GIS Based Flood Hazard Mapping and Vulnerability Assessment Due to Climate Change: a case study from Kankai Watershed, Eastern Nepal

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GIS-Based Flood Hazard Mapping and Vulnerability to Climate Change Assessment: A Case Study from Kankai Watershed, Eastern Nepal

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Abstract

Flooding due to excessive rainfall in a short period of time is a frequent hazard in the flood plains of Nepal during monsoon season. In this study, we have assessed flood hazards, their impacts, and the resilience of communities at the watershed level. The main objective of this study was to integrate flood simulation model, remotely sensed data with topographic and socio-economic data in a GIS environment for flood risk mapping in the flood plain of Kankai river in Nepal. The identification and mapping of flood prone areas are valuable for risk reduction. The results obtained from GIS modeling were then verified through vulnerability assessment. Flood danger level and warning level were identified by using maximum instantaneous discharge data and gauge height. Water level at 3.7m is assigned as warning level and 4.2m as danger level. The flood frequency analysis was done by three different methods and finally Gumbel distribution was adopted for the hazard mapping. A 25-year-return period flood hazard map and another 50 year-return period flood hazard maps were prepared. The potential damage of the study area was calculated. A total of 59.3 sq. km and 59.8 sq.km of the study area will be flooded in a 25-year-return period flood and 50 year-return period flood respectively. The result shows that agriculture system of the study area is in a geographically vulnerable position. The hazard prone area will considerably increase from 25-year-return period flood to 50 year-return period flood. Level of hazard shows that high hazard area will be increased and more settlement will be under the high hazard zone. Vulnerability assessment regarding flooding and climate change depict that peoples' livelihoods are worsening each year.

Key words: floods, rainfall, hazard, monsoon, GIS (Geographic Information System), modeling, vulnerability, climate, disaster

1. Introduction

Floods are the most common natural disasters that affect societies around the world. Dilley *et al.* (2005) estimated that more than one-third of the world's land area is flood prone affecting some 82% of the world's population. About 196 million people in more than 90 countries are exposed to catastrophic flooding, and some 170,000 deaths were associated with floods worldwide between 1980 and 2000(UNDP 2004). These figures show that flooding is a major concern in many regions of the world. Globally, the economic cost of extreme weather events and flood catastrophes is severe, and if it rises due to climate change, it will hit poorest nations the hardest. The number of major flood disasters in the world has risen over recent time. There were six in the 1950s, seven in the 1960s, eight in 1970s, 18 in the 1980s, and 26 in the 1990s (UNDP 2004).

Nepal, the central part of the Hindu-Kush Himalayan, has more than 6,000 rivers and rivulets. Floods and landslides, which are triggered by heavy precipitation, cause 29% of the total annual deaths and 43% of the total loss of properties in Nepal (DWIDP 2004).The Tarai region, despite comprising only 17% of the total area of the country is regarded as the granary of Nepal. The problem of flooding in this region is of utmost concern due to its important role in meeting the food requirement of the country. In recent years, between 1981 and 1998, three events of extreme precipitation with extensive damage have been reported (Chalise & Khanal 2002). Floodplain analysis and flood risk assessment of the Babai Khola, using GIS and numerical tools (HEC-RAS & AV-RAS) was carried out by Shrestha (2000). Similarly, GIS was applied for flood risk zoning in the Khando Khola in eastern Tarai of Nepal by Sharma *et al.* (2003). Awal (2003, 2007) and Awal *et al.* (2005) used hydraulic model and GIS for floodplain analysis and risk mapping of Lakhandei River. After the disastrous climatologic event of 1993, hazard maps were prepared for the severely affected areas of central Nepal (Miyajima & Thapa 1995).

In the context of global warming, the probability of potentially damaging floods occurrence is likely to increase as a consequence of the increase in the intensity of extreme precipitation events (i.e., >100 mm/day)(Baidya *et al.* 2007) and the condition of glacial lakes in high mountain areas, Global Circulation Model projects a wide range of precipitation changes, especially in the monsoon: 14 to +40% by the 2030s increasing 52 to 135% by the 2090s (New *et al.* 2009). The monsoon precipitation pattern is changing too; with fewer days of rain and more high-intensity and incessant rainfall events.

Flooding is a serious, common, and costly hazard that many countries face regularly. Identification and mapping of flood prone areas are valuable for risk reduction. Flood risk mapping consists of modeling the complex interaction of river flow hydraulics with the topographical and land use characteristics of the floodplains. Integrating hydraulic models with geographic information systems (GIS) technology is particularly effective.

The main objective of this study is to integrate flood simulation model and remotely sensed data with topographic and socio-economic data in a GIS environment for flood risk mapping in the flood plain of Kankai river in the eastern Nepal.

2. Study Area

The study was conducted on Kankai Watershed in eastern Nepal. The Kankai River is one of the class II type rainfed perennial rivers of eastern Nepal. It originates from Mahabharat range at Chamaita Village Development Committee (VDC) in Ilam district. At the place of its origin it is called Deomai Khola. The catchment area of the study basin is $1284 km^2$. The altitude of its origin is about 1820m above the mean sea level. The altitude in Sukedangi near the district border of Ilam and Jhapa is about 120m, and about 70m in the Indo-Nepal border. Fourty-eight VDCs (40 VDCs of Ilam and 8 VDCs of Jhapa) lie inside the watershed covering the Ilam and Jhapa districts. The total population of the watershed is 322,951 (CBS 2003).

Kankai river basin lies in the south-eastern part of the country. It has tropical and

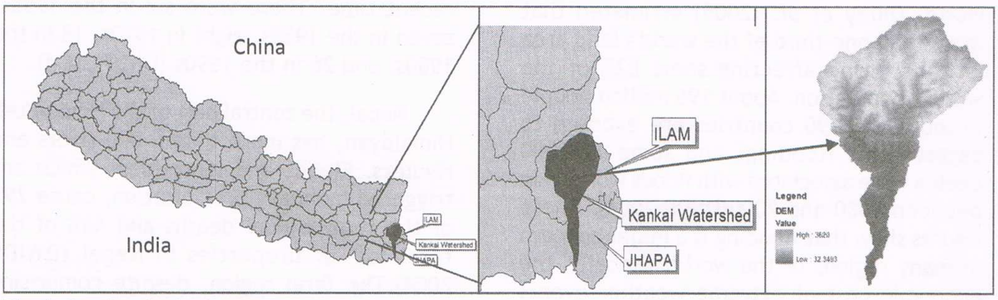

Fig. 1. Map showing Study area

subtropical climate regime. The period from March to June is predominantly hot and dry, July to August is hot and humid, September to October is pleasant, and November to February is cool and dry. The hot wave during the summer and cold wave during the winter reflects harshness of the climate in the study area. The temperature ranges up to 46 °C in the summer to 2 °C during winter. The mean daily temperature at Gaida meteorological station (25.58° N, 87.90° E, elevation 143m) has been estimated as 24.5 °C. Similarly, relative humidity (RH) is 75% and vapour pressure is 23.79. Kankai watershed falls in the class of 75-85% annual average RH. The estimated mean daily vapour pressure is 20. The average sunshine hour for almost 8 months of a year is about 80%, and falls below 50% during monsoon.

Hydro-meteorology: The annual mean precipitation in the study area ranges from

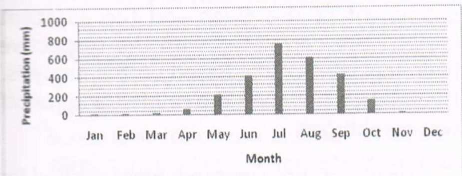

Fig. 2. Average monthly rainfall at Gaida meteorological station for 1972-2005

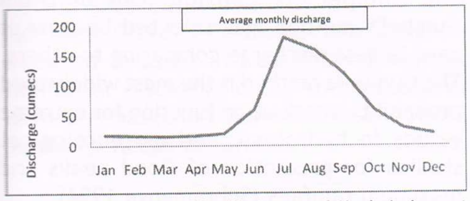

Fig. 3. Average monthly discharge of Kankai river at Mainachuli (Source: DHM 2010)

2,000 to 3,000mm. The average annual precipitation at Gaida station, Damak station, Sanischare station and Ilam Tea state stations are 2,734mm, 2,369mm, 2,794mm, 1,574mm respectively.

The Mainachuli gauging site (Station no. 975) has stream flow record from 1972 to date. The average monthly variation of flow at this station is shown in figure 3. The annual average discharge at this station is 58.9m^3/s (based on 1972-2006 data). The discharge increases rapidly from May and reaches maximum in July.

3. Methods

The proposed methods of this research involved several steps: (1) Data on rainfall, stream flow, topography as well as geology and land use were collected, stored and preprocessed. (2) Flood frequency analysis was done using the Gumbel's Method. This method is most widely used for probability distribution functions for extreme values in hydrological and meterological studies for predication of flood peaks and maximum rainfall. It was used in this research for calculating peak discharge of the river. (3) The general method adopted for floodplain analysis and flood risk assessment in this study basically consist of five steps: (a) Preparation of TIN in ArcView GIS 3.3, (b) Preparation of land cover map, (c) GeoRAS Pre-processing to generate HEC-RAS Import file, (d) Running of HEC-RAS to calculate water surface profiles and (e) Post-processing of HEC-RAS results and floodplain mapping.

Data collection: The information needed for flood hazard and vulnerability mapping was obtained from three different sources: i) maps, aerial photographs, and imagery; ii) field survey and group discussions; and iii) published and unpublished documents. Meteorological data, particularly rainfall and temperature of the nearest stations, Gaida station, and similarly, the hydrological data of Kankai river; Mainachuli station were collected from the Department of Hydrology and Meteorology. The walkover survey field was conducted to prepare a surface geological map on a scale of 1:25000 for the overall research area. The field survey was conducted for gathering information on landslide types their size and distribution as well as for river undercutting, debris flow, and flooding in the watershed.

Verification of flood mapping in the field: Field mapping was conducted in order to prepare a hazard map. During the field study, detailed information regarding old river courses, old flood marks, bank height, river undercutting, channel shifting, and effect of flooding on civil structures were collected. Local people were interviewed to get information on the history of river flooding, observed flood levels, socioeconomic impact of floods, and hazard assessment perception of the community.

Preparation of triangulated irregular network (TIN): The contour data provided by the Department of Survey, cross section data & spot height data were used for Triangulated Irregular Network generation. ArcView 3.3 was used to generate TIN which was used as Digital Elevation Model (DEM) required in GeoRAS environment in order to prepare data sets required as input to the HEC-RAS simulation.

Model application: PreRAS, postRAS and GeoRAS_Util menus of HEC-GeoRAS extension in ArcView GIS environment were used for creating required data sets, making import file for model simulation in HEC-RAS.

(a) Pre GeoRAS application: The preRAS menu option was used for creating required data sets for creating import file to HEC-RAS. Stream centerline, main channel banks (left and right), flow paths, and cross sections were created. 3D layer of stream centerline and cross section was also created. Thus, after creating and editing required themes, RAS GIS import file was created.

(b) HEC RAS application: This is the major part of the model where simulation is done. The import file created by HEC-GeoRAS was imported in Geometric Data Editor interface within HEC-RAS. All the required modification, editing was done at this stage. The flood discharge for different return periods were entered in steady flow data. Reach boundary conditions were also entered in this window. Then, water surface profiles were calculated in steady flow analysis window. After finishing simulation, RAS GIS export file was created. Water surface profiles were computed from one cross section to the next by solving the energy equation.

The flow data were entered in the steady flow data editor for two return periods as (25 year and 50 year). Boundary condition was defined as critical depth for both upstream and downstream. Sub critical analysis was done in steady flow analysis. Then after, water surface profiles were computed. The resulted was exported creating the RAS GIS export file.

Flood frequency analysis: Although a number of methods exist for the determination of maximum flood magnitudes, the historical hydro-meteorological data recorded during the past events was more reliable for the estimation of maximum probable flood. The monthly rainfall data recorded in the catchment of the given and the adjacent basins were correlated with the respective hydrological records. Based on the analysis, the relation between the rainfall and runoff was established.

Different three methods were applied for the flood frequency analysis Modified Dicken's formula, Regional analysis by WECS method and Gumbel distribution. Out of them Gumbel's method was selected because it gave largest discharge comparing to others. The Gumbel's method is the most widely used probability distribution function for extreme values in hydrologic and meteorological studies for prediction of flood peaks and maximum rainfalls (Subramanya 1994).

Vulnerability assessment: Vulnerability assessment of the study area was carried out by two different methods:

(a) GIS based flood vulnerability assessment, where 25-year return period and 50 year return period flood were calculated through Gumbel distribution. After that with the help of HEC-GeoRAS, HEC-RAS, ARCView GIS 3.3, ArcGIS 9.3, a flood map was produced and finally vulnerable areas were identified for 25 years flood and 50 years flood as mentioned in results;

(b) another method applied to analyze past impact by the changing climate, perception of people on climate change and adaptation practice was carried out through Participatory Vulnerability Approach (PVA) tools where household questionnaire survey, interview with key informants were done within the study area. PVA is considered to be an effective tool for climate change impact studies and for developing adaptation strategies. The future impact will also be stimulated through the people's perception and their coping capacity. Walkover survey (transact walk), time line, cause and effect, problem tree, social mapping, focus group discussion, key informant survey were used during the field survey. And finally by rating the entire variables, final vulnerability scores were calculated using a manual published by Livelihoods & Forestry Programme (2010). The formula used for calculating vulnerability score is as follows: Vulnerability Score = (Frequency + Area of Impact)*Magnitude

Data analysis: Flood frequency analysis of 2, 10, 25, 50, 100 and 200-Years Return Period was calculated by Gumbel,and Modified Dickens Formula. This program intended to assist in frequency analysis of rainfall or discharge data. The procedures used are based on Gumbel's distribution. Similarly, floods of different return periods were calculated using WECS/DHM method. Software ARC GIS 9.3 and ArcView 3.3 were used for analysis and interpretation of GIS data. All the statistical data was entered and analyzed using Microsoft Excel 2007. For socio-economic data, Excel and SPSS software were used to analyze socio-economic data.

4. Results and Discussion

Hydro-meteorological analysis: Warning level and danger level of flood within Kankai watershed was calculated using the maximum instantaneous discharge data from 1972-2006 (DHM 2010). Up to DHM gauge height of 3.7m at Mainachuli, there is no inundation to the flood plain. So this is the threshold value above which the flooding begins (DHM 2010). Hence, the water level at 3.7 m is marked as warning level and corresponding discharge for the height is about 1,900m^3/s. Gauge height exceeding 4.2m causes flooding in the settlements, the inundation depth being greater than 1.5m. Therefore, gauge height of 4.2m is demarcated as danger level and corresponding discharge for this water level is about 3,250m^3/s. Figure 4 shows the corresponding gauge heights of maximum instantaneous discharge in comparison to the warning level and danger level at the station. It can be seen that the warning level is frequently exceeded and the danger level also exceeded at different times by annual instantaneous maximum floods and the trend of discharge has been consistently increased since 1995, this might be due to change in precipitation pattern and change in climate regime of the study area.

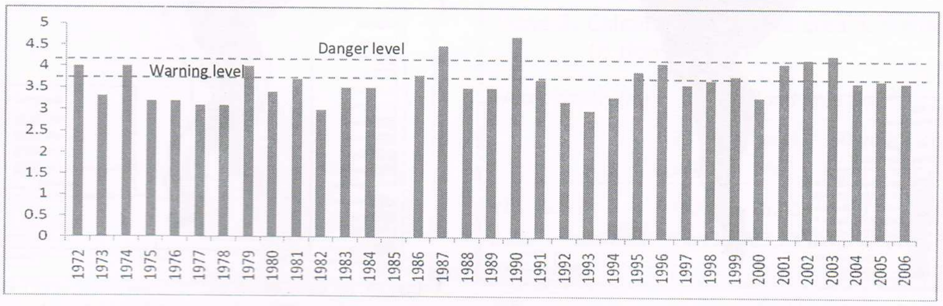

Fig. 4. Annual instantaneous maximum flood gauge height with warning and danger level

Flood frequency analysis: Flows required for the study have been estimated based on three empirical and one probability distribution methods. Peak designs have been determined by comparing the three methods with each other for greater reliability. Modified Dickens's equation, WECS method and Gumbel distribution method have been used to determine peak flows. The result of 2, 5, 10, 50, 100 and 200-year Return Period Flood Frequency Analysis based on Maximum Instantaneous flow recorded at Kankai River(Gaida Station) from year 1972- 2003 using Gumbel, modified Dicken's formula and by WECS/DHM Method are summarized below in Table 1.

Comparing all the three methods, maximum peak flow is obtained by Gumbel's method, so this method is adopted rather than other two methods for the flood estimation. Therefore peak flows for 25 years designed flood and peak flows of 50 years designed flood are 8007.84 m^3/s and 9,148.31m^3/s respectively and both the value exceed the danger level discharge of 3,200m^3/s. This data shows that there might be catastrophic flooding on the watershed because the discharge value for 4.2m height water level is only about 3,250m^3/s and it is very small with compared to 25 years designed flood and 50 years designed flood discharge.

Table 1. Flood frequency analysis for various return period

Return	Flood frequency	
Period (T)	Gumbel's method	WECS method
100	10280.36	2874.328
50	9148.31	2575.389
25	8007.84	2299.37
20	7637.63	2149.389
10	6470.53	1827.97

TIN of Kanaki watershed: The contour and spot height along with the walkover survey data were used in Arc View GIS to generate the Triangulated Irregular Network (TIN) of the study area. The observed elevation of study area ranged from less than 100m up to 3,620m.

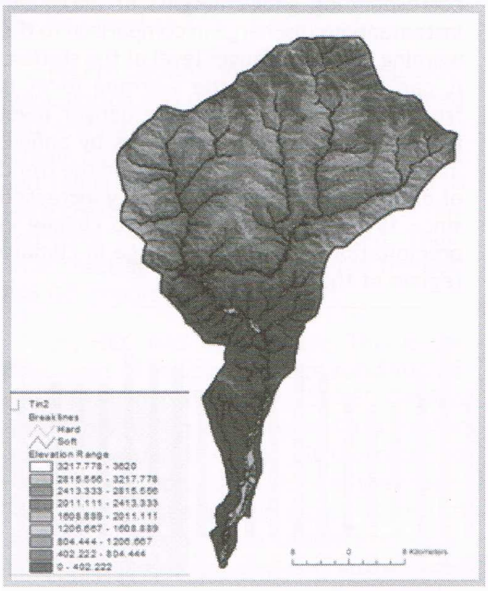

Fig. 5. TIN of the study area

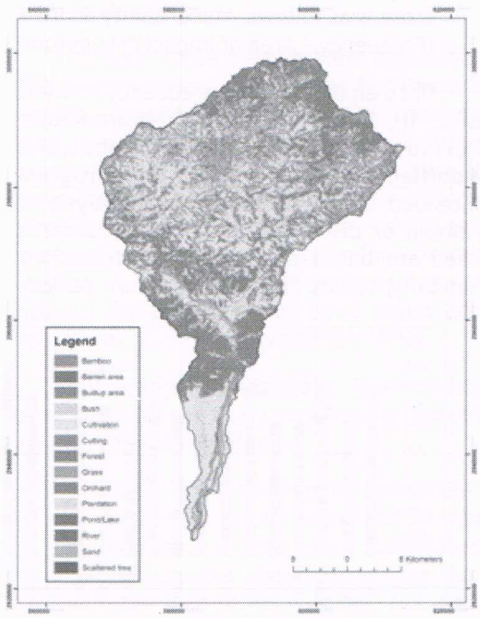

Fig. 6. Land use map of the study area

Preparation of landuse map: The land use map of the Kankai river watershed derived from the 1992 toposheet along with field verification is shown in Figure 5. Forest occupies the largest area of the watershed 45.7% of the total area, while agricultural land occupies about 43.3% of the total area.

Table 2. Landuse pattern of the study area

S.N	Landuse class	Area (sq km)	%
1	Builtup area	0.02	0.0014
2	Cutting	0.97	0.0755
3	Cultivation	556.07	43.3353
4	Forest	586.48	45.7059
5	Orchard	0.08	0.0065
6	Plantation	4.87	0.3794
7	Grass	64.63	5.0371
8	Bush	14.06	1.0960
9	Bamboo	0.06	0.0049
10	Scattered tree	0.02	0.0012
11	Sand	42.67	3.3255
12	Barren area	2.27	0.1769
13	River	10.68	0.8324
14	Pond/ Lake	0.28	0.0218
	Total Area	1283.17	100

25 year-return period: flood hazard map

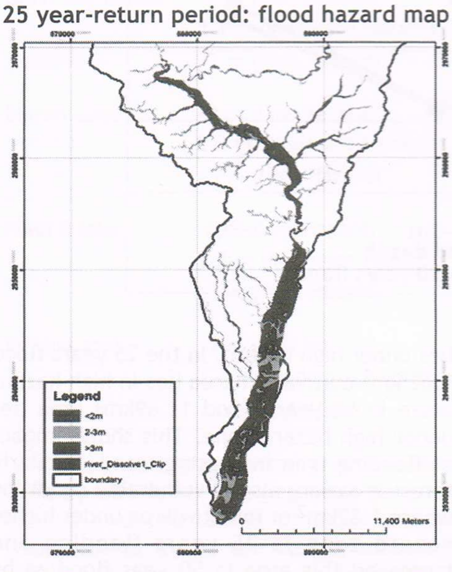

Fig. 7. Flood hazard map of the study area for 25 year return period flood

Flood hazard analysis: The hazard aspect of the flooding is related to the hydraulic and the hydrological parameters. The results of this assessment are summarized in Table 3 and Figures 7 and 8. The classification of flood depth areas indicated that 47.64% and 52.7% of the total flooded areas had water depths greater than 3m. The total area under the water depth of 2-3m was 23.83% on 25 year flood and 23.8% on 50 years flood. Flood hazard maps of the study area for 20-year and 50-year return periods was prepared by overlaying flood grid depths with the TIN. The table shows that how much area is under high risk, moderate and low risk.

50 year-Return Period: flood hazard map

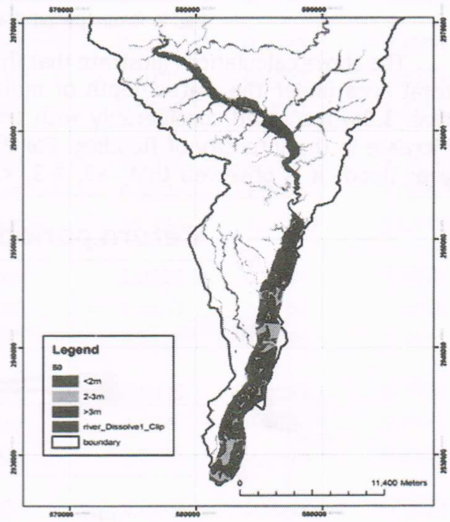

Fig. 8. Flood hazard map of the study area for 50 year return period flood

Table 3. Calculation of flood area according to flood hazard

Water depth (m)	Total flood area (km^2)			
	25 year flood		50 year flood	
	Area	%	Area	%
<2m (low)	16.92	28.53	14.0	23.5
2-3m (moderate)	14.13	23.83	14.2	23.8
>3m (High)	28.25	47.64	31.5	52.7
Total	59.30	100.00	59.8	100.0

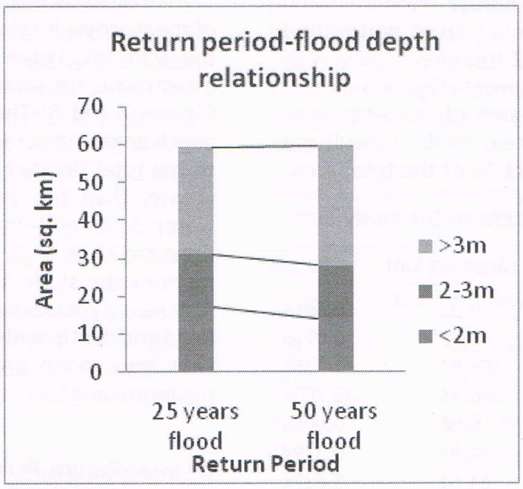

Fig. 9. Return period-flood depth relationship

The above calculations illustrate that the total area under the water depth of more than 3.0m increased considerably with the increase in the intensity of flooding. For 25 year flood, it is observed that >3, 2-3, <2 meter were 16.92, 14.13& 28.25 sq. km respectively and for 50 year flood were 14, 14.2 and 31.5 sq. km respectively. These shows that high hazard of flood is increased in 50 years flood.

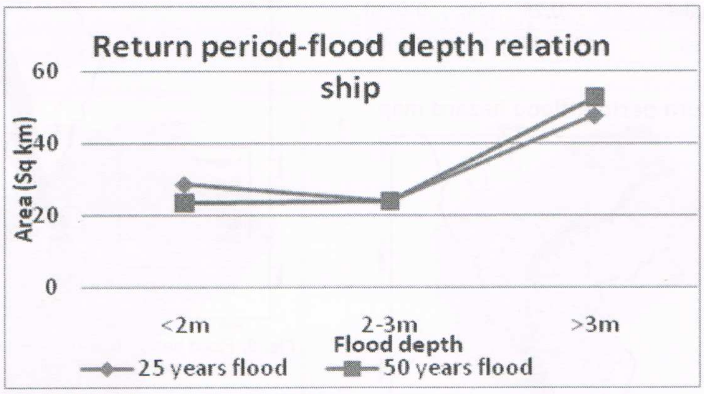

Fig. 10. Flood depth-area relationship

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 depicts the vulnerability aspect of the flood risk in the particular area in terms of the presence or the absence of flooding of a particular return period as a binary model. The assessment of the flood areas indicated that a large percentage of cultivation area lies under high hazard. In the 25 years flood 9.62 km^2 cultivation area lies in high hazard while in 50 years flood 11.69km^2 area lies under high hazard zone. This shows impact of flooding is in increasing trend. Similarly forest areas are also in vulnerable condition where 1.87km^2 of forest will be under higher hazard zone in 25 years flooding and increased this area in 50 year flooding by 2.0042 km^2. Similarly high hazard zone of settlement will also increase.

Table 4. Vulnerable areas for 25 years and 50 years flooding

Land use type	Flood depth	Total vulnerable area			
		25 year flood		50 year flood	
		Area (km^2)	%	Area (km^2)	%
Forest	<2 m (Low Hazard)	0.3450	0.5818	0.2446	0.4091
	2-3 m (Moderate Hazard)	0.2535	0.4274	0.2957	0.4945
	>3 m (High Hazard)	1.8731	3.1586	2.0042	3.3515
Cultivation	<2 m (Low Hazard)	6.0761	10.246	4.4641	7.4651
	2-3 m (Moderate Hazard)	5.2643	8.8774	4.9860	8.3378
	>3 m (High Hazard)	9.6227	16.227	11.6929	19.5534
River	<2 m (Low Hazard)	2.5159	4.2426	1.6962	2.8364
	2-3 m (Moderate Hazard)	1.7085	2.8812	2.1622	3.6157
	>3 m (High Hazard)	3.6142	6.0948	3.9935	6.6781
Orchard	<2 m (Low Hazard)	0.0047	0.0079	0.2446	0.4091
	2-3 m (Moderate Hazard)	0.0117	0.0198	0.1957	0.3273
	>3 m (High Hazard)	0.0024	0.0040	1.0042	1.6793
Sand	<2 m (Low Hazard)	6.5058	10.971	5.5429	9.2690
	2-3 m (Moderate Hazard)	5.6513	9.5301	4.3826	7.3287
	>3 m (High Hazard)	11.4153	19.250	12.6887	21.2186
Grass and bambo	<2 m (Low Hazard)	1.2204	2.0580	0.8714	1.4572
	2-3 m (Moderate Hazard)	0.9270	1.5633	1.0764	1.8000
	>3 m (High Hazard)	1.8869	3.1820	2.1295	3.5611
Barren Land	<2 m (Low Hazard)	0.0258	0.0435	0.0093	0.0156
	2-3 m (Moderate Hazard)	0.0047	0.0079	0.0326	0.0545
	>3 m (High Hazard)	0.4024	0.6785	0.0518	0.0860
Pond & lake	<2 m (Low Hazard)	0.0024	0.0040	0.0047	0.0078
	2-3 m (Moderate Hazard)	0.0024	0.0040	0.0023	0.0039
	>3 m (High Hazard)	0	0.0000	0.0023	0.0039
Builtup area	<2 m (Low Hazard)	0	0.0000	0.0000	0.0000
	2-3 m (Moderate Hazard)	0.0023	0.0039	0.0058	0.0097
	>3 m (High Hazard)	0	0	0.005	0.0084

Vulnerability assessment of the study area by VDC level: The degree of danger or threat and the levels of exposure and resilience to threat are closely associated with location. Hence, spatial vulnerability is a function of location, exposure to hazards, and the physical performance of a structure, whereas socioeconomic vulnerability refers to the socioeconomic and political conditions in which people exposed to disaster are living. VDC wise flood hazard mapping is shown in Table no.5.

Table 5. VDC wise flood hazard mapping

VDC Name	25 years return period Flooded area in sq. km			50 year return period Flooded area in sq. km		
	<2m	2-3m	>3m	<2m	2-3m	>3m
Jitpur[1]	0	0	0.003	0	0	0.003
Banjho[1]	0.048	0.003	0.073	0.003	0.015	0.073
Danabari[1]	0.800	0.473	3.653	0.498	0.580	3.920
Ibhang[1]	0	0	0.08	0	0	0.080
Mahamai[1]	1.523	1.638	6.233	1.178	1.435	6.925
Satasidham[2]	1.230	0.443	2.123	1.078	0.380	2.288
Surunga[2]	1.930	1.860	5.540	1.558	1.793	5.990
Sarnamati[2]	1.153	0.715	2.403	1.045	0.700	2.525
Shivjung[2]	3.060	3.758	1.933	2.383	3.710	2.590
Mahabhara[2]	0.583	1.935	1.688	0.403	1.875	1.995
Panchgachhi[2]	0.760	0.158	0.285	0.725	0.190	0.313
Tagandubba[2]	1.185	0.560	1.333	1.015	0.583	1.480
Kumarkhod[2]	4.663	2.513	2.935	4.063	2.910	3.400
	16.935	**14.056**	**28.282**	**13.949**	**14.171**	**31.582**

Note: [1]lies in Illam district ; [2]lies in Jhapa district

From the above calculation, it can be concluded that Kumarkhod, Shivjung, Surunga, Mahamai,Mahavara & Danabari VDCs are most vulnerable because these VDCs lie in low elevation zone of the watershed. Floods occur every year in these VDCs, with most of them being considered "normal" floods. Normal floods occur during July, August, September, and they last for approximately 6-7 days. The height of the flood is between 0.5m in the village, and up to 3m in the paddy fields. Discussions in both villages revealed that the most recent flood that caused serious damage occurred in 1990, 1999 and 2008. During these years, about 200 household were displaced by floods and they still live as flood refugees. Local villagers observed that flood characteristics have not changed significantly in the last 10-15 years. However, they noted that damaging floods appear to have occurred with higher frequency in recent years. Losses of property increased and villagers suffered from flood each year from 1990-2009.

Impact of flooding and climate change: Impacts of flooding and climate change on various social variables were analyzed using participatory vulnerability assessment and semi structured questions among 150 respondents. Perceptions of local people regarding climate change and flooding were drawn. The general relation between increasing flooding and climate change were identified through the people's perception. Altogether six key impacts were experienced. The impact of flooding and climate change was highest in agriculture productivity through reduction in crop production (mainly rice) and damage in rice fields. The other key impacts are loss of barren land and household livestock losses. The details are shown in figure 11.

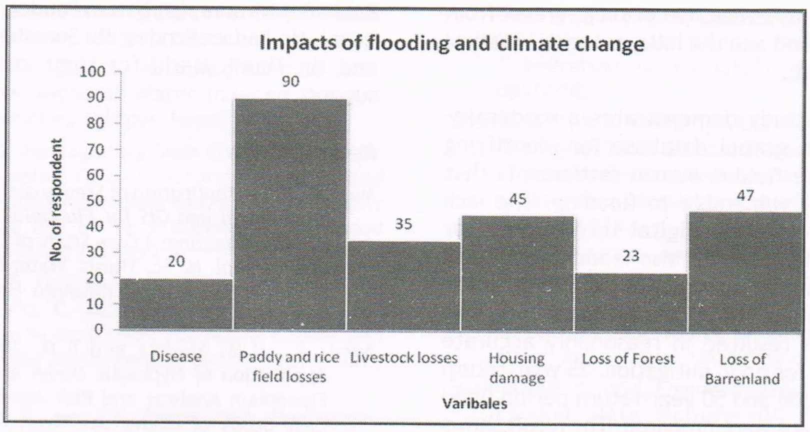

Fig. 11. Impact of flooding and climate change

Vulnerability score: Vulnerability score for the study area was calculated using a standard method provided by Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options, a manual published by Livelihoods & Forestry Programme (2010). The different values were assigned through the questionnaire survey, key informant discussion and according to people's perception. All the rated values were analyzed using following an empirical formula. The results show that agriculture system is in much vulnerable.

(Frequency + Area of Impact)*Magnitude = Vulnerability Score

Table 6. Vulnerability score

Sector	Vulnerability score	Vulnerability in percentage
Agriculture	50	45.87
Forest	28	25.69
Infrastructure	8	7.34
Biodiversity	2	1.83
Settlement	21	19.27

The five sectors were identified from people's perception during field survey. The variables were then ranked with rating values and final vulnerability score were calculated. From vulnerability assessment it was found that Agriculture system is much more vulnerable than other sector.

5. Conclusion

Flood has remained a major problem of the Kankai river for years. These floods have been reported to be more destructive to the VDCs bordering India. While fire, snakebites, droughts, epidemics are also prevalent in the lower basin, flood induced inundation, sedimentation and bank cutting are the major problems of the study area. The main problem associated with Kankai River is its eroding nature. Valuable agricultural land and residential area is being lost with each flood season due to bank cutting and water impoundment. It can be stated with certainty that river is showing avulsion tendencies at some places and meandering in various place. There is clear indication that the river morphology is changing. The deposition of sands in the farmland by the torrents originating from the Chure/Siwalik range, inundation due to flooding and bank cutting at various locations along Kankai River are affecting lives and livelihoods of the people. This change is related to intensification of human activity in the catchment area. Such activities are deforestation within the catchment area, unpredicted weather condition, change in monsoon period, extension of agricultural land into the river flood plains, extraction of rock, gravel from the river bed and the hills, extreme weather events, etc.

This study demonstrates a moderate-resolution spatial database for identifying agriculture field & human settlements that are highly vulnerable to flooding. The lack of high-resolution digital terrain data for developing countries also leads to difficulty in assessing the accuracy of the classification results. In spite of these constraints, the study has resulted in reasonably accurate database for flood mitigation. 25 year-return period flood and 50 year-return period flood hazard maps were prepared. The result shows that 59.3 km^2 and 59.8 of the study area lie in flooding area in 25 years flood and 50 years flood respectively. Hazard assessment proved that the area under high hazard zone was considerably increased from 47.64% in 25 years flood to 52.7% in 50 years flood. From the flood warning and danger level analysis it was found that the discharge trend has been consistently increased since 1995. The discharge value obtained from flood frequency analysis for 25 years return period flood and 50 years period flood, both exceeds the discharge value 3,200m^3/s and lies on danger level and responsible for flooding on the watershed. More than 10 km^2. of the agriculture land is in high hazard zone. Eastern districts are major sources of rice for the country. But this result makes the agriculture system of the country in vulnerable position. Change in precipitation pattern and human intervention were identified as the main causes of flood hazards. Changes in climate and monsoon pattern made these areas more vulnerable. Special attention of the concerned body on this disaster should be drawn for the mitigation and to minimize loss from damage.

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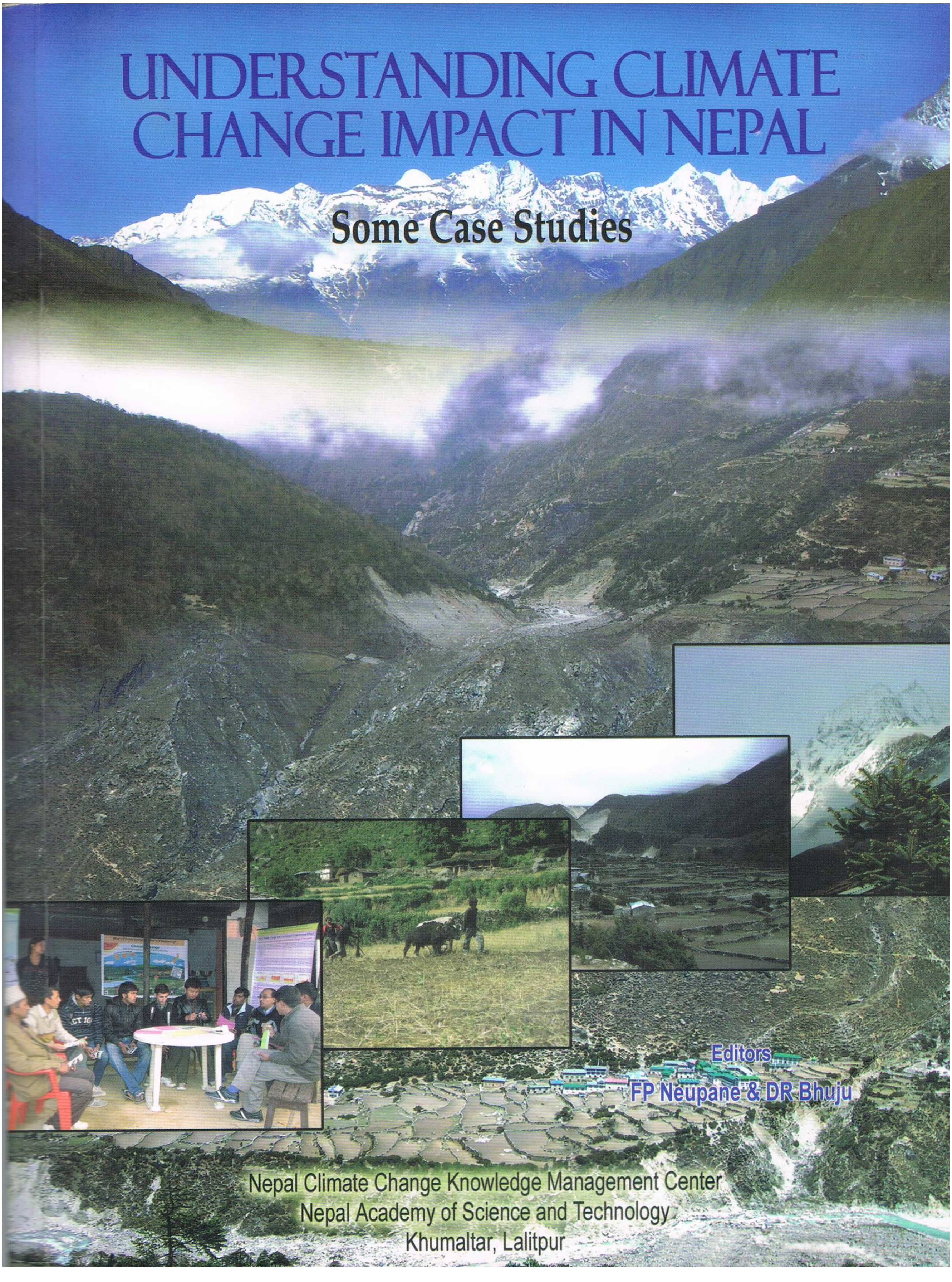
UNDERSTANDING CLIMATE CHANGE IMPACT IN NEPAL

Some Case Studies



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NEPAL'S NATIONAL ADAPTATION PROGRAMME OF ACTION (NAPA) TO CLIMATE CHANGE

The concept of National Adaptation Programme of Action (NAPA) was developed to strengthen the adaptive capacity of Least Developed Countries (LDCs) to climate variability and extremes. It provides a process for LDCs to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage. The Government of Nepal has prepared the NAPA through a consultative process. It is a strategic tool to assess climatic vulnerability and systematically respond to climate change adaptation issues by developing appropriate adaptation measures. The Nepal NAPA report is structured according to decision 29/CP.7 and the guidance and annotated guidelines developed by the Least Developed Countries' experts Group (LEG).

NAPA envisions that mainstreaming climate change into national development agenda will contribute to poverty reduction, livelihood diversification and building community resilience. It aims to enable to respond strategically to the challenges and opportunities posed by climate change. The main objectives of NAPA are to i) assess and prioritize climate change vulnerabilities and identify adaptation measures ii) develop proposals for priority activities iii) prepare, review and finalize the NAPA document iv) develop and maintain a knowledge management and learning platform and v) develop a multi-stakeholder framework of action on climate change. NAPA has described six major areas that are impacted by climate change which are the basic themes for its development. The six thematic area includes i) Agriculture and food security ii) Water resources and energy iii) Forests and biodiversity iv) Public health v) Urban settlement and infrastructures and vi) Climate-induced disasters.

The NAPA report has set out introduction and national setting, the Nepal adaptation Programme Framework, NAPA preparation processes and the methods and criteria used in prioritizing the proposed interventions, identification of key adaptation needs, lists of priority adaptation actions and finally conclusions. Out of about 250 adaptation options proposed by the Thematic Working Groups (TWG), nine integrated projects have been identified as the urgent and immediate national adaptation priority. NAPA is expected to provide a basis for the government to guide the future climate change governance and manage financial resources in a coherent and coordinated manner. The Government will also use it to communicate its urgent and immediate adaptation needs. Ministry of Environment (MoE) is responsible for NAPA implementation through national and international support.