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Flood Risk Mapping of Kankai Basin: A Case Study of Shivasatakshi Municipality and Kankai Municipality

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ABSTRACT−Floods are probably the most frequent, widespread, and disastrous hazards in the world. It causes loss of life, casualties, financial loss, and displacement. Heavy monsoons, fragile geography, and constructions along the embankments cause the river to flood. The increase of population and squatter settlement of landless people living at the bank of the river has tremendous pressure on encroachment of flood plain making them vulnerable to flood damage. This study aims to develop HEC-RAS models for the Kankai River basin for preparation of 1D flood plain maps, vulnerability, risk assessment of RCC building in Shivasatakshi Municipality ward 10, and Kankai Municipality ward 4. Flood frequency analysis for 2, 10, 25, 50, 100, 200 and 1000 years return was carried out by Log Pearson III, Gumbel and Log Normal method based on maximum instantaneous flow recorded at Mainachuli station. The result of flood frequency analyzed by Log Normal method for 2, 10, 25, 50, 100, 200 and 1000 years return period floods shows higher among the results obtained using different methods. The flooding impact of the Kankai River being a large catchment with braided river form inundates vast downstream flood plain regions during high flood levels. With numerous people living along the river and downstream plains, flood risk is predominately high in the Kankai River catchment. With increasing flood intensity, higher flood depth increases and lower flood depth decreases. The inundation of a large area of Shivasatakshi Municipality ward 10 and Kanaki Municipality ward 4 at the bank of the Kankai river indicates that human lives and the physical infrastructure will be more vulnerable to flood disasters in the future. According to a study, the largest areas affected by floods with return periods of 2, 10, 25, 50, 100, 200, 1000 years, respectively, are 1843.24 ha, 1967.96 ha, 2016.32 ha, 2049.48 ha, 2079.64 ha, 2109.4 ha and 2176.08 ha of the whole basin. As a result, the study may help in future disaster planning and management.

KEYWORDS− Flood Inundation, HEC-RAS, Log Normal Method, Vulnerable, Flood Risk, Return Period

1. INTRODUCTION

A flood is a significant water flow that exceeds a river's capacity. The occurrence of floods has been more frequent than in the past possibly due to the change in the climate and/or the environmental change happening on the ground [1]. Heavy monsoons, fragile geography, and constructions along the embankments cause the river to flood. Flood disaster affects human lives, property, infrastructure, agriculture, wildlife, and the environment both directly and indirectly. Flooding is the most frequent natural hazard on the planet, resulting in significant economic losses, agricultural losses, damage, and loss of life [2]. Flooding is a common disaster in Nepal during the rainy season. It has been the most common, damaging, and widespread natural hazard [3].

A flood hazard is the probability of occurrence of a potentially damaging flood event of a certain magnitude within a given time period and area. Therefore, sufficient and reliable flood predictions and proper design of control and mitigation measures remain major challenges everywhere. However, this requires a proper understanding of rivers' underlying hydrological and hydro-dynamic processes and associated catchment characteristics. The increment in the exposure of people and properties in the flood plain has drastically increased the flood risk. Management methods for reducing flood hazards are classified as structural or non-structural. Various structural and non-structural measures have been implemented to mitigate flood damage in flood plains. Structures such as embankments, levees, and spurs, for example, have not proven to be effective in the long run. Non-structural measures, on the other hand, such as flood forecasting and warning, flood plain mapping, flood hazard mapping, and flood plain zoning, may prove to be quite effective in reducing flood losses. Flood zoning as a non-structural method using the Geographic Information System is an effective tool for flood damage mitigation management. Hydraulic and hydrologic analysis of such exposed areas can direct the path of flood mitigation. One of the most important non-structural measures in comprehensive flood loss prevention and management is flood forecasting and warning. The flood was mapped using the hydrodynamic model HEC-RAS and the ArcGIS software tool in this study. HEC-RAS is commonly used to identify the flood plain and observe floods and flood-related dangers [4]. HEC-RAS was used to run the hydrodynamic model in Nepal’s several basins [5-7].

Flood inundation models are required to understand, assess and predict flood events and their impact on the areas. The results from hydraulic models can be used in flood risk mapping, flood damage assessment, and river system hydrology. Good inundation maps could help in designing flood risk management strategies and their implementations. In 2009, seven VDCs were flooded by swollen Kankai and Biring rivers in southern Jhapa. More than 500 houses were submerged and 100s of bighas of paddy field were inundated. Hundreds of people from Topgachhi, Panchgacchi, Tanghadubba, Rajgadh, Dangibari and Sarnamati fled their villages to safer places after the floods entered the VDCs. While the flood in Kankai caused much damage in Topgachhi 8 & 9, Rajgadh VDC also suffered badly. Even if no loss of life were reported, the villagers incurred a heavy loss of property as hundreds of bighas of land have been turned into the riverbed. The worst affect was on those people who had paddy fields near the river banks. Also in July,2016 two people died and 900 households were displaced due to floods in Mechi, Ninda, Biring, Kankai and Ratuwa rivers. Similarly, in 2017, 4 people died and more than 1249 houses were inundated after monsoon rain triggers flood in Jhapa. The trend of flood is seen almost every year due to heavy rainfall in kankai catchment area. So impact of flood in kankai river seems to be very high with greater chance of human and property loss. Being a rainfed catchment, the flood discharges of Kankai River are highly affected by the extreme rainfall events.Preparedness activities and timely response can be undertaken if the forecast information comes with the level of risk is predominately high in the Kankai River catchment.

This study aims to prepare "Flood Hazard Mapping of Kankai River Basin" using one dimensional hydraulic model HEC-RAS, ArcGIS and HEC-GeoRAS to interface between HEC-RAS and ArcGIS. Using HEC-RAS 1D model, inundation maps for 2-year, 10-year, 25-year, 50-year, 100-year, 200-year and 1000-year floods will be generated and their potential impacts across the adjoin area will be discussed with possible recommendations on flood management strategies.

2. STUDY AREA

Kankai River basin, as shown in Figure 1, is situated in the eastern part of Nepal bordering India on two sides. The latitude and longitude of the Kankai basin lie between 26°41' to 27°07' N and 87°44' to 88°09' E respectively. One of the largest river basins, Koshi is located in the western side of this basin. Kankai is the major river in the basin originating from the border of the Ilam and Panchthar districts. The catchment area of the Kankai River basin is Nepal overall has a monsoon climate. However, in a close study, two different climatic conditions exist within the Kankai River basin. The upper Kankai basin lies in a hilly region and the lower part of the basin is in flat plains. Hence, a huge geographic variation exists in the basin. Relatively, the upper Kankai basin has a sub-tropical and temperate climate and the lower part has a tropical climate. There is no precipitation in the form of snow in this basin. The average temperature in this basin ranges from 12˚C in winter up to 27˚C during summer in the upper hilly region. In the lower

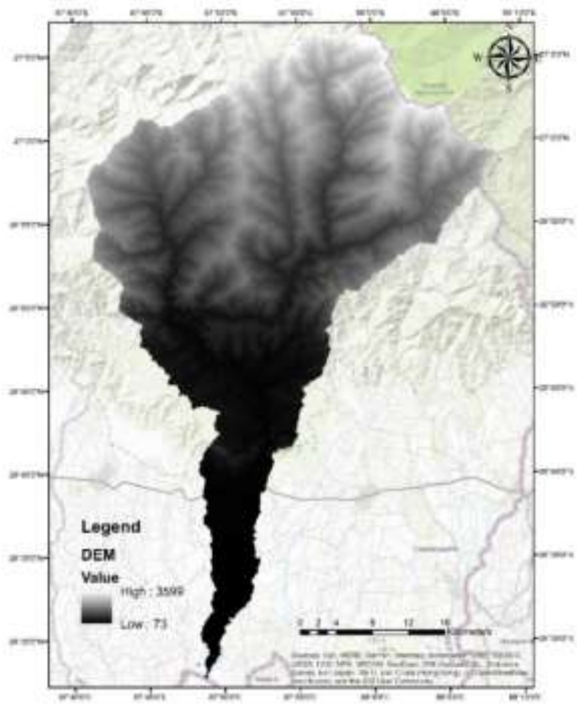

Figure 1. Kankai DEM

region, winter temperature ranges from 7˚C to 23 ˚C and summer temperature from 24˚C to 35˚C, sometimes exceeding 37 ˚C. The yearly average evapotranspiration in Nepal is around 1200 mm/year. On average, the 1284 km^2. The elevation of the catchment area varies from 73 m to 3599 m above mean sea level. The topography of the Kankai basin is highly varied. The upper part of the basin lies in a hilly region with steep terrain while the lowermost narrowed part of the impact of the flood. The flooding impact of the Kankai River being a large catchment with braided river form inundates vast downstream flood plain regions during high flood levels. With numerous people living along the river and downstream plains, flood the basin lies in flat plains with mild slopes. The entire basin area is dominated by forest and cropland.

The entire catchment area of the Kankai basin is considered for flood hazard mapping, but only a portion of the basin area, namely

Shivasatakshi Municipality ward 10 and Kankai Municipality ward 4 (Figure 2), is considered for vulnerability mapping and risk mapping.

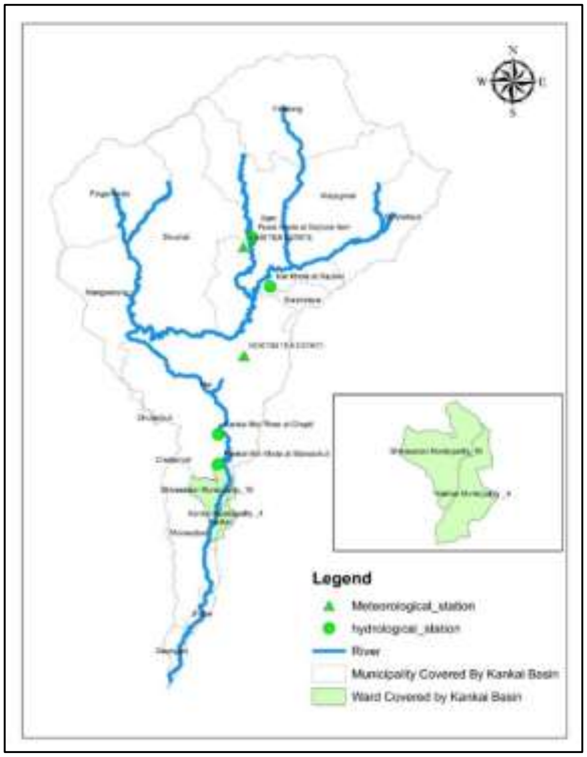

Figure 2. Study Area (Shivasatakshi Municipality ward no. 10 and Kankai Municipality ward no. 4) warmest month is July, the coolest month is February, July/August is the wettest month and March/April is the driest month.

Kankai River is a transboundary rain-fed perennial river that drains into Mahananda river of India. It originates from Mai Pokhari in the Mahabharat range in Ilam district. It is called as Deumai Khola (river) at its origin and the altitude at its origin is about 1820 m AMSL. The extent of the Kankai Mai river starts from Mainachuli weather station. The major tributary of this river is Puwa Khola. Kankai Mai lies entirely in the flat plain of the basin. The longest flow path in this basin i.e. Jog Mai and Kankai Mai stretches for 109 m.

3. METHODOLOGY

Hydraulic analysis of the river system was performed with the help of HEC-RAS along with HEC-GeoRAS, an extension in ArcGIS. The following steps were carried out:

(i) Pre-RAS or preprocessing using HEC-GeoRAS
(ii) One-dimensional steady hydrodynamic modelling in HEC-RAS
(iii) Post processing or flood inundation mapping using HEC-GeoRAS with Arc GIS as an interface.
(iv) Preparation of the Inundation Map for different flood scenarios.
(v) Preparation of the Hazard Map for different flood scenarios.
(vi) Preparation of the Vulnerability Map for different flood scenarios.
(vii) Preparation of the Risk Map for different flood scenarios.

For a better understanding, a flowchart (Figure 3) is developed which includes the above steps for hydrodynamic modelling of Kankai River Basin.

3.1 Pre-processing: Developing geometry of river in ArcGIS

Firstly, TIN was generated based on the DEM available for the study areas. Based on the generated TIN and aerial photograph of the study area, geometric layers like stream centerline, bank lines, flow path centerlines and cross section cut lines were created. These layers represented the actual river system. Stream centerline, bank lines, flow path centerlines, cross-section cut lines and bridges were created as polylines. The cross-sectional cut lines were generated automatically in HEC-GeoRAS at a regular

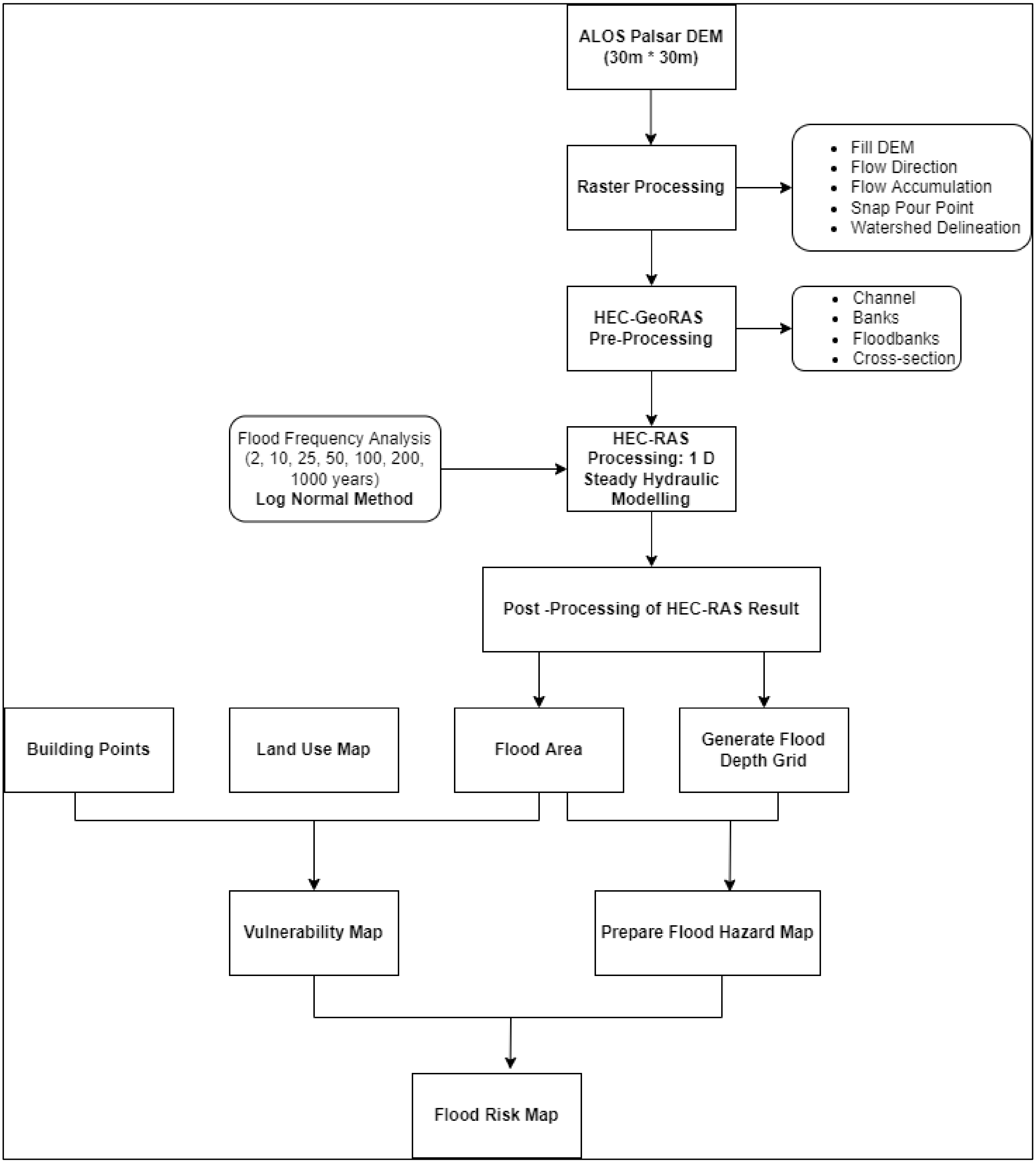

Figure 3. A flow chart for hydrodynamic modelling methodology.

interval which were further refined manually based on their necessity. All the layers were to generate their attributes like name, length, topology, elevation, positioning for them to be identified while importing them to HEC-RAS. Further, land use layer was also used to generate the values for Manning's coefficient on all the cross-sections.

3.2 Processing: Performing hydraulic computation in HEC-RAS

All the geometric data were imported into HEC-RAS and the verification of quality of data was done. To run the flood analysis, 1D Steady flow simulation was carried out under Critical flow regime. Flood values for 2, 10, 25, 50, 100, 200 and 1000 return periods were calculated using Log Normal Method. These flood values along with suitable boundary conditions were used as input for steady flow data. Since the selected flow regime was critical, boundary condition was defined only at the downstream end of the river. It was defined by the normal depth which is the slope of the river bed. The boundary condition at the junction were predefined by the software. The output of the simulation was water level for all the flood values. The water level can be viewed in cross-sections or longitudinal section of the river. Water surfaces for 2, 10, 25, 50, 100, 200 and 1000-year flood and river centerline were exported back to ArcGIS. The file exported from HEC-RAS to ArcGIS was in spatial data format (SDF).

In Kankai, flood mapping of river after Mainachuli gauging station was done using flow data of that station. These data were calculated from the yearly maximum instantaneous discharge values. One highest discharge from the daily discharge per year was taken as maximum instantaneous discharge. Using the maximum discharge data and applying flood probability frequency analysis, values for different year return period were predicted. In this case Log Normal method was used to predict future flood. The values of predicted floods for Kankai is shown in Table 1.

Table 1. Calculation of flood discharge using Log Normal method

Return Period (year)	Discharge (m^3/s)
	Mainachuli
2	3443.75
10	6783.83
25	8693.45
50	10204.32
100	11782.99
200	13448.52
1000	17649.30

3.3 Post-Processing: Processing RAS results in ArcGIS

The file exported from HEC-RAS in SDF was first converted to XML which is readable by ArcGIS. In this step, mapping of flood inundated area, depths and velocity of inundation were carried out. Firstly, before processing the outputs from HEC-RAS, a new set of layers were created and terrain model (TIN) generated in pre-processing step was specified for performing the floodplain delineation. The rasterization cell size for output DEM was also specified in this step. Then, the outputs from HEC-RAS previously converted to XML was imported into ArcGIS. While doing so stream centerlines, cross-section cut lines, bank points, velocity points and bounding polygon were created in ArcMap. The software creates different bounding polygons, the spatial limit for floods, based on the water surface elevation at cross-section cut lines for different year floods.

Finally, inundation mapping was carried out in two steps: water surface generation and floodplain delineation using raster. In water surface generation, TINs for water surface for 2, 10, 25, 50, 100, 200 and 1000-year floods were created from the altitude of water surface in each cross-section. Floodplain delineation was carried out using water surface that TINs generated in previous step and terrain model TIN. Thus, floodplain boundaries and their depths were calculated. The flood inundation areas for different flood values were represented by polygons while their respective depths were represented by DEM (raster format). In this project for the study area, rasterization cell size was set as 20 map units. Flood maps were created with 30m resolution DEM for Kankai basin. The major flood plain area for Kankai lies at the lower part of the basin which is the Terai (flat) region of Nepal, flood mapping of the lower flat plain has been done.

3.4 Preparation of Hazard Map

The flood effect varies from one place to another. With greater hazard, the vulnerability also increases, and hence the effect is high when the exposure is also more. The hazard due to flood can be classified for a better understanding of vulnerability and risk. The hazard level depends upon flood depth and flood discharge. Hence the effect of the flood can be quantified using water depth as a primary measure. Flood depth is considered as the most important indicator of the intensity of flood hazards. So for quantifying the flood hazard, three levels of hazard are categorized in this study as shown in Table 2.

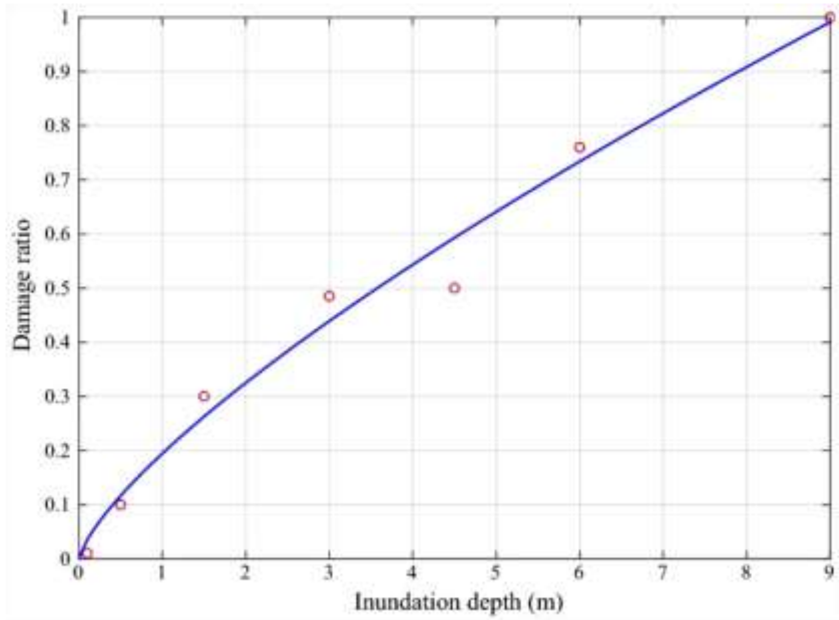

Figure 4. Empirical flood vulnerability curve for RC buildings (Reproduced from (Gautam et. al., 2022) with

Table 2. Classification of Hazard levels

S.N.	Flood Depth	Hazard Level
1	Less than 1.5m (<1.5 m)	Minor to Moderate Hazard
2	1.5m – 5.6m	Major to Severe Hazard
3	Greater than 5.6 m(>5.6m)	Extensive Hazard

It is assumed that lesser flood depth has less effect on the people and properties and higher ones have a larger effect. Flood hazard maps for various flood scenarios were prepared by overlapping depth grids with open street maps. In this study, for flood hazard mapping, all of the Kankai basins are taken into consideration.

3.5 Preparation of Vulnerability Map

The vulnerability analysis or mapping has been done only for the RCC Buildings. For the study, only a certain portion covered by the catchment area was taken into consideration. The study area includes Shivasatakshi Municipality ward 10 and Kankai Municipality ward 4. A point shapefile for buildings is created in GIS using open street map. The settlement area of study area is clipped by the flood depth boundary polygon. To obtain flood vulnerability functions, most of the researches have used inundation depth as intensity measure [8]. In this research, existing vulnerability curve (Figure 4) as depth damage curve is used for determining damages that are directly caused by flood donate the flood damage that would occur at specific water depths as per asset. For up to 3 m inundation, the damage ratio is less than 50% and it reaches 75% if 6 m inundation (roughly corresponding to two stories) takes place. We adopt three damage classes to disaggregate the total data minor to moderate, major to severe, and extensive to collapse. The minor to moderate damage state indicates the damage ratio up to 25%, major to severe corresponds to a damage ratio between 25 and 70%, and extensive to collapse corresponds to greater than 70% damage ratio. For quantifying flood vulnerability, three levels of vulnerability are categorized in this study as shown in Table 3.

Table 3. Classification of vulnerability levels

S.N.	Damage Ratio	Vulnerability Level
1	Less than 0.25 (<0.25)	Minor to Moderate
2	0.25 – 0.7	Major to Severe
3	Greater than 0.7 (>0.7)	Extensive to Collapse

3.6 Preparation of Risk Map

UNISDR defines risk as “The combination of the probability of an event and its negative consequences.”

Mathematically,

Risk = Hazard * Vulnerability * Exposure

Flood and extreme precipitation events are common phenomenon in Kankai basin. One of the probable causes might be the change in land use. Researches have already stated the change in landuse greatly affects the intensity and potential impacts on the people, infrastructure and goods by flood events. The settlements and infrastructures built along the banks have increased the vulnerability and exposure to floods. For the study, the risk map was generated by using raster calculator in which the input was flood hazard map and vulnerability map. For quantifying flood risk, three level of risk are categorized in this study as shown in Table 4.

Table 4. Classification of risk levels

S.N.	Value Hazard*Vulnerability	Risk Level
1	Less than 0.375 (<0.375)	Minor to Moderate
2	0.375 – 3.92	Major to Severe
3	Greater than 3.92 (>3.92)	Extensive

4. RESULTS AND DISCUSSIONS

The one-dimensional steady hydraulic simulation by HEC-RAS was used to prepare the flood inundation, hazard map, vulnerability maps, and risk maps for the different return periods. The inundation and hazard map provides a qualitative picture of the extent of the flooding plain as well as the hazard due to depth. Finally, they are quantified for better understanding in terms of percentage.

4.1 Flood Frequency Analysis

Using the available instantaneous discharge data for the available stations, the flood frequency analysis was done for a return period of 2, 10, 25, 50, 100, 200, and 1000 years using different approaches (Log Pearson –III Method, Gumbel's Method, Log Normal Method). The summary of flood frequency analysis for the different return periods of the hydrological station has been tabulated below:

Table 5. Flood Frequency Analysis for Kankai River at Mainachuli

Return Period	Log Peason-III	Gumbel	Log Normal
2	3687.43	3611.57	3443.75
10	6389.93	6666.01	6783.83
25	7432.97	8203.35	8693.45
50	8093.10	9343.83	10204.3
100	8667.79	10475.8	11782.9
200	9171.06	11603.8	13448.5
1000	10207.2	14216.5	17649.3

The above table (Table 5) and chart (Figure 5) shows that the discharge is greater from the Log-Normal method. Hence the flood data obtained from the Log-Normal method was taken for study. The discharge that had been taken for the hydraulic model for 2, 10, 25, 50, 100, 200 and 1000 years return period were 3443.75 m^3/s, 6783.82 m^3/s, 8693.45 m^3/s, 10204.32 m^3/s, 11782.99 m^3/s, 13448.52 m^3/s and 17649.30 m^3/s respectively. The volume of discharge increased as the return period increased, which is similar to a natural phenomenon in

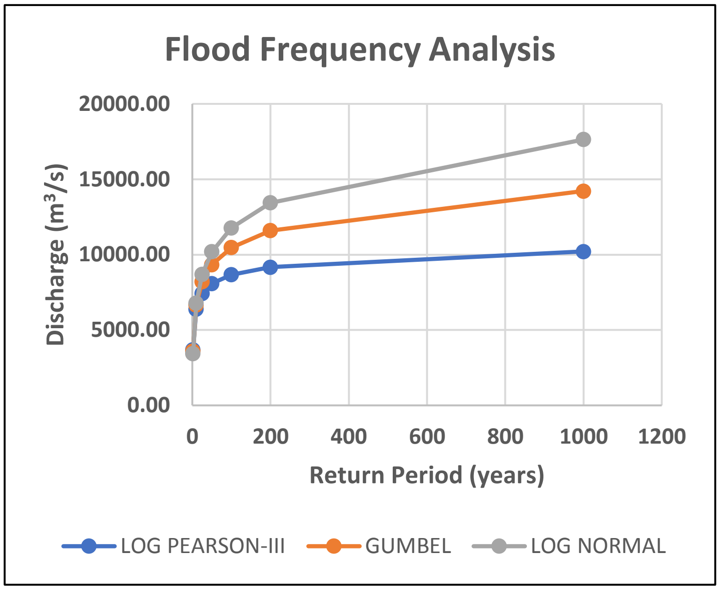

Figure 5. Relation of return period and peak discharge derived by Log Pearson III, Gumbel and Log Normal Method.

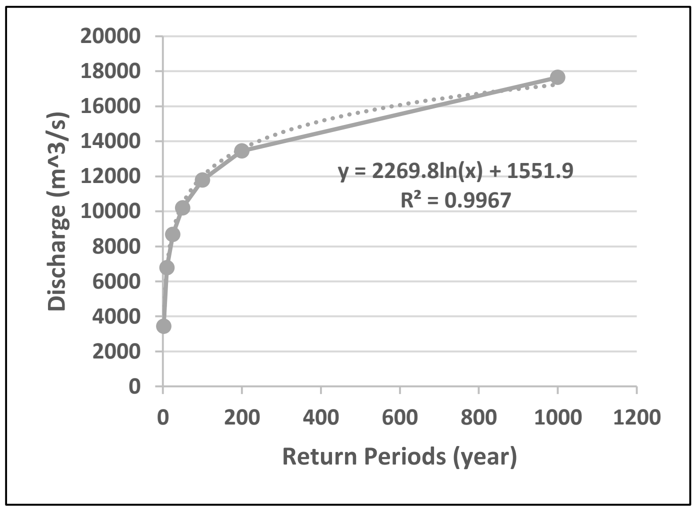

Figure 6. Relation of return period and peak discharge derived by Log Normal Method.

general.

There is a logarithmic trend relationship between return period and peak discharge value having more than 99 % coefficient of determination value. It revealed that there is no simple linear relation between the return period and peak discharge as shown in Figure 6. Peak discharge increases very fast at the decreases as the return period increases.

4.2 Flood Hazard Analysis

Flood hazard maps for the return period of 2, 10, 25, 50, 100, 200, and 1000 years are prepared by overlaying the flood depth with an open street map. The area inundated for various hazard levels is calculated and summarized in the Table 6 and Table 7.

Table 6. Area inundated for various hazard levels

Hazard Level	Flood area (%) for different Return Period			
	2yrs	10yrs	25yrs	50yrs
Minor to Moderate (<1.5 m)	15.16	11.76	10.77	10.18
Major to Severe (1.5 – 5.6m)	66.78	39.55	28.10	23.08
Extensive (>5.6m)	18.05	48.69	61.14	66.74
Total	100	100	100	100

Table 7. Area inundated for various hazard levels

Hazard Level	Flood area (%) for different Return Period		
	100yrs	200yrs	1000yrs
Minor to Moderate (<1.5 m)	9.70	9.26	8.50
Major to Severe (1.5 – 5.6m)	20.19	18.57	17.08
Extensive (>5.6m)	70.11	72.17	74.42
Total	100	100	100

A maximum of 1843.24 ha, 1967.96 ha, 2016.32 ha, 2049.48 ha, 2079.64 ha, 2109.4 2-year, 10-year, 25-year, 50-yeasr, 100-year, 200-year and 1000-year respectively. The estimated total area of inundation is increasing as the return period increases.

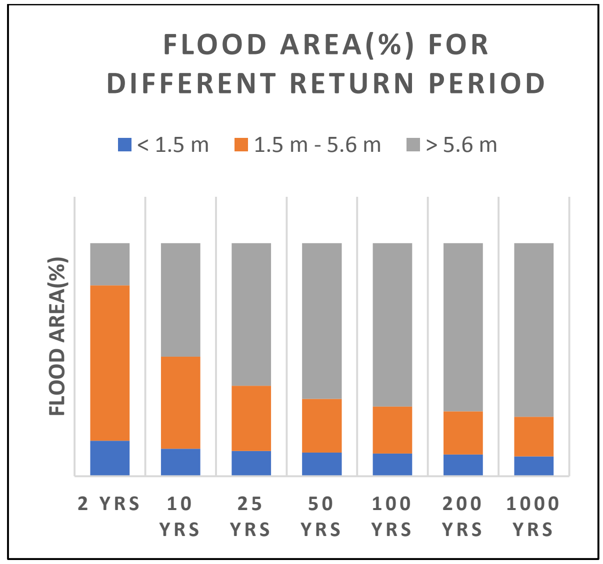

Figure 7. Flood area (%) according to hazard class for different return periods

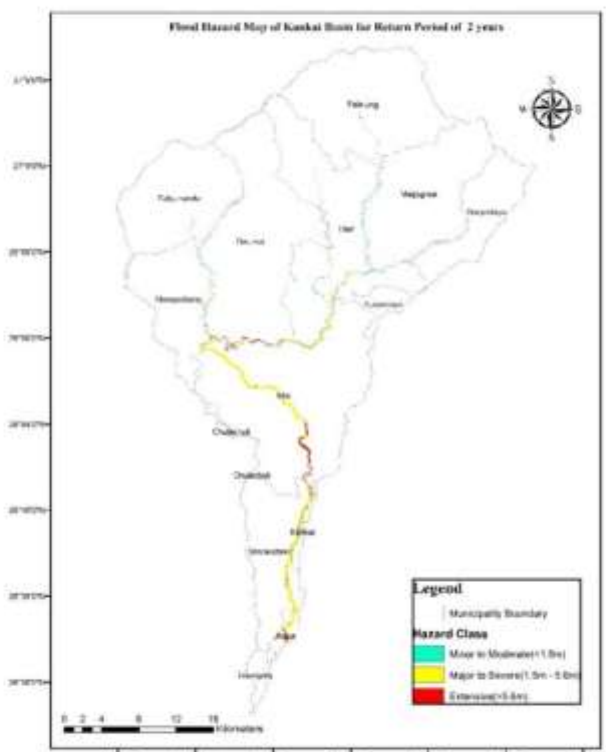

Figure 8. Flood Hazard Map of Kankai Basin for Return Period of 2 years

The result plotted in Figure 7 shows area of depth less than 1.5 m decreases from 15.16 % to 8.50 %, for depth 1.5 – 5.6 m the area decreases from 66.78 % to 17.08 % and for depth greater than 5.6 m, the area increases from 18.05% to 74.42%. It can be seen that greater the flood intensity, lower flood depth area decreases and higher flood depth area increases. The assessment of the flood areas indicates that existing RC building around 98.42% of the inundated area gets damaged at the damage ratio of 25% to 70% within the 2 years of return period. Similarly, the trend of damage shows from major to moderate to extensive to collapse of above 70% damage factor with increase of return period which is shown in Table below. The flood hazard map

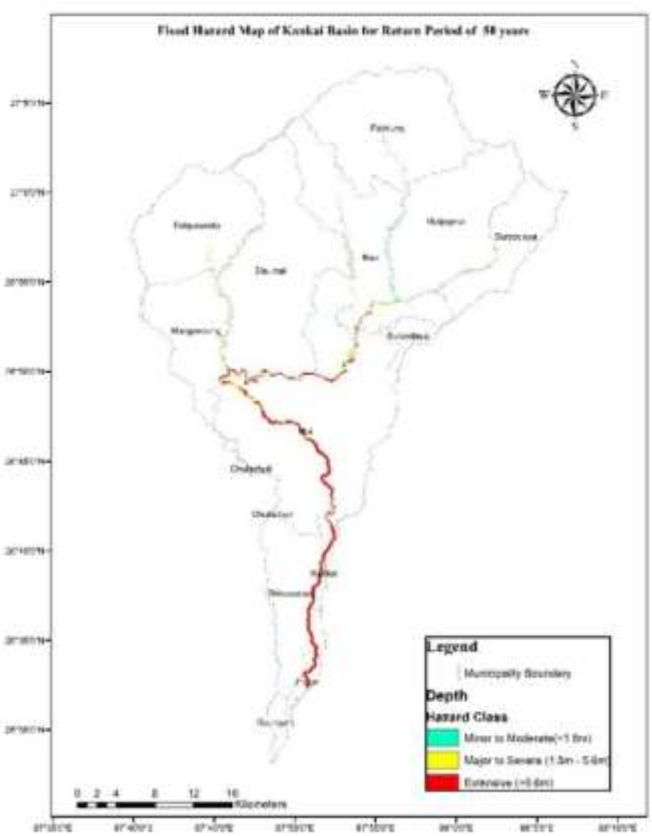

Figure 9. Flood Hazard Map of Kankai Basin for Return Period of 50 years

for the return period of 2 years and 50 years is shown in Figure 8 and Figure 9 respectively.

4.3 Flood Vulnerability Analysis

Table 8. Area inundated for various vulnerability classes

Vulnerability Level	Flood area (%) for different Return Period			
	2yrs	10yrs	25yrs	50yrs
Minor to Moderate (<0.25)	1.58	0.04	0	0
Major to Severe (0.25 – 0.7)	98.42	86.26	54.11	7.64
Extensive to Collapse (>0.7)	0	13.70	45.89	92.36
Total	100	100	100	100

Table 9. Area inundated for various vulnerability classes

Vulnerability Level	Flood area (%) for different Return Period		
	100yrs	200yrs	1000yrs
Minor to Moderate (<0.25)	0	0.0	0
Major to Severe (0.25 – 0.7)	0.32	0.12	0
Extensive to Collapse (>0.7)	99.68	99.88	100
Total	100	100	100

Figure 10 (Table 8 and Table 9) shows that highest percentage increase from 2 to 50 yrs

return period, which is followed by 100 to the 1000 years.

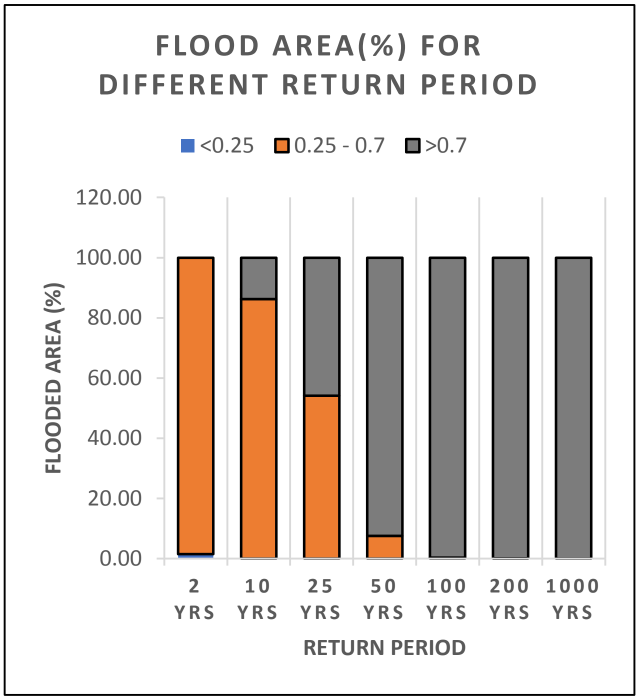

Figure 10. Flooding area percentage according to vulnerability level for different return period

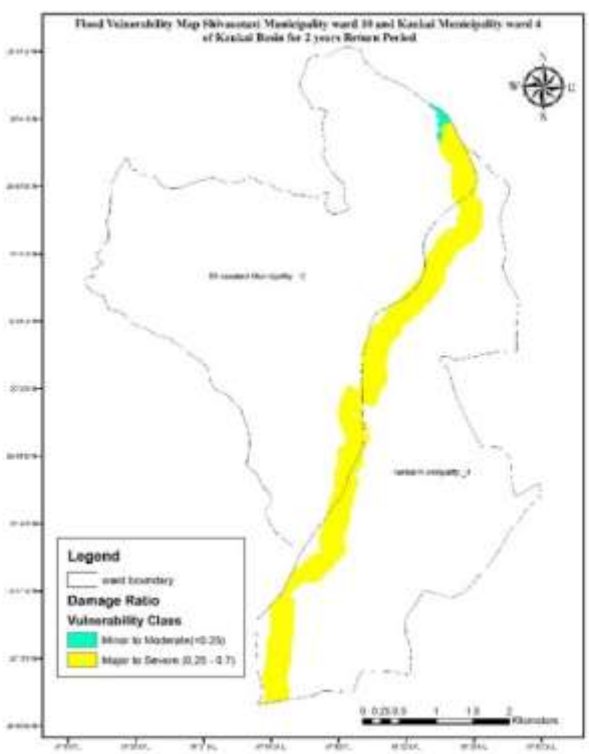

Figure 11. Flood Vulnerability Map of Shivasatakshi Municipality ward 10 and Kanaki Municipality ward 4 of Kankai Basin for 2 years Return Period.

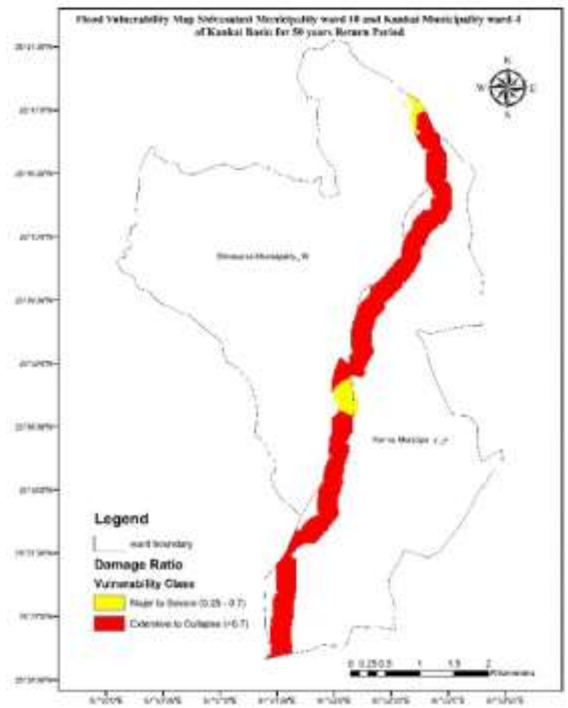

Figure 12. Flood Vulnerability Map of Shivasatakshi Municipality ward no. 10 and Kanaki Municipality ward no. 4 of Kankai Basin for 50 years Return Period.

The flood vulnerability map of return period 2 years and 50 years for the study area has been shown in Figure 11 and Figure 12 respectively.

4.4 Flood Risk Analysis

The study revealed that the risk level increase from minor to extensive drastically within 2 to 10 years of return period. The summary of risk level at different return period has been shown below (Table 10, Table 11 and Figure 13).

Table 10. Area inundated for various risk levels

Risk Level	Flood area (%) for different Return Period			
	2yrs	10yrs	25yrs	50yrs
Minor to Moderate (<0.375)	1.92	0.23	0.03	0.02
Major to Severe (0.375 – 3.92)	97.74	56.19	17.56	5.71
Extensive (>3.92)	0.34	43.59	82.41	94.27
Total	100	100	100	100

Table 11. Area inundated for various risk levels

Risk Level	Flood area (%) for different Return Period		
	100yrs	200yrs	1000yrs
Minor to Moderate (<0.25)	0.03	0.02	0.08
Major to Severe (0.25 – 0.7)	1.50	0.89	0.41
Extensive to Collapse (>0.7)	98.47	99.10	99.51
Total	100	100	100

The flood risk map of return period 2 years and 50 years for the study area has been shown in Figure 14 and Figure 15 respectively.

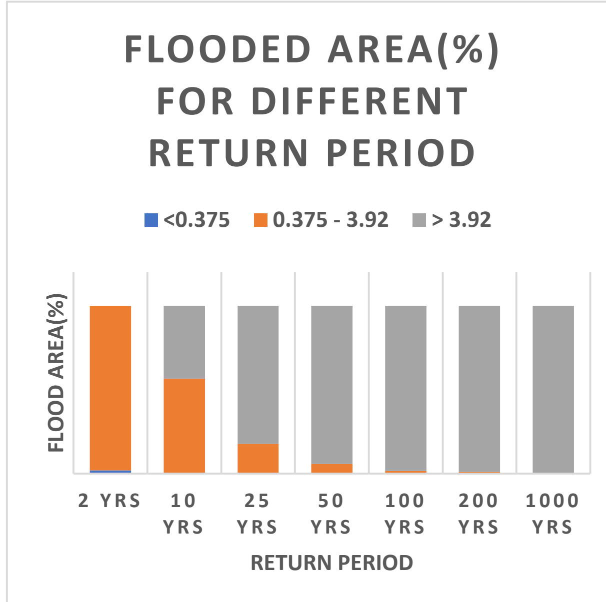

Figure 13. Flooding area (%) according to risk level for different return periods.

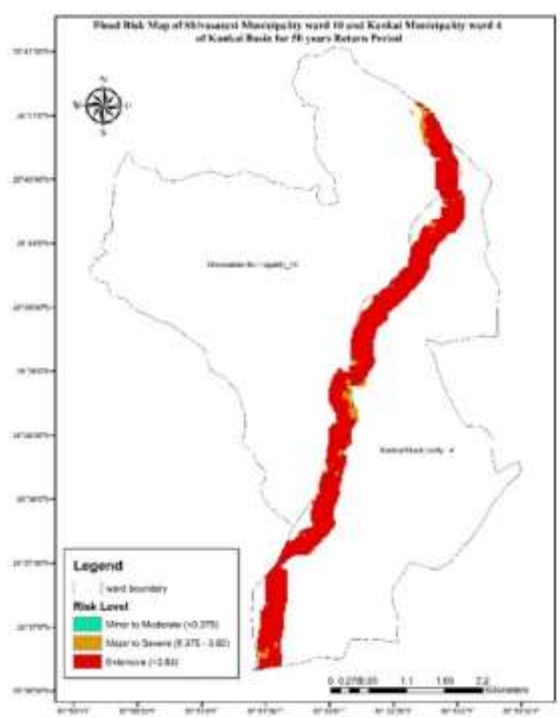

Figure 14. Flood Risk Map of Shivasatakshi Municipality ward 10 and Kanaki Municipality ward 4 of Kankai Basin for 2 years Return Period.

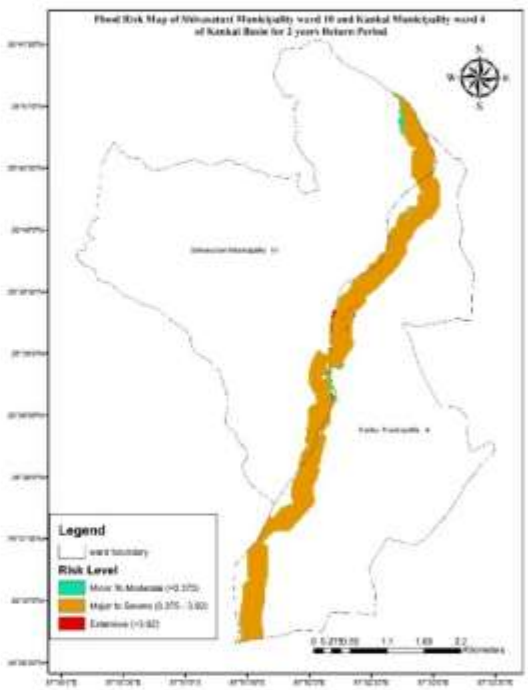

Figure 15. Flood Risk Map of Shivasatakshi Municipality ward no. 10 and Kanaki Municipality ward no. 4 of Kankai Basin for 50 years Return Period.

4.5 Discussion

Developing countries like Nepal have problems with floods and landslides every monsoon period of the year. Each year the loss of lives and property due to floods has been increasing significantly. Public facilities and buildings are also affected by the flood. Hence to study the future impacts of such floods, nonstructural measures of study are a must which helps in mitigating the future impacts as well as policy makers.

Log Normal method was used for the computation of flood discharge. The discharge is used to simulate a one-dimensional steady hydraulic model using HEC-RAS and finally the outputs are used to prepare inundation, hazard, and vulnerability and risk maps. One dimensional steady hydraulic modelling was done for the flood with return period 2, 10, 25, 50, 100, 200, and 1000 years at Mainachuli hydrological station. The result of the simulation shows that there is significant inundation along the sides of the bank in the river which can be easily observed in inundation maps presented in Annexes. Since the catchment consists of the higher elevation at the north and lowland towards the south. Shivasatakshi Municipality and Kankai Municipailty lies nearly at the middle of the sub-basin and the inundation is significant there than the other places of the subbasin. Hence the hazard, vulnerability and exposure analysis are mainly concentrated in Shivasatakshi Municipality ward 10 and Kankai Municipality ward 4 in this study. Moreover, the inundation map illustrates that necessary preparedness and mitigate efforts are required to reduce the vulnerability of the exposed household. Hence this model can be used to evaluate the inundated areas and make necessary policies as well as to implement structural measures such as constructions of embankments and dikes where necessary.

The flood hazard analysis shows that the area under inundation due to more than 5.6 m depth is the most posing high hazard to the settlement near the river. However major areas of high hazard lie in the river section and lower depth towards the banks. Though less depth of inundation was seen at the banks, the river depth of even 1.5 m can pose an enormous threat to the people and infrastructures. In the study to assess the hazard level of Balkhu River by Dangol, 2014, suggested for the relocation of the settlements near the river banks and also suggested to maintain a minimum of 20m distance between development activities and the river bank. The inundation map shows that there is a need for such an approach.

The result shows that the most vulnerable area due to flood is agricultural areas and then built-up areas. Hence preventive and mitigative efforts are essential to reduce such vulnerability. Moreover, the exposure to the hazard in term of RCC also shows that building is exposed to the flood of 50 years return period. Therefore, to reduce the risk of those vulnerable people and landcover, effective measures are still lacking.

Hydrological and hydraulic modelling are the non-structural measures widely used in the field of flood forecasting and hazard mapping. This helps to asses and analyze the potential impacts of the flood in various scenarios. Moreover, to reduce the impacts that flood can invite can be minimized through flood forecasting units, use of Early Warning System (EWS) technology as well as awareness campaigns which is mainly supported by the hydrological and hydraulic modelling study. The major input for the study is the data. The accuracy of the data required (topographical data, rainfall data, discharge data, river geometry data, other meteorological data) for the study is the basis for the accuracy of the output. The data used in the study are the best which can be acquired from free source. However due to some uncertainties in discharge and rainfall data, resolution of the topographical data and other constraints the result sometimes might be overestimated.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study is done to prepare hazard map using HECRAS for one dimensional steady hydrodynamic modeling, Arc GIS as the interface for spatial data analysis and processing and HEC-geoRAS for linking Arc GIS and HECRAS. The result shows that greater the value of discharge greater is the affected areas. The affected area with HIGH hazard class has increased from 18.05% in return period 2 years and 74.42% in 1000 years return period. The assessment of Flood Hazard Map shows that as the flood intensity increases lower flood depth decreases and higher flood depth area increases which means the area under HIGH hazard zone increases. The assessment of vulnerability maps prepared shows that vulnerability of Building lands and agricultural lands i.e. the fertile land is increasing due to increasing discharge which will directly effect on the food security of the area. The trend of inundation/vulnerable area for high hazard class as well as land use vulnerability shows that the hazard and vulnerability both are increasing with respect to the flood intensity. Since risk is a function of hazard and vulnerability and greater the hazard and vulnerability higher will be the risk. Hence the study suggests that flood risk for Shivasatakshi Municipality and Kankai Municipality is also increasing which indicates the need of effective land use planning. The results presented in the form of maps provides a new perspective for visualization and quantification of flood hazard and vulnerability which can help the decision makers to understand the problems and take necessary action.

5.2 Recommendation

The boundary of inundation map can be used to set Right of Way (ROW) along the banks of the rivers where no any structures are to be made. The hydraulic model can be used to determine warning and danger levels for the river. Policies must be made in order to optimize amount of extraction of sediments and point out the possible locations for that. Local level disaster committee must be established to deal with the hazards existing in the respective metropolitan city/ municipalities/rural municipalities. Provision of Early Warning System to inform the vulnerable people exposed to flood hazards. Flood inundation and hazard maps can be used by local authorities for effective land use planning as well as determining evacuation sites. Training must be given to the people regarding how and what to do during flood events.

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