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# Flood Hazard Mapping in an Urban Context: A Case Study of Hanumante Stream, Bhaktapur (Nepal)

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**Abstract**

The combination of climate change and rapidly increasing urbanization is posing serious flood risk in urban areas. Climate is increasing the probability of extreme events like flood whereas urbanization is intensifying flood by increasing the number of impermeable surfaces and modifying flow paths. Implementation of traditional flood protection measures along with flood hazard and flood risk management is very crucial at present to prevent urban flood damage[1]. The primary objective of this study is to present a case study on flood hazard mapping and inundation mapping at Hanumate Basin, Bhaktapur using geographic information systems and hydraulic modelling (HEC-RAS 5.0.7). The study also presents the maximum rainfall frequency analysis for different return period for the 4 stations located in the study area. The Hanumante catchment having area of 143 square kilometer is the study area.

The survey data of Hanumante River from High-Powered Committee for Integrated Development of the Bagmati Civilization (HPCIDBC), Guheshwori was taken to generate Digital Elevation Model for extraction of geometrical data for the river. Since the river is not gauged, catchment area proportion method was used to find out the extreme flows with different return periods. The Bagmati catchment at Sankhamul was taken as the reference gauge station. The flood peaks were input into HEC-RAS model to compute the steady flow water levels for different return period floods along the river reach. The results obtained from HEC-RAS were exported to ArcGIS to prepare floodplain maps for different return periods. By overlaying the floodplain map over Google earth from 2005 to 2018 showed that the built-up areas are more vulnerable to flooding.

The flood hazard maps are created using hydraulic and topographic modelling, not historical flood observations, so one can more accurately visualize a wider range of flooding scenarios. Thus the main intent of this study is to fill a critical knowledge gap regarding the extent of urban flooding for a small ungauged Hanumante stream for various return periods. Also the study helps to change public flood perception as it is a key importance of flood hazard mapping. People would be less inclined to live in flood plain areas once they are informed about possible depth of flooding.

**Keywords**

Flood Hazard Mapping, HEC RAS, Urban Flooding

## 1. Introduction

Floods are among the major climate related disasters and cause enormous damage all over the world [2].Flooding, a global phenomenon occurring most frequently among all-natural hazards cause major economic losses, devastation and human lives losses [3]. Urban flooding is a serious and growing development challenge and this challenge is particularly more serious to the residents of rapidly growing cities in developing countries [4]. Rapid urbanization and urban development have significantly increased risk of flooding [5]. The three factors rapid demographic growth, urbanization trends and climate changes are increasing the frequency as well as impacts of floods [6].

According to a research by [7], extreme precipitation due to global warming is the main cause behind increase in frequency of floods. The same research revealed that by 2030s, precipitation is predicted to increase by 14-40 percent and by 2090s the change increase by 52-135 percent. This wide range of precipitation changes is likely to cause more flooding. The warmer climate because of alterations in meteorological pattern is believed to be the main drivers of increased flooding [8]. According to recent

1.5 degrees report by IPCC (2018), there is medium confidence that global warming of 2 degree C would cause significant increase in runoff and flood hazard compared to global warming of 1.5 degree C.

Urbanization in case of Nepal is a new concept. In the last five decades from 1951-2001, there has been sixteen-fold increment in urban population in Nepal while the number of urban centers increased from 10 to 58 in the same time period [9]. This rapid rate of urbanization has contributed to significant transformation of its landscapes resulting in substantial land use changes in new growing urban centers causing impacts on the environment [10] and urban pluvial flooding [11].

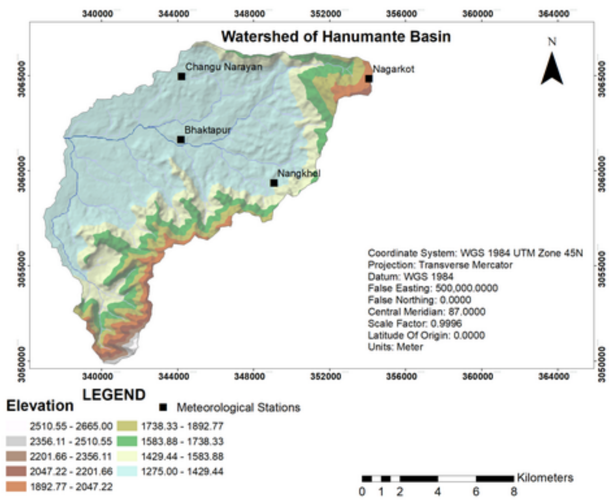


**Figure 1:** Hanumante catchment with meteorological station and elevation

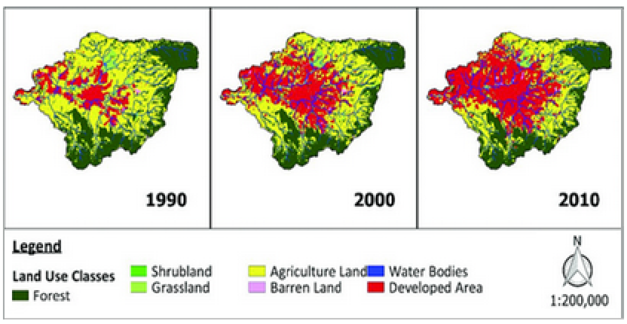


**Figure 2:** Land-use map from 1990 to 2010

Bhaktapur witnessed two major flood events; one in August 27, 2015 and the other in July 12, 2018. According to online newspaper, river encroachment could be one of the reasons behind Bhaktapur flooding [12]. Also, haphazard sand mining as well as encroachment of riverbanks are to be blamed for the flood events [13]. Urbanization in Bhaktapur is happening in expense of cultivable lands and are gradually transformed to built-up area which has increased from 1.8 percent to 24 percent from 1988 to 2015 [14]. In the past three decades for haphazard settlement more than 60 percent of agricultural land has been used which can be clearly illustrated in land-use map as shown in Figure 2 [15].

## 2. Objectives

The major objective of this research is to understand the urban flood event that occurred in the Hanumante Streamr in Bhakatapur (Nepal) in 2018 and more specifically

- To prepare a flood hazard map of Hanumante Stream to show hazard prone areas.
- Understand the implications of urban flooding at hazard prone locations in Bhaktapur.

## 3. Methodology

### 3.1 Data Collection

This study was a quantitative research. The literature study was done through research reports, journals. Topographical data that include DEM, survey data, hydro-meteorological data covering daily precipitation and discharge used for this study. For flood inundation mapping, topographical data are crucial and it is best to use recent and accurate topographical data. Survey data of Hanumante River for a river stretch of 9km was collected from High Powered Committee for Integrated Development of the Bagmati Civilization (HPCIDBC), Guheshwori Nepal. The survey data was used to create DEM in ArcGIS.As one of the main inputs for HEC-RAS is Triangulated Irregular Network (TIN), the created DEM file is later used as an input for TIN creation in HEC-RAS. From Department of Hydrology and Metrology, metrological datas of Nagarkot Station (1043), Bhaktapur Station (1052), Changunaryan Station (1059), Nangkhel Station (1082) and hydrological data of Gaurighat Station (530) were collected. The data was then entered on Microsoft Excel 2013 for necessary computations.

The flood hazard mapping for an river lacking hydrological stations consists of some pre-calculation procedures for hazard parameters before going to the main modeling HEC-RAS and ArcGIS.

### 3.2 Flood Frequency Analysis and Extreme Maximum Rainfall Frequency Analysis

Gumbel's distribution is a statistical method often used for predicting extreme hydrological events such as floods. In this study, flood frequency analysis and extreme rainfall frequency analysis is done using maximum yearly flow and maximum rainfall by the Gumbel's Distribution method. The Quantile Quantile (Q-Q) plot test showed that the flow datasets are normally distributed which means that Gumbel's distribution is suitable for predicting the expected flow in the river.

### 3.3 Estimation of Peak flow of study area

The peak flow of study area for 5, 10, 25, 50 100 and 500-year return periods were calculated using watershed area ratio method.

#### 3.3.1 Watershed Area Ratio Method

In absence of real field discharge data, one of the most common method which is used extensively in several studies for estimating flow in an ungauged catchment is the watershed area ratio method [16]. This method estimates flow for sites where no stream flow are collected by multiplying the measured flow at the nearby stream flow gauging station by the area of ungagged to gaged watersheds [17].

$$Q_{ungauged} = Q_{gauged} * A_{ungauged} / A_{gauged}$$

Where, Q= flow A=watershed area

The reference watershed used in this study to calculate discharge of study site is Bagmati watershed. The main reason behind choosing Bagmati watershed at Sankhamul as reference gauged station is due to geographic proximity, similar catchment characteristics like slope, soil condition and similar climatic condition. As per [18], the mean annual temperature for Kathmandu and Bhaktapur is 12 ºC-18ºC. Also, by analyzing the extreme yearly rainfall of Gaurighat Station (530) and Bhaktapur station (1052), the rainfall pattern is almost similar. This method can be applied if the ratio of gauged site to ungauged drainage areas is between 0.5 and 1.5 [19]. The ratio of gauged site (Bagmati watershed) to ungauged drainage area (Hanumante watershed) lies between 0.5 and 1.5, so this method can be applied.

#### 3.3.2 Calculating Peak flow of gauged station

On the basis of maximum instantaneous flow recorded at Gaurighat Station (530) from year 1991 to 2015, flood frequency analysis for 6 different return periods using Gumbel's method is calculated. The calculated maximum discharge for Gaurighat station is used to calculate flood scenarios for Hanumante station using watershed area ratio method.

### 3.4 Hydraulic Modellling

Assessment of flood hazard by preparing a flood hazard map was carried out by hydrodynamic simulation using HEC-RAS version 5.0.7. The created DEM from survey data of study river stretch was used as an input for Triangulated Irregular Network (TIN) creation in HEC-RAS. The geometric data are created in HEC-RAS in RAS mapper. These geometric data include stream center lines, bank lines, flow paths, cross sections and land use along with Manning's roughness coefficients. For different land use the value of Manning's roughness coefficients is different which is presented in Figure 3 below.

| Land use | Manning's roughness coefficient |
|---|---|
| Roads (asphalt) | 0.016 |
| Landscape and residential vegetation | 0.060 |
| Forest | 0.150 |
| Meadows | 0.040 |
| Arable land | 0.035 |
| Water bodies | 0.035 |
| Stream (natural channel) | 0.035 |
| Stream (modified channel) | 0.027 |
| Built-up area | 0.020 |

**Figure 3:** Manning's roughness coefficients for different land use

### 3.5 Inundation Mapping in ArcGIS

The results from HEC-RAS were used for water surface generation and floodplain delineation. The quantification of flood hazard was made calculating the inundation areas for different categories of depth for each flow situation.

## 4. Result

### 4.1 Bhaktapur Flooding (Analysis of 24 hour Rainfall)

From DHM, the 24 hours cumulative rainfall recorded in 11th, 12th and 13th July for 4 stations located at

Hanumante catchment was collected. The rainfall recorded in 11th, 12th and 13th July is given in Figure 4 below which shows that except Changu Narayan, other 3 stations have recorded over 100 mm of rainfall.

**Table 1:** 24-hr cumulative Rainfall for different stations in Bhaktapur

| Station | Date | Rainfall | Highlights |
|---|---|---|---|
| Nagarkot (1043) | 11th July | 17.5 | 100 mm rainfall falls in between 24 hours period |
| | 12th July | 117 | |
| | 13th July | 41 | |
| Bhaktapur (1052) | 11th July | 10.2 | 122 mm rainfall falls in between 24 hours period |
| | 12th July | 129.6 | |
| | 13th July | 8 | |
| Changu Narayan (1059) | 11th July | 30 | 57 mm rainfall falls in between 24 hours period |
| | 12th July | 76.2 | |
| | 13th July | 19.1 | |
| Nangkhel (1082) | 11th July | 10.5 | 104.1 mm rainfall falls in between 24 hours period |
| | 12th July | 111.7 | |
| | 13th July | 7.6 | |

## 4.2 Time Series Analysis of rainfall for 4 stations

Based on daily rainfall recorded at Nagarkot station from year 1971 to 2017, at Bhaktapur station from year 1998 to 2017, at Changu Narayan from year 1974 to 2017 and at Nangkhel station from year 2000 to 2017, time series analysis. The threshold water level was taken as 100 mm. Figure 5 shows the number of years where rainfall was above the threshold level and Figure 6 shows the extreme maximum rainfall for the 4 stations based on historical datasets.

**Table 2:** Number of days when rainfall greater than 100 mm in 24 hours

| Station Name | Year | Days (rainfall >100mm) |
|---|---|---|
| Nagarkot | 1971-2017 | 10 |
| Bhaktapur | 1998-2017 | 2 |
| Changu Narayan | 1974-2017 | 5 |
| Nangkhel | 2000-2017 | 3 |

**Table 3:** Extreme Maximum rainfall for the 4 stations based on historical datasets

| Station | Extreme Maximum Rainfall (mm) |
|---|---|
| Nagarkot | 179.4 |
| Bhaktapur | 195 |
| Changu Narayan | 165.5 |
| Nangkhel | 191.5 |

Data from Figure 5 indicates that there have been sporadic events when rainfall has exceeded more than 100 mm in 24 hrs expect for Nagarkot in the Hanumante catchment.

## 4.3 Extreme maximum rainfall frequency Analysis

Based on maximum rainfall recorded at Nagarkot station from year 1998 to 2071, at Bhaktapur station from year 1998 to 2017, at Changu Narayan from year 1974 to 2017 and at Nangkhel station the result of 5, 10, 25, 50, 100 and 500 years return period rainfall analysis using Gumbel's method is summarized in Figure 7 below. The result shows that probability of rainfall occurring in any year for all the stations is above 100mm except for Changu Narayan station.

**Table 4:** Maximum rainfall frequency calculation of Bhaktapur, Nagarkot, Changu Narayan and Nangkhel stations

| Return Period (Years) ⇒ | 5 | 10 | 25 | 50 | 100 | 500 |
|---|---|---|---|---|---|---|
| Station | Maximum Rainfall (mm/day) | | | | | |
| Nagarkot (1043) | 109.68 | 125.41 | 14519 | 16(103 | 174.67 | 208A9 |
| Bhaktapur (1052) | 107.98 | 130.35 | 158.6 | 179.56 | 200.37 | 248.45 |
| Changu Narayan (1059) | 95.10 | 108.93 | 126.41 | 139.37 | 152.24 | 181.99 |
| Nangkhel (1082) | 117.22 | 144.53 | 179.04 | 204.64 | 230.05 | 288.77 |

Analysis suggests that the magnitude of rainfall that occurred in 12 July 2018 for Nagarkot and Bhaktapur corresponds to the value for a 10 Year return period event however it's lower for Changunarayan and Nangkhel stations.

Results from Figure 6 and Figure 7 show that, historically there have been incidents where maximum rainfall corresponds to events having a 100 return period for the Nagarkot, Bhaktapur, Changu Narayan stations whereas for Nangkhel station maximum rainfall corresponds to 50 years return period in the Hanumante Stream.

## 4.4 Maximum Discharge Calculation of Hanumate Catchment (Flood scenarios)

### 4.4.1 Watershed area ratio method

The necessary inputs for calculating maximum discharge for project site are the maximum discharge at the reference watershed (Bagmati watershed), area of reference watershed and area of watershed of interest. The area of project site and Bagmati catchment at Sankhamul as calculated using Arc GIS are 143 square kilometer and 74 square kilometers respectively. So, at first the flood frequency analysis for Bagmati watershed was done for 6 different return periods. Then using Watershed area ratio method, the maximum discharge for different return periods calculated for study site is tabulated in Figure 8 below.

**Table 5:** Maximum Discharge at Hanumante watershed using Watershed area ratio method

| Hanumante Watershed | | | | | | |
|---|---|---|---|---|---|---|
| Watershed area ratio method | Return Period (Years) | | | | | |
| | 5 | 10 | 25 | 50 | 100 | 500 |
| Maximum Discharge (m3/s) | 135.14 | 158.50 | 1888.02 | 209.91 | 231.65 | 281.88 |

## 4.5 Steady Flow Analysis

The steady flow analysis showed that the inundation areas were 829288 square meter, 851280 square meter, 873156 square meter, 886108 square meter, 895090 square meter and 912272 square meter for 5-year, 10-year, 25-year, 50-year, 100-year and 500-year return periods respectively showing a moderate increase which is shown in Figure 9 below.

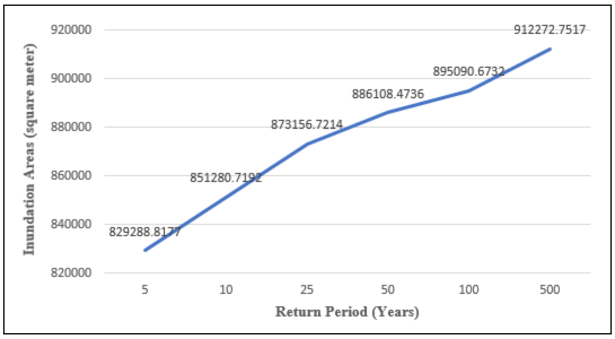


**Figure 4:** Inundation areas with respect to different return periods

## 4.6 Flood Hazard Analysis

Based on hydrological parameters like flood depth, the hazard aspect of flood was analyzed, the result of which is summarized in Figure 10 and Figure 11 below. It is observed that the inundated area which increased from 4.5 percent to 20.62 percent has flood depth of greater than 3 m with increase in return period.

**Table 6:** Area inundated for different return period as per depth

| Water Depth (m) | Flood Area ($m^2$) 5-year flood | 10-year flood | 25-year flood | 50-year flood | 100-year flood | 500-year flood |
|---|---|---|---|---|---|---|
| <1 | 261034 (31.48%) | 238144 (27.97%) | 205576 (23.54%) | 189959 (21.44%) | 175210 (19.57%) | 144004 (15.79%) |
| 1 – 2 | 317274 (38.26%) | 323417 (37.99%) | 329936 (37.79%) | 323359 (36.49%) | 313218 (34.99%) | 289922 (31.78%) |
| 2 – 3 | 213632 (25.76%) | 228322 (26.82%) | 244316 (27.98%) | 255529 (28.84%) | 266336 (29.76%) | 290240 (31.82%) |
| >3 | 373458 (4.5%) | 61398 (7.21%) | 93328 (10.69%) | 117261 (13.23%) | 140325 (15.68%) | 188104 (20.62%) |

Figure 5 shows that the total area under classified water depths of 2-3 m and greater than 3 m increased with increase in intensity of flood.

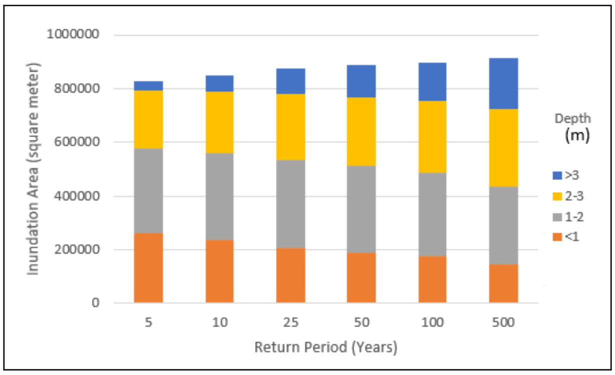


**Figure 5:** Return Period - Flood Depth Relationship

The flood hazard maps of the study area prepared by overlaying flood depth with Google earth of river are shown in Figure 12,13,14, 15, 16 and 17 for 5-year, 10-year, 25-year, 50-year, 100-year and 500-year return periods respectively.

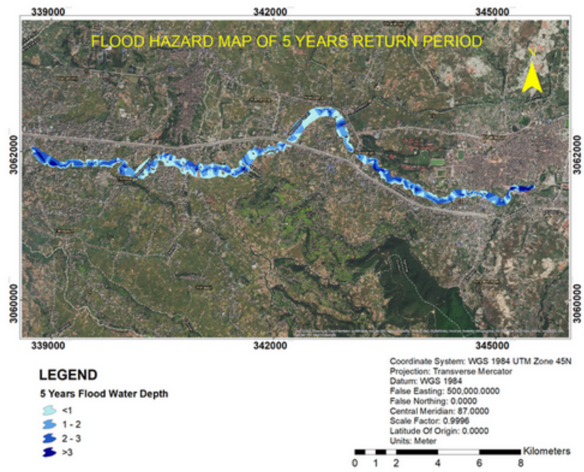


**Figure 6:** Flood hazard map of 5 years Return Period Flood

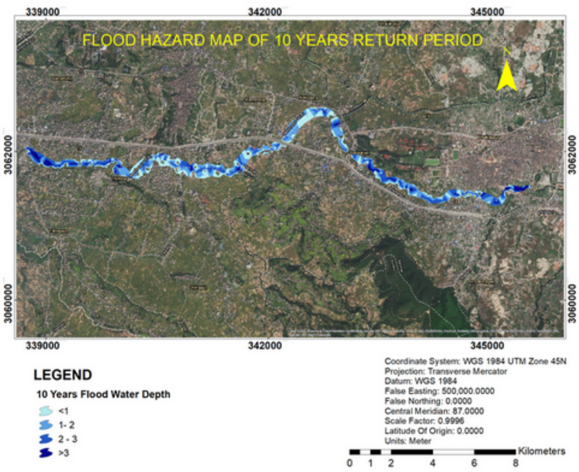


**Figure 7:** Flood hazard map of 10 years Return Period Flood

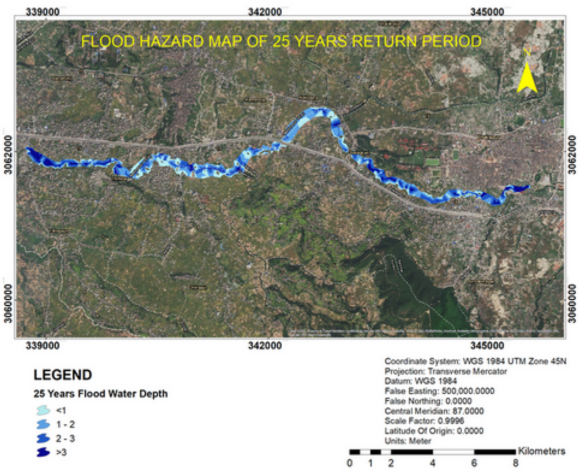


**Figure 8:** Flood hazard map of 25 years Return Period Flood

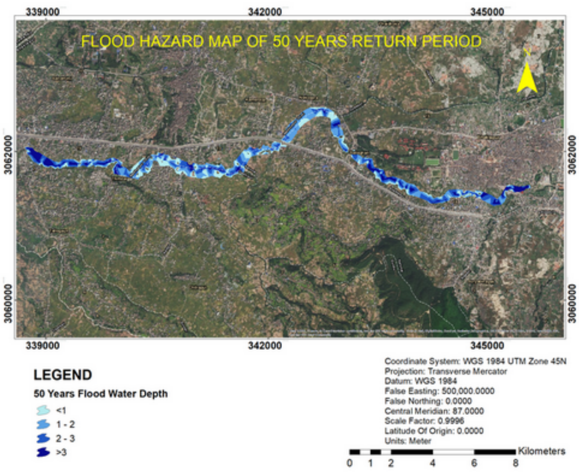


**Figure 9:** Flood hazard map of 50 years Return Period Flood

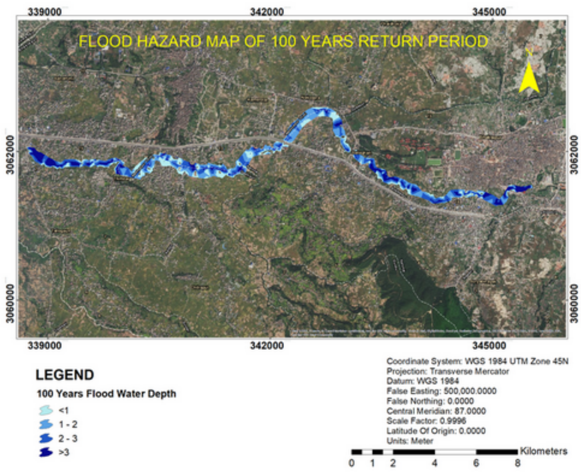


**Figure 10:** Flood hazard map of 100 years Return Period Flood

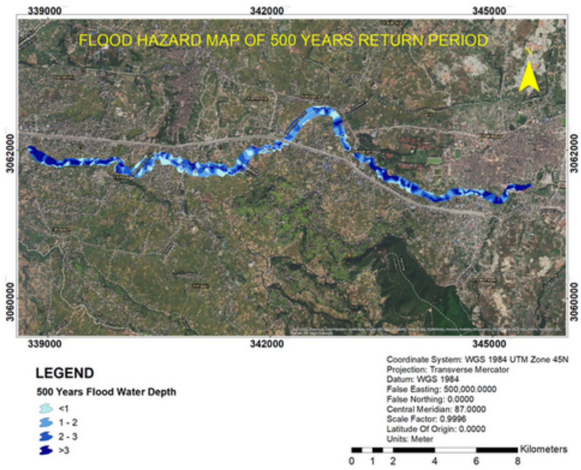


**Figure 11:** Flood hazard map of 500 years Return Period Flood

## 5. Discussion

### 5.1 Change in Land use across study area

The increase in urban cover along with built-up areas considerably increase the level of imperviousness. Increase in impermeable surfaces cause increase run-off thereby reducing the ability of land to absorb rainfall-runoff. Study of land cover in Kathmandu valley has showed increased imperviousness from 18.71 percent in 1990 to 73.67 percent in 2010. To compare the land use for different years, 6 images for the study area were clipped from Google history imagery from year 2005 to 2018. These images taken from Google earth for different series of time showed how land use and land cover had changed over the period. Most of the agricultural lands in that area were transformed into urban/built-up lands. The major land use transition during the period of 2012 were observed. The main reason behind this transition is construction of Tinkune- Suryabinayak road in 2011 that significantly enhanced the urbanization process in the study area. The agricultural lands mostly near the road and Hanumante River, were converted to built-up areas.

The research by [20] have explored how increased imperviousness and extreme precipitation events because of climate change increase urban runoff and flooding for Kathmandu Valley which includes my study location. So, based on the research and the visual results as seen from the images clipped from Google earth, it can be said that likelihood of flooding in the study area is because of increased level of imperviousness due to land use change.

## 5.2 Areas at Risk in Bhaktapur

The radhe-radhe area at Thimi, Bhaktapur is one of the area at risk. Flood hazard map of this area is prepared with Open Street Map as base map. It can be clearly seen from the map how the areas at the flood plain are at risk of flooding. As the flood-return period increases, the area of inundation for 4 different categories of flood water depth increases. The maps shown in Figure 18, 19, 20, 21, 22 and 23 below for 6 different return periods provide insight into the most exposed and vulnerable areas.

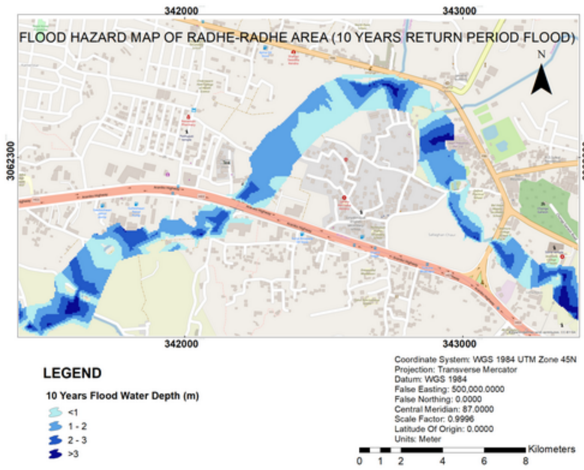


**Figure 13:** Flood hazard map (Radhe-Radhe area) of 10 years Return Period Flood

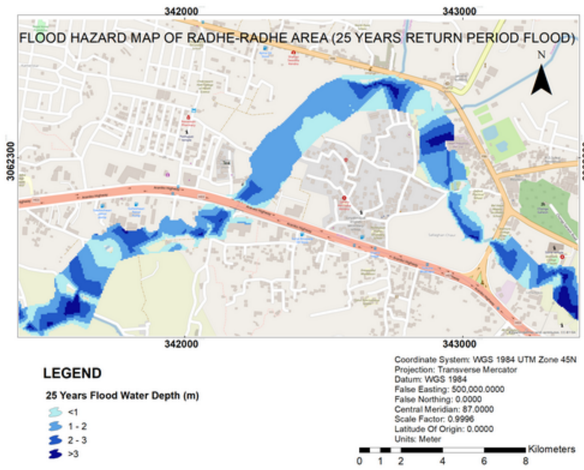


**Figure 14:** Flood hazard map (Radhe-Radhe area) of 25 years Return Period Flood

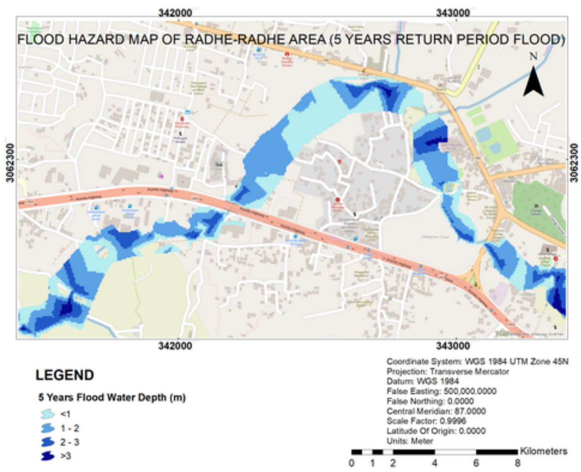


**Figure 12:** Flood hazard map (Radhe-Radhe area) of 5 years Return Period Flood

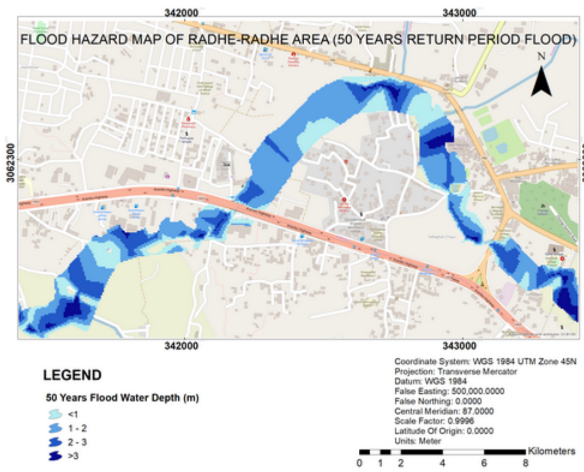


**Figure 15:** Flood hazard map (Radhe-Radhe area) of 50 years Return Period Flood

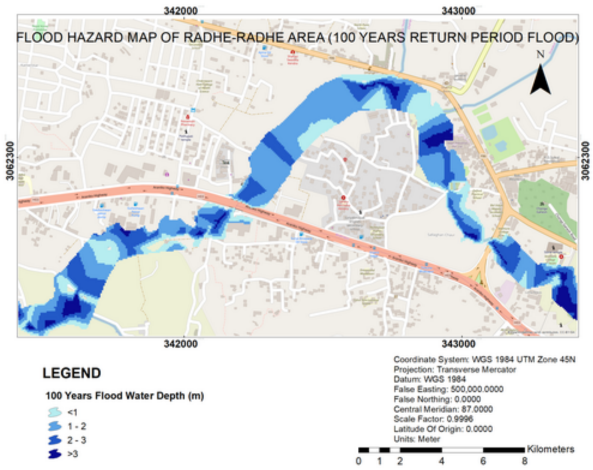


**Figure 16:** Flood hazard map (Radhe-Radhe area) of 100 years Return Period Flood

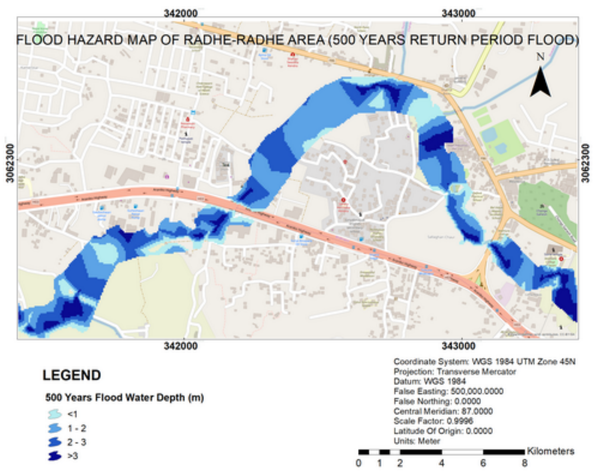


**Figure 17:** Flood hazard map (Radhe-Radhe area) of 500 years Return Period Flood

### 5.3 Implications of climate change on urban flooding

The contribution of Nepal as greenhouse gas emitter is less than 0.03 percent. Despite the lower emissions, Nepal is facing consistent and continuous warming and extreme variability in rainfall [21]. The future projection on precipitation shows an increase in rainfall in the range of 15-20 percent all over Nepal [22]. Erratic rainfall during summer cause increased flooding due to excessive surface runoff. In case of urban areas, the urban services like paved street, roofs, and parking lots absorb less rainfall-runoff. This reduces infiltration of water to the ground and accelerates the runoff thereby resulting in urban flooding.

Climate change resulting in increased frequency and intensity of rainfall leads to extreme events like urban flooding in any urbanized with increased imperviousness. How to cope with the imminent threat of climate change and land use change in urban flooding should be the new focus of Nepal. A focus should be given to increase pervious area in urbanized areas. Also, land use regulations should be strictly enforced by all concerned authorities so as to prevent construction of buildings along the flood plains. For easy infiltration of surface runoffs during rainfall, adequate space should be maintained within urban landscape.

## 6. Conclusion

This study presents a systematic approach in the preparation of hazard map with the application of HEC-RAS and GIS for a small stream Hanumante in an urban context in Bhaktapur.

- The water depth for different return-period floods shows that the levels of inundation increases for increase in return period floods, but ground based validation is required which was not possible and is beyond the scope of this research (requires real time satellite imagery).
- Flood hazard maps for Radhe-Radhe area helped to visualize the exposed and vulnerable areas that are at risk.
- This research has filled a critical knowledge gap regarding the extent of urban flooding for a small ungauged stream Hanumante for various return periods.
- Google satellite imagery of the study area from year 2005 to 2018 shows that the basin is encroached by the unmanaged urbanization which has led to increase in flood risk in specific areas of the Hanumante Stream.

## 7. Limitations of Research

Due to data gaps, there are few limitations of this research which are listed below

- The area ratio method provides discharge estimates for Hanumante Stream which may not represent the actual discharge of the study catchment and also has many inherent uncertainties in the values due to assumptions in Manning's co-efficient.

- Flood plain mapping was conducted on 40 m section along the river stretch (20 m towards each bank from river center) with 1 m contour.

However, in absence of further study, this may be considered satisfactory for the time being.

## 8. Recommendation

Based on analysis and literature review, following recommendations are made to the policy makers and concerned authority. The flood hazard mapping of Hanumante catchment is carried out under major constraints of data availability. For future studies, following recommendations are made:

- Due to unavailability of discharge measuring gauging station in the study site, area proportion method was used for discharge calculation which may not represent the true discharge of the study catchment. So, it is recommended that the gauging stations should be established in the catchment if possible with support of Department of Hydrology and Meteorology.
- The effective waterway of Hanumante river has been reduced over the years due to silting. According to Department of Water Induced Disaster Management, Hanumante needs 50 meters width to pass flood effectively. However, the recent survey data by HPCIDBC shows that Hanumante has minimum width of 8 m in some sections. Thus, it is recommended to the concerned authority to implement suitable measures to increase the carrying capacity of the river. There is a need to work with local governments in this respect.

## 9. Areas for Future Research

The areas for the future research are listed as

a) In this study, inundation mapping was done for a river stretch of 9 km. For true representation of the affected areas by flooding, the entire catchment needs to be analyzed.

b) Flooding was assessed only in the main Hanumante channel. The other reaches that contribute to flood hazard in main river channel are not considered. So future research considering flow from other river reaches can be done.

c) To understand the impacts of climate change on urban flooding statistical downscaling under different scenarios of climate change can be done.

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