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Title	Flood risk mitigation by inundation mapping and socioeconomic analyses in two river basins of Nepal [an abstract of dissertation and a summary of dissertation review]
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Citation	北海道大学. 博士(環境科学) 乙第7166号
Issue Date	2022-12-26
Doc URL	http://hdl.handle.net/2115/87954
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Type	theses (doctoral - abstract and summary of review)
Additional Information	There are other files related to this item in HUSCAP. Check the above URL.
File Information	Thapa_Bhabana_abstract.pdf (論文内容の要旨)

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学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Flood risk mitigation by inundation mapping and socioeconomic analyses in two river basins of Nepal
（ネパールの2つの河川流域における浸水域予測地図作成と社会経済分析による洪水リスク軽減）

Floods often cause enormous damage to human life, property, agricultural field, and infrastructure. Sudden floods frequently occur in the Himalaya under changing climate. Rapid melt of glaciers has resulted in the formation of glacial lakes and associated hazards such as glacial lake outburst floods (GLOFs). In addition, global warming is believed to increase the magnitude and frequency of extreme rainfall events, thus potentially impacting riverine disasters. Global warming also destabilizes steep glacier-ice walls as well as steep mountain slopes with permafrost. A flash flood that occurred in the Seti River, north of Pokhara, central Nepal on May 5, 2012 is one of such examples. Floods can be also triggered by earthquake. The Tamakoshi River basin in the Dolakha district, an epicenter of one of the largest aftershocks of the devastating earthquake in 2015, is well known for Tsho Rolpa, one of the largest glacial lakes in the Himalaya, with potential danger of GLOFs. Therefore, the Seti River basin near the second largest city of Nepal and the Tamakoshi River basin in one of the rural areas of Nepal are characterized as flood-prone areas but as contrasting urban and rural settings.

This study, focusing on flood issues in the mountains of Nepal, aimed to identify safe and at-risk houses and availability of routes for emergency evacuation, and to analyze the relationships between the inundation risk and socioeconomic situation in the Seti River basin (Pokhara District) and the Tamakoshi River basin (Dolakha District). This study chose three settlements in the Seti River basin because these settlements are densely populated and situated along the river. Similarly, this study chose 13 settlements in the Tamakoshi River basin. Detailed hazard maps were created based on the results from unmanned 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 to the mappings. For inundation mappings, peak discharge was assumed to be the same as that observed during the Seti River Flood on May 5, 2012, i.e., 1,450 m^3/s for the Seti River basin. In the Tamakoshi River basin, the same peak discharge was used for inundation mapping along with the value of 382 m^3/s from the Department of Hydrology and Meteorology. Evacuation-route mapping was based on UAV photogrammetry, toposheets, and field surveys. The questionnaire, focus-group, and key-informant surveys helped identify the socioeconomic situations in both basins.

This study found that all of the Masinabagar, Laltinbazar, and KI-sing areas in the Seti River basin are highly susceptible to future flooding. Inundation maps in the basin showed a maximum inundation water level (depth) to attain 13 m in Masinabagar, 17 m in Laltinbazar, and 21 m in KI-sing. In Masinabagar 268 households (population: 976) among 466 (population: 2,303) are situated in the inundation area. In Laltinbazar, 232 of 329 households (population: 1,800) is located either on the floodplain or along the slopes with 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 pedestrian routes to be newly created can be used for emergencies: 27 new routes are necessary to be urgently created in Masinabagar, 25 routes in Laltinbazar, and 9 routes in KI-sing. This study also found 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 ($p<0.001$). Similarly, the locations of laborers' houses were significantly correlated with inundation risk ($p<0.001$).

In the Tamakoshi River basin, the inundation maps showed that Gongar, Singati, Jagat, Bhorle, Jamune, Kattike and Tamakoshi are highly susceptible to future flooding. The maximum inundation depth was calculated as 19 m in Gongar, 10 m in Jagat, 6 m in Bhorle, 10 m in Jamune, 19 m in Singati, 14 m in Kattike, and 19 m in Tamakoshi. In Singati, 97 houses out of 154 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, and all 6 houses (population 17) in Tamakoshi are situated in the inundation zone. It was suggested that new evacuation routes that need to be created should be 7, 5, 3, and 4 in Gongar, Singati, Kattike, and Tamakoshi, respectively. The result highlighted that the relationship between occupation and income was statistically not significant ($p<0.003$).

This study developed an evacuation system by considering short-term and long-term measures. Land that is outside the inundation area can be temporary evacuation sites, even though many of them do not have shelters at present. Introducing a simply early warning system by mobile phone network was suggested in the study areas because many of the poor families have mobile phone handsets. 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 land for relocation. This study found that most riverside residents remain unaware of the preparation and risk associated with flood emergency evacuation in both river basins; therefore, adaptive capacity-building strategy programs, disaster preparedness training, and evacuation drills must be urgently incorporated.

This research contributes to reducing impacts of flood disasters, and the proposed evacuation system will help save human life. This study will be useful for planners with respect to flood preparedness, early warning system, and safe evacuation. Further, 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.