

Flood risk zoning of Satluj River Basin, Himachal Pradesh, India

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ABSTRACT

Increasing intensity and frequency of rainfall coupled with gradual retreating of glaciers due to climate change in Himalayan region likely to increase the risk of floods. A better understanding of risk zones which are vulnerable to flood disasters can be evolved from the detailed studies on slope, geomorphology and land use/ land cover pattern. Information of these parameters is an important input for the identification of vulnerable areas. Flood risk maps provide useful information about places that may be at risk from flooding. It offers a cost-effective solution for planning, management and mitigation strategies in risky areas. Traditional methods of flood risk mapping are based on ground surveys and aerial observations, but when the phenomenon is widespread, such methods are time consuming and expensive. The possible combination of DEM and other maps of area using an overlay operation method within the Geographical Information System (GIS) platform can lead to derivation and the understanding of spatial association between various parameters which could be used to predict flood risk zones. The study area i.e. Satluj River Basin has been broadly divided into five risk zones viz., very low, low, moderate, high and very high which helped to differentiate between areas that are at risk of different intensities of flood. The very high flood risk zone covers only 3.25 % of total study area, while the very low risk zone covers 13.63 %. The area falls within the very high and high risk constitutes 9.52 % of total basin area. Domain of moderate risk covers an area of 30.66 %. But the maximum area of river basin is constituted by low risk zone i.e. 46.19 %. Identification of such zones will help in timely adopting of mitigation and adaptation measures. Preparation of flood risk zoning maps also helps in regulating indiscriminate and unplanned land use practices in risky areas.

1. INTRODUCTION

Flooding refers to the inundation of an area by unexpected rise of water by dam failure or/and extreme rainfall duration and intensity. Glacial Lake Outburst Floods (GLOF) will likely become a more serious issue in the mountainous region due to the gradual retreat of glaciers and increased melt rates. Increased rainfall intensity and runoff resulting from climate change are likely to increase the risk of floods. It is an inevitable natural phenomenon occurring from time to time in all rivers and natural drainage systems which not only damages the lives, natural resources and environment, but also causes the loss to economy and health. Flood risk maps provide useful information about places that may be at risk from flooding. Such maps show more direct and stronger impression of spatial distribution of the flood risk. It offers a cost-effective solution for planning, management and mitigation strategies in flood prone areas.

Flood risk management aims to reduce the likelihood and/or the impact of floods. The most effective approach is through the development of flood risk management strategies by incorporating the elements of prevention, protection, preparedness, emergency response and recovery. A better understanding of risk zones which are vulnerable to flood disasters can be evolved from the detailed studies on slope, geomorphology and land use/ land cover pattern. Information of these parameters is an important input for the identification of vulnerable areas. What is that risk? What will be the consequences if an extreme flood event occurred? What can be done to minimise the risk? These questions require serious thought. A careful consideration shows that to answer these and other

related questions, it is required to involve a risk analysis and assessment. The analysis could be carried out to identify the vulnerable areas which are likely to be affected by flooding events.

Traditional methods of flood risk mapping are based on ground surveys and aerial observations, but when the phenomenon is widespread, such methods are time consuming and expensive. Digital Elevation Model (DEM) and various parameters extracted from it also have a major role to play in hazard mapping, especially flood risk mapping (Sugumaran, 2000). The possible combination of DEM and other maps of area using an overlay operation method within the Geographical Information System (GIS) platform can lead to derivation and the understanding of spatial association between various parameters which could be used to predict flood risk zones.

Flood is the most catastrophic disaster, resulting from typical tropical monsoon climatic features in the lower reaches of mountainous rivers and melting of glacier in the upper part, in addition to the intensifying geomorphic, topographic characters and recent climate change. Given current reported and projected trends in global environmental change, exposure to risk and vulnerability in mountain communities can increase in coming decades. Mountain communities can be exposed to various hazards simultaneously, such as earthquakes, landslides, and floods. Here, an attempt has been made in this study to demarcate the flood risk areas in the Satluj River Basin using GIS. The basin has been broadly divided into five risk zones viz., very low, low, moderate, high and very high which helped to differentiate between areas that are at risk of different intensities of flood. A multi-parametric approach for delineating the flood-risk areas in the river basin is used in a GIS environment. As a first step, it will be necessary to prepare zoning maps of the flood prone areas that will help in reducing flood damages.

Amounts and intensities of rainfall are most important factors controlling climate change impacts on water erosion (Nearing *et al.*, 2005) which affect many geomorphological processes, including slope stability, channel change and sediment transport (Rumsby and Macklin, 1994). The increased cutting and erosion of river banks due to high rainfall intensities would exacerbate such problems. Human settlements on steep hill slopes are particularly vulnerable to increased water erosion and landslides. Temperature based impacts, such as changes in the timing and volume of ice melt related stream flows, tend to be more robust (Maurer and Duffy, 2005). Land use/land cover maps obtained primarily from optical remote sensing can be overlaid on the flood maps for assessing the degree of damage and vulnerability on different categories. Varieties of land use classification strategies have been adopted to estimate flood risk (Sanyal and Lu, 2004). The basic concept of flood risk zone management is to regulate land use by scientifically demarcating areas under different degrees of risk from floods and limits the indiscriminate development in such zones (Rangachari, 2006).

By means of weighting, a number of causative factors including annual rainfall, size of watershed, side slopes of watershed, gradient of river and stream, drainage density type of soil and land use, communication line and infrastructures, and population density can be considered for rating the degree of hazard and risk (Pramojanee *et al.*, 2001). Remote sensing technology is used to define the land use information from satellite imagery. The spatial analysis which is part of GIS is employed for geomorphologic map analysis, DEM analysis, isohyet map analysis and creating the flood hazards map (Suryanta, 2010).

Conventional flood management programmes have provided limited relief in the flood prone areas. Now, the main emphasis should be on management of the upstream area where runoff generation and distribution take place (Jain and Sinha, 2003). The adaptation strategies are required to reduce the vulnerability to climate change induced natural disasters. The effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints. Array of potential adaptive responses are available to human societies i.e. technological, behavioural, managerial and policy (IPCC, 2007).

2. STUDY AREA

The Satluj River (Vedic name - Satudri and Sanskrit name - Shatadru), also known as the Langqên (Chinese) and Sutlej (Indian), is the principal and easternmost tributary of the Indus River

system. The basin area falls in Lahaul & Spiti, Kinnaur, Shimla, Kullu, Mandi, Solan and Bilaspur districts of Himachal Pradesh. The geographical limits of area lie between 30°45' N to 33°00' N latitudes and 76°15' E to 79°00' E longitudes in the western Himalayas (Figure 1). The total catchment area of Satluj River, from origin to Bhakra dam, is about 56,875 km² (21,960 Sq. miles). The upper part of river basin is considerably wider than the lower one. In Himachal Pradesh, Satluj Basin has catchment area of 20,398 Km² which is 30.7% of the total catchment area of river systems. Indian part of river up to Bhakra Dam is elongated in shape and covers the part of outer (Shiwalik range), middle (Dhauladhar range) and greater Himalayas (Zaskar range).

Satluj River originates from the southern slopes of Kailash Mountains i.e. from Rakas Lake, near the Mansarovar Lake as Longchen Khabab River at an elevation of about 4,572 m (15,000 ft), above msl. Total length of river is approximately 1,448 km (320 Km in China, 758 Km in India and 370 Km in Pakistan). It enters India from East of Shipki La (altitude – 3,048 m, above msl) after traversing a length of about 320 km (200 miles) in the Tibetan province of Nari Khorsam, through a narrow gorge in the Kinnaur district of Himachal Pradesh and flows in southwesterly direction. The river is supported by a number of mighty tributaries on either side. Main tributaries are Spiti, Baspa and Gambhar at Khab, Karchham and Kangri at an elevation of 2,600, 1,750 and 450 m above msl respectively. Near Rampur, it crosses the Dhauladhar range and then traverses through a series of successive Shiwalik ranges. Before leaving the Himachal Pradesh, it cuts a gorge in Naina Devi Dhar and mingles with the water of Govind Sagar Lake. It enters the plains of Punjab near Bhakra where Asia's one of the highest gravity multipurpose dam (Capacity to generate electricity -1,325 MW and height - 740 ft/225.55 m) has been constructed. It finally drains into the main Indus River in Pakistan.

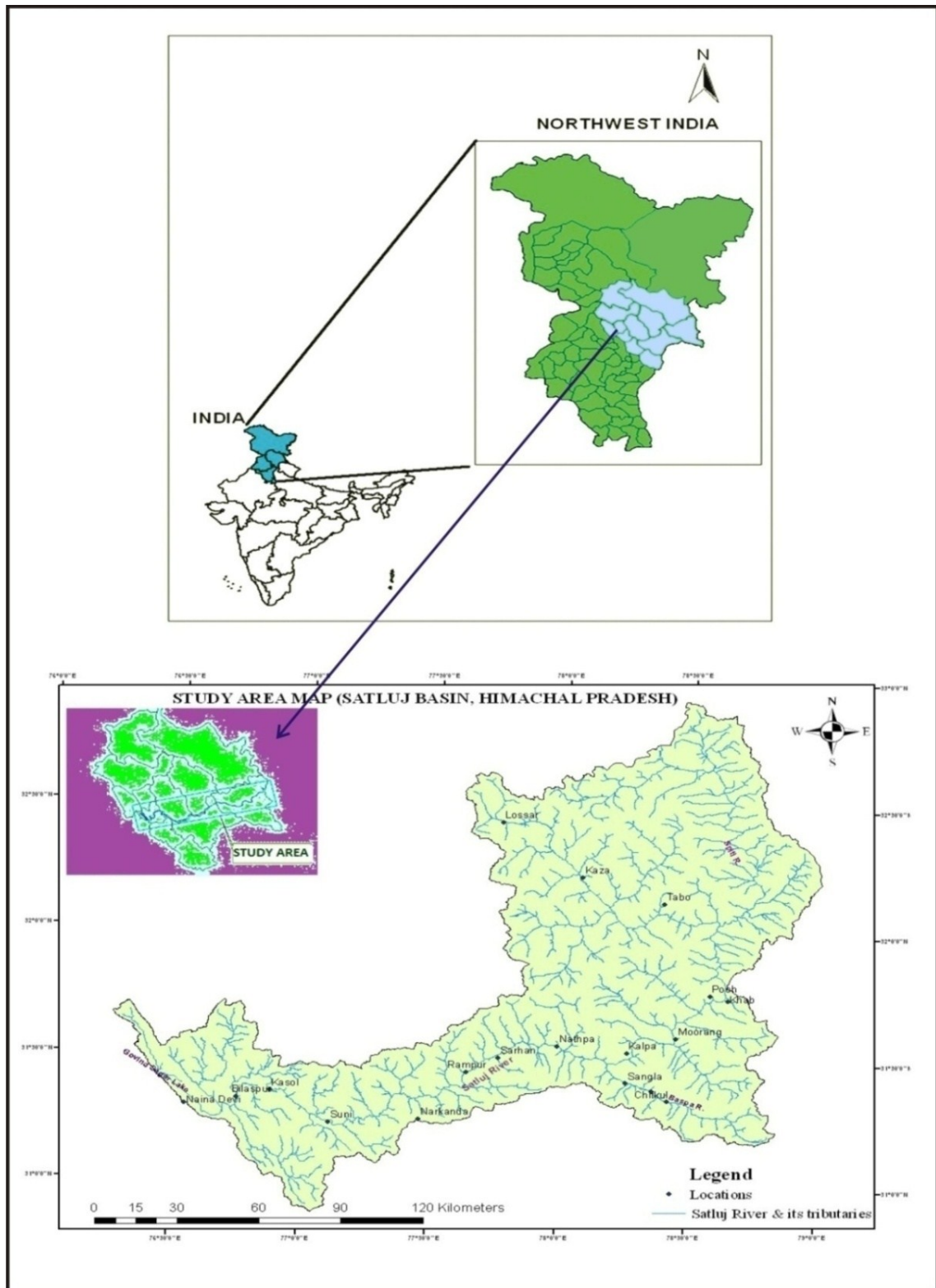


Figure 1. Schematic showing the study area map of Satluj River Basin up to Bhakra Dam, Himachal Pradesh.

Based on the amount of annual precipitation and the variation in temperature, the study area, from North to South, has been divided into three broad climatic zones (Figure 2). Each zone is characterised by its own peculiarities of climatic factors, geomorphic and topographic features (Gupta *et al.*, 1994; Bartarya *et al.*, 1996):

1. Semi-arid to arid temperate zone (Cold desert) - This zone lies in the upper Satluj Valley, upstream from Morang. Towards North of Morang, the cold desert conditions prevail which are characterised by very low monsoonal precipitation, high speed of cold winds and the precipitation generally occurs in the form of snowfall during winter season.

2. Sub-humid to humid temperate zone - This zone covers the middle Satluj Valley between the Wangtu and Morang. It is the transitional zone which receives low rainfall during the monsoon period and moderate to heavy snowfall in the higher reaches during winter.
3. Wet temperate or Monsoonal zone - It lies in the lower Satluj Valley downstream of Wangtu. This zone is under the great influence of monsoonal winds and receives heavy rainfall during rainy season from mid June to mid September.

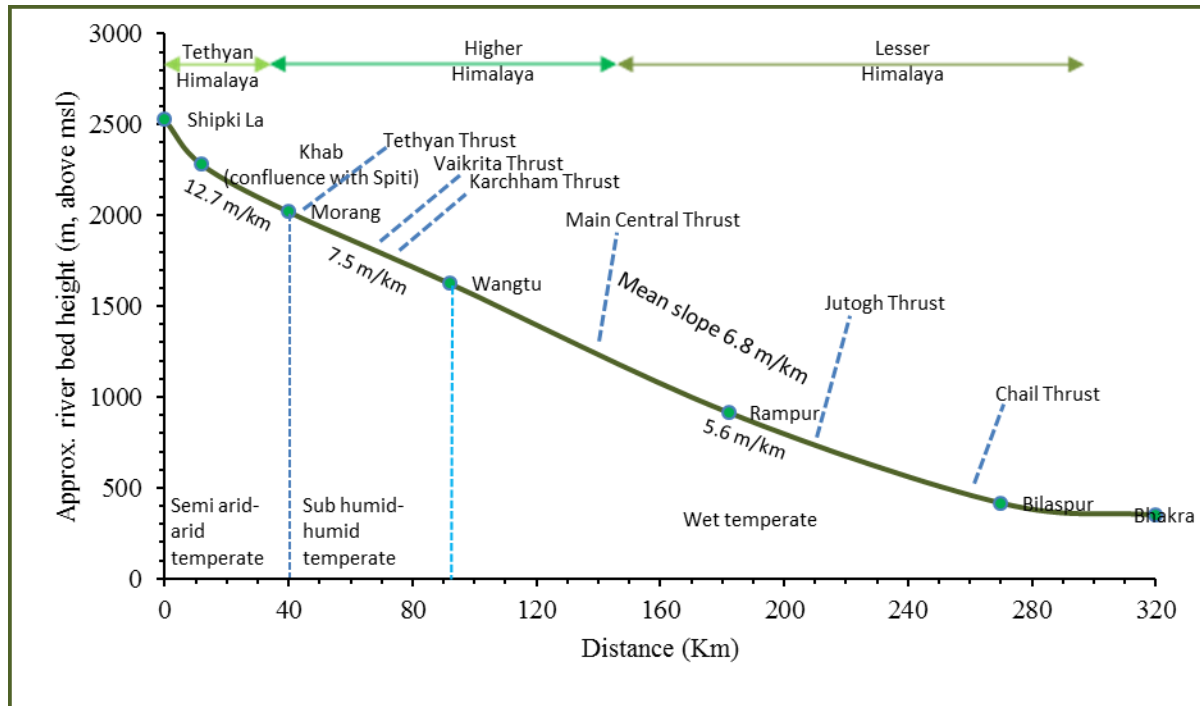


Figure 2. Longitudinal profile of Satluj River from Shipki La to Bhakra Dam. Three climatic zones are demarcated along with the major thrusts.

The fall of Satluj from its source to the plain areas is very uniform. A gross fall of 2,180 m is available in the river bed from Shipki La to Bhakra in a length of about 320 Km (Figure 2). The altitude in the study area increases from West to East and South to North. Based on broad climatic conditions, the Satluj River Basin has following four seasons: Winter (December to March), Pre-monsoon (April to June), Monsoon (July to September), Post-monsoon (October, November).

3. MATERIALS AND METHODS

The data used for delineation of flood risk areas are land use/land cover, settlement, slope and geomorphology which were generated at Remote Sensing Cell, SCST & E, Shimla, Himachal Pradesh where hardware, software and other facilities were provided. As some features are weak in the river basin which are prone to erode away with the increase in runoff during floods. So, it is necessary to understand the land use/land cover, settlement, slope and geomorphology of the region for the delineation of flood risk zones.

The issue of preparing a reliable risk map is one of the latest concerns for flood management. There are several methods for flood risk mapping, primarily based on hydrological, meteorological and geomorphological approaches. Particularly, in mountainous region where hydro-meteorological data are commonly insufficient and sparsely available and restricted to generate flood risk models, the geomorphologic method demonstrated its effectiveness and appropriateness (Wolman, 1971; Lastra *et al.*, 2008). This method implies interpretation of satellite imageries and field investigation of flood evidences to study geomorphologic characteristics in relationship with historical or future flood events.

The features extracted from raw data i.e. satellite imageries were imported in ArcGIS 9.3. Different layers were imported in GIS software to integrate and analyse. By overlay analysis of

geomorphological features, settlement, slope and land use/land cover categories, statistics of flood risk areas was extracted by identifying and mapping of potential flood risk zones.

Weighting and scoring scheme was applied for the preparation of composite risk index, based on multi-parametric analysis (Table 1). The scoring of each feature of various indicators was given on the basis of its estimated significance of influence by flooding. The significance of each indicator which may be at risk was indicated by weighting.

Table 1. Weight and score of indicators and their categories for flood risk zoning.

No.	Indicators/parameters	Weight	Categories/features	Score
1.	LULC	1	Built up	8
			Agriculture	7
			Water bodies	6
			Wetlands	5
			Forests	4
			Grasslands	3
			Snow covered	2
			Wasteland	1
2.	Slope	2	>70 %	9
			50-70 %	8
			35-50 %	7
			15-35 %	6
			10-15 %	5
			5-10 %	4
			3-5 %	3
			1-3 %	2
			0-1 %	1
3.	Geomorphology	3	Flood plains	7
			Alluvial plains-Younger	6
			Terraces	5
			Piedmont slopes	4
			Denudational hills	3
			Structural hills	2
			Glacial plains	1

This study shows a simple method of creating flood risk map by using geographical information system, remote sensing and computer analysis techniques. The formula for identifying risk zones:

$$A = (W_1 \times S_1) + (W_2 \times S_2) + \dots + (W_n \times S_n)$$

where A is risk level; W is weight to each indicator and S is score to each category.

Various stages involved in the preparation of flood risk zoning maps are:

1. The first stage involves the generation of various thematic maps of study area such as land use/land cover, geomorphology, slope and settlement using satellite images, DEM, topographic maps, other ancillary data and field observation to check the accuracy.
2. The second stage involves the incorporation of these thematic data into GIS through digitising and creation of attribute tables for each theme.
3. Thirdly, it involves the use of weighted overlay operation in arcGIS 9.3.
4. The fourth stage deals with the generation risk maps on the basis of weighting of indicators and scoring/ranking of their different features.
5. Finally, all data have been integrated in a GIS environment to prepare a flood risk map and identification of area covered under different domains of risk which are prone to increasing trends of flood peaks and flooding events in the region. This will help in providing a means of mitigation and adaptation strategies for quick response and recovery against natural disasters.

From the obtained values of weighted overlay, risk levels were estimated. Clearly defined domains of flood risk are very high (5-7), high (4-5), Moderate (3-4), low (2-3) and very low (1-2). The evaluation scale of rated values varies from 1 to 9 by 1. The higher values indicate the higher

level of risk while the lower values indicate the lower risk levels. Rating was done in accordance with the risk posed on different features of various parameters.

4. RESULTS AND DISCUSSION

Naturally, the areas which have the greatest danger of flooding are the flood plains and lower river terraces where settlements along with socio-economic activities are intense. The cultivated fields in terraces are generally at considerable height from river banks. But, due to increasing flood peak values, flash floods and subsequent down cutting of banks, the chances of collapsing the terraces increases. Human occupation in risky areas in form of settlement, agricultural practices and other infrastructure development activities increase the vulnerability to flood hazards. The haphazard construction started by local people near Rampur, on the low-lying areas along Satluj make the region more vulnerable to floods.

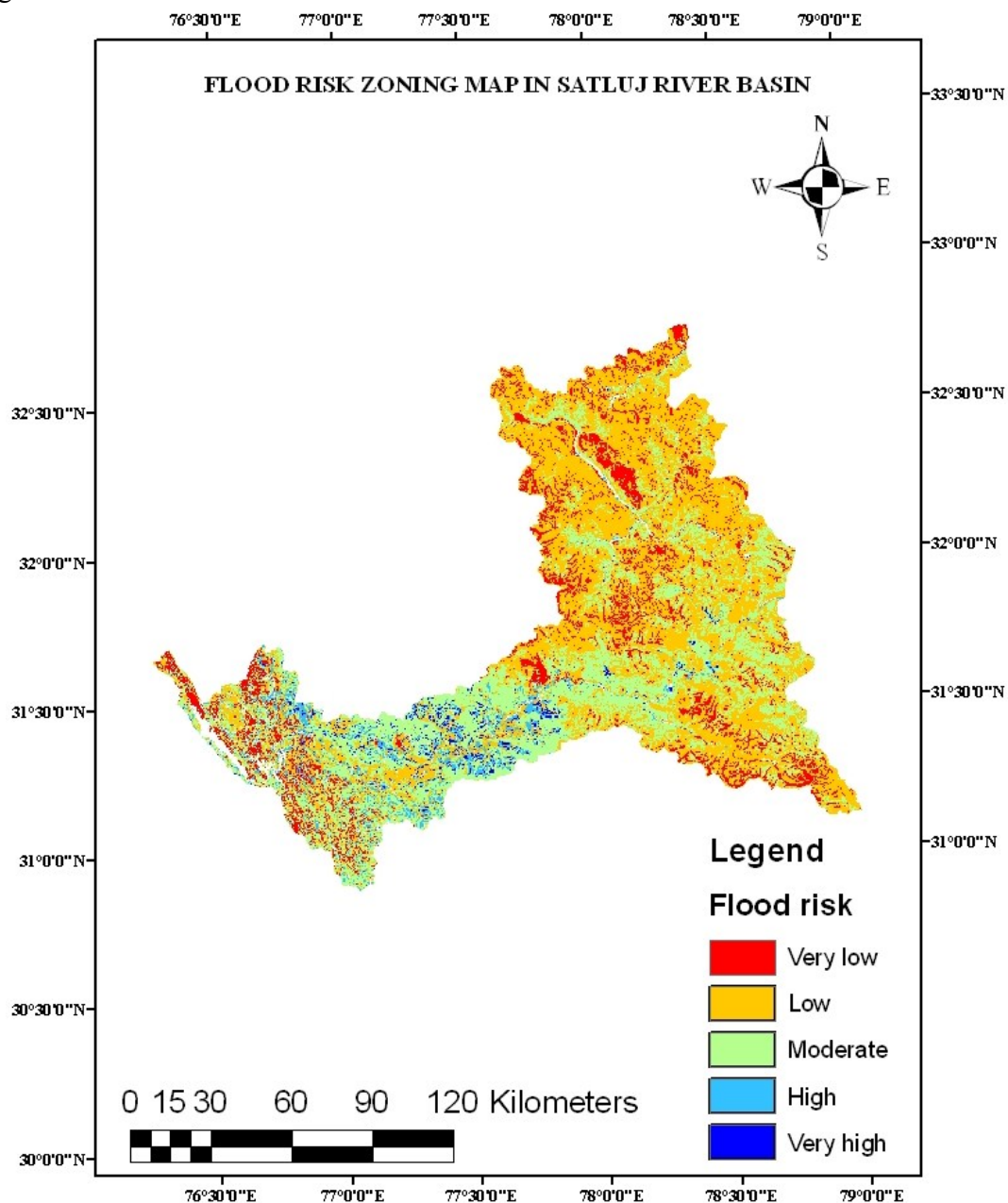


Figure 3. Flood risk zones in Satluj River Basin.

Figure 3. shows various risk zones, delineated by weighting and scoring of different parameters such as LULC, slope, geomorphology and their features which are at different levels of flood risk.

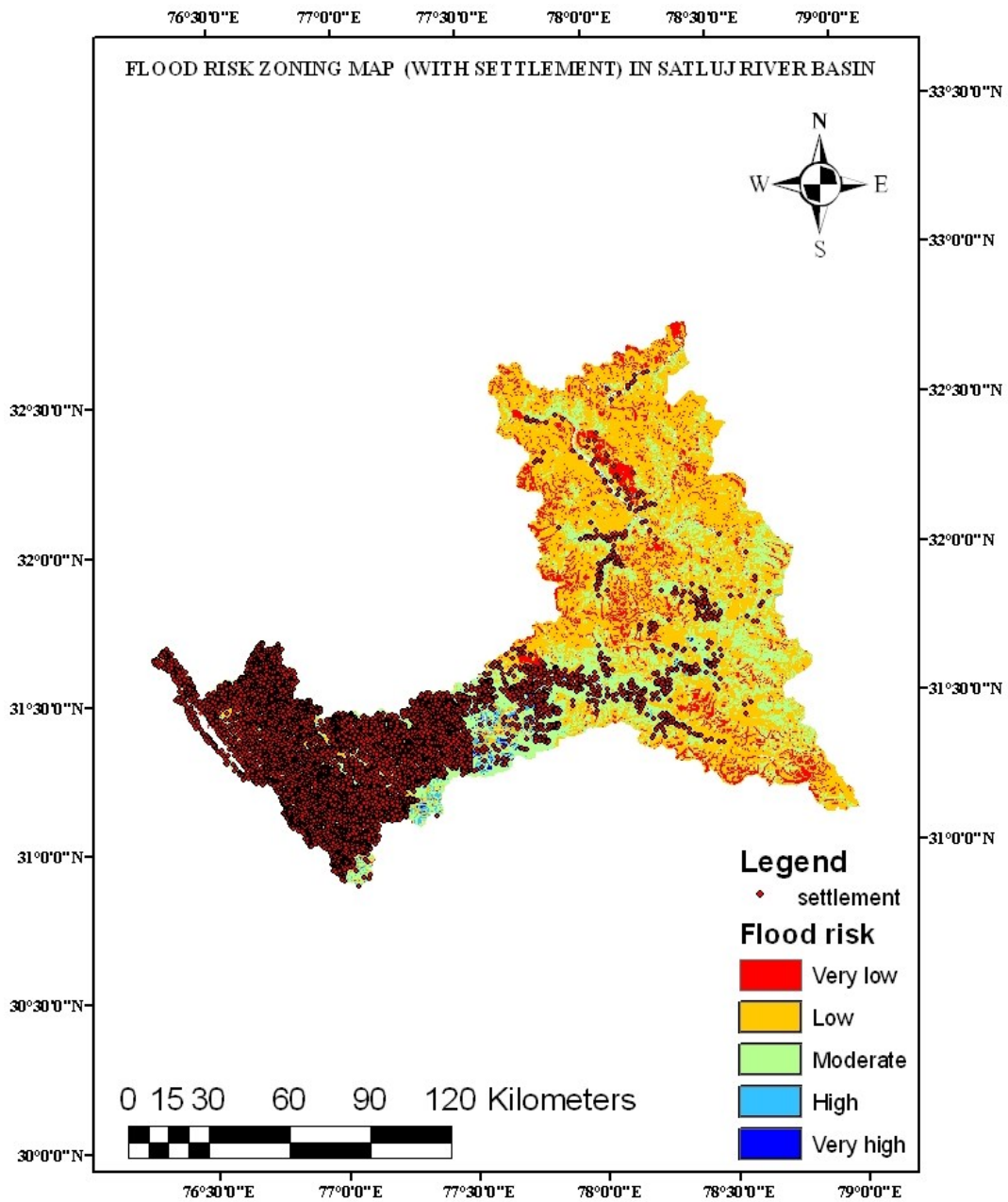


Figure 4. Flood risk zones (with settlement) in Satluj River Basin.

Figure 4. shows various risk zones, with settlement which are dominant in villages, towns and cities in Satluj River Basin. This clearly shows that the lower areas of basin have dominance by more human settlement than the upper region. So, the lower region is at great risk of hydro-meteorological disasters, especially flash floods.

Table 2. Statistics of various flood risk zones in Satluj River Basin.

Domains of risk	Area (Km ²)	Percentage
Very high	661.5	3.25
High	1276	6.27
Moderate	6241.5	30.66
Low	9400.5	46.19
Very low	2774.5	13.63
Total	20354	100

Table 2. shows that very high flood risk zone covers only 3.25 % of total study area, while the very low risk zone covers 13.63 %. The area falls within the very high and high risk constitutes 9.52

% of total basin area. Domain of moderate risk covers an area of 30.66 %. But the maximum area of river basin is constituted by low risk zone i.e. 46.19 %.

An important aspect in flood mitigation is comparative risk assessment associated with future extreme events that may expose societies to dangerous situations. Risk is the product of the three components hazard, vulnerability and management. Vulnerability means the degree to which an area, people, physical structures or economic assets are exposed to loss, injury or damage caused by the impact of a hazard. On the basis of vulnerability, the flood risk map can be obtained. Flood risk zones are the areas which are affected by the occurrence of floods and where the vulnerability exceeds the acceptable level. Flood risk assessment provides an accurate picture of risks so that timely mitigation and emergency planning measures can be taken. Therefore, a flood risk map is a very crucial tool for monitoring vulnerability of an area to floods.

Flash-flood events have major social and economic impacts. Apart from human losses, thousands of people lose their houses and other infrastructures which need high costs for recovering damages. After a destructive flood, it is often claimed that man-induced effects have increased its severity. The number of people and economic assets located in flood risk zones are expected to further increase, resulting in higher damage potential. Flood risk mapping can reduce potential economic and other damages along with raising the risk awareness to the population. Changes in climate may change the risk of floods.

It is impossible to control flood completely, however, its extent of damage may be minimised by adapting proper mitigation measures. Apart from awareness about flood risk areas, other approaches such as prediction, prevention, warning and monitoring of flood events minimises the loss in terms of life, property, economic and environmental losses. Hence, a sustainable flood risk management can only be achieved by working with the natural responses of the river basin. Necessity is to implement and enforce the detailed provisions of the land use planning programmes in order to reduce the vulnerability to natural disasters.

The left bank of Satluj River in the downstream reaches i.e. near Rampur is more vulnerable to flooding by virtue of its low topography. Flood vulnerability of the left bank was best exemplified during the 2005 flood events. The quantum of floods damage is found to increase due to indiscriminate development and settlement in the flood risk areas. In order to keep minimum environmental degradation due to developmental activities, it is essential to identify the vulnerable areas which are at risk of flood hazards.

5. CONCLUSIONS

From the present study, it has been concluded that certain areas are quite fragile from the point of slope, geomorphology and land use/land cover. As the intensity and frequency of climate change induced floods and runoff increases, the severity of these sensitive areas will increase. So, the need of the hour is to identify these areas as precautionary measures. Identification of such zones will help in timely adopting of mitigation and adaptation measures. Preparation of flood risk zoning maps also helps in regulating indiscriminate and unplanned land use practices in risky areas. Therefore, a hazard map is a very crucial tool for monitoring flood risk. The sensitive areas adjacent to river bed which are vulnerable to floods should be banned for cultivation, settlement and other developmental activities. In addition to enhancing scientific understanding, it is imperative to generate useful information on the basis of which practical interventions can be crafted for strengthening links between policy makers and practitioners.

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