Advances in Engineering and Technology
An International Journal

Flood Risk Mapping of Kamla River Basin using HEC-RAS 2D Model

Birendra Pandit*, Pawan Bhattarai

Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal

Abstract

Flood is a natural disaster that occurs repeatedly in Nepal and causes significant losses in terms of life and property particularly in low land areas around the river courses. Kamla basin is highly susceptible to flooding and had experienced many disastrous floods in the past. Flood mitigation measures generally consists of two main methods which are structural and non-structural methods. Nowadays, the importance of using nonstructural method such as flood hazard map and flood risk map are increasing because of environmental and economic aspects. In this study, the assessment of flood hazard and risk was carried out for Kamla River basin. Floods are simulated using the HEC-RAS 2D hydraulic model. The flood hazard map was prepared using the simulation result by classifying into four hazard level, corresponding to different inundation depth. The exposed elements considered for the vulnerability assessments are building, population and agriculture area. Finally, to evaluate the flood risk, a flood risk map of wards under the study area was prepared for 25year,50year and 100-year return period flood events based on the product of flood hazard and vulnerability weightage. The study's findings may help in the planning and management of Kamla River flood plain region to avoid future likely disasters.

Keywords: Flood Hazard, Vulnerability, Risk, HEC-RAS 2D

1. Introduction

Flood is an overflow of enormous quantity of water beyond its normal limits. Flooding is regarded as one of the most destructive natural disasters in world [1]ensemble-based techniques have become popular in flood susceptibility modelling due to their greater strength and efficiency in the prediction of flood locations. Thus, the aim of this study was to employ machine learning-based Reduced-error pruning trees (REPTree. According to data from the United Nations Office for Disaster Risk Reduction (UNISDR), from 1996 to 2015, there were about 150,061 flood incidents worldwide, which resulted in 11.1% of all catastrophe fatalities [2]and they cause major economic losses and seriously affect peoples' lives and health. This paper addresses the development of a flood susceptibility assessment that uses intelligent techniques and GIS. An adaptive neuro-fuzzy inference system (ANFIS. It is estimated that globally, 3.0 billion people live in places that are exposed to some level of flood risk and with a global population of 7.9 million, nearly one-fourth of the world's population is vulnerable to significant flood risk [3].

*Corresponding Email: bpanditt35@gmail.com (B. Pandit), nepal.pawan@gmail.com (P. Bhattarai)

In South Asia, Nepal is the second-highest risk country for flooding [4]. The study carried out in 2004 by UNDP/BCPR, among 200 countries of the world, Nepal stands at 11th and 30th respectively with regard to relative vulnerability to earthquake and flood. Floods in Nepal between 1954 and 2018 resulted in 7,599 fatalities, 6.1 million impacted, and 10.6 billion USD in losses to the economy and on average, 300 people were killed annually [5].

All of the Terai's rivers are in spate during the monsoon season, from June to September, causing floods and inundation when they discharge at bank-full levels. Due to overall climate change and changes in rainfall pattern/intensity in particular, the problems of floods and inundation in the Terai are more serious [6].

Kamla basin is highly susceptible to flooding due to heavy monsoon rains, fragile geological formations, and rough topography. Flooding in the Kamala Basin and nearby areas affects lives and causes extensive damage [7]. The Kamla basin had experienced many disastrous floods in the years 1983, 1987, 2003, 2007,2008,2009 and 2017 which causes the damage of life and property [8]. In the 2007 floods, the river flowed along alternate courses in the districts of Dhanusha and Siraha, and the waters inundated the flood plains for almost a week due to overbank flow [7] .

For the purpose of flood management there are mainly two methods which are structural and non-structural methods. Structural methods consist of construction of structures like dyke, flood walls, spur whereas nonstructural methods consist of preparation of flood hazard maps, vulnerability and risk assessment. [9] mentioned that only structure approach is inadequate to combat the recurrent floods. Hence, the flood hazard and risk assessment is a fundamental non structure measure to protect infrastructure and human lives [10]60 km long reach of the River Swat (Khwazakhela Bridge–Chakdara Bridge. Nowadays, the importance of using nonstructural method such as flood hazard and risk map is effective tool for reducing flood damage instead of structural method because of environmental and economic aspects.

Several mathematical models for flood inundation have been developed, based on the spatial area, dimensionality, and mathematical complexity[11]. The U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) model is widely used for analyzing flooding and flood-related hazards, as well as locating floodplains worldwide [12]. The traditional approach for simulating flow in river channels is one-dimensional (1D) hydraulic modeling. Because the performance of the 1-D model in plain topography is inadequate many 1D hydraulic models are being replaced by 2D hydraulic models[13].Many researcher have successfully applied the HEC-RAS 2D model for flood inundation mapping worldwide such for river Swat in Pakistan [10], Krishna River Basin in India [11], Purna basin in India[14] ,[15] in Palemnang city,[16] in Januwa river basin and many more have successfully developed the HEC-RAS 2D model for floodplains. Researcher like, ,[13] in Ratuwa river ,[17] in Kankai river basin and [18] in Babai river basin in Nepal have successfully applied HEC-RAS 2D model for floodplains.

In this study, an attempt was taken to evaluate the flood risk by developing flood risk map for Kamla river basin through HEC-RAS 2D unsteady flood model based on the digital elevation model (DEM). The flood risk map was prepared based on the product of hazard (inundation depth) weightage and vulnerability (i.e. exposure of population, building and agriculture land to flood) weightage.

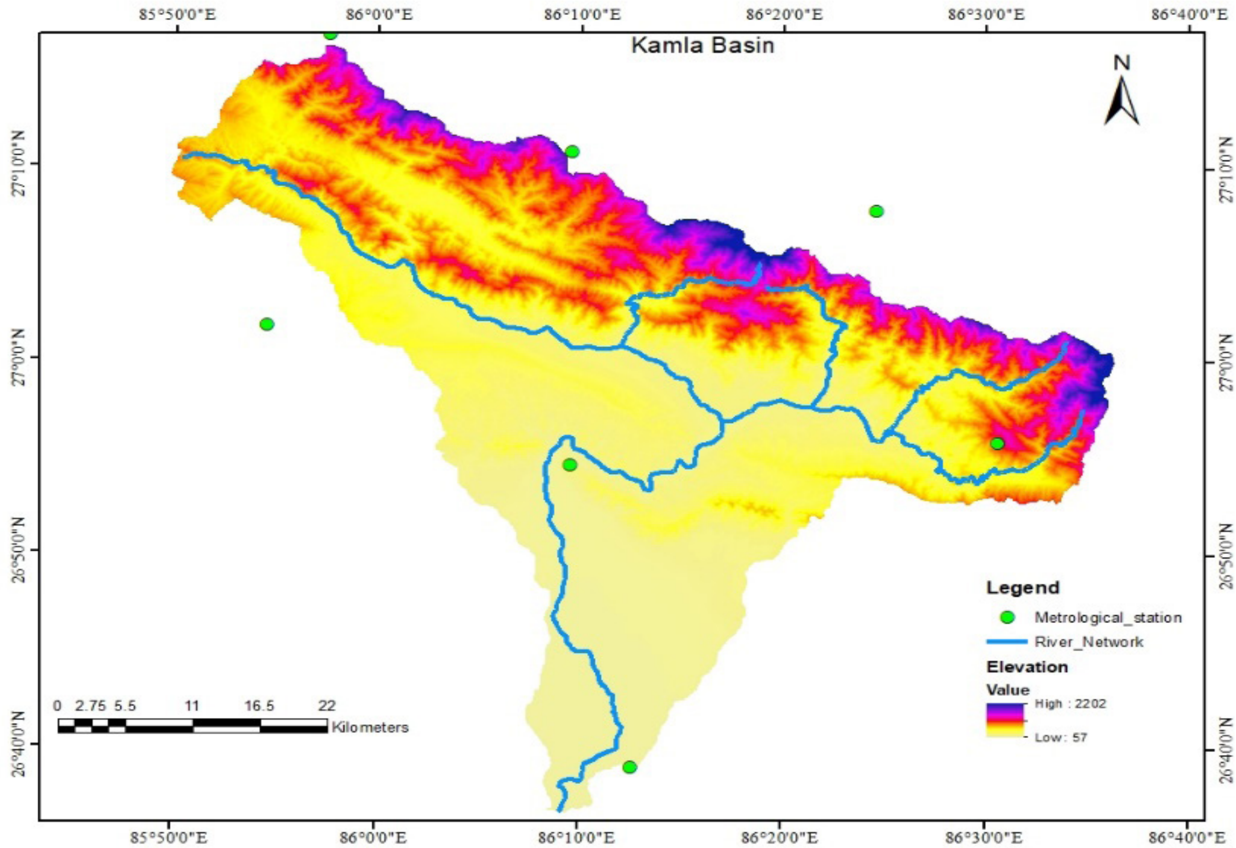
2.Materials and Method

2.1 Study Area

The present study area, Kamala basin is located in the south-east of Nepal, near the border with India. Administratively, the basin lies in the three provinces and four districts. The district of Udayapur in Koshi province, Siraha and Dhanusha in Madhesh province and Sindhuli in Bagmati province. The Kamala River originates in the Mahabharat Range, also known as the Middle Mountains, and flow through Chure to the Terai plains before entering India. The Kamala basin has a catchment area about 2083 sqkm at the Nepal-

India border. Its catchment has an elevation ranging from 57 masl to 2207 masl. About 67% of the basin's area is below 600 masl, 27% is between 600 masl and 1,200 masl, and the remaining 6% is above 1,200 masl. Geographically, the Kamala Basin is divided into three physiographic zones: the Middle Mountains (20%), the Chure or Siwalik (64%), and the Terai (16%). The basin lies below the 3000 masl, so snowfall does not contribute the hydrology to the basin. The Hydrology is mainly dominated by the summer monsoon. The annual rainfall ranges from 940 mm to 2,594 mm, with a significant spatial variation. The average annual rainfall in the basin is about 1681mm.There is no any gauging station within the study area. There are eight metrological stations within and close to the basin area are maintained by Department of Hydrology and Metrology (DHM) and these metrological stations are at Sindhuli Gadhi, Bahun Tiplung, Tulsi, Kurle Ghat, Janakpur Airport, Chisapani Bazar, Udaypur Gadhi and Siraha. The Kamala Basin is shaped like a 'T,' with wider parts at the headwaters and narrowing from the middle where it emerges into the Terai plain. The basin is narrow at the tail end where it enters into India. The location map of study area is shown in figure 1

Figure 1: Location map of study area



2.2 Methodological Framework

The general methodology is to prepare flood risk map of the study area by processing data in Arc GIS and HEC-RAS tool as two-dimensional flood model. The flow chart of methodology adopted to simulate 2D flood model in HEC-RAS has been presented in the figure 2.

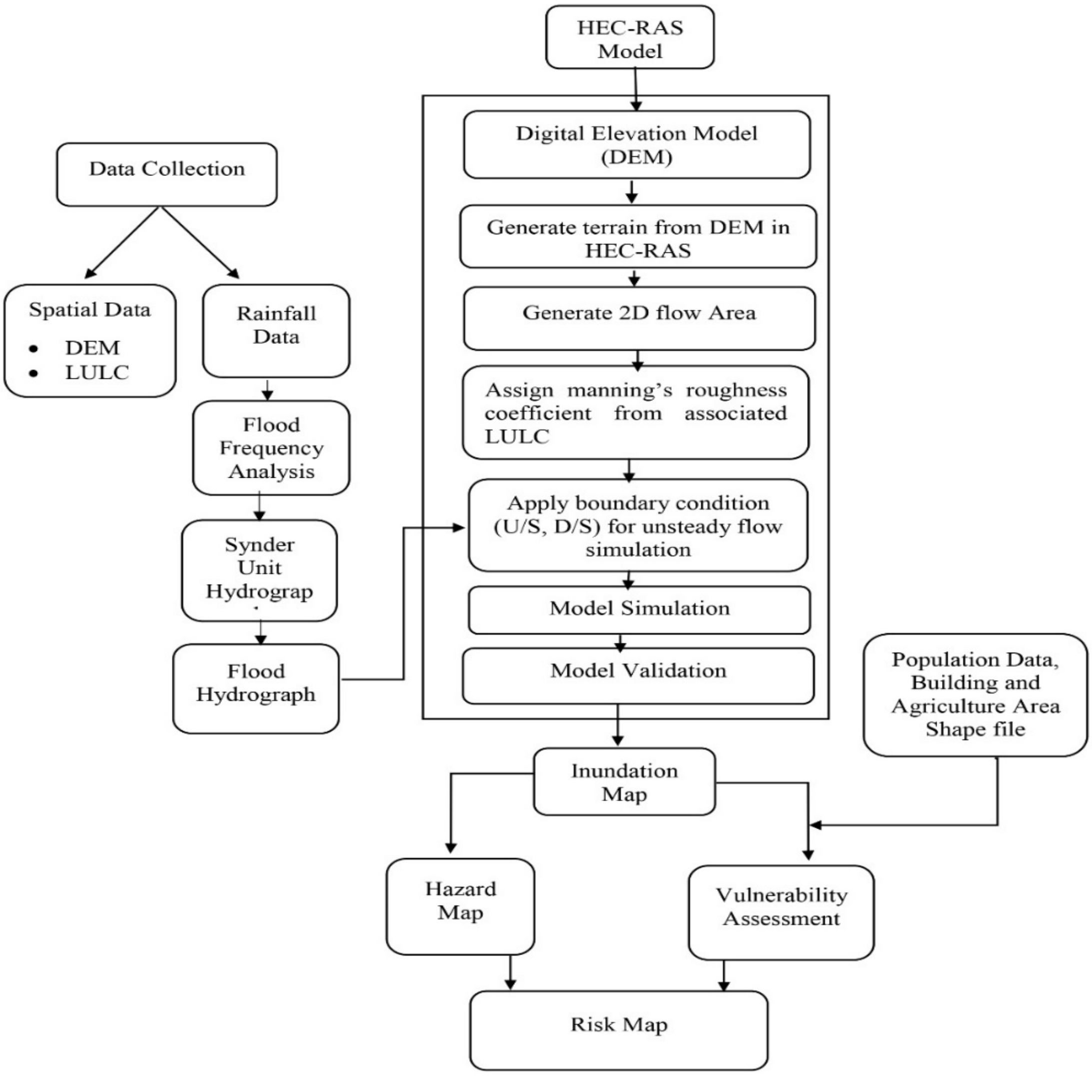


Figure 2:

Methodological Chart of study

2.2.1 Hydrological Analysis

Hydrological analysis is carried out to calculate the discharge of water draining from a watershed over time. As, Kamla River basin is ungauged river, the hydrologic analysis is done by using empirical formula. By reviewing different empirical formula, the Synder Unit Hydrograph (SUH) was found to be best. Therefore, for this study too, the hydrologic analysis was done by using Synder Unit Hydrograph (SUH).

The drainage characteristics of the Kamla Basin have been evaluated with the help of DEM. DEM was processed by using HEC-HMS GIS tools. The eleven number of sub-basins was created for this study. To calculate the average rainfall of each sub basin, the Thiessen Polygon method was used because of its simplicity to apply. Numerous frequency distribution methods can be used to conduct statistical analysis and estimate the potential flooding's potential. For this study, Gumbel's distribution method was used to predict extreme level of precipitation for various return period using observed precipitation. Once unit hydrograph is found, the direct runoff hydrograph is obtained by multiplying the ordinate of unit hydrograph by rainfall amount of different return period. For this study, 2,10, 25,50 and 100 years return period direct runoff hydrograph was obtained. The obtained direct run off hydrograph was used for upstream boundary condition in HEC-RAS 2D model.

2.2.2 HEC-RAS Modelling and Risk Assessment

For the HEC RAS simulation, DEM is downloaded from respective sites and is processed by using Arc GIS. Downloaded DEM data has been imported in HEC-RAS to create the terrain model in RAS-Mapper which is then used for establishing the geometry and hydraulic properties. Computational cells with a resolution of 50m X 50m are produced along the river reach's 2D flow area. The hydraulic properties of each cell are then generated by using RAS Mapper's geometric pre-processor. The land cover with appropriate roughness coefficient has been imported in RAS map and has been associated with terrain used for simulation and calculations. In the U/S boundary condition, stream hydrograph is assigned, whereas for D/S boundary condition normal depth channel slope is assigned. Based on Courant condition criteria, the computational time step was adjusted. It is based on the solution's numerical stability, mesh size, and computational regime's velocity profile. Then, an unsteady-state 2-D flow simulation is performed. The model result is validated by capturing the flood extent obtained from satellite image. After the validation of model, the model was simulated for different return period. The flood hazard map (based on inundation depth) and flood vulnerability map (based on the exposure of population, building and agriculture land to flood) were constructed. Finally, to evaluate the flood risk of that area, a flood risk map was prepared where risk is defined as the product of hazard and vulnerability.

3. Result and Discussion

3.1 Validation of Model

The simulated result obtained from HEC-RAS model has been compared with the satellite image for validation of model. The area was used as main basis for validation of result obtained from HEC-RAS. It is assumed that, flood marks obtained from satellite images are of recurrent flooding event and considered as 2 years return period of flood. Summary of Validation of Simulation result with satellite image is summarized table 1.

Table 1: Validation of Inundation Extent

River ID	River Name	2 years Inundated Area as per HEC-RAS (Sqkm)	Flooding area as per satellite image (Sqkm)	Model validity (%)
		2D		2D
1	Kamla	198.09	190.11	95.97

As shown in table 3.1, the flooding extent obtained from the HEC-RAS model of 2 years return period is 198.09 sqkm and from satellite image is 190.11 sqkm. The percentage of model validity in terms of flooding area is found to be about 95.97 %. This result indicates that the simulated result is very close to observed value.

Hence, the validation result shows satisfactory result.

The inundation extent in the study area is simulated by HEC-RAS 2D is comparable to other study conducted in similar basin of Nepal. Study conducted by [18] in Babai river basin,[17] in the Kankai river basin and [13] in the Ratuwa river basin of Nepal by using HEC-RAS 2D model was found that the percentage of model validity in terms of inundation area were 95.7%, 85% and 85.6% respectively. Their result showed that good validation with results obtained from the satellite imagery database.

3.2 Inundation Extent

The inundated area for 2 ,10,25,50 and 100-year return period for the study area is shown in figure 3.

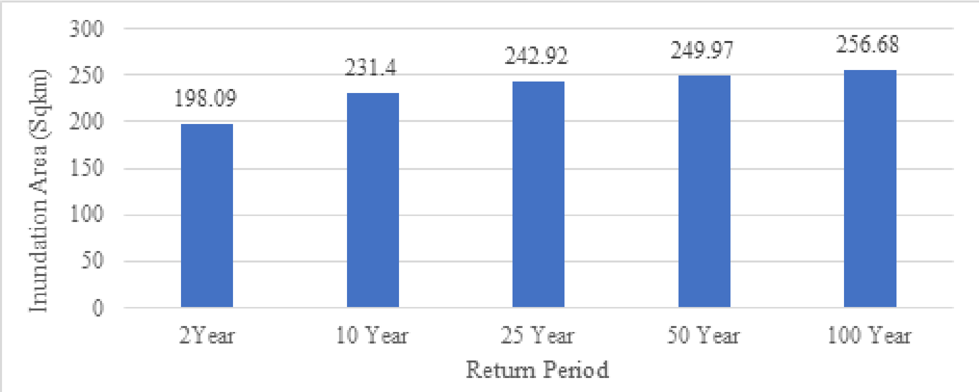


Figure 3: Inundation extent for different return period flood

3.3 Flood Hazard and Risk Assessment

3.3.1 Flood Hazard Mapping and Analysis

Water depths reached during floods can be used to quantify flood hazard levels and determining its potential damage. A flood hazard map was created using the simulated result obtained from HEC RAS by categorizing into four classes, corresponds to different inundation depth. The hazard classes used in this study are low (<0.6m), Medium (<0.6m to 1m), High (<1m to 3.5m) and Very High (>3.5m) based on the inundation depth. The areas enclosed by each flood polygon were estimated to determine the hazard level. The flood hazard result for 25,50 and 100 years return period of the study region is presented in the table 2 and figure 4.

Table 2: Summary of flood hazard

Hazard Level	Affected Area (Sqkm)					
	25-year	%	50-year	%	100-year	%
Low	41.32	17.05	38.13	15.31	36.69	14.33
Medium	32.45	13.39	31.12	12.49	29.05	11.35
High	151.48	62.53	159.47	64.02	166.52	65.06
Very High	17.01	7.02	20.37	8.18	23.67	9.25
Total	242.26	100.00	249.09	100.00	255.93	100.00

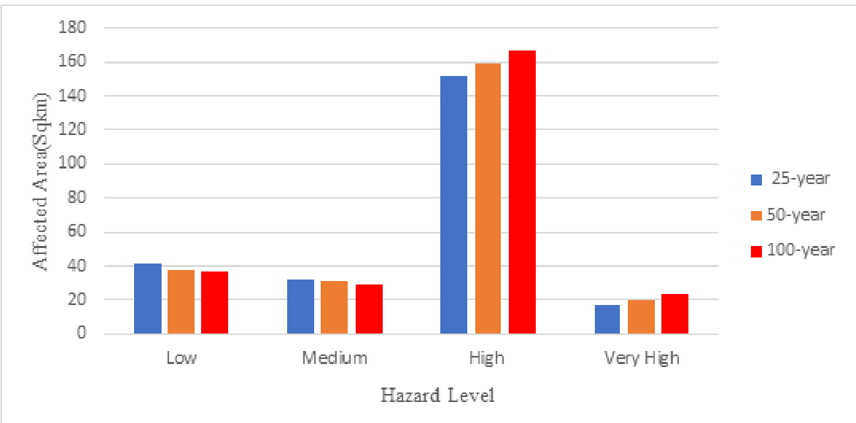


Figure 4: Flood hazard area for 25yr,50yr and 100 yr flood event

It can be observed from the table that the area of high and very high hazard class increases with flood return period while the low and medium class flood hazard area decreases with increase in flood return period. The most area covers in each return period flood event in under high hazard class. The hazard map for 25 year, 50-year return 100-year return period is shown in figures 5 to 7.

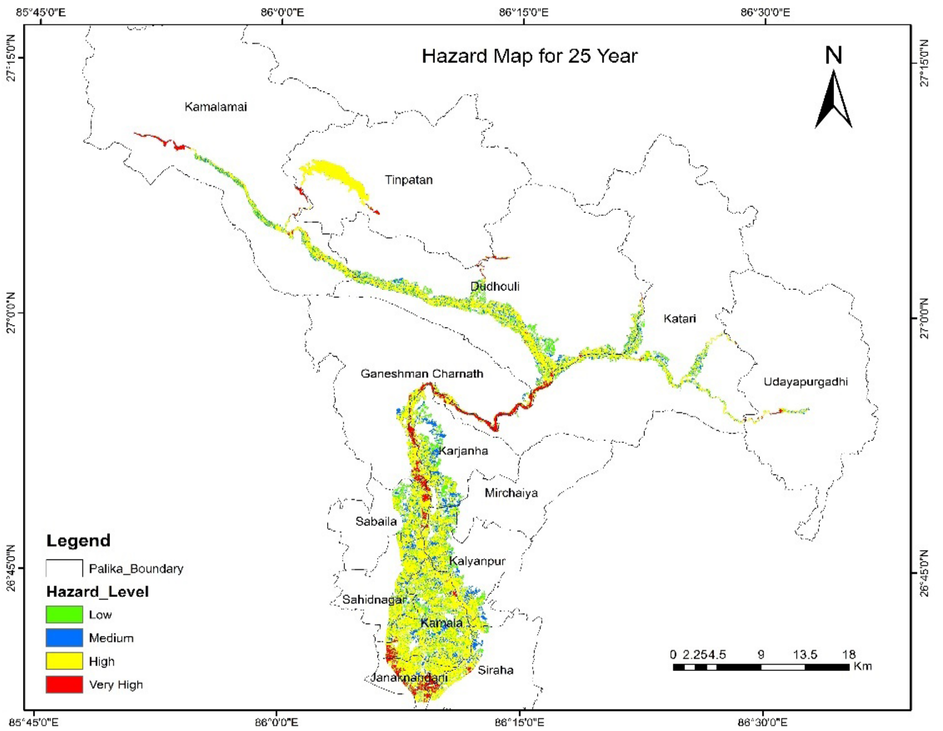


Figure 5: Flood Hazard Map for 25 Year Flood

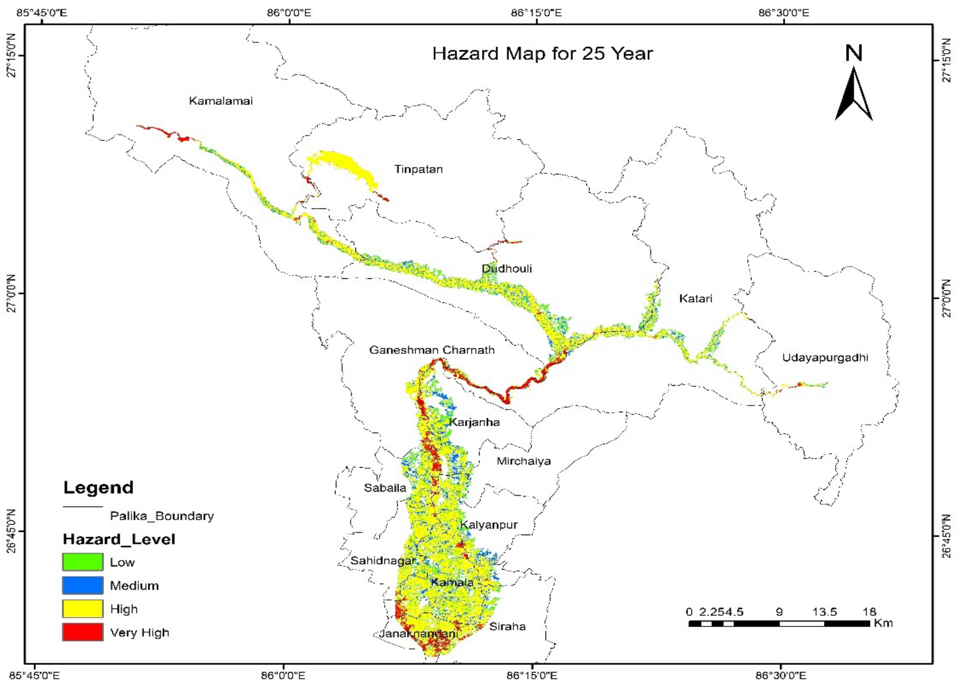


Figure 6: Flood Hazard Map for 50 Year Flood

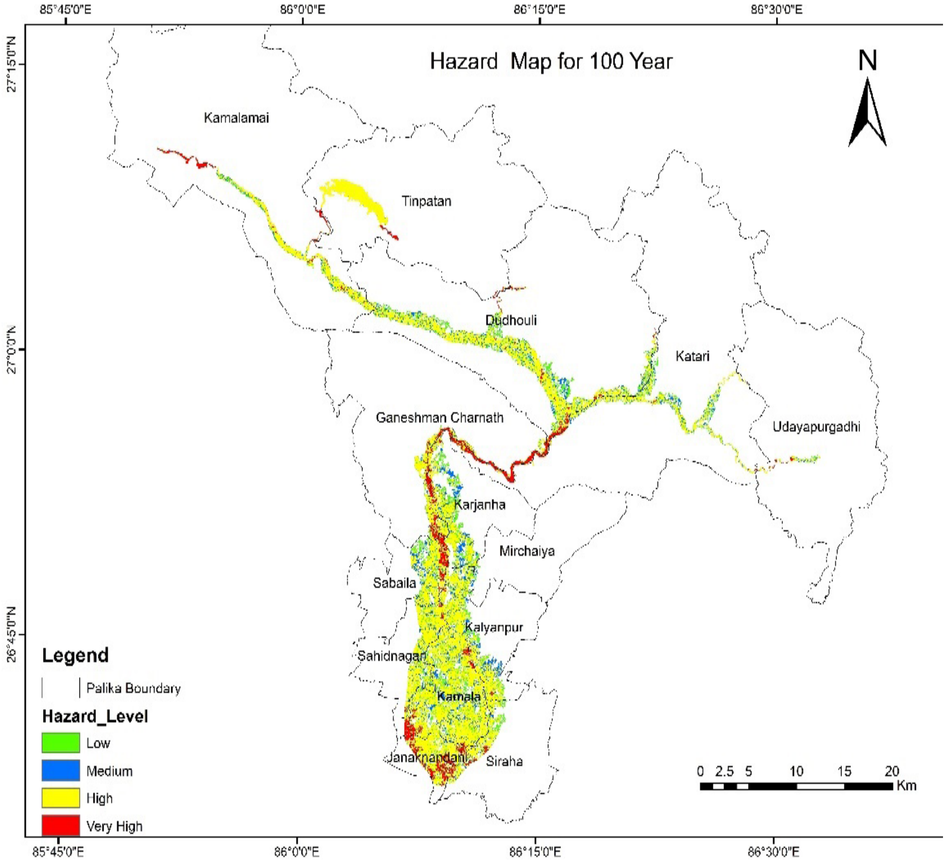


Figure 7: Flood Hazard Map for 100 Year Return Period

3.3.2 Flood Vulnerability Assessment

In flood risk zoning, vulnerability assessments of the flooded area are essential. The exposed elements under different hazard level are presented in table 3. The vulnerability map was constructed by intersecting the flood hazard map and shapefile of building and agriculture for each ward considered under the study. The vulnerability map of building and agriculture area for 25 year and 50-year 100-year return period are shown area dedicated in figures 8 to 13 respectively.

Table 3: Exposed Elements in Hazard Level

Hazard Level	Exposed Building (No)			Exposed Population (No)			Exposed Agriculture Area (Sqkm)		
	25-year	50-year	100-year	25-year	50-year	100-year	25-year	50-year	100-year
Low	5455	5872	5742	26184	28346	27749	30.04	27.8	27.22
Medium	3693	3724	3861	17726	18053	19668	22.97	22.29	20.59
High	7439	8056	9274	35707	38979	45429	91.12	97.35	105.18
Very High	262	421	488	1258	2050	2696	6.49	7.69	9.38
Total	16849	18073	19365	80875	87428	95542	150.62	155.13	162.37

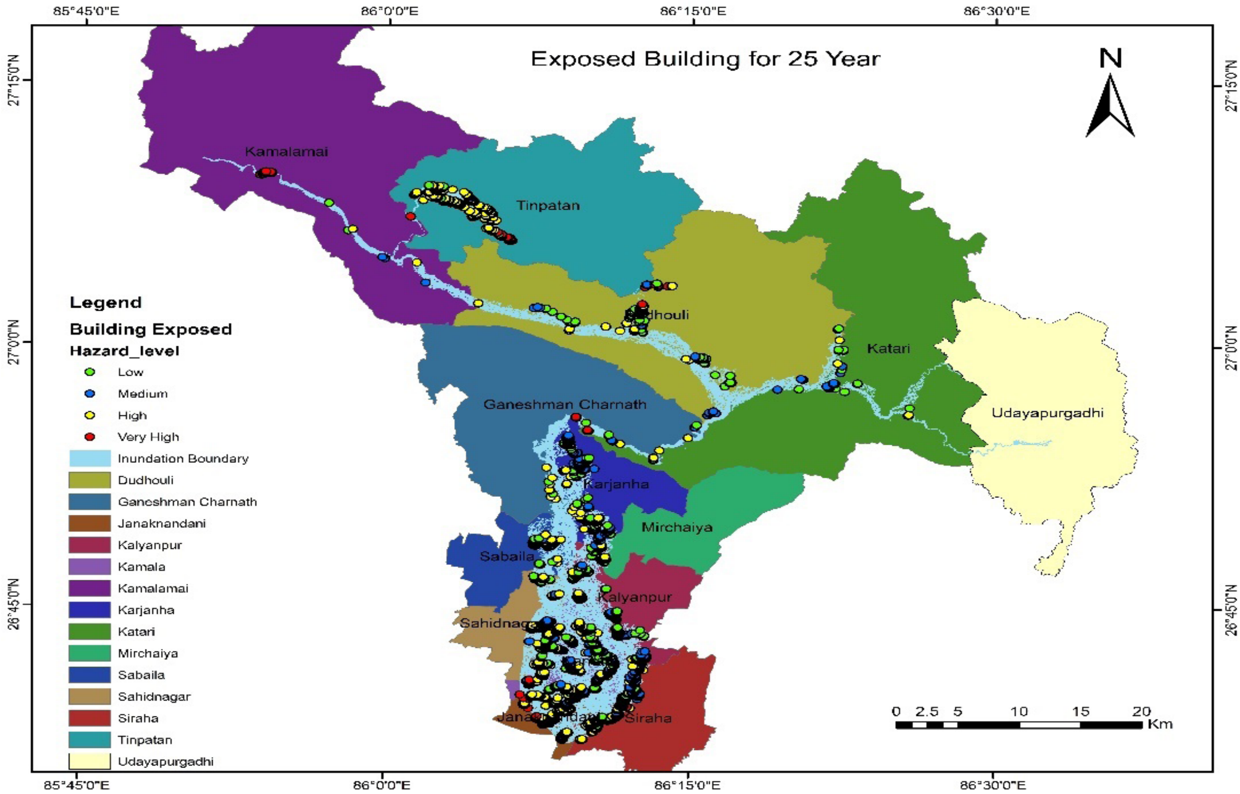


Figure 8: Flood Vulnerability Map of Building for 25 Year Flood

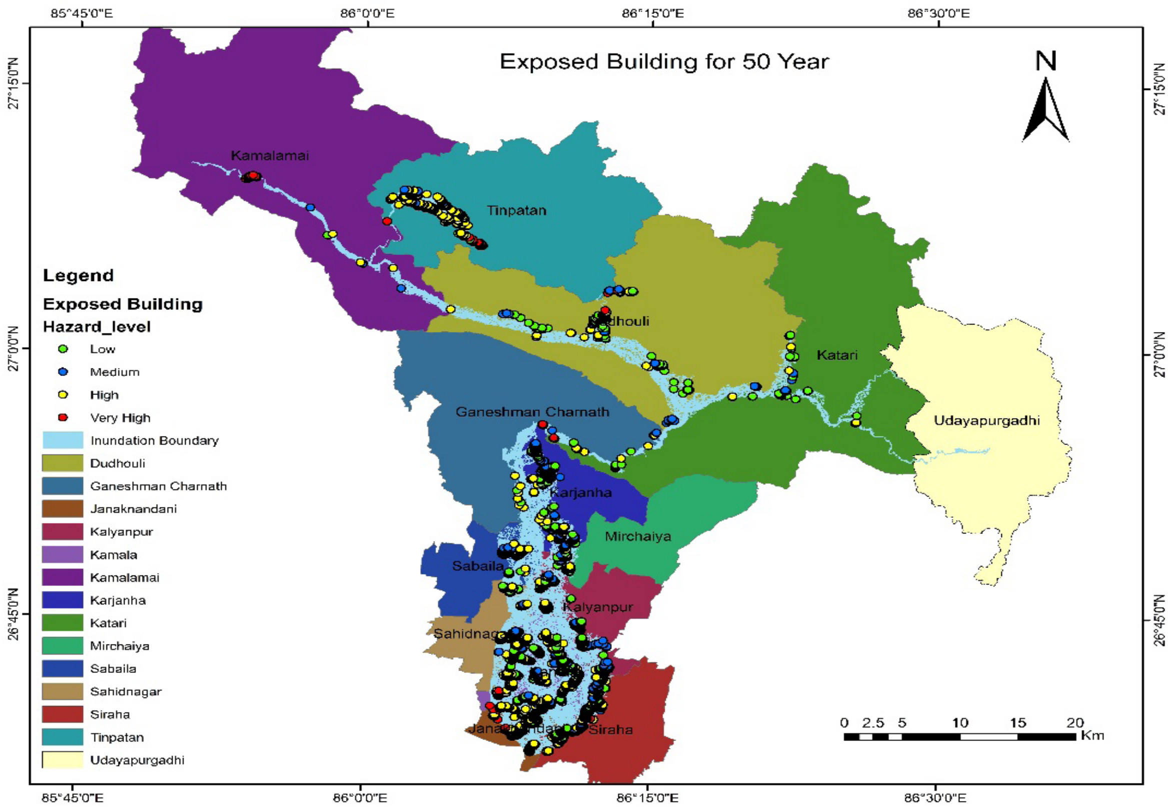


Figure 9: Vulnerability Map of Building for 50 Year Flood

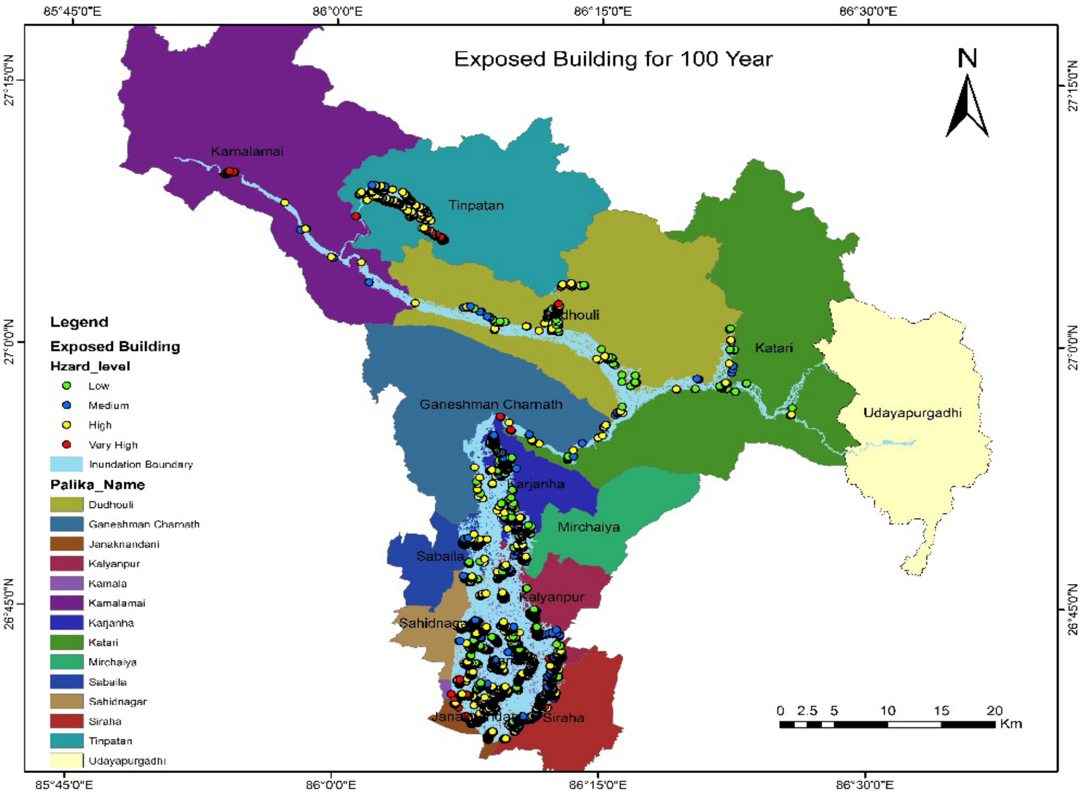


Figure 10: Vulnerability Map for building for 100 Year flood

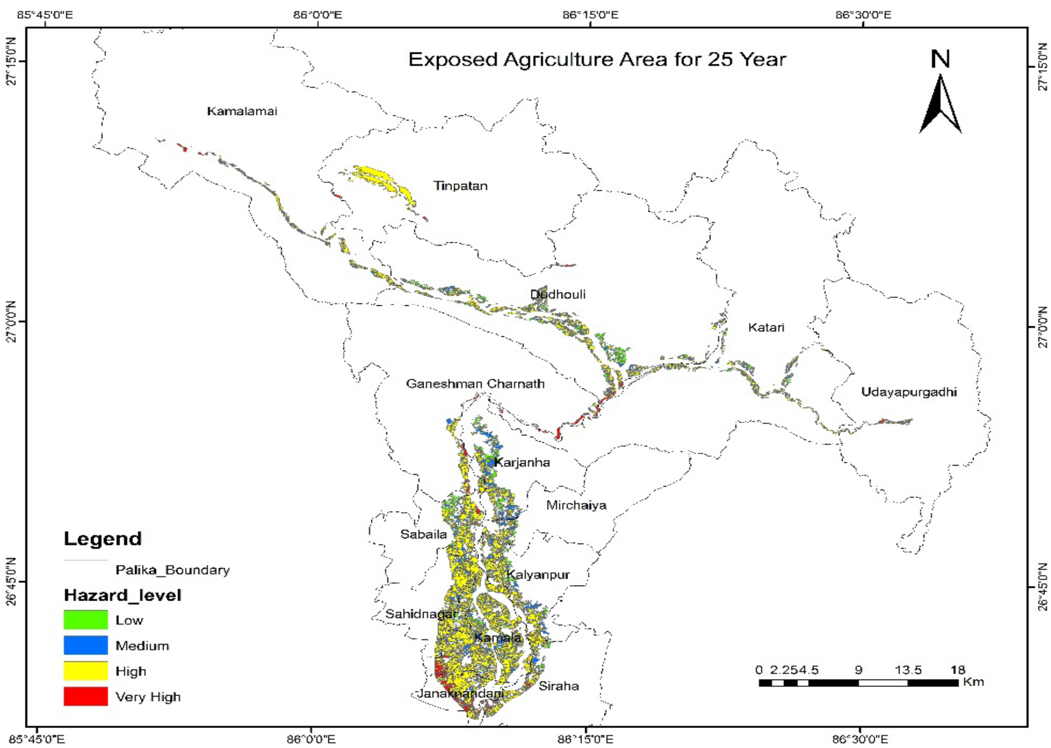


Figure 11: Vulnerability Map for Agriculture area for 25 Year flood

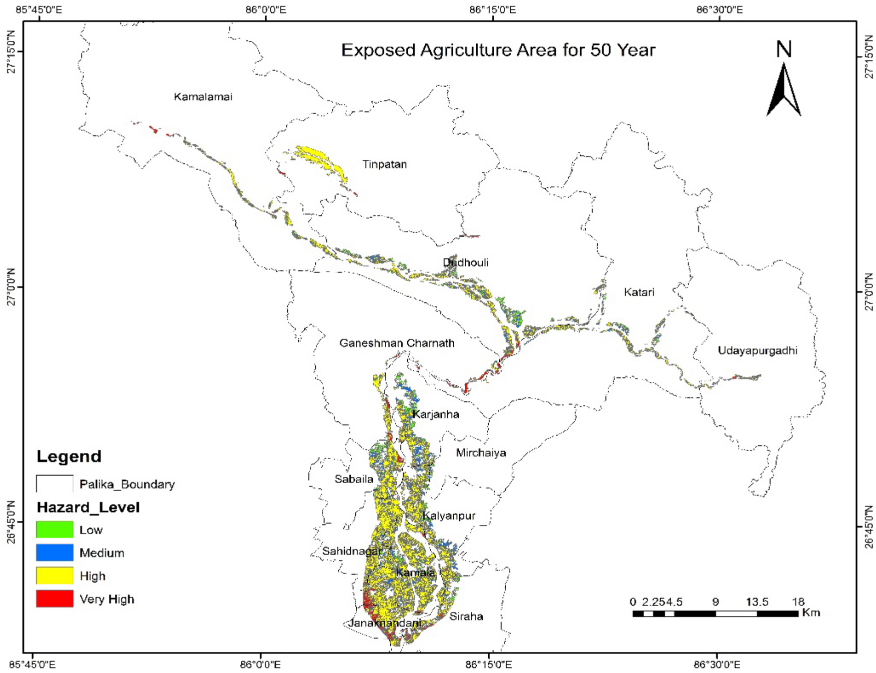


Figure 12: Vulnerability Map for Agriculture area for 50 Year flood

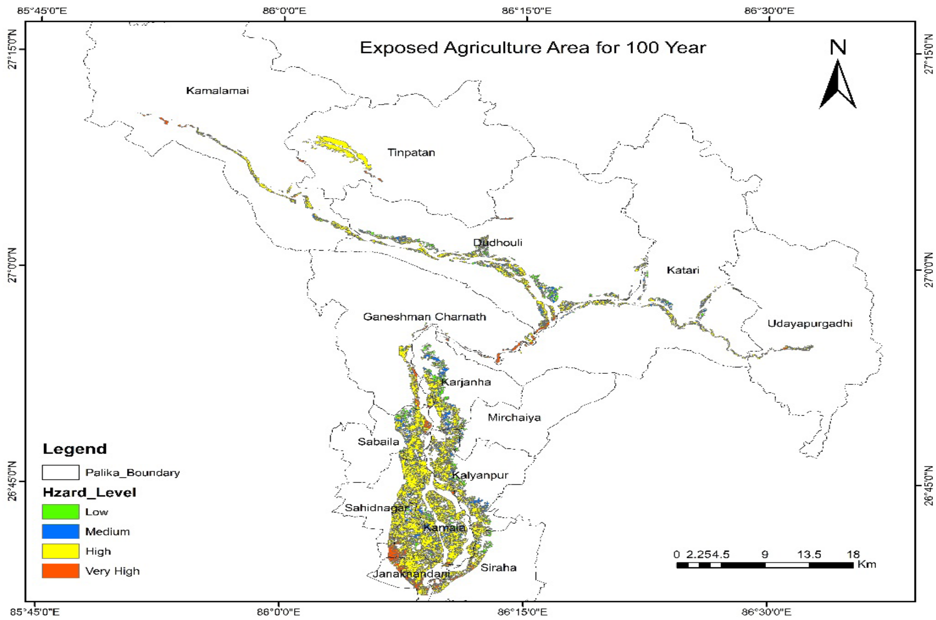


Figure 13: Vulnerability Map for Agriculture area for 100 Year Flood

3.3.3 Flood Risk Assessment and Mapping

A flood risk map was prepared by the classifying into five different risk zone namely no risk, low risk, medium risk, high risk and very high risk where risk was determined by the product of weightage of flood hazard which is based on the inundation depth and weightage of vulnerability (i.e. the exposure of people, building and agriculture area). In this study, the risk map of 14 palika consisting 166 wards were constructed. The number of wards fall under different risk zone for 25 year,50year and 100-year return period flood event are shown in table 4 and same have been presented figure 14 (bar chart).

Table 4: Number of Wards under Risk Class

Return Period	Number of Wards under Risk				
	No	Low	Medium	High	Very High
25 Year	82	36	27	19	2
50 Year	82	36	26	19	3
100 Year	82	34	24	22	4

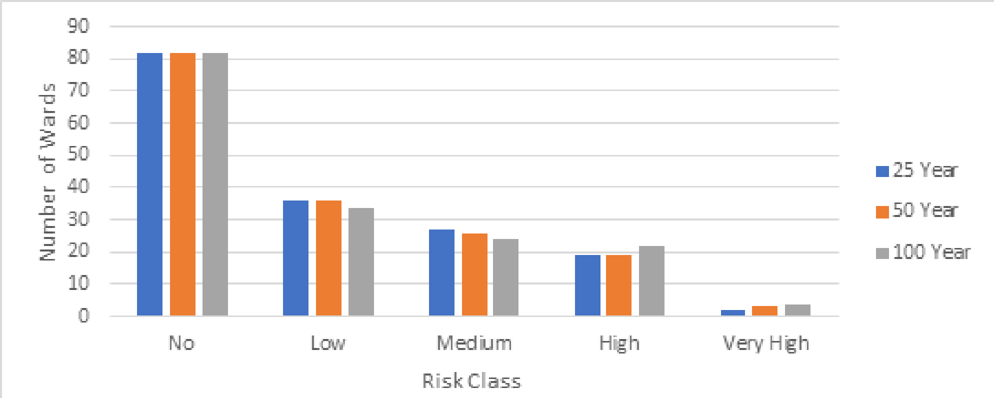


Figure 14: Wards under Risk Class

From the table it can be seen that the larger number of wards is under no risk zone followed by low risk zone and medium risk and high-risk zone and very high-risk zone. Also, it can be seen that the a few numbers of wards are under very high-risk zone and it is mostly located in the adjacent of river courses. These wards are under very high-risk zone because of the high-risk value in the corresponding wards. In 25-year return period flood event, 82 number, 36 number,27 number, 19 number and 2 number of wards lies in no risk, low risk, medium risk, high risk and very high-risk respectively. Similarly, in 50 years return period flood, the number of wards lies under no risk, low, moderate, high and very risk level are, 82 number, 36 number,26 number, 19 number and 3 number respectively. Furthermore, in 100-year return period flood event, 82 number, 34 number,24 number, 22 number and 4 number of wards lies in no risk, low risk, medium risk, high risk and very high-risk respectively. The 25 year ,50 year and 100-year flood event ward risk map is shown figures 15 to 17.

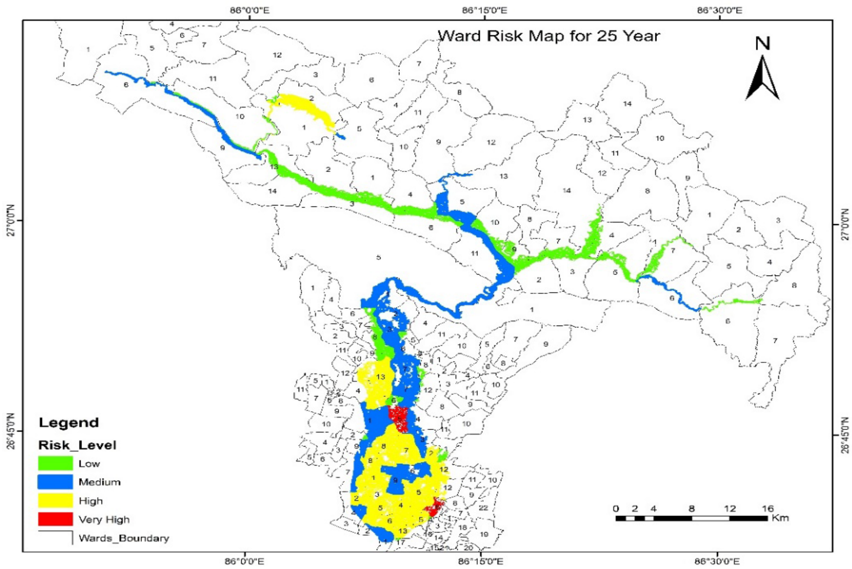


Figure15: Flood Risk Map for 25 Year Food event

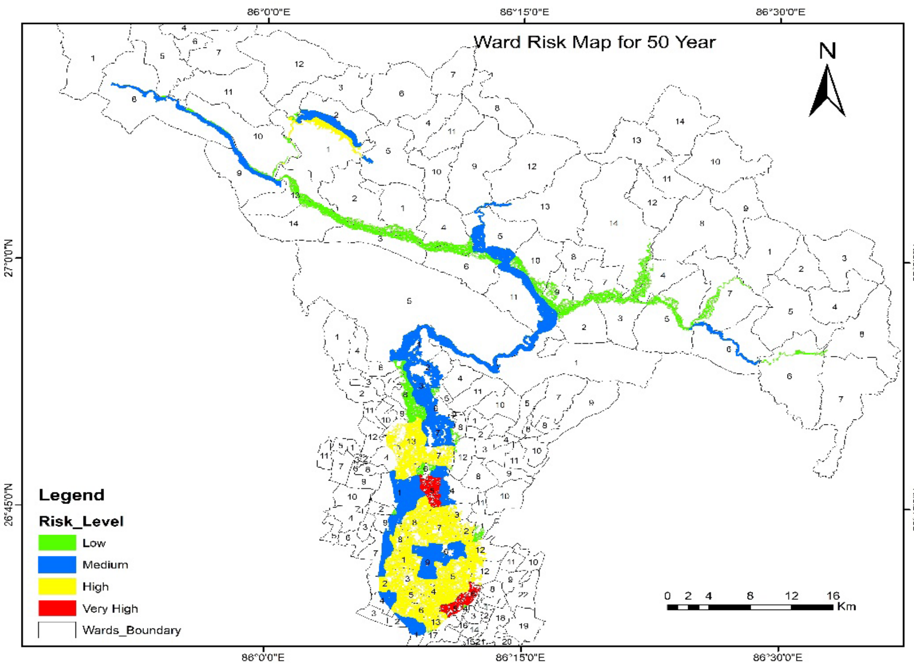


Figure 16: Flood Risk Map for 50 Year flood event

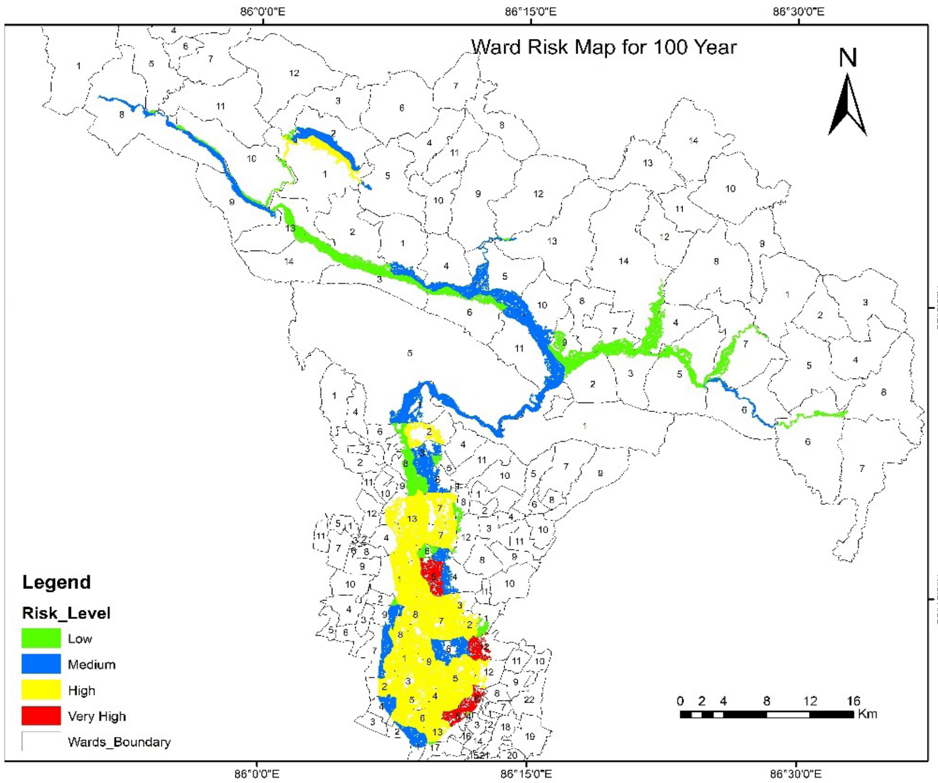


Figure 17: Flood Risk Map for 100 Year flood event

4. Conclusion

For the development of the hydrodynamic model of Kamla River basin HEC-RAS 2D unsteady model has been used in this study. The designed hydrograph has been obtained by using Synder method. The simulated result obtained from HEC-RAS model was validated with the satellite image obtained from Rastrapati Chure conservation program. The percentage of model validity in terms of flooding area is found to be about 95.97 %. The followings conclusion can be made from the study.

- The flood inundation area increases with increase of flood return period. For 2,10,25,50 and 100 years return period flood 198.09 Km2, 231.40 Km2, 242.92 Km2, 249.97 Km2 and 256.68 Km2 area were found to be inundated.
- The flood hazard assessment shows that the most area covers in each return period flood event in under high hazard class and least area covers under the very high hazard class.
- The flood hazard map was prepared using the simulation result by classifying into four hazard level, corresponding to different inundation depth.
- The flood vulnerability map has been prepared with the exposed elements like building and agriculture area.
- The risk map of each wards under the study area was constructed with considering flood hazard and vulnerability. The exposed building, populations and agriculture area are considered for vulnerability factors.
- The result of risk assessment showed that larger number of wards is under no risk zone followed by low risk zone and medium risk and high-risk zone and very high-risk zone for 25 year,50year and 100-year return period flood event.

The study presented the result in the form of risk map can be helpful to the people and decision makers. This map will raise the public awareness regarding the flood risk and information about the flood risk management

Conflict of Interest

Not declared by the authors.

5. References

[1] W. Chen et al., “Flood susceptibility modelling using novel hybrid approach of reduced-error pruning trees with bagging and random subspace ensembles,” J. Hydrol., vol. 575, no. May, pp. 864–873, 2019, doi: 10.1016/j.jhydrol.2019.05.089.

[2] H. Hong et al., “Flood susceptibility assessment in Hengfeng area coupling adaptive neuro-fuzzy inference system with genetic algorithm and differential evolution,” Sci. Total Environ., vol. 621, pp. 1124–1141, 2018, doi: 10.1016/j.scitotenv.2017.10.114.

[3] J. Rentschler, M. Salhab, and B. A. Jafino, “Flood exposure and poverty in 188 countries,” Nat. Commun., vol. 13, no. 1, 2022, doi: 10.1038/s41467-022-30727-4.

[4] MoHA and DPNet, “Ministry of Home and Nepal Disaster Preparedness Network-Nepal Nepal Disaster Report 2009: The Hazardscape and Vulnerability. Jagadamba Press, Kathmandu, Nepal,” 2009, [Online]. Available: https://en.climate-data.org/asia/nepal/central-development-region/kurintar-203057/

[5] B. R. Shrestha, R. K. Rai, and S. Marasini, “Review of Flood Hazards Studies in Nepal,” Geogr. Base, vol. 7, pp. 24–32, 2020, doi: 10.3126/tgb.v7i0.34266.

[6] B. R. Adhikari, “Flooding and Inundation in Nepal Terai: Issues and Concerns,” pp. 59–65.

[7] A. C. Almeida et al., “State of the Kamala River Basin, Nepal,” vol. 8, p. 28, [Online]. Available: https://doi.org/10.25919/10mp-bc20

[8] M. R. Kafle, “(18) (PDF) Comparative Study of Flood Impacts and Damages by Major Trans-Boundary Rivers in Nepal using MCDM,” J. Water Resour. Pollut. Stud., vol. 5, no. 2, pp. 7–17, 2020.

[9] M. Masood and K. Takeuchi, “Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using DEM and 1D hydrodynamic model,” Nat. Hazards, vol. 61, no. 2, pp. 757–770, 2012, doi: 10.1007/s11069-011-0060-x.

[10] M. Farooq, M. Shafique, and M. S. Khattak, “Flood hazard assessment and mapping of River Swat using HEC-RAS 2D model and high-resolution 12-m TanDEM-X DEM (WorldDEM),” Nat. Hazards, vol. 97, no. 2, pp. 477–492, 2019, doi: 10.1007/s11069-019-03638-9.

[11] K. Vashist and K. K. Singh, “HEC-RAS 2D modeling for flood inundation mapping: a case study of the Krishna River Basin,” Water Pract. Technol., vol. 18, no. 4, pp. 831–844, 2023, doi: 10.2166/wpt.2023.048.

[12] D. Aryal et al., “A model-based flood hazard mapping on the southern slope of Himalaya,” Water (Switzerland), vol. 12, no. 2, 2020, doi: 10.3390/w12020540.

[13] S. Niraula and N. M. Shakya, “Study on flood inundation mapping for Ratuwa River catchment using HECRAS 2D,” Proc. 8th IOE Grad. Conf. Tribhuvan Univ., vol. 8, pp. 620–625, 2020.

[14] A. Khan, I. Pathan, and P. G. Agnihotri, “2-D Unsteady Flow Modelling and Inundation Mapping for Lower Region of Purna Basin Using HEC-RAS.” [Online]. Available: www.neptjournal.com

[15] M. Farid, A. Marlina, and M. S. B. Kusuma, “Flood hazard mapping of Palembang City by using 2D model,” AIP Conf. Proc., vol. 1903, no. November, 2017, doi: 10.1063/1.5011619.

[16] R. R. Syafri, M. P. Hadi, and S. Suprayogi, “Hydrodynamic Modelling of Juwana River Flooding Using HEC-RAS 2D,” IOP Conf. Ser. Earth Environ. Sci., vol. 412, no. 1, 2020, doi: 10.1088/1755-1315/412/1/012028.

[17] G. Dahal, R. Krishna, and S. Adhikari, “Optimization of model parameters of HEC-RAS 2D model on flood inundation mapping : a case study of Kankai River Basin,” Proc. 10th IOE Grad. Conf., vol. 10, no. March 2022, pp. 879–887, 2021.

[18] A. Dahal, P. Kumar, and S. Maharjan, “Analyzing the Future Flooding and Risk Assessment under CMIP6 Climate Projection Using HEC-HMS And HEC-RAS 2D Modelling of Babai River Basin,” vol. 8914, pp. 1870–1878, 2022.