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Floodplain Analysis and Risk Assessment of Lakhandei River

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Abstract

Flooding is one of the serious, common, and costly natural disasters that many countries are facing. One of the non-structural measures for risk reduction is the delineation of flood-prone areas. Flood risk mapping involves modeling the complex interaction of river flow hydraulics with topographical and land use features of the floodplains. From conventional flood hazard mapping technique based on field investigation to a knowledge-based system, the study integrated the hydraulic model with the Geographic Information System (GIS) and presented a systematic approach of this application with a case study of Lakhandei River in Nepal.

The study focused on the preparation of Triangulated Irregular Network (TIN) from available cross section data, contours and spot elevations, calculation of water surface profiles by steady and unsteady flow analysis, delineation of the flood areas, risk mapping, and creation of flood animation.

The approach adopted for the study consisted of dividing the risk into vulnerability associated with land use pattern and hazard associated with hydrological and hydraulic parameters. The results of these analyses were combined to see relationships such as discharge-flood area and flood depth-land use. A series of maps were prepared depicting different relationships, such as discharge-flood area and flood depth-land use. This provided a framework that would help administrators and planners to identify areas of risk and prioritize their mitigation and response efforts. This would also raise the public's awareness of flood risks and enable them to prepare mitigation activities. The research also prepared a general flood action plan. Using satellite images, the study further assessed changes in river course.

Problem Addressed

Nepal is a mountainous country. About 17% of its land bordering India is flat Terai Plain, which is most vulnerable to flooding every year. As the rivers emerge into the plain from steep and narrow mountain gorges, they spread out with an abrupt gradient decrease that has three major consequences: deposition of the bed load, changes in river course, and frequent floods (Jollinger, 1979). Each year, floods of varying magnitudes occur due to intense, localized storms during the monsoon months (June to September) in Nepal's numerous streams and rivers.

The Lakhandei River Basin is located in Sarlahi District of the Central Development Region of Nepal. Originating from the eastern Siwalik Hills, this river passes through the Terai plain, crosses the Nepal-India border at Bhadsar, and merges into the Bagmati River at Darbhanga in India. The basin area of the Lakhandei River is 300 sq km, consisting of 106 sq km of mountainous area and 194 sq km of plain area. The study area extends from the base of Siwalik Hills to the Indian border whose total length is about 30 km. The length of the meandering river is about 52 km. This area suffered from one of the biggest floods in 1997 that resulted in the loss of lives and damage to property (see Figure 1).

Figure 1. (A) Location of study area and river basin and (B) Losses of life and damage to property due to the 1997 flood (Source: JICA/DOI, 1999).

(A)

Loss of	Life	14	nos.
	Cattle	398	nos.
	Crops	8675	ton
	Land	234	hac
	Houses	236	nos.
Damage of	Crops	3052	ton
	Land	1263	hac
	Houses	691	nos.
	Public Facilities		
	Road	275	m
	Culvert	7	nos.
	School	6	nos.

(B)

Flood hazard mapping and risk assessment in Nepal is still very rudimentary. Most of the flood protection works are carried out at the local level without proper planning and without considering the problem at the river basin scale. Apart from piecemeal approaches on a limited scale, no pragmatic efforts at comprehensive flood risk assessment and hazard mapping have been done. In view of increasing flood disasters and the growing realization of the need to address the problem at a regional level, the government of Nepal has initiated a systematic study of its rivers. Thus, the Japan International Cooperation Agency (JICA), in collaboration with the Government of Nepal (GON) Department of Irrigation (DOI), undertook "The Study on Flood Mitigation Plan (FMP) for Selected Rivers in the Terai Plain in the Kingdom of Nepal" (JICA/DOI, 1998, 1999a, 1999b, & 1999c).

Originating from and covering a significant area in the Siwalik range, Lakhandei River is one of the most flood-prone rivers in Nepal. It was also one of the eight selected rivers for the FMP study. The FMP study made various analyses, including flood flow analysis using an unsteady flow simulation model and flood hazard maps based on field investigation and personal interviews. The simulated result showed that in many cross sections, the simulated water levels went far beyond the river cross-sections that could not represent the actual flood water levels. These maps, however, did not have a relationship with the intensity of flood and floodwater depth. Thus, the FMP study pointed out the need to prepare new flood hazard maps that refine those prepared for the study (JICA/DOI, 1999a).

The Department of Hydrology and Meteorology (DHM) prepared a flood risk mapping of Lakhandei River (July 1998) using the one-dimensional Ida method to determine flood levels along river cannels and river valley bottoms. However, with just seven river cross-sections surveyed in some 42.5 km of river, it used an insufficient number of cross sections and did not survey longitudinal sections.

To address this gap, this study prepared a flood vulnerability, hazard, and risk map by integrating the hydraulic model and GIS. It made the transition from conventional flood hazard mapping technique based on field investigation to a knowledge-based system. The application of a computer-based model could provide effective and efficient means of floodplain analysis and flood risk assessment. This could also provide a framework for decision makers that would enable them to assess and evaluate alternative strategies for flood management. Flood risk assessment and mapping of flood-prone areas according to magnitude and frequency of flooding provide vital information in flood management.

Below are the study's main objectives:

1. To analyze the floodplain by using the one-dimensional steady and unsteady flow model.
2. To make a flood risk map of the study area that depicts the relationship between vulnerability of land use and hazards related to hydraulic and hydrologic parameters.

Methodology

Data required for the study and results of previous studies were collected from different sources:

- **Documents from previous studies.** Different documents related to flooding in the study area, such as the study by the Water Induced Disaster Prevention Technical Center (DPTC, 1993), DHM

(1998), JICA/DOI (1999) and other studies related to flooding and hazard mapping in Nepal were collected.

- **Stream flow and precipitation data.** Stream gauge data of Lakhandei River at Pattharkot was collected from DHM. As the measured stage and flow (39 times) from 1996 to 2001 was not sufficient to produce a rating curve, different regional approaches were used to estimate flood of different return periods. The rainfall data of nearby station Manusmara, Malangawa, and Patharkot were likewise obtained from DHM.

- **Population data.** Population data of Village Development Committees (VDCs) affected by flood of Lakhandei River were obtained from the Central Bureau of Statistics (CBS).

- **Topographical map and survey data of previous studies.** Topographical maps (1998) of the Lakhandei River Basin with a scale of 1:25,000 (published by Government of Nepal, Survey Department) were collected. Longitudinal survey data and fifty two river cross-section survey data at the interval of about 1 km were also obtained from the FMP.

- **GIS/Remote Sensing (RS) data.** GIS based digital layers of the topographic sheets were obtained from the Survey Department. These layers included contours, spot height, drainage, land use, and land cover, settlements, and infrastructure. Topographical map with 1:10,000 scale prepared under the FMP Study was also available in analog format. The satellite image Landsat ETM+, captured on 24 October 2001 (Shilpakar, 2003), was used by pseudo-natural color combination (Red-B3, Green-B4, Blue-B2) for the study of the shifting course of Lakhendei River.

Model Development and Application. The flood vulnerability map, flood hazard map, and flood risk map were prepared based on the general approach described below:

The major data for the model development consisted of the topography and river channel and hydrologic data for the floods of different return periods. For the preparation of TIN digitized data (from the Survey Department, GON), digitized contour at interval 2.5 m and spot heights from 1:10,000 topographical map prepared for the FMP study (JICA/DOI, 1999) and cross sections at the interval of about 1 km from the river survey of 1998 were used.

Different empirical methods were used to estimate the probable maximum flood for different return period at various sites along the Lakhandei River. For unsteady flow analysis, the triangular hydrograph adapted in FMP study was used. The water surface profiles computations were made for the floods of 2, 5, 10, 20, 50 and 100 year return periods.

The risk assessment methodology in this study followed the approach developed by Gilard (1996), similar to the method adapted in the flood risk assessment of Babai River in Nepal (Shrestha, 2000, 2002). The flood risk was divided into hazard and vulnerability components. The vulnerability assessment was based on the presence or absence of a flood of particular intensity in a particular land use type. The spatial coexistence model was used for the hazard assessment, reclassifying the floodwater depth. The results of these two analyses were combined for the flood risk assessment.

In this study, Global Positioning System (GPS) was used to collect more information about the extent and depth of flood in a few locations of the study area during site visit. Most of the observed locations lie within the area flooded by two-year return period flood. The flood depth reported by local people, however, could not be linked with the flood of particular return period. The GPS was also used to identify the some points of river course shifting during site visit.

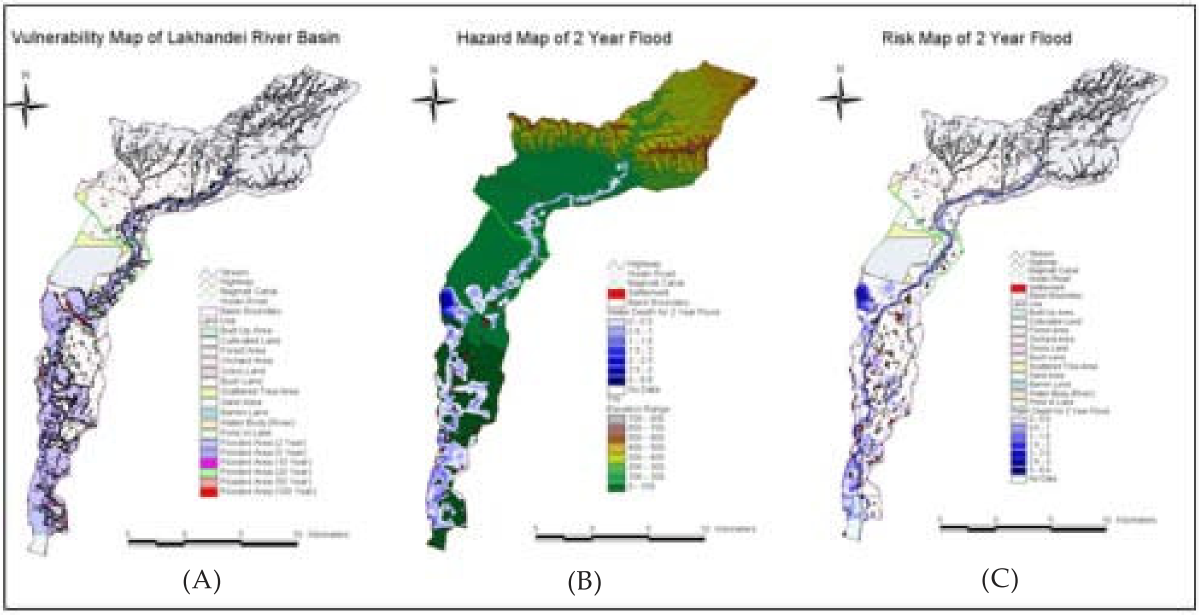
Key Findings

This study presented a systematic approach for the preparation of flood vulnerability, hazard, and risk map with the application of hydraulic model and GIS. The key findings are as follows:

Flood risk mapping based on hydraulic model and GIS. The flood map could be prepared for flow of different return periods by the steady flow model. It could also be mapped for particular flooding event by using the unsteady flow model. The automated floodplain mapping and analysis using these tools provided more efficient, effective, and standardized results, saving time and resources. The presentation of results in GIS provided a new perspective to the modeled data—facilitating a transition from a flood hazard model based on field investigation to a knowledge-based model that could be related to flood intensity.

Flood risk assessment. Providing a new perspective to the modeled data, the visualization and the quantification of the flood risks could help decision makers to better understand the problem. This study identified flood risks by combining land use vulnerability and the magnitude and extent of flood hazard. The graphical output created by this system for the different flooding scenarios could inform the decision making process regarding the desirable levels of protection. The flood vulnerability map and flood hazard map and flood risk map for two-year flood are shown in Figure 2.

Figure 2. (A) Flood Vulnerability Map, (B) Flood Hazard Map for Two-Year Flood and (C) Flood Risk Map for the Two-Year Flood



The assessment of vulnerability to flooding was made in relation to the land use pattern in the flood areas, which indicated that a large percentage (about 75%) of the vulnerable area consisted of cultivated land. Part of built up area was also affected by floods of different return period including other land use categories. Flooding had a considerable impact on the livelihood of the local people.

The study also made an assessment of flood hazards in relation to the return period of floods and their water depth. Most of the flooded areas had a water depth of less than two meters. The percentage of flooded areas under the floodwaters with a depth of more than two meters was not more than 5% for a different return period flood.

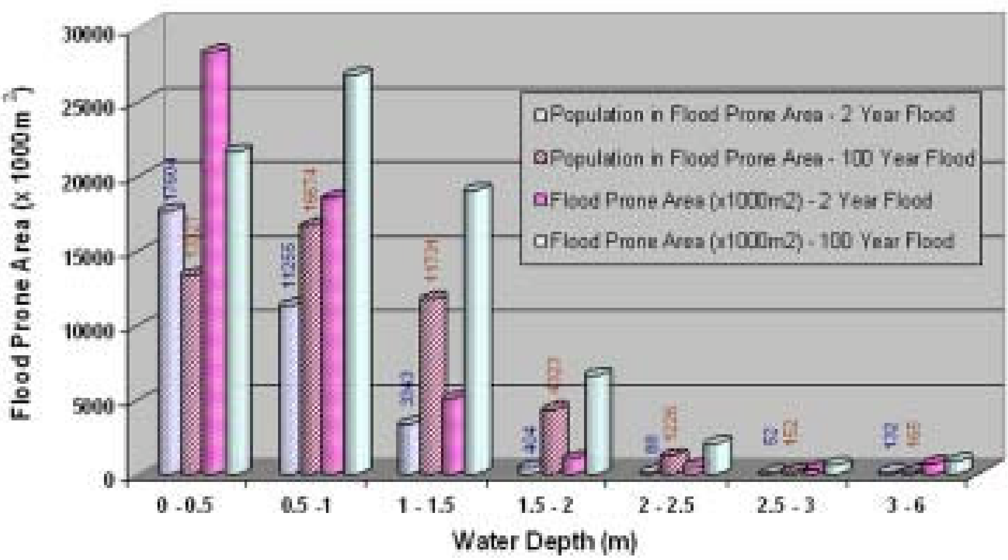
The flood risk assessment was made by combining the results of vulnerability and hazard assessments. There was only a small percentage of settlement areas with floodwater depth of more than one meter. However, there were many agricultural areas with floodwaters of more than one meter, indicating that flooding had a significant impact on agriculture.

Based on the average population density of different VDCs, the number of people that will be affected by 2-year and 100-year flood is estimated to be 32,875 and 47,594, respectively (Figure 3).

Animation of flooded area. Results of the unsteady flow model could be animated to help to present flood-related problems in a visual way for decision makers and the general public.

Shifting river course. The examination of the historical change in the river course indicated that the shifting of river course in the upper reaches was not severe but the river course actively shifted in the lower reaches.

Figure 3. Flood-prone areas and approximate population (based on population density of different villages (Population Census 2001, CBS) in flood-prone areas for 2-year and 100-year floods



Impact of global climate change. For sustainable flood plain management, the impact of global climate change should be considered. It is anticipated that the total number of average flood days a year and the number of consecutive flood days will increase, so the severity of flood will also increase in the future (Thapa, 2003).

Participation of community in flood management. Flood risk maps are essential for assessing potential damage and successfully implementing a range of flood hazard mitigation measures, such as land use regulation, emergency measures. These maps would also inform the public of the risks. Flood management needs the active involvement and participation of all. A general flood action plan was also prepared as an extension of this study.

Some of the practical applications of this study were derived from the use of an automated floodplain modeling process; some from the resulting floodplain maps. The potential applications of this study consist of the following: design of flood control structures and other structures, floodplain zoning, and real-time flood warning mapping. An example of a practical application is the creation of scenario maps that would indicate the need to issue a flood warning.

Recommendations to Stakeholders

- Adopt an appropriate land use plan in flood-prone areas (prohibitive, restrictive, and warning zone).
- Adopt sabo works, promote aforestation, watershed conservation efforts in the upper reaches, and implement both structural and non-structural flood control measures in the lower reaches of the river (integrated approach for the management of water related disasters in the whole river basin).
- Encourage the community to be involved in the flood action plan to mitigate the flood hazard and improve their awareness on the negative consequences of flooding.
- Establish evacuation centers at different settlements.

Dissemination Strategy

This study was part of the author's master's thesis. Its output was disseminated during the thesis presentation. A paper related to this study was also included in the proceedings of an international conference (Awal et al., 2005). Currently, the author is involved in a study on landslide dam failure and resulting flooding. Further dissemination of study will be done to governmental and nongovernmental organizations working in flood disasters.

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Annex A

Technical Description of Methodology

The flowchart of the floodplain analysis and risk assessment using HEC-RAS (1-D model), GIS, and HEC-GeoRAS is shown in Figure 1. The general procedure consisted of five basic steps: (1) preparation of TIN in ArcView GIS; (2) HEC-GeoRAS pre-processing to generate HEC-RAS import file; (3) running of HEC-RAS to calculate water surface profiles; (4) post-processing of HEC-RAS results; and (5) floodplain mapping and flood risk assessment. The flood risk assessment methodology followed the approach developed by Gilard (1996). A similar approach was adapted in the flood risk assessment of Babai River in Nepal (Shrestha, 2000, 2002). The flood risk was divided into hazard and vulnerability components. The vulnerability assessment used the binary model, based on the presence or absence of flood of particular intensity in a particular land use type. The spatial coexistence model was used for the hazard assessment and reclassification of floodwater depth. The results of these two analyses were combined for the flood risk assessment.

Model Development

The major data for model development consisted of the topography and river channel and hydrologic data for the floods of different return periods. For the preparation of TIN digitized data (from the Survey Department, GON), digitized contour at interval 2.5 m and spot heights from 1:10000 topographical map prepared for the FMP study (JICA/DOI, 1999) and cross sections at the interval of about 1 km from the river survey of 1998 were used.

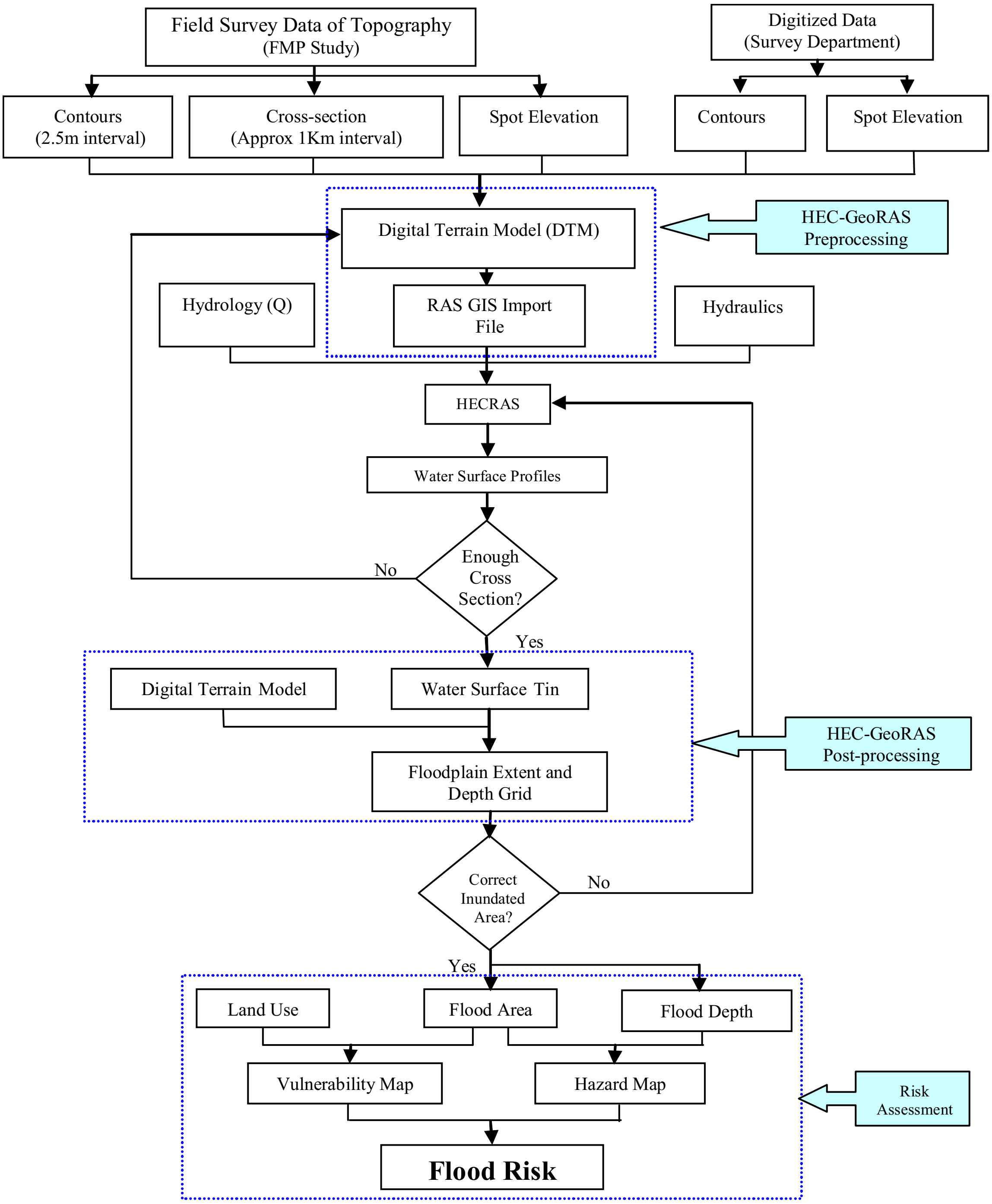
As the Lakhandei River is not gauged, the peak discharges were estimated by different empirical methods such as Creager's formula adopted in the FMP study, WECS/DHM, Modified Dicken's, B.D. Richard's, and Synder's method. Probable maximum flood for different return period at various sites along the Lakhandei River is shown in Table 1. For unsteady flow analysis, the triangular hydrograph adapted in FMP study was used. The water surface profiles computations were made for the floods of 2, 5, 10, 20, 50 and 100 year return periods. The flood vulnerability map, flood hazard map, and flood Risk map were prepared based on the methodology already described.

- Motivate and strengthen the coping capacity of local institutions through government and NGO support.
- Include housing design on building codes for strict implementation.
- Update hazard maps by incorporating additional survey data of all man-made structures with field verification.
- Identify evacuation centers and evacuation routes in the flood hazard map.
- Reestablish water level gauging station at Pattharkot to incorporate reliable flood discharge in the hydraulic model.
- Acquire RS data at flood peak time to help in model verification, to assess damage, and support post disaster mitigation measures.

Table: 1 Probable Maximum Flood for Different Return Period at various sites along the Lakhandei River

Distance from Indian Boarder (km)	Catchment Area (km^2)	Probable Discharge (m^3/s)					
		Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}
51.04	65	178.00	288.36	359.56	428.98	519.76	587.40
42.28	107	242.00	392.04	488.84	583.22	706.64	798.60
39.67	155	302.00	489.24	610.04	727.82	881.84	996.60
36.43	174	323.00	523.26	652.46	778.43	943.16	1065.90
30.74	208	357.00	578.34	721.14	860.37	1042.44	1178.10
11.82	289	428.00	693.36	864.56	1031.48	1249.76	1412.40
3.86	300	437.00	707.94	882.74	1053.17	1276.04	1442.10

Figure 1. One-Dimensional Floodplain Analysis Using HEC-RAS, GIS and HEC-GeoRAS

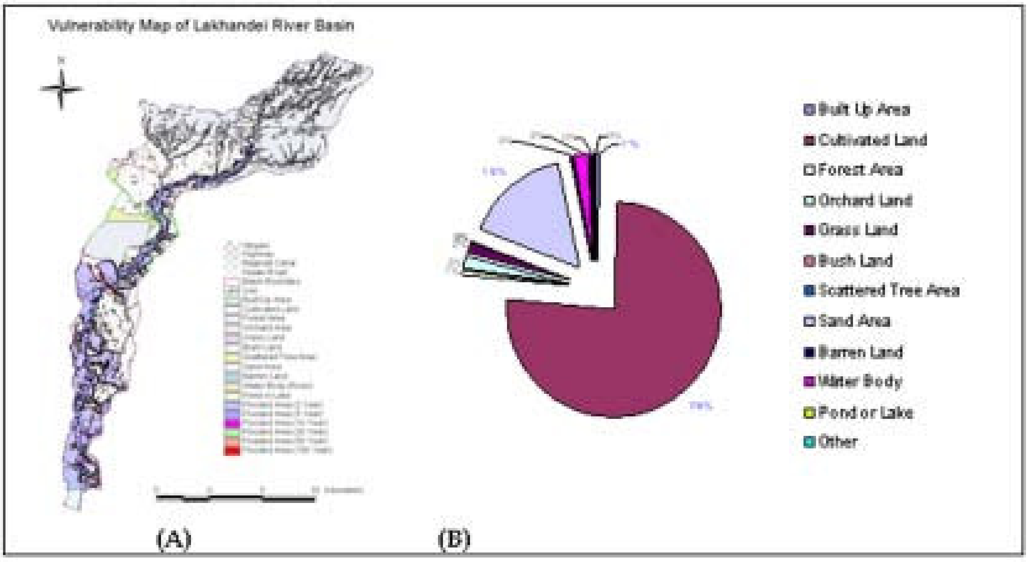


Flood Vulnerability Analysis

The vulnerability maps for the flood areas were prepared by intersecting the land use map of the floodplains with the flood area polygon for each of the flood event being modeled. This depicted the vulnerability aspect of the flood risk in the particular area in terms of the presence or absence of flooding of a particular return period as a binary model. The result of the model is shown in Figure 2(A) and the land use areas covered by the modeled flood are summarized in Figure 2(B).

The assessment of the flood areas indicated that large percentages (73% to 76%) of vulnerable areas were cultivated land. Flooding also affected some settlement areas, indicating that flooding had a considerable impact on the livelihood of the local people.

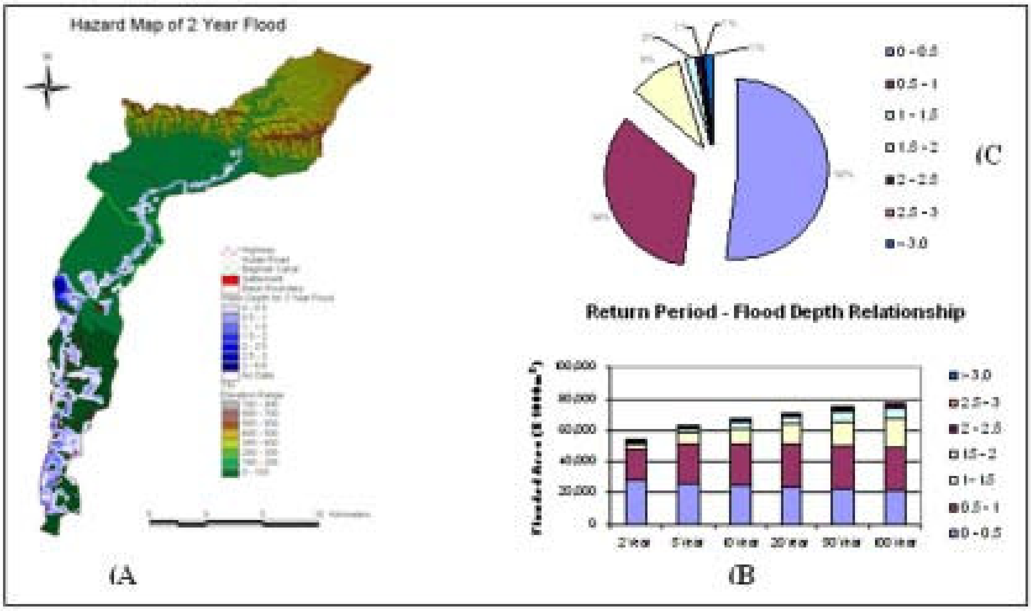
Figure 2. (A) Flood Vulnerability Map; (B) Flood Vulnerability Classification for Two-Year Flood



Flood Hazard Analysis

Water depth was a determining parameter for the quantification of the flood hazard and potential of damage. The weighted spatial coexistence model facilitated the analysis by ranking the hazard level in terms of water depth. In this study, the hazard level was determined by reclassifying the flood grids flood depths polygons bounding the water depth at the intervals of 0-0.5, 0.5-1.0, 1.0-1.5, 1.5 - 2.0, 2 - 2.5, 2.5 - 3.0 and >3.0. The areas bounded by the flood polygons were calculated to make an assessment of the flood hazard level. The results of this assessment are shown in Figure 3 (A), (B), and (C).

Figure 3. (A) Flood Hazard Map for Two-Year Flood; (B) Return Period-Flood Depth Relationship; and (C) Flood Hazard Analysis for 2 Year Flood.



The classification of flood depth areas indicated that 27% to 52% of the total flooded areas had water depths of less than 0.5 m. Most of the flooded areas had water depth of less than 2 meters. The flooded area with a water depth of more than 2.5 meters was quite small. Flooded areas under the water depth of 0.5 to 2 meters increase considerably with the increase in the intensity of flooding.

Flood Risk Analysis

The flood risk analysis included the combination of the results of the vulnerability and hazard assessments. This was defined by the relationship between the land use vulnerability classes and the flood depth hazard classes in a particular area. The flood risk maps were prepared by overlaying the flood depth grids with the land use map (Figure 4A). The land use and hazard classes were translated into color classes for the visualization of the level of flood hazards in the vulnerable areas. The flood depth polygons prepared during the hazard analysis are intersected with the land use vulnerability polygons. The resulting attribute tables are reclassified to develop the land use-flood depth relationship [Figure 4(B)]. This depicts potential flood areas in terms of both the land use vulnerability classes and water depth hazard classes.

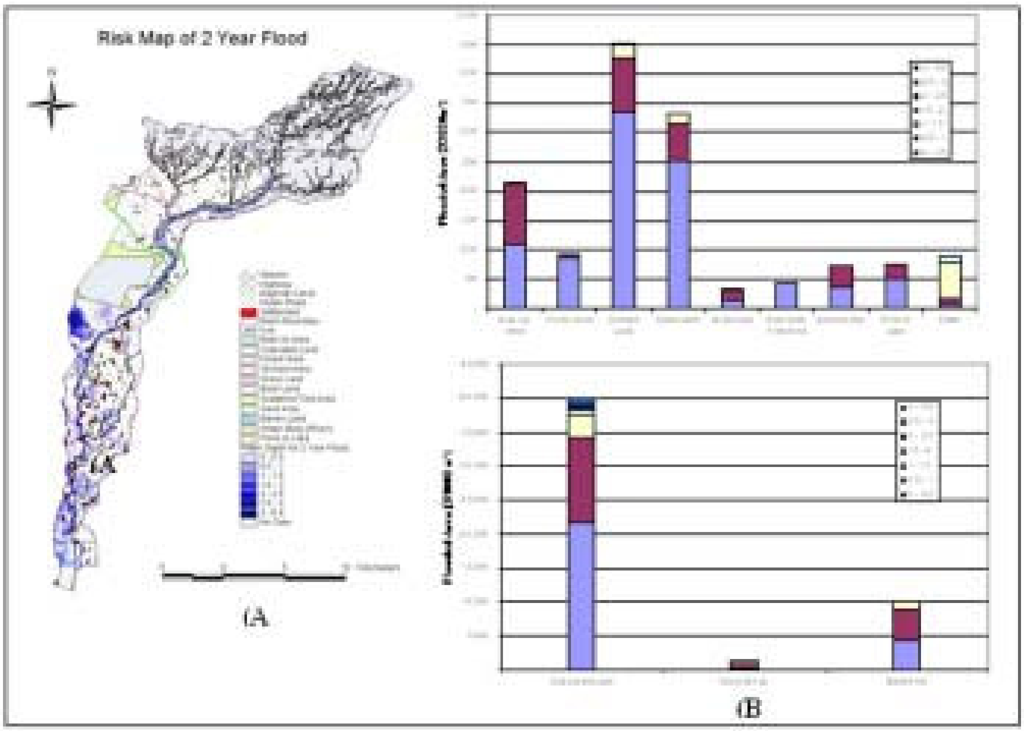
Only a small percentage of settlements were covered by floodwater with a depth of more than one meter. However, there were many areas of cultivated land that had floodwaters of more than one meter, indicating that flooding had a significant impact on cultivated land.

The spatial coverage of the different magnitude of flood risk was varied in different VDCs of the basin. The details of extent of spatial coverage for different return period were calculated. Based on the average population density of different VDCs, the number of people that will be affected by a two-year return period flood is estimated to be 32,875; while he number of people that will be affected by a 100-year return period flood is estimated to be 47,594.

Comparison of Steady and Unsteady Flow Modeling

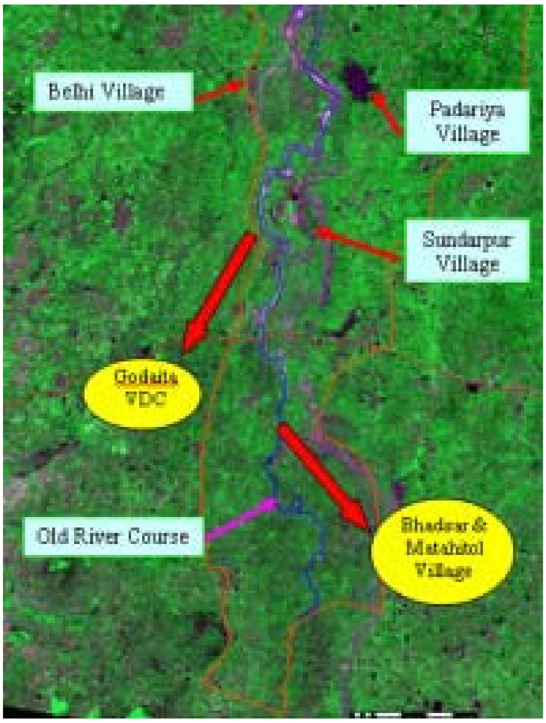
An additional analysis of the part of the study area was conducted using the HEC-RAS unsteady flow model to compare the result of steady and unsteady flow modeling. Based on the comparative study of steady and unsteady flow analysis, the water surface elevation computed by unsteady model was less than the steady flow analysis. In the steady analysis, the flooded area was about 2.84% more. When using a steady flow model, most modelers consider the peak runoff flows at the boundary conditions for a specified storm event, resulting in water stage height being significantly higher than one for the unsteady flow model. Thus, the steady flow analysis tends to overestimate flow. The unsteady flow model considers flood duration as a factor in flood analysis. Real property can be significantly affected by the difference in inundation time. The result of unsteady flow model could be animated to help present the flood-related problems in a visual way for decision makers and the general public.

Figure 4. (A) Flood Risk Map for 2 Year Flood; (B) Land Use-Flood Depth Relationship



River Course Shifting

Satellite image Landsat ETM+ was used for the study of river course shifting. The examination of the historical change in the river course indicated that the shifting of river course in upper reaches was not severe. The shifting seemed to remain within the meandering. However, river course actively shifted in the lower reaches.



Lakhandei River formed on the side of Belhi village merged with the Purano Lakhandei Nala. Due to increase in discharge in Purano Lakhandei Nala, the flooding of Madhopur village and Godaita village has increased in recent years. The new channel formed on the left bank at about 1.5 km downstream from the Phulparasi Bridge is carrying significant floodwater of Lakhandei River and flows toward Bhadsar and Matahitol villages. The frequent change in river course and formation of several river courses show that the use of the two-dimensional model is required for better floodplain analysis and mapping in the lower reaches.

Impact of Global Climate Change in Flood Hazard

Flood management including water resources management has been traditionally based on the assumption of stationary or unchanged climate and land-use conditions. A number of recent floods of exceptional severity and a long lasting drought have belied this assumption. Precipitation is the most significant aspect of climate change. Climate change impacts on the hydrologic resources of a country.

A case in point is the Bagmati River, which flows parallel to Lakhandei River in the Terai. The peak projected flows have occurred in a cyclic order, volume of runoff has increased, and monsoons have occurred early. Based on rainfall runoff simulation and analysis for the projected period of 2041 to 2059 (Thapa, 2003), the total number of average flood days a year and the number of consecutive flood days are expected to increase. If mitigation measures are not taken, the increase in flooding event will result in huge losses of lives and property.

General Flood Action Plan

Flood risk maps are essential for assessing potential damage and successfully implementing a range of flood hazard mitigation measures, such as land use regulation and emergency measures. These maps would also inform the public of the risks. Flood management needs the active involvement and participation of all. A general flood action plan was also prepared as an extension of this study. The action plan emphasized community participation and suggested the formation of a Community Flood Management Committee. The NGOs and voluntary organizations can act as interface between the committee, government, and other organizations. The functions of Community Flood Management Committee would consist of flood preparedness, flood response (i.e., relief, post-flood rehabilitation, and maintenance), and flood mitigation.