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Use of GIS and HEC-RAS tools in the flood hazard mapping of an ungauged river: A case study of the Malekhu Khola, central Nepal.

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Abstract: Flood has always been one of the major problem in developing countries like Nepal.Flood hazard maps for 2 years, 25 years, 50 years, 100 years and 200 years return periods were prepared for the Malekhu Khola section between the Cheuritar and the old Malekhu Bridge using Arc GIS with HEC-GeoRAS extension and HEC-RAS. For this ungauged river, field parameters were used along with empirical formulas for the peak discharge calculation and Manning's n value. The geometric parameters were determined through fieldwork, topographic maps and google images in Arc GIS 9.3. Then, the input parameters were put in HEC-RAS to produce a flood inundation map. Then, the map was analyzed in GIS to produce a flood hazard map. It was observed that the downstream portions are comparatively more affected by the flood rather than the upstream section. There is only a slight change in the floodprone area at different return periods. The graphical plot of the flooded area versus the return period shows that there is no significant change in the low and moderate hazard zones for most of the return periods but the hazard levels increase with the increase in return periods.
Keywords: HEC-RAS, ungauged river, flood hazard analysis, Malekhu Khola

Introduction

Floods can be defined as a temporary covering of land by water outside its normal confines (FLOODsite-Consortium 2005). The probability of the occurrence of potentially damaging flood events is called flood hazard (cf. ITC 2004). Flood hazard mapsprovide flood hazard information in terms of the relationship between the flood probability and flood intensity. Such maps should be produced for areas where flooding could cause considerable damage (Bund *et al.*, 2006).Use of the GIS and flow modeling tools like HEC-RAS is one of the computer-based methods to get better visualization of the flood condition of a particular area. Flood is one of the devastating and frequently occurring natural phenomenon in Nepal. Nepal has a diverse topography ranging from high snow fed peaks, deep river valleys, green hills and flat plains while moving from north to south respectively. Most of the perennial rivers originating from the hills and mountains have high gradient which makes them powerful enough to cause natural disasters such as flood and landsides. The rivers (also known as Khola in Nepali) are fed not only by snow but also by the rainwater which get collected and recharged during monsoon. So, any anomalous behavior in rainfall may gradually lead to flood and other consequences. Every year, flood occurs in various rivers of Nepal during monsoon causing huge loss of lives and properties. After the disastrous climatologic event of 1993, hazard maps were prepared for the severely affected areas of Central Nepal (Miyajima and Thapa, 1995). The Malekhu Khola (Figure 1) is a south to north flowing, rainfall-fed river, originating from the steep hills of the southern part of the Dhading district. This 24.83 km long sixth-order river has made its way through the steep hills and making wider flood plains in downstream sections. The Malekhu River Bridge was swept away in the flood of 1993 while the area was badly affected during the flood of 2002 also.

This research intends to analyze the flood hazard in the Malekhu Khola section between the Cheuritar and the old Malekhu Bridgefor 2 years, 25 years, 50 years, 100 years and 200 years return periods.

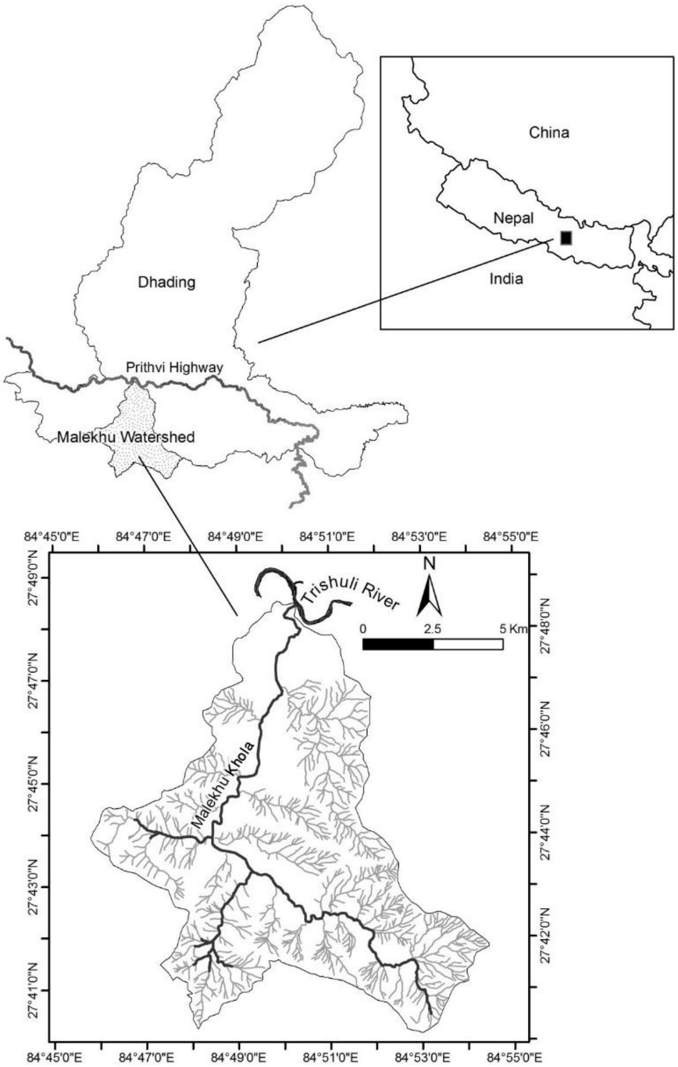

Figure 1: Location map of the study area

Materials and Methods

Topographic maps of 1:25,000 scale produced by the Survey Department, Government of Nepal were used as the base maps. Similarly, Google Earth images were used for detail information of the study area as well as analysis in GIS. Google Earth, Arc GIS 9.3 and HEC-RAS 4.1 were the major software used for the research. Ushikata Theodolite (model?) was used for the topographic survey along the river banks during the fieldwork.

The flood hazard mapping for an ungauged river consists of some pre-calculation procedures for hazard parameters before going to the main modeling in GIS and HEC-RAS.

Estimation of the peakflow

In absence of the real field discharge data, the empirical methods of the WECS/DHM (1990) and Modified Dickens Method were used for the calculation of the flood discharge.

The DHM/WECS (Nepal) formula was developed between the discharge and catchment area below 3000 m within Nepal. The equations used for the calculation of the peak flow are as follows:

$Q_2 = 2.29(A_{<3k})^{0.86}$

$Q_{100} = 20.7(A_{<3k})^{0.72}$

$Q_f = \exp(\ln Q_2 + s\sigma)$

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

where, Q_2 is two year instantaneous flood, Q_{100} is 100 year instantaneous flood, Q_f is instantaneous flood at any other return period (f), $A_{<3k}$ is the basin area below 3000 m elevation level.
Modified Dicken's formula also uses drainage basin area to estimate the peakflow. The formula is
$Q = C.A^{0.75}$
Where, Q = discharge in m^3/s, A = drainage basin area in km^2, C = coefficient ranging from 10 to 35 and is estimated using following formula:
C = 2.342 log0.6T*log1185/P+4 (6)
Where, T = return period in years, P = (a+6)/(A+a), (A+a) is total drainage basin area in $km^2$and a is perpetual snow area in km^2.

Flood Hazard Analysis

Arc GIS 9.3 with HEC-GeoRAS extension and HEC-RAS 4.1 were used for the analyzing and mapping of flood hazard zones (Figure 2) from the Cheuritar section to the confluence of the Malekhu Khola and the Trishuli River. First of all, geometric data was prepared in GIS using GeoRAS extension. For this, aTriangulated Irregular Network (TIN)of the study area was created. Then, different RAS layers including Stream Centerline, Flowpath Centerline, Banklines, Cross-section lines and other optional layers were created using GeoRAS.

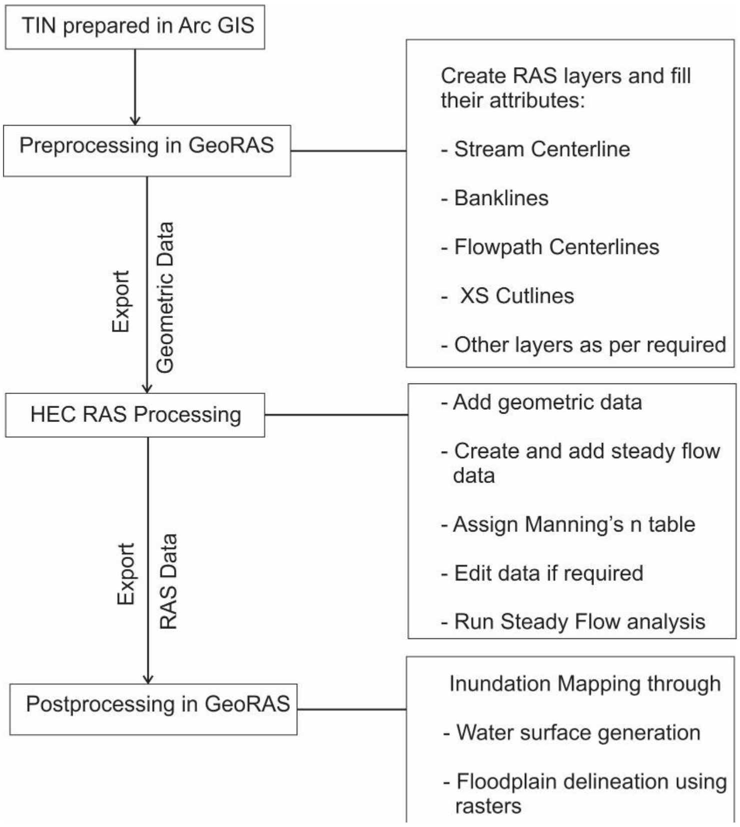

Figure 2:Schematic diagram for the preparation of flood inundation map in Arc GIS and HEC-RAS.

Then, the geometric data was exported to HEC-RAS and further editing was done if required. The Manning's n table (Arcement & Schneider 1989) was created on the basis of the landuse map and the n value calculated during the fieldwork for the channel. The steady flow analysis was used for this research. So, steady data was created for 2 years, 25 years, 50 years, 100 years and 200 years return period. Then, the data was saved and steady flow analysis was performed. The whole project was saved and again exported to GIS for post-processing. The imported file from HEC-RAS was opened in GIS and the inundation mapping was done using the water surface generation and floodplain delineation options.

Preparation of the flood hazard map

Flood hazard maps for different return periods were prepared in GIS on the basis of the depth data generated after the post-processing. The critical depth was fixed on the basis of the field observation of the flood prone level. So, the hazard zones were divided as high (depth >2m), moderate (depth = 0.9-2m) and low hazard (depth <0.9m) zones.

Results and Discussion

The results were divided into two sections, a) estimation of the peakflow required to for steady flow analysis and b) flood hazard mapping.

Estimation of peakflow

Due to the lack of the gauging stations in the study area, the peakflows (Table 1) were calculated using the empirical formula. The peakflows obtained from the DHM/WECS method and Modified Dickens method for different return periods are as follows:

Table 1: *Peakflow at the Malekhu Khola for different return periods*.

Peakflow (cumec) at						
Location	Malekhu Bridge		Khani Khola Confluence		Aap Khola Confluence	
Return Period (Yr)	DHM/WECS	Modified Dickens	DHM/WECS	Modified Dickens	DHM/WECS	Modified Dickens
2	122	142	18	26	18	26
25	370	330.9	75	40.61	76	40
50	481	383	94	53	94	52
100	577	435	117	58	117	58
200	681	486.71	143	71.8	142	70

The values obtained from the DHM/WECS method are higher than that of the Modified Dickens in general, so the DHM/WECS values were accepted for the analysis.

It was observed that the peak discharge and the recurrence interval for the Malekhu Khola have very high positive correlation (Figure 3) which means that there is significant increase in the peak discharge with the increase in the recurrence interval. But, it should not be considered that the 25 years flood will only occur in around 25 years-time period. There are several factors such a precipitation, ground condition, duration of precipitation etc, required for occurring of the flood for a certain magnitude. Any magnitude flood can occur in any year if the suitable conditions prevail. For example, if the ground condition is wet and there is long duration of precipitation, then there might be a chance of occurring of a high magnitude flood even within few years-time intervals. In the case of the Malekhu Khola also, two major flood events occurred in 1993 and 2002 which are comparatively less time intervals. So, we cannot exactly predict the future flood events but we can have a better approach to their possibility on the basis of statistical tools and past flood events.

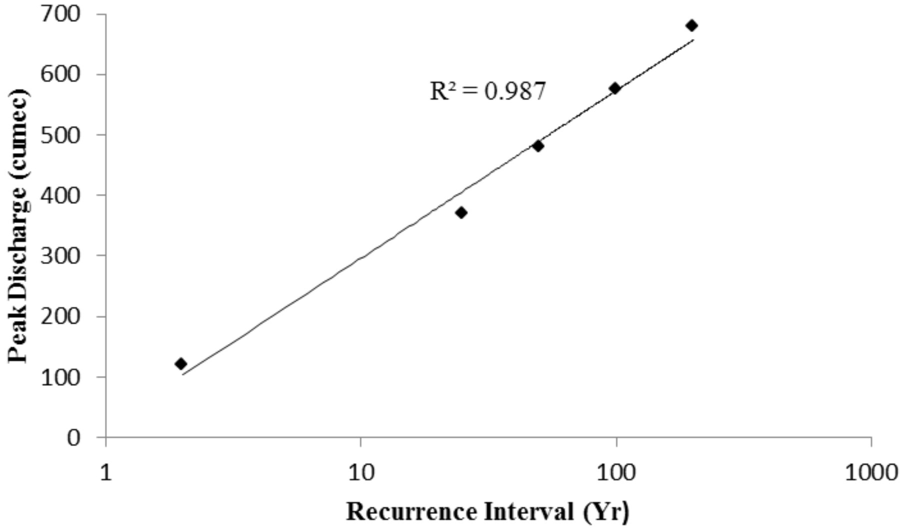

Figure 3: Relationship between the peak discharge and recurrence interval at the Malekhu Khola shown through a trend line drawn between the peak discharge and their respective recurrence interval

Flood Hazard Mapping

Flood hazard maps (Figure 4) of the Malekhu Khola were prepared for the 2 yr, 25 yrs, 50 yrs, 100 yrs and 200 yrs return periods using the GIS and HEC-RAS tools. The Malekhu Khola doesn't have vast flood plains like that of the rivers in the flat areas of the Terai (Indo Gangetic Plain). It is a channelized river flowing through steep hills of the Mahabharat Range and bedrocks of the Lesser Himalaya. So, wider floodplains can only be seen at some areas, majorly in the downstream section.

Table 2: Flood hazard analysis result for the Malekhu Khola

Depth (m)	Hazard Zone	Return period									
		2 years		25 years		50 years		100 years		200 years	
		Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
<0.9	Low	0.3	24.79	0.25	16.34	0.24	14.72	0.25	14.54	0.24	13.41
0.9 - 2	Moderate	0.34	28.1	0.34	22.22	0.3	20.25	0.32	18.6	0.31	17.32
>2	High	0.57	47.11	0.94	61.44	1.06	65.03	1.15	66.86	1.24	69.27
Total		1.21	100	1.53	100	1.6	100	1.72	100	1.79	100

The downstream sections of the Malekhu Khola are most affected by the flood as observed from the generated flood hazard maps. Areas such as Simthali, Kajitol, Mawatar and Malekhu Bridge area are mostly affected by the flood. The areal extent of the flood is not considerably increasing with the increase in return period. The high hazard zone covers the majority of the area (Table 2) in all of the return periods.

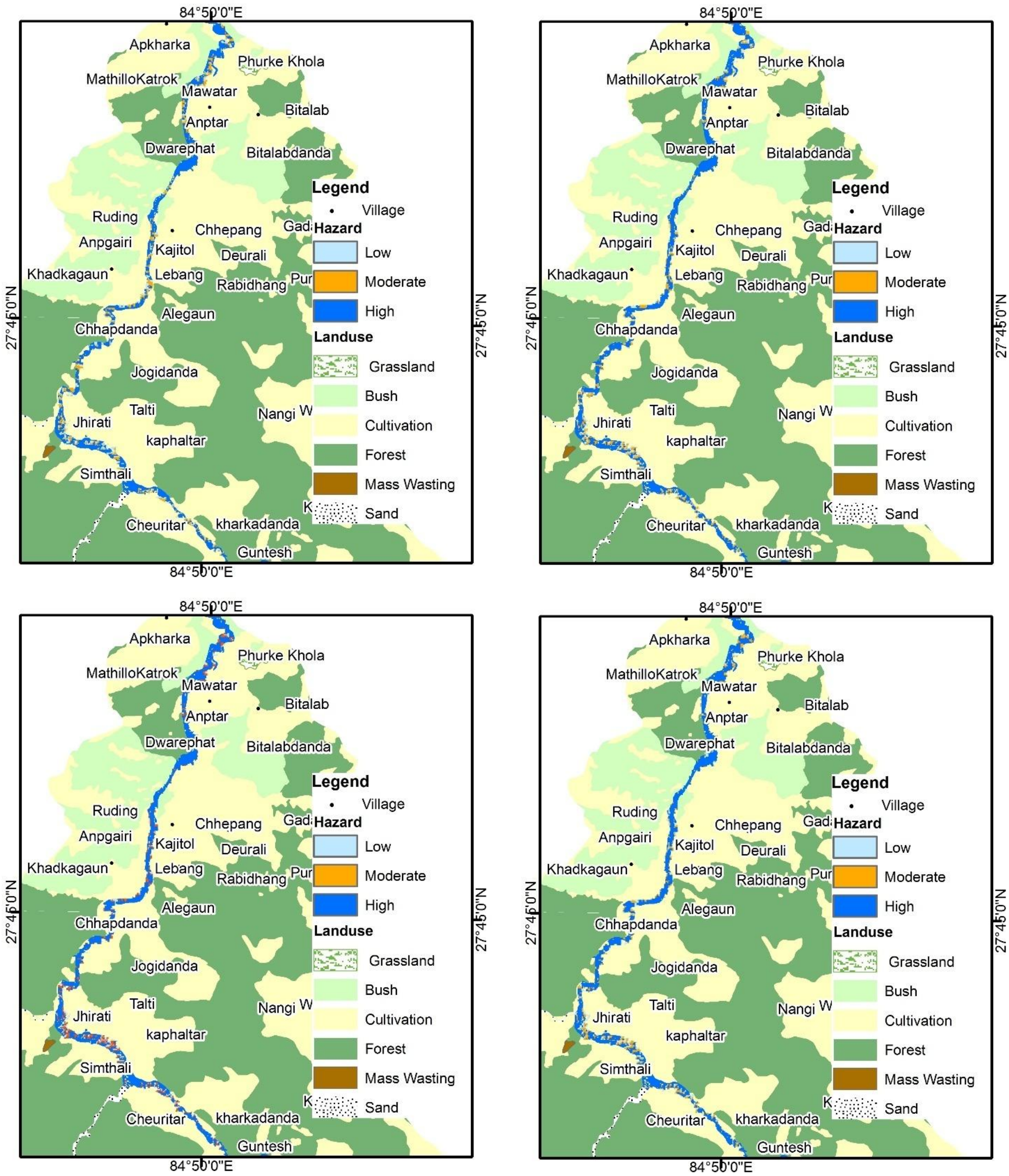

Figure 4: Flood hazard maps of the Malekhu Khola for 2yr, 25yr, 50yr and 100yr return periods respectively

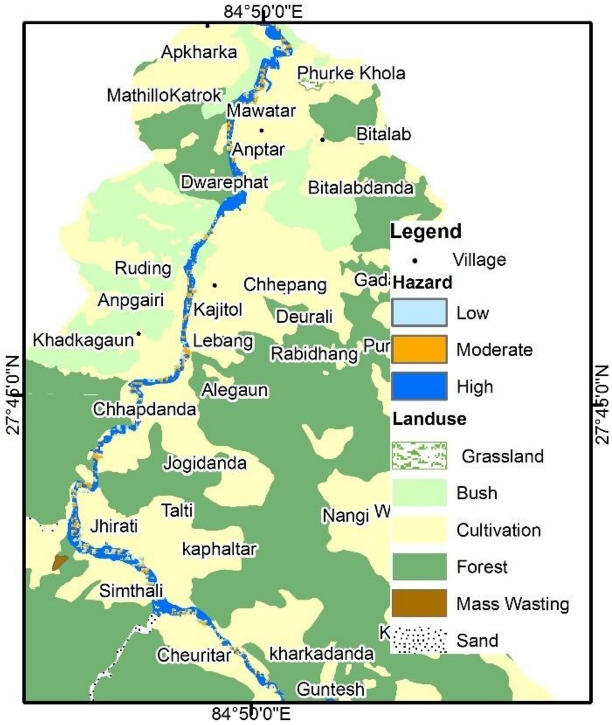

Figure 4 contd: Flood Hazard Map of the Malekhu Khola for 200yr return period.

The comparison of the areal percentage of the hazard zones with their respective return periods (Figure 5) showed that there is significant increase in the high hazard zones with increase in the return periods. But, the overall area of the hazard zones haven't changed so much throughout the return periods (Table 2). The reason can be well explained from Figure 5. The increase in the area of the high hazard zones is compensated by the decrease in the area of the moderate and low hazard zones.

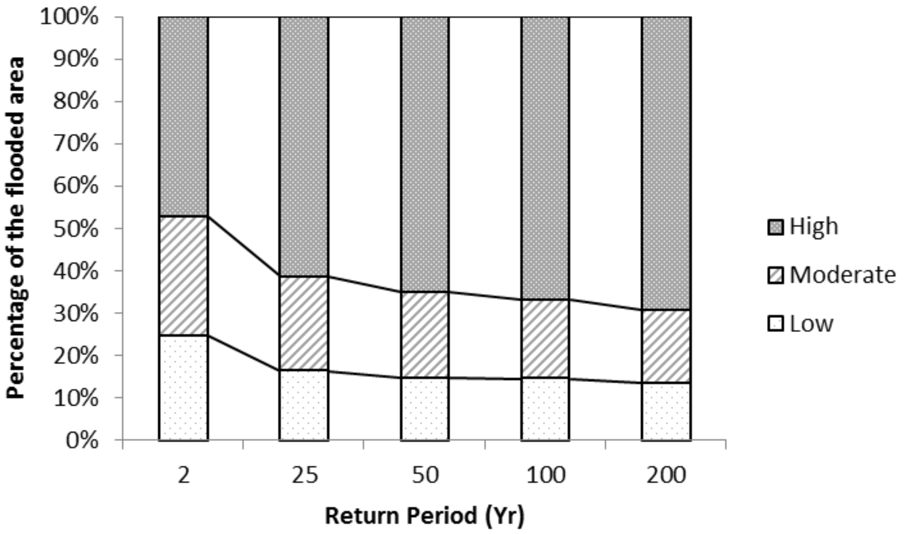

Figure 5: Graphical comparison of the areal percentage of individual hazard zones with their respective return period.

Conclusion

Use of computer-based flood hazard analysis helps in getting the overall scenario of the flood condition in a particular area in shorter time. The outcomes of such analysis give more accurate results if field observations and data are considered during the preparation of the input data. GIS and HEC-RAS, together gives the one-dimensional flood model for a particular area. For ungauged rivers, the required discharge can be estimated empirically. Landuse also plays a vital role in predicting the flood effects, since it is used to generate one of the major input parameters for flood modeling. The Malekhu Kholais a spring originated, channelized river flowing by making its way through hard bedrocks. It has lesser floodplain area and are located mainly in the downstream sections. The downstream areas such as Malekhu Bridge section, Mawatar and Simthali are more affected by flood.Generally, the flooded area increases with the increase in the return period but in the case of the Malekhu Khola, the flooded area doesn’t increase significantly. The hazard level changed from low and moderate to high in general instead of increasing the overall flooded area.

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