & Mishra, A. (2021). The last mile: Flood risk communication for better preparedness in Nepal. *International Journal of Disaster Risk Reduction*, *56*(June 2019). https://doi.org/10.1016/j.ijdrr.2021.102118

Shrestha, S., Yao, T., Kattel, D. B., & Devkota, L. P. (2019). Precipitation characteristics of two complex mountain river basins on the southern slopes of the central Himalayas. *Theoretical and Applied Climatology*, *138*(1–2), 1159–1178. https://doi.org/10.1007/s00704-019-02897-7

Simonovic, S. P. (1999). Social criteria for evaluation of flood control measures: Winnipeg case study. *Urban Water*, *1*(2), 167–175. https://doi.org/http://dx.doi.org/10.1016/S1462-0758(99)00017-5

Smith, P. J., Beven, K. J., Leedal, D., Weerts, A. H., & Young, P. C. (2014). Testing probabilistic adaptive real-time flood forecasting models. *Journal of Flood Risk*

Management, *7*(3), 265–279. https://doi.org/10.1111/jfr3.12055

Smith, Paul J., Brown, S., & Dugar, S. (2017). Community-based early warning systems for flood risk mitigation in Nepal. *Natural Hazards and Earth System Sciences*, *17*(3), 423–437. https://doi.org/10.5194/nhess-17-423-2017

Sorensen, J. H., & Sorensen, B. V. (2007). *Community processes: Warning and evacuation*. 183–199. https://doi.org/10.1007/978-0-387-32353-4_11

Sridarran, P., Keraminiyage, K., & Amaratunga, D. (2018). Enablers and barriers of adapting post-disaster resettlements. *Procedia Engineering*, *212*(2017), 125–132. https://doi.org/10.1016/j.proeng.2018.01.017

Statista. (2021). *Mobile network coverage as share of population in Nepal in 2016, by type*. https://www.statista.com/statistics/898773/nepal-mobile-network-coverage-by-type/?fbclid=IwAR0WVUDk8Fsgcf5wfTsrHtc6WMfo-hbHH8s3NWf9uW31wDDQfIY_dvuOVRY

Stepanov, A., & Smith, J. M. G. (2009). Multi-objective evacuation routing in transportation networks. *European Journal of Operational Research*, *198*(2), 435–446. https://doi.org/10.1016/j.ejor.2008.08.025

Stive, M. J. F., Fresco, L. O., Kabat, P., Parmet, B. W. A. H., & Veerman, C. P. (2011). How the Dutch plan to stay dry over the next century. *Proceedings of the Institution of Civil Engineers: Civil Engineering*, *164*(4), 114–121. https://doi.org/10.1680/cien.2011.164.3.114

Tasnuva, A., Hossain, M. R., Salam, R., Islam, A. R. M. T., Patwary, M. M., & Ibrahim, S. M. (2020). Employing social vulnerability index to assess household social vulnerability of natural hazards: an evidence from southwest coastal Bangladesh. *Environment, Development and Sustainability*, *0123456789*. https://doi.org/10.1007/s10668-020-01054-9

Tate, E. C., Maidment, D. R., Olivera, F., & Anderson, D. J. (2002). Creating a Terrain Model for Floodplain Mapping. *Journal of Hydrologic Engineering*, *7*(2), 100–108. https://doi.org/10.1061/(asce)1084-0699(2002)7:2(100)

Thakuri, S., Chauhan, R., & Baskota, P. (2020). Glacial hazards and avalanches in high mountains of Nepal Himalaya. *Journal of Tourism and Himalayan Adventures*, *2*(July), 87–104.

Thanvisitthpon, N., Shrestha, S., & Pal, I. (2018). Urban Flooding and Climate Change: A Case Study of Bangkok, Thailand. *Environment and Urbanization ASIA*, *9*(1), 86–100. https://doi.org/10.1177/0975425317748532

Thapa, D. R., Tao, X., Fan, F., & Tao, Z. (2018). Aftershock analysis of the 2015 Gorkha-Dolakha (Central Nepal) earthquake doublet. *Heliyon*, *4*(7), e00678. https://doi.org/10.1016/j.heliyon.2018.e00678

Thapa, P. (2020). Spatial estimation of soil erosion using RUSLE modeling: a case study of

Dolakha district, Nepal. *Environmental Systems Research*, *9*(1). https://doi.org/10.1186/s40068-020-00177-2

Thapa, S., Shrestha, A., Lamichhane, S., Adhikari, R., & Gautam, D. (2020). Catchment-scale flood hazard mapping and flood vulnerability analysis of residential buildings: The case of Khando River in eastern Nepal. *Journal of Hydrology: Regional Studies*, *30*(March), 100704. https://doi.org/10.1016/j.ejrh.2020.100704

The World Bank (2021). *The World Bank*. https://data.worldbank.org/indicator/IT.CEL.SETS.P2?fbclid=IwAR3k8FlL0ynixW_WyfJZm7hvv5wMh7W6AckRWUINmsMsN9pt1CL8pB_RPYk&locations=NP&most_recent_value_desc=true . Access on 2021.10.9.

Thompson, I., Shrestha, M., Chhetri, N., & Agusdinata, D. B. (2020). An institutional analysis of glacial floods and disaster risk management in the Nepal Himalaya. *International Journal of Disaster Risk Reduction*, *47*, 1–13. https://doi.org/10.1016/j.ijdrr.2020.101567

Tingsanchali, T. (2012). Urban flood disaster management. *Procedia Engineering*, *32*, 25–37. https://doi.org/10.1016/j.proeng.2012.01.1233

Towfiqul Islam, A. R. M., Talukdar, S., Mahato, S., Kundu, S., Eibek, K. U., Pham, Q. B., Kuriqi, A., & Linh, N. T. T. (2021). Flood susceptibility modelling using advanced ensemble machine learning models. *Geoscience Frontiers*, *12*(3). https://doi.org/10.1016/j.gsf.2020.09.006

Tuladhar, G. (2012). Disaster management system in nepal - Policy issues and solutions. *Journal of Risk Analysis and Crisis Response*, *2*(3), 166–172. https://doi.org/10.2991/jrarc.2012.2.3.2

Tuladhar, G., Yatabe, R., Dahal, R. K., & Bhandary, N. P. (2015). Disaster risk reduction knowledge of local people in Nepal. *Geoenvironmental Disasters*, *2*(1). https://doi.org/10.1186/s40677-014-0011-4

UNDP, U. N. D. P., & NSET, N. S. for E. T.-N. (2009). *Global assessment of risk Nepal country report draft final*.

UNDRR. (2019). Disaster risk reduction in Nepal: Status report 2019. In *Disaster Risk Reduction of Nepal*. Government of Nepal.

UNISDR, & WMO (2015). Disaster risk and resilience: Thematic think piece. In *UN System Task Team on the Post-2015 UN Development Agenda*. http://www.un.org/millenniumgoals/pdf/Think Pieces/3_disaster_risk_resilience.pdf

VanRooyen, M., & Leaning, J. (2005). After the tsunami — facing the public health challenges. *New England Journal of Medicine*, *352*(5), 435–438. https://doi.org/10.1056/nejmp058013

Vij, S., Russell, C., Clark, J., Parajuli, B. P., Shakya, P., & Dewulf, A. (2020). Evolving disaster governance paradigms in Nepal. *International Journal of Disaster Risk Reduction*, *50*, 101911. https://doi.org/10.1016/j.ijdrr.2020.101911

Vuichard, D., & Zimmermann, M. (1987). The 1985 catastrophic drainage of a moraine-dammed lake, Khumbu Himal, Nepal: cause and consequences. *Mountain Research & Development*, *7*(2), 91–110. https://doi.org/10.2307/3673305

Wagemann, E. (2017). Need for adaptation: transformation of temporary houses. *Disasters*, *41*(4), 828–851. https://doi.org/10.1111/disa.12228

Walch, C. (2018). Evacuation ahead of natural disasters: Evidence from cyclone Phailin in India and typhoon Haiyan in the Philippines. *Geo: Geography and Environment*, *5*(1), 1–16. https://doi.org/10.1002/geo2.51

Watanabe, T., Lamsal, D., & Ives, J. D. (2009). Evaluating the growth characteristics of a glacial lake and its degree of danger of outburst flooding: Imja Glacier, Khumbu Himal, Nepal. *Norsk Geografisk Tidsskrift*, *63*(4), 255–267. https://doi.org/10.1080/00291950903368367

Water and Energy Commission Secretariat, W. (1990). *Sedimentation- A great threat to hydro-power generation in Nepal*.

Wei, H. L., Wu, H. C., Lindell, M. K., Prater, C. S., Shiroshita, H., Johnston, D. M., & Becker, J. S. (2017). Assessment of households' responses to the tsunami threat: A comparative study of Japan and New Zealand. *International Journal of Disaster Risk Reduction*, *25*(March), 274–282. https://doi.org/10.1016/j.ijdrr.2017.09.011

Wiering, M., & Winnubst, M. (2017). The conception of public interest in Dutch flood risk management: Untouchable or transforming? *Environmental Science and Policy*, *73*, 12–19. https://doi.org/10.1016/j.envsci.2017.03.002

Williams, G. (2011). Study on disaster risk reduction, Decentralization and political economy: The global assessment report on disaster risk reduction 2011. In *The Political Economy of Disaster Risk Reduction STUDY*.

Wilson, M. (2011). *Emergency Shelter: An Architectural Perspective* (Issue May 2011). https://www.researchgate.net/publication/260980994_Emergency_Shelter_An_Architectural_Perspective_2011

Worni, R., Huggel, C., Clague, J. J., Schaub, Y., & Stoffel, M. (2014). Coupling glacial lake impact, dam breach, and flood processes: A modeling perspective. *Geomorphology*, *224*, 161–176. https://doi.org/10.1016/j.geomorph.2014.06.031

Xiong, M., Zeng, D., Yao, H., & Li, Y. (2016). A crowd simulation based uav control architecture for industrial disaster evacuation. *IEEE Vehicular Technology Conference*, *2016-July*. https://doi.org/10.1109/VTCSpring.2016.7504062

Yamanaka, M., Yoshida, K., & Arita, K. (1982). Terrace landform and quaternary deposots around Pokhara Valley, central Nepal. *Journal of Nepal Geological Socity*, *142*(2), 113–142.

Yoshitsugu, N., Abe, S., & Yamamoto, K. (2020). Method for deriving evacuation routes considering disaster risk. *Journal of Information Processing*, *28*, 1065–1072.

https://doi.org/10.2197/ipsjjip.28.1065

Yusoff, M., Ariffin, J., & Mohamed, A. (2008). Optimization approaches for macroscopic emergency evacuation planning: A survey. *Proceedings - International Symposium on Information Technology 2008, ITSim*, *4*. https://doi.org/10.1109/ITSIM.2008.4631982

Zhang, G., Setunge, S., & van Elmpt, S. (2014). Using shipping containers to provide temporary housing in post-disaster recovery: social case studies. *Procedia Economics and Finance*, *18*(September), 618–625. https://doi.org/10.1016/s2212-5671(14)00983-6

Appendices: Table A1

Table A1. Spatial relationshipes between the destinations (safe places) and the residential section, and the population depending on the evacuation routes

Name	Sections	Distinationn number	A: Distination elevation (m)	B: Residence elevation (m)	Relative height between A and B (m)	Horizontal distance between A and B (m)	Height above the estimated inundation level (m)	Horizontal distance between estimated inundation level and destination (m)	Depending population (residents) per route	Population (Redsidents) below the inundation level	Houses below inundation level
Masinabagar	a	1	916	889	27	81	20	52	66	61	11
		2	918	890	28	63	25	43	47	15	4
		3	918	891	27	68	23	52	50	20	4
		4	918	892	27	78	23	59	54	21	6
		5	918	891	27	76	23	51	93	68	14
		6	916	891	25	92	22	64	90	45	8
		7	911	892	19	88	16	57	91	60	11
		8	916	892	25	117	21	81	94	39	8
		9	911	893	18	109	15	65	85	63	15
		10	908	895	13	124	11	74	31	0*	9
	b	L1	898	889	9	120	9	96	86	58	10
		L2	905	887	19	116	19	78	76	52	9
		L3	898	886	11	96	11	80	57	27	4
		L4	893	885	8	92	8	91	38	7	1
		L5	894	885	9	105	9	87	81	40	6
		L6	905	892	13	88	12	75	9	5	2
		L7	902	891	11	72	11	71	13	4	1
		R1	906	888	18	136	4	113	39	39	8
		R2	905	886	19	121	3	87	59	59	12
		R3	901	883	19	109	3	72	78	48	10
		R4	902	883	19	113	3	81	58	58	10
		R5	900	883	18	122	3	88	59	42	9
		R6	900	882	18	117	3	79	79	48	10
	c	1	892	877	14	103	13	77	71	28	6
		2	901	877	24	86	22	57	63	48	5
		3	900	878	23	82	22	53	37	23	4
		4	894	877	17	61	17	37	76	24	7
	d	1	884	876	8	124	8	90	5	5**	5
Laltinbazar	a	1	890	871	19	68	10	44	20	20	4
		2	896	871	24	79	16	46	30	30	6
		3	897	865	32	126	23	93	27	14	3
		Construction not needed	867	864	3	122	3	122	52	0	0
		4	867	861	7	176	2	137	59	26	4
		5	867	859	9	198	1	142	106	47	8
		6	867	860	8	188	2	145	128	66	12
		7	866	858	8	196	1	158	100	56	9
		8	865	859	6	202	1	168	101	33	7
		9	865	859	6	219	3	179	46	17	6
		Construction not needed	864	856	9	155	4	192	82	0	0
	b	1	860	853	8	148	5	114	40	21	4
		2	861	855	6	94	5	75	90	30	6
		3	861	853	8	101	5	57	80	43	8
		4	861	852	10	82	5	46	85	66	12
		5	861	850	11	78	5	31	93	66	12
		6	861	849	13	84	4	35	94	89	16
		7	862	849	13	104	3	32	99	75	13
		8	875	849	26	68	26	38	34	34	7
		9	881	849	31	77	30	57	32	32	5
		10	878	848	30	70	28	48	60	40	7
		11	879	847	33	110	33	80	70	65	11
		12	856	847	9	110	9	74	77	68	13
		13	853	846	6	104	5	75	85	48	9
		14	853	845	8	115	6	89	97	38	7
		15	854	845	10	132	9	97	105	44	8
		16	860	843	17	136	16	106	93	57	10
		17	876	844	33	146	32	116	48	37	7
		18	877	843	35	146	35	106	78	78	15
Ki-sing	Left bank	Construction not needed	880	876	4	86	21	103	80	0	0
		L1	882	876	6	98	3	94	39	5	1
		L2	883	874	9	121	1	87	46	13	3
		L3	884	876	8	124	1	86	50	21	4
		L4	882	874	8	127	1	94	72	26	6
		Construction not needed	882	880	2	85	7	101	51	0	0
		L5	882	874	8	102	4	105	37	4	1
		L6	882	873	9	90	1	62	57	21	5
		L7	881	876	5	97	1	64	39	11	2
		L8	881	875	6	79	2	48	25	8	3
		L9	881	874	7	73	1	48	27	6	1
		Construction not needed	879	872	7	55	7	56	27	0	0
	Right bank	R1	871	856	15	84	8	49	17	17	9
		R2	873	841	32	189	17	94	18	4	22
		R3	870	847	23	90	11	64	14	0***	10
		R4	871	839	32	142	3	91	47	9	4

* Nine buildings are located here. These nice buildings are toiltet and canteen for a school, livestock farms and a crenatorium centre. Therefre, construction of a evacuation route is necessary although the nighttime populatio

** There are five nightime residents here; however, 172 students stay there during day time.

*** The houses below the inundation level are community centers; therefore, there are no residents.

B. Questionnaire Sheet

Graduate School of Environmental Science
Hokkaido University
Questionnaire for Earthquake Victim

Latitude:
Longitude:

Personal information:

Name: Age: Sex:

Address: Occupation: Religion:

Education:

Illiterate	Literate	Primary	Lower secondary	Secondary	Higher Secondar y	Bachelor's	Master's

Family Description:

S. N	Name	Age	Sex	Marital status	Occupation

Socio economic Information:

1. How many years have you lived in this site?

....

2. Are you migrant or Local….? If migrants ….

a. How did you find this

place?...

b. Why did you choose this

place?..

c. What is the main purpose of choose this

place?...

d. Who suggested you to migrant this

place?..

e. What kind of problems did you face in previous

place?..

3. What are the income sources in your family and estimate how much you earned per month?

Income Source	Amount

4. Which type of house do you have?

a) Temporary (grass thatched and mud walls) (b) Semi-permanent (timber wall) (c)

Permanent (stone/brick walls) (d) Other (name) ________________________________

5. Do you have land used for agriculture? If yes, ……………………..

< 10 Ropani 20 – 30 Ropani □ > 20 Ropani □

6. What are the major crops cultivated in your farm?

1.) …………2) ………….3) …………4) ……………5) ……….6) ………….

7. How long the production from your own farm support food for your family?

3-6 months □ 6- 9 months □ 1 year □ Surplus

8. Do you have your own land? A. Yes (how much) …………… B. No

9. Do you have livestock? A. Yes B. No

If yes

Have you lost any livestock during earthquake? If yes ………………….

Livestock Types	Number
Goat	
Cow	
Buffalo	
Horse/donkey	
Sheep	
Other(name)	

Earthquake damage Information:

10. What is the present condition of your house?

(a) Completely destroyed (b) Partly damage (c) Well condition

(If completely destroyed….) Have you got any means of temporary Salter or tent from Government/NGO after earthquake?

If yes ………………………

From	Goods (name)	Amount/Quantity	Time (when you get)
Government			
NGO			
INGO			
People			
Other			

12. Is the temporary shelter or tent effective or are there any problems?

A. Effective B. Not effective C. Not enough for all family member

13. Which sticker government put on your house (if house is remaining?)

(a) Red (b) Yellow (c) Green

14. Have you lost any member of your family or got injured? If yes…

No	Age	Sex	Occupation	Death	Injured

15. Do you know about disaster preparedness methods? If yes, where did you get that knowledge? A. Government B.NGO C. INGO D. Others

16. Do you think your family is relatively well prepared for a disaster? A. Yes B. No

17. Have you discussed disaster preparedness with your family? A. Yes B. No

18. Do you have 72-hour minimum disaster supplies on hand? A. Yes B. No

19. Has your family discussed where to meet outside if there is a disaster in your home? A. Yes B. No

If yes. Do you show me that location (using map)?

………………………………………………………………………………………

20. Do you have regular drill (practice) to evacuate to safe site? A. Yes B. No

If yes…. Please show me on Map.

21. Do you know the safe site in and near your house? A. Yes B. No

If Yes …How many minutes does it take to the site by foot? Is it easy for all family members, such as baby or elderly people? A. Yes B. No

If no, do you want to make that type of site in future? A. Yes B. No

22. Do you know what a hazard map? A. Yes B. No

If yes, when, how, from whom did you receive the map?

....

Name of the organization ....Date ………………

23. What do you think should be done to Government for rebuilt this place?

………………………………………………………………………………

24. What do you think should be done to reestablish your home? ……………………………………………………………………………

25. Have you got any loan or compensation from government? ……………………………………………………………………………