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Flood Hazard and Risk Assessment of Settlement at the Bank of Bagmati River of Kathmandu Valley, Nepal

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Abstract

Bagmati River originates from Northern hills of Kathmandu valley and flows through the middle of the valley. Kathmandu valley is vulnerable to flood hazard due to rapid encroachment of settlement in flood plains of the Bagmati River. This objective of this study is analyzing the flood hazard and risk of settlement at the bank of Bagmati River from Shankhamul to Balkhu of Kathmandu valley and the expected number of people affected. The flooded areas along the catchment area have been mapped based on the flow rates for different return periods using the HEC-RAS model and GIS for spatial data processing and Analysing the result from HEC-RAS 6.3.1. The areas along the Bagmati River from Shankhamul to Balkhu in the study area were simulated to be inundated for 50 and 100 years return periods. An inundation map displays the spatial extent of probable flooding for different scenarios and can be present either in quantitative or qualitative ways. The flood inundation maps for 50 and 100 years return periods were prepared using HEC RAS and Risk on the basis of depth map generated from Arc Map GIS. Population under risk is analyze on the basis of population density and Inundated area. The major findings in the study is 31391 & 32141 Population and 1.835575 & 1.879375 km2 area are in the inundated in 50 and 100 years return Period respectively. Therefore, proper flood management can be adopted to reduce the adverse effects of flooding of Settlement living at the bank of Bagmati River.

Key words: Bagmati river, Flood Management, Hydrograph, Vulnerability

Introduction

Flood is one of the striking water induced disaster that hits most of the part of the world. In Nepal also it is one of the serious disaster which affect the human lives and huge amount of property. The increase of population and squatter settlements of landless people living at the bank of the river has tremendous pressure in encroachment of floodplain making them vulnerable to flood damage [4].

In South Asia, there is an increasing trend in the number of people affected by floods. India has the highest number of people affected by floods followed by Bangladesh. In the period from 1976 to 2005, 332 flood events killed about seven million and affected billion people 1 in South Asia [2]. Developing countries are particularly vulnerable to extreme weather events especially given the current climatic instability which can cause substantial economic damage [11].

Concerns for flooding and the associated human impacts are clearly of global significance, especially when allied with the fears of climatic change and associated changes in rainfall events and sea level rise [9]. The rapidly growing urban environments in many areas correspond with a lack of urban planning strategies, the deterioration and lack of capacity of urban drainage infrastructure and an increased rate of development on floodplains. Floods that cause substantial devastation in Nepal are triggered by five different mechanisms: continuous rainfall and cloudbursts, glacial lake outbursts, landslide dam outbursts, failure of infrastructure, and sheet flooding or inundation as a result of excessive rain, bank overflow, or obstruction to the flow from infrastructural development. According to [6] Nepal falls in 11th position on disaster venerability in the world and half of its population is under the threat of four types of disaster at a time including flood. Nearly 77% of the total losses caused by water-induced disasters – floods, landslides, and avalanches occur where in the Terai region the main water-induced disasters are floods.

Floods have always been natural disasters, which are associated with human and financial losses and have influenced human's life [1]. While the number of deaths has not been increasing, there have been observed increases in the total number of people affected and monetary damages [13]. Floods are natural events and not only replenish alluvial soils, substantially increase the yield of the land, and sustain rich habitat for natural systems, but also inflict substantial damages on human activities in the floodplain [12].

The Bagmati River emerge into the Kathmandu from steep and narrow mountain gorges, they spread out with an abrupt gradient decrease causes deposition of the bed load, changes in river course, and frequent floods. Each year, floods of varying magnitudes occur due to intense, localized storms during the monsoon months (June to September). The settlement at the bank of Bagmati river of Kathmandu valley increases rapidly and population density is high. People residing in settlements having problems like improper sanitation, unhygienic environmental conditions, social, economic, health, educational and cultural. The informal buildings made of GI sheets and some of houses are solid, due to their generally poor or non-existent structural detailing and the material used for their construction, are particularly vulnerable to water infiltration and seepage during extreme rainfall and/or flooding. The lack of formal engineering criteria in the construction of informal settlements together with their generally poor construction quality renders them particularly vulnerable to extreme natural phenomena [5].

Bagmati River Basin and settlement of Kathmandu

The Bagmati River is the main cradle of the Kathmandu valley having very rich in cultural as well as aesthetic value. The Bagmati River originates in Baghdwar of Shivapuri hills in the north of the Kathmandu Valley. The river is fed by numerous tributaries originating from the Mahabharata and Siwaliks range before it reaches the Terai at Karmaiya and to the Gangetic plain. The total catchment area of the Bagmati River is about 157 sq. km with the length of 44 km from its origin at an elevation of 2732m to Katuwal daha, which lies at an elevation of 1140m. The Bagmati is the principal river of the Bagmati basin in Nepal. The Bagmati basin is characterized as medium or dry basin fed by springs and monsoon rainfall [3].

The Bagmati river system includes seven tributaries - Bagmati, Bishnumati, Dhobikhola (Rudramati), Manahara, Nakkhu, Balkhu and Tukucha (Ichhumati) rivers and the five sub-tributaries Godavari, Hanumate, Sangla, Mahadev and Kodku Khola. The water flowing in the Bagmati River is considered holy and is used for cultural and ritual ceremonies practiced at the many significant temples located along its banks. In 1985 it was estimated that there were only 17 settlement communities in Kathmandu, but now the number has grown to 40. There are a total of 12,726 people (6,612 males and 6,114 females) living in 2,735 households in the

40 settlements of the valley [9]. Similarly, about 2.9% of the total population of Kathmandu lives in informal settlements (KMC/ WB, 2001).

Table 1: Name of River and Settlements close to bank of river of Kathmandu valley

S.N	River of Kathmandu valley	Name of Settlements
1	Bagmati River	Shanti Nagar, Bijay Nagar, Jagrit Nagar, Gairigaun, Chandani Tole, Pragati Tole, Kalimati Dole, Kimal Phant, Bansighat, Kuriyagaun and Sankhamul
2	Bishnumati River	Dhikure Chouki, Kumaristhan Buddhajyoti Marga, Balaju Jagriti Tole, Sangam Tole, and Ranibari
3	Hanumante River	Manohara Bhaktapur
4	Dhobikhola	santi Binayak, Devi Nagar, Bishal Nagar, Kupondole and Pathivara
5	Tukucha Khola	Narayantole, Maharajgung and Khadipakha Maharajgung
6	Others location	Palpakot, Anamnagar, Maijubahal, Kumarigal, Radhakrishna Chowk, Mulpani, Kapan Dhungen, Subigaun, Ramhiti, Mahankal, Dhumbarahi Sukedhara, Mandhikhatar, Galfutar, Ramghat, Dhaukhel and Bhimmukteshwor

Above table shows number of settlement and household population of settlement, it shows maximum number of household and population along the Bagmati River. It is a question that the existing morphology of a river system can accommodate these frequent and prolonged high floods. The other question is the increasing settlement at the bank of Bagmati River modifying the floodplains of river systems. All these factors contribute to the increasing damages and risks caused by floods. Due to fast growing and opportunities in Kathmandu valley, increasing Settlement encroachments which make the population more vulnerable to frequently occurring floods.

Those factors emphasize the importance of mitigating flood related disasters of settlement. At present structural measures are not suitable in that task due to the question of sustainability of such measures. Most of the time non-structural measures like flood forecasting, proper early warnings and conducting awareness programs among the flood affected community etc, can be very effective. Modelling of watersheds with modern technology makes this easy. Application of GIS and remote sensing technology to map flood areas will make it easy to plan non-structural measures which reduce the flood damages and risks involved. HEC RAS is one-dimensional hydrodynamic model capable of performing water surface profile calculation for steady and unsteady flow in natural or constructed channels [7]. It will be a great benefit to the people to implement a flood management program that consists of the digital data were overlaid on the image and flood hazard mapping was done.

Developing reliable watershed simulation models and calibrating as well as validating them for watersheds with measured and simulated data is a challenging issue [3]. The study presented here consists of hydraulic modelling and flood damage assessment focusing on the settlement near to Bagmati river of from Balkhu to shankhamul. The hydraulic model of the Bagmati stream bed was developed using the Hydrologic Engineering Center's River Analysis System (Hec-RAS).The flooded Area of settlement was identified with Arc GIS Software. The study presents Practical action and solution to increase safety of settlement by flood protection in the study area of Kathmandu. The study focused on impact of flood and assessment of the proposed flood mitigation measures and the selection of the best alternative of the flood protection for settlement settlement1 at the bank of river.

2. Materials and Methodology:

The case-study focuses on flood risk assessment for the settlements located from shankhamul (27°40'43.16‖ N, 85°20'1.26‖ E) to balkhu (27°41'5.2‖ N, 85°17'59.3‖E) near to bagmati river of Kathmandu valley. The settlements of study area are Shankhamul,UN park, Balkhu are lies in flood-prone area of Bagmati River. The flood hazard mapping is created between Shankhamul to Balkhu. The River originates in the Kathmandu Valley,which comprises about 15% of the area of the Bagmati basin in Nepal.

The data used in this study are Settlement Data and Hydrologic data which includes DEM of Bagmati River Catchment of Spatial resolution 5x5 m collected from Department of Water Resource and Irrigation analysis daily maximum river discharge data from gauge stations 550.05 for a period 1992 to 2010 years collected from Department of Hydrology and Meteorology. Land use data from USGS, GIS data from department of survey, and others various data from Cross sections along the river channel created by the HEC-RAS, different

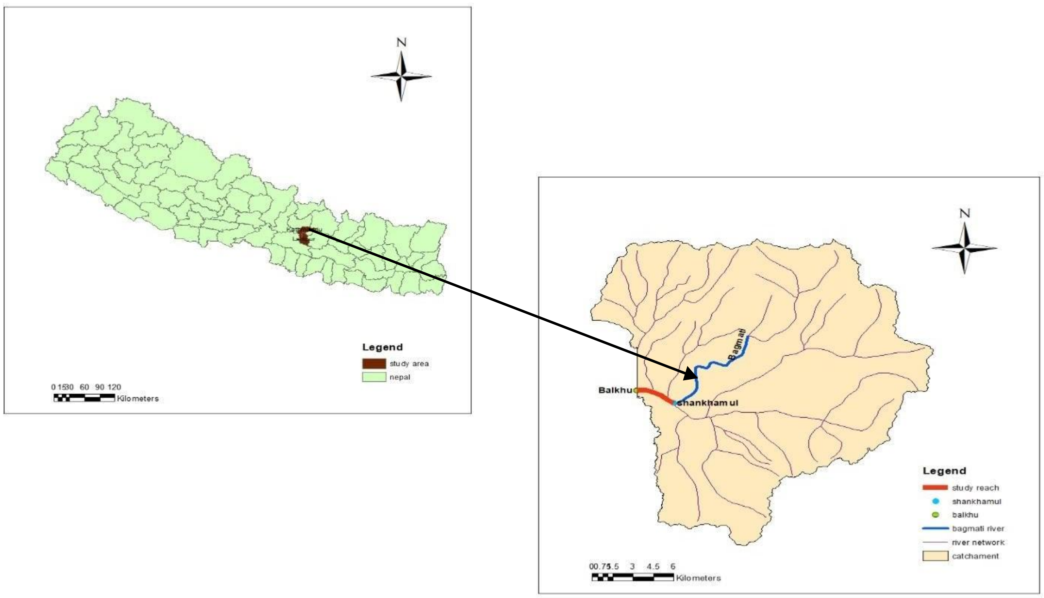

Figure 1: Study Area of Bagmati River Basin (Produce From GIS)

sources, like college library, ICIMOD library, Central Bureau of Statistics, and Department of Survey.

From the data various analysis was carried out like hydrograph analysis, Catchment area ratio Analysis, flood frequency ratio analysis, vulnerability analysis of settlement, Flood risk analysis of settlement and Flood plain mapping. The general method for creating floodplain maps for a river has following major stages:

Step 1. Setting up the HEC-RAS model

Step 2. Creating RAS

Step 3. Adding river attributes

Step 4. Creating RAS mapper

Step 5. Run HEC-RAS model.

Step 6. Export HEC-RAS Output

Step 7. Mapping inundated areas in HEC-RAS and Analysis of Output Result in GIS

2.1 Mapping inundated areas in HEC-RAS and Analysis of Output Result in GIS

Inundation area with depth can be seen in RAS mapper and output exported is analysed in GIS. Classify different depth area and Hazard and Vulnerability and risk map are generated and data find out.

Floods are prevalent and recurring natural hazards that disrupt social and economicactivities. This hazard leads to many fatalities and extensive damage to livelihood systems, property, infrastructure, and utility services (Amarasinghe et al. 2020). This can be attributed to various factors, including rising urbanization, increased developmental and economic activities in flood plains, and global warming. Recent research has also shown that large-scale human interference in nature's order (deforestation, increased sedimentation rate in river channels, intrusion of human settlement in riverbank areas, etc.). The floodplain mapping for this study was done with ArcGIS (Arc Map 10.4) and HEC-RAS(6.3.1version). The processing stage was done completely within HEC-RAS using the river geometry prepared in the previous stage. The final stage consists of analysing the results from the HEC-RAS model within ArcMap.

No of settlement household were used for assessment of vulnerability of flood prone areas. Vulnerability was assessed for using data of no. of household. The household Polygon was overlaid with flood extent maps corresponding to 50 and 100 year return period flood events. Household vulnerability maps were produced corresponding to 50 and 100 year return period floods. Considering risk as a function of Hazard & Vulnerability, map multiplication was done in ArcGIS environment to generate the Risk Maps corresponding to 50 and 100 year flood event with respect to household. Then risk of settlement is obtained by multiplying risk map with population.

Flow chart of the whole process is shown below:

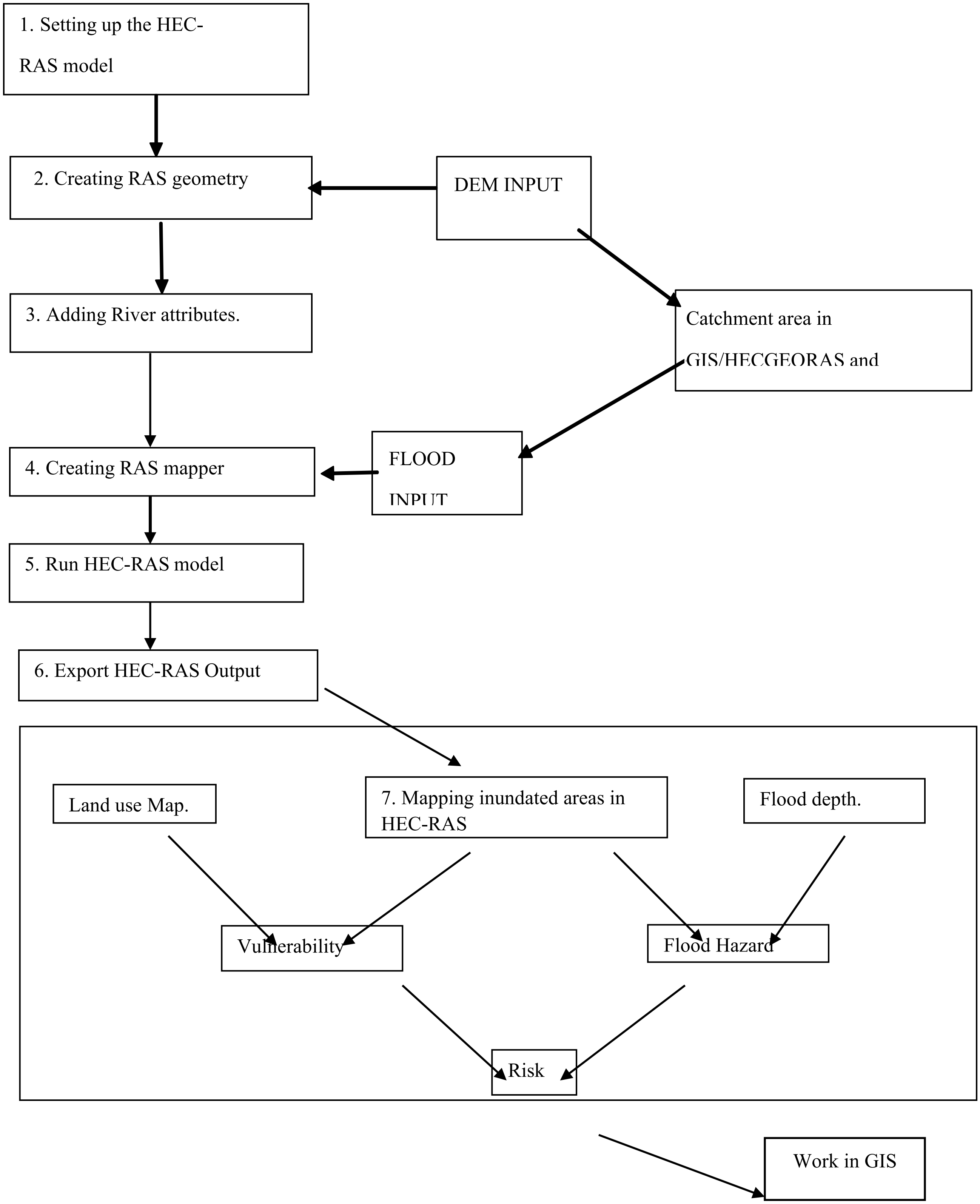

Figure 2: Flood Hazard Modelling Flow Chart

3. Result and Discussion:

The average size of household of settlement of Bagmati River is 4.5 (10). Kathmandu District is a district located in Kathmandu Valley, Bagmati Province of Nepal. It is one of the 77 districts of Nepal, covers an area of 413.69 km2 (159.73 sq mi), and is the most densely populated district of Nepal with 1,081,845 inhabitants in 2001, 1,744,240 in 2011 and 2,017,532 in 2021. The administrative headquarters of Kathmandu district is located in Kathmandu and population density of Kathmandu metropolitan city is 17,103 per square kilometre (Kathmandu District - Wikipedia), With the help of formula Population =population density in per square kilometer * area in square kilometer population was calculated and shown in table.

3.2 Hydrograph Analysis

Hydrograph is plotting of mean maximum monthly discharge of gauge station 550.05 at Khokana of Bagmati River can be seen in figure below. Maximum discharge of each month of the year1992 to 2010 taken. Mean monthly maximum discharge of each month is obtained by average of maximum discharge of each month of each year.

Table 2: Mean Monthly discharge of Bagmati River

Month	Bagmati River discharge(m3/s)
Jan	9.11
Feb	7.27
Mar	5.90
Apr	7.38
May	20.24
Jun	72.03
Jul	220.20
Aug	205.09
Sep	108.71
Oct	29.75

Nov	11.35
Dec	8.85

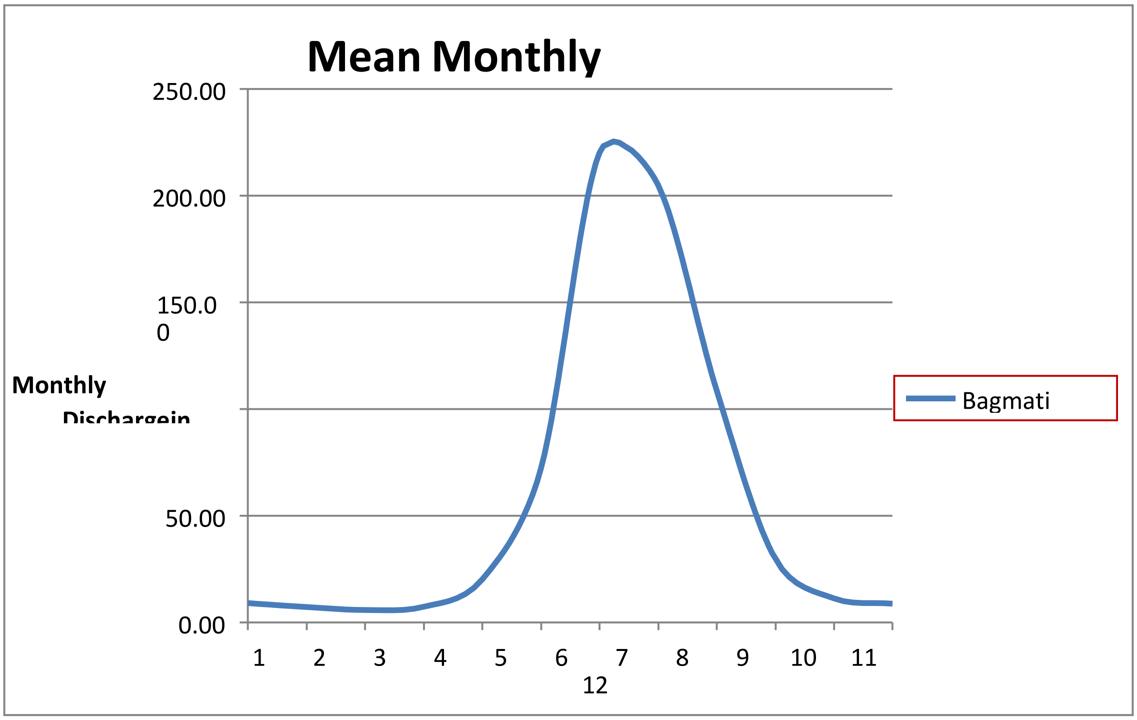

Figure 3: Mean monthly Hydrograph of Bagmati River

3.3 Catchment Area Ratio Analysis

The Catchment area of Gauge station (550.05) and study area at Balkhu of Bagmati Riverare 606 & 445.40 km2 respectively as shown in table 6 below.

Table 3: Catchment area of Bagmati Rivers

S.N.	Location	Catchment Area (km2)	Area Ratio
1	Gauge station(550.05)	606	

2	Balkhu (27º41’5"N, 85º17'58‖E)	445.4	0.7349

Cathment area of Bagmati River At Balkhu

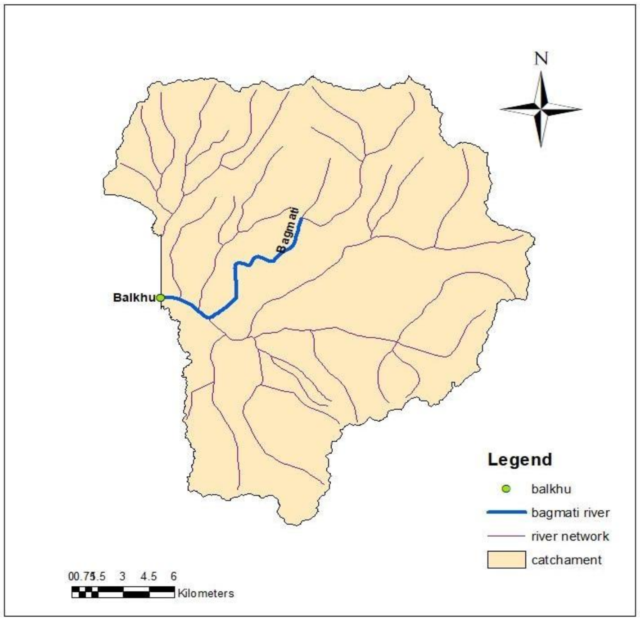

Figure 4 : Catchment of Bagmati River for study Area at Balkhu

Cathment area of gauge station(550.05) 0f Bagmati River

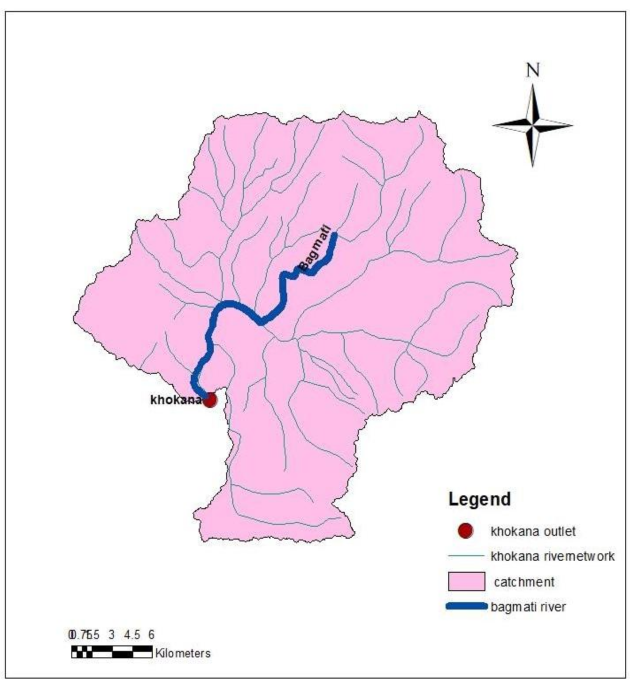

Figure 5: Catchment of Bagmati River of gauge station (550.05) at Khokana

Table 4: Maximum Discharge of gauge station and study area at Balkhu of Bagmati River

S. N.	Year	Q_550.05(Khokana)m3/s	Area Ratio (A_Balkhu/ A _550.05)	Q_Balkhu m3/s
1	1992	103	0.735	75.705
2	1993	447		328.545
3	1994	318		233.73
4	1995	230		169.05
5	1996	266		195.51
6	1997	367		269.745
7	1998	501		368.235
8	1999	349		256.515
9	2000	331		243.285
10	2001	211		155.085
11	2002	814		598.29
12	2003	265		194.775
13	2004	195		143.325
14	2005	197		144.795
15	2006	122		89.67
16	2007	340		249.9
17	2008	103		75.705
18	2009	348		255.78
19	2010	221		162.435

The above table shows the discharge of study area at Balkhu Outlet using CAR Method from year 1992 to 2010.discharge at Balkhu calculated by multiplying discharge of gauge station with area ratio of catchment.

3.4 Flood Frequency Analysis

Flood frequency analysis is a used calculates flow values corresponding to specific return periods or probabilities along a river. Using annual peak flow data that is available for a number of years At Balkhu of Bagmati River, flood frequency analysis is used to calculate using Gumbel's, Log Pearson Type III (LP III) and the Log Normal (LN) Method are summarized below in Table 2.

The Table 5 shows that flood frequency analysis calculate by Gumbel showed discharges of 610 and 690 m3/sec for 50-years and 100-years return periods respectively, which were slightly higher as compared to the results obtained by Log-pearson type III Distribution and, Log Normal method, Maximum discharge obtained from Gumbel method of different return Period is used for modelling.

Table 5: Flood frequency analysis using Gumbel's, Log Pearson Type III (LP III) and theLog Normal (LN)

Return period	Gumbel (m3/s)	Log-Pearson type 111 Distribution (m3/s)	Log Normal Distribution (m3/s)
2	203.7	195	195
5	333.9	303	304.5
10	420.1	382	384.4
20	502.8	463	466
50	610	576	579
100	690	668	669
200	769.9	765	763
500	875	903	895.5

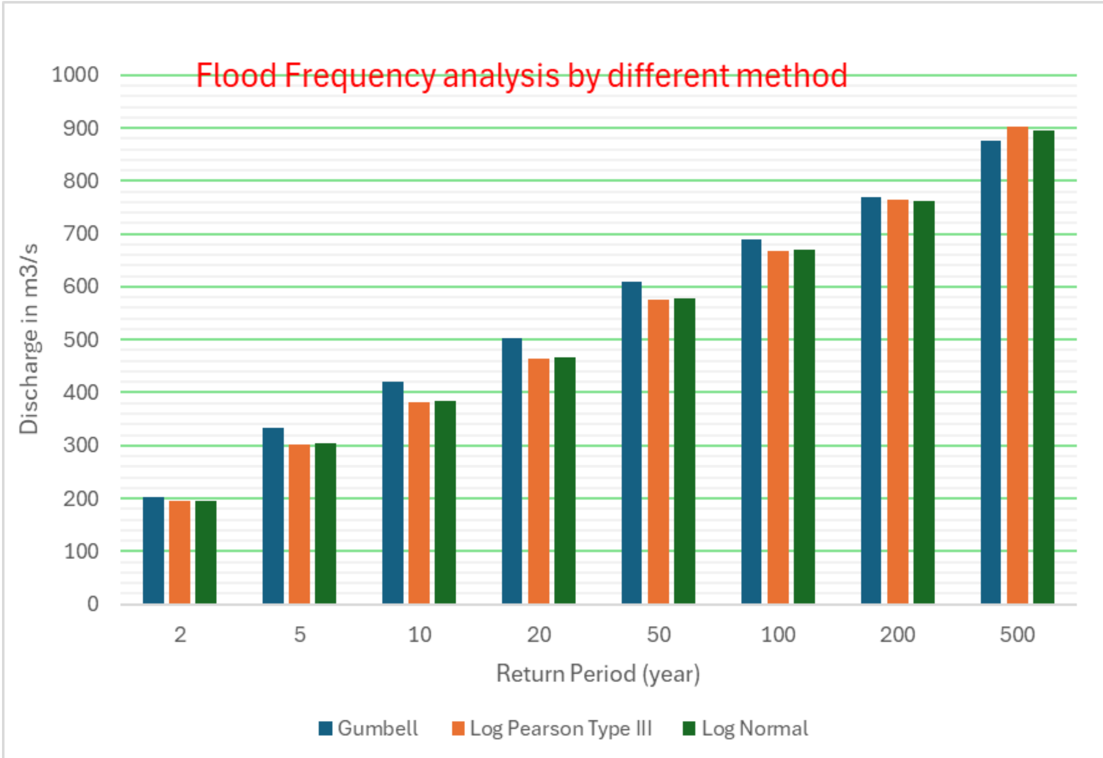

Figure 6: Flood frequency Analysis results in different Method

3.4 Flood Hazard Mapping Analysis

The floodplain mapping for this study was done with ArcGIS, HECGeoRAS, and HEC- RAS. The Preprocessing stage consisted mostly of model input data preparation and was done in ArcGIS using the HECGeoRAS extension. The processing stage was done completely within HEC-RAS using the river geometry prepared in the previous stage. Thefinal stage consists of analyzing the results from the HEC-RAS model. Within ArcMap. HEC-GeoRAS helps in creation of the data needed for the HEC-RAS model and the transfer of data between ArcGIS and HEC-RAS.

The preprocessing stage consisted mostly of collecting and preparing data for the hydraulic model. To begin, a section of the major Bagmati River was defined in the study area. Once the study area was defined, the features that might be affected in the event of flooding can be deduced. In order to create the necessary Bagmati river geometry for HEC-RAS, elevation data were needed. Digital elevation model data of 5m resolution is use as shown in figure. The elevation data were converted to a triangulated irregular network (TIN) elevation model, then the next step was to create the river geometry in ArcGIS (Figure).

The HEC-GeoRAS extension was used to set up the necessary features that would be needed for the HEC-RAS model (i.e., stream centerline, bank lines, cross sections, etc.). HECRAS uses these features to obtain an accurate layout of the river and to establish the cross-sectional elevations of the potential floodplains. The cross sections must extend far enough to ensure that all water from the flood is contained within the cross-sectional area. Methods for setting up the model using HEC-GeoRAS were taken from the HEC-GeoRAS user manual. The river geometry was digitized using the ArcGIS editing features. Figure (shows the digitized river features on top of the TIN. HEC- GeoRAS uses the line features in conjunction with the TIN to extract elevations for the cross sections and flow profile. The Manning's roughness values

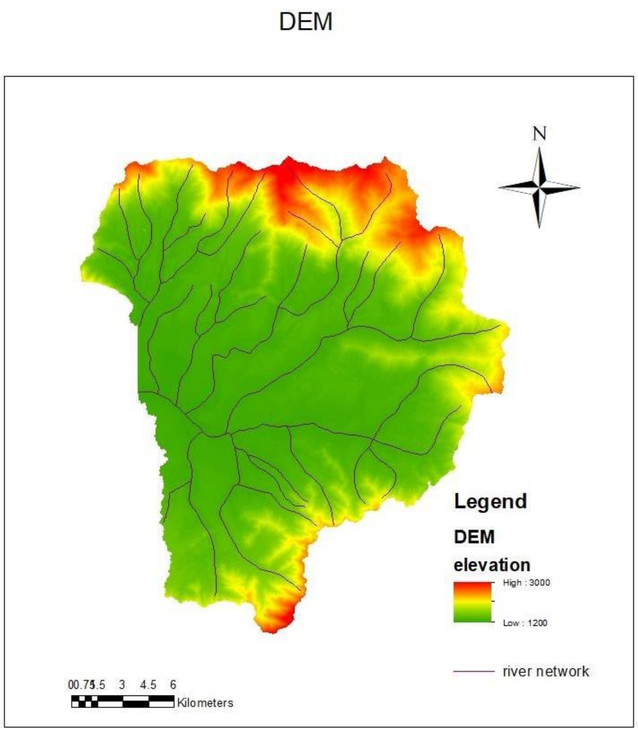

Figure 7: DEM of Bagmati river Basin

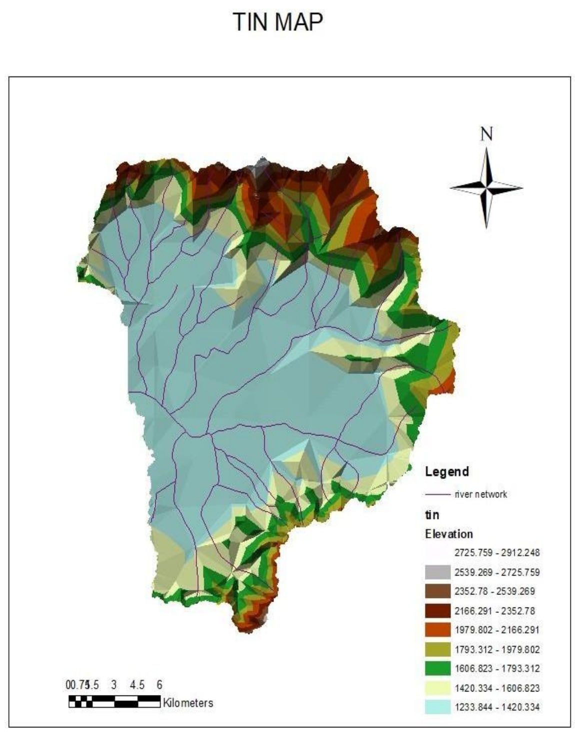

Figure 8: TIN of Bagmati Basin

represent the roughness of the channel surface, which can influence the overall flow rates and velocities in the channel. The land cover data for the study area were downloaded and converted from a raster to a polygon shape file. A value of Manning's roughness was assigned to each land cover category.

Pre-Processing

The geometry data created in ArcMap were exported into HECRAS. Once in HEC-RAS, it was necessary to modify and correct the designated left and right banks of the river. Theleft and right banks defined in ArcMap using the HEC-GeoRAS extension didn't match the actual left and right banks. The solution to this problem was to use the cross section editor in HECRAS and manually select the left and right banks based off of the cross section geometry. After correcting the geometry, a steady flow analysis was used to route two flows of 609.79 and 689.99m3/s through the river. The steady flow analysis producedwater surface profiles and the extents of each floodplain. HEC-RAS uses a number of input parameters for hydraulic analysis of the stream channel geometry and water flow.

These parameters are used to establish a series of cross-sections along the stream as shown in Figure 6. In each cross-section, the locations of the stream banks are identified and used to divide into segments of left floodway, main channel, and right floodway. HEC-RAS subdivides the cross sections in this manner, because of differences in hydraulic parameters. For example, the wetted perimeter in the floodway is much higher than in the main channel. Thus, friction forces between the water and channel bed have a greater influence in flow resistance in the floodway, leading to lower values of the Manning coefficient. As a result, the flow velocity and conveyance are substantially higher in the main channel than in the floodway.

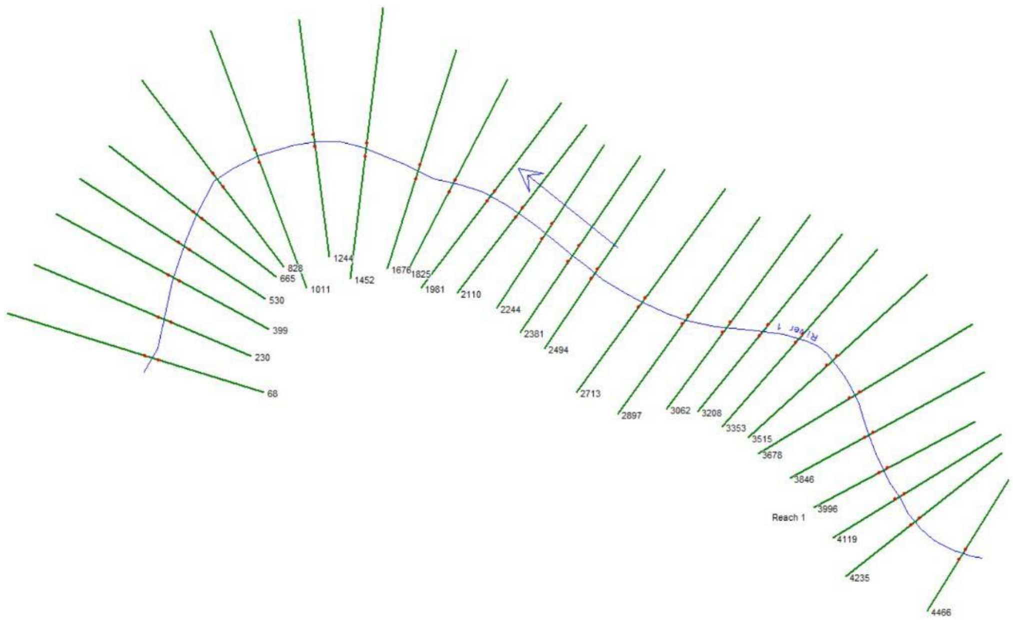

Figure 9: Location of the selected cross sections along the main reach of Bagmati River

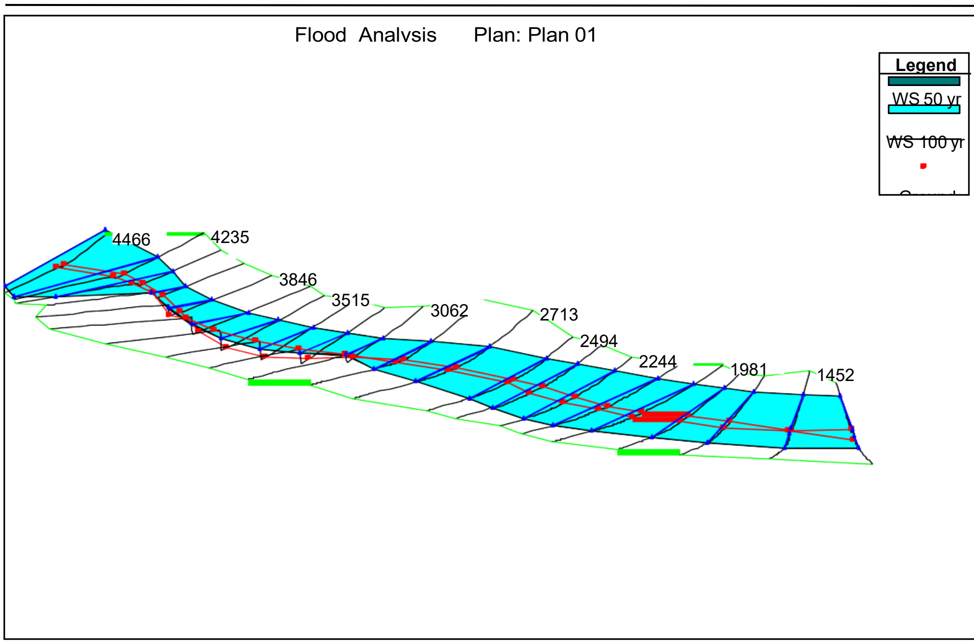

Fig10: view of water surface profile for a flood of 100 years return period.

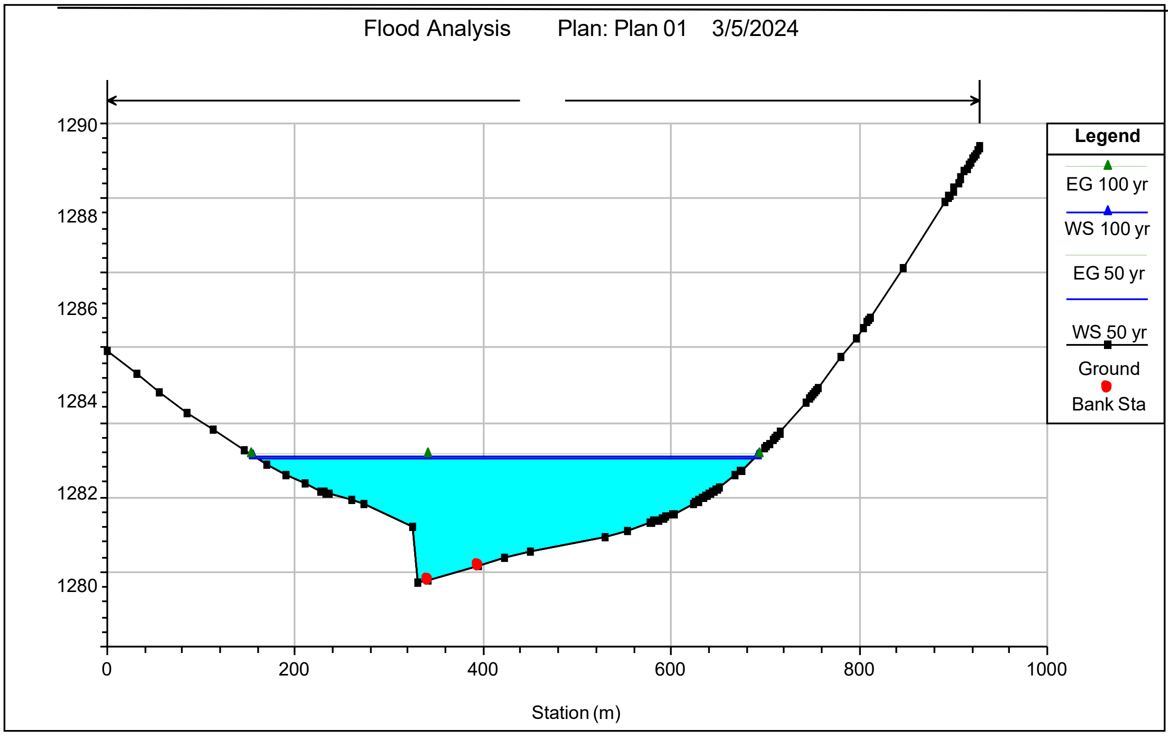

Figure 11: Cross-section for a flood of 100 years return period

Post processing

The results from the HEC-RAS model were then imported back into ArcMap using the HEC-GeoRAS tool. After importing the results into ArcMap it was clear it was necessary to correct errors in the extents of the flood plains. The error seen in the HEC-RAS model results was flooding being shown in ineffective flow areas. Ineffective flow areas are areas of low elevation that do not connect with the main floodplain area. If not defined, HEC-RAS will route water through these areas in the simulation. The solution to this problem was to use the cut tool in ArcMap, and remove the erroneous results.

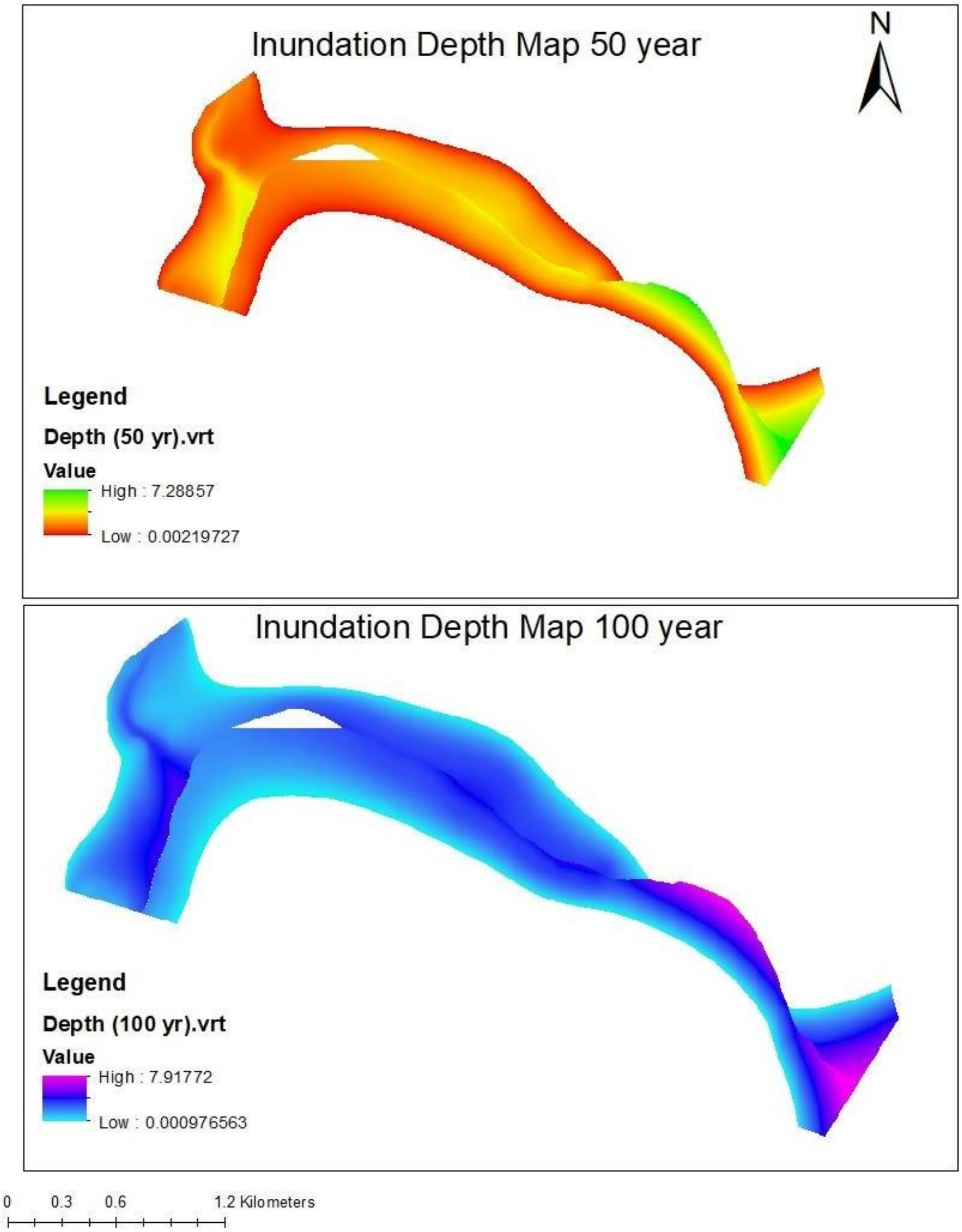

Fig12: Inundation Map of river for 100 Year Return Period

Flood hazard is categorized based on the level of difficulties in daily life and/or damage to properties. Flood hazard assessment is the estimation of overall adverse effects of flooding. It depends on many parameters such as depth of flooding, duration of flooding, flood wave velocity and rate of rise of water level. One or more parameters can be considered in the hazard assessment. In the present study, depth of flooding was considered for hazard assessment.

3.5 Vulnerability Analysis

No of household were used for assessment of vulnerability of flood prone areas. Vulnerability was assessed for using data of no. of household. The household Polygon was overlaid with flood extent maps corresponding to 50 and 100 years return period flood events. Household vulnerability maps were produced corresponding to 50 and 100 years return period floods. Can be shown in figure

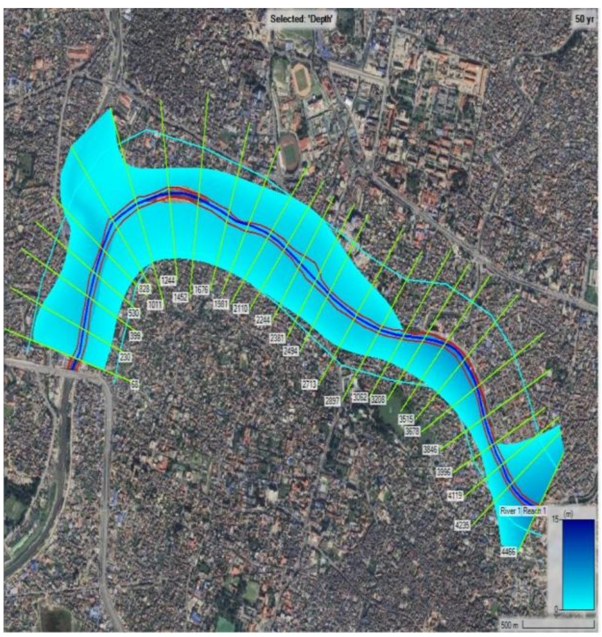

Figure 13: Vulnerability Map of Settlement Household of Bagmati River of 50 Year Return Period

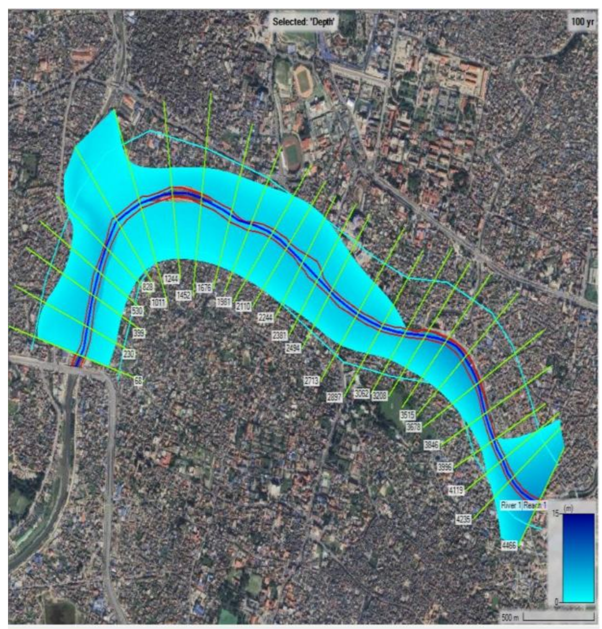

Figure 14: Vulnerability Map of Settlement Household of Bagmati River of 100-year return period

3.6 Flood Risk Analysis of settlement

Considering risk as a function of Hazard & Vulnerability, map multiplication was done in ArcGIS environment to generate the Risk Maps corresponding to 50 and 100-year flood event with respect to household. Then risk of settlement is obtained risk map multiply by population.

The assessment of flood indicates that number houses of located under more than 1m depth of flood is high. It seen from map that 31391and 32141 population of settlement are under the risk of flood of 50yr and 100 year return period respectively. Flood risk of settlement increased with increase in depth of flood. For 50-year flood and 100 flood are high risk population are 11278 and 12134 respectively. From result it shows that All people in this zone are not safe in their homes but at the most they may be safe on their roofs. All building types vulnerable to structural damage. Flood risk analysis showed that settlement at the bank of Bagmati River live under high flood risk. This indicated potential damages to settlement.

Table 6: Flood Risk of Number of Household and Population of Settlement

SN	Hazard	Depth(m)	Area of Inundation for 100 yearReturn period(Sqkm)	Vulnerable Population for 100 yearReturn period as per population density 17,103per sqkm	Area of Inundation for 50 year Return period(sqkm)	Vulnerable Population for 50 year Returnperiod as per population density 17,103per sqkm
1	Very Low	<0.5	0.200375	3427	0.208125	3559
2	Low	0.5-1	0.2863	4896	0.305625	5227
3	Medium	1.0-2.0	0.62505	10690	0.612275	10471
4	High	2.0-5.0	0.7095	12134	0.65945	11278
5	Extreme	>5	0.05815	994	0.0501	856
	Total		**1.879375**	**32141**	**1.835575**	**31391**

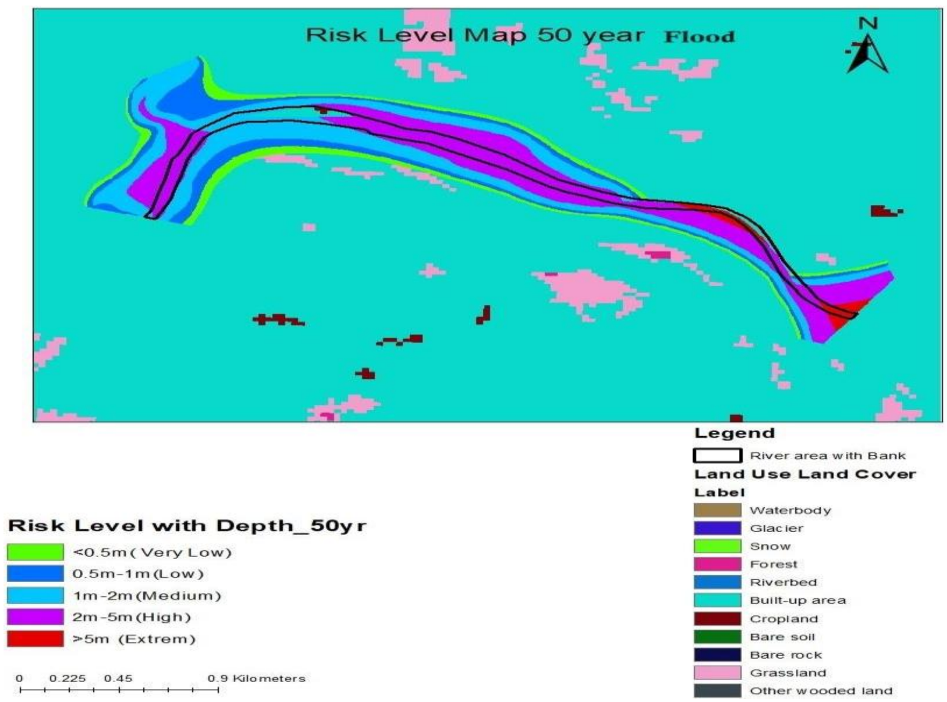

Figure 15: Risk Map of Settlement of Bagmati River 0f 50 Year Return Period

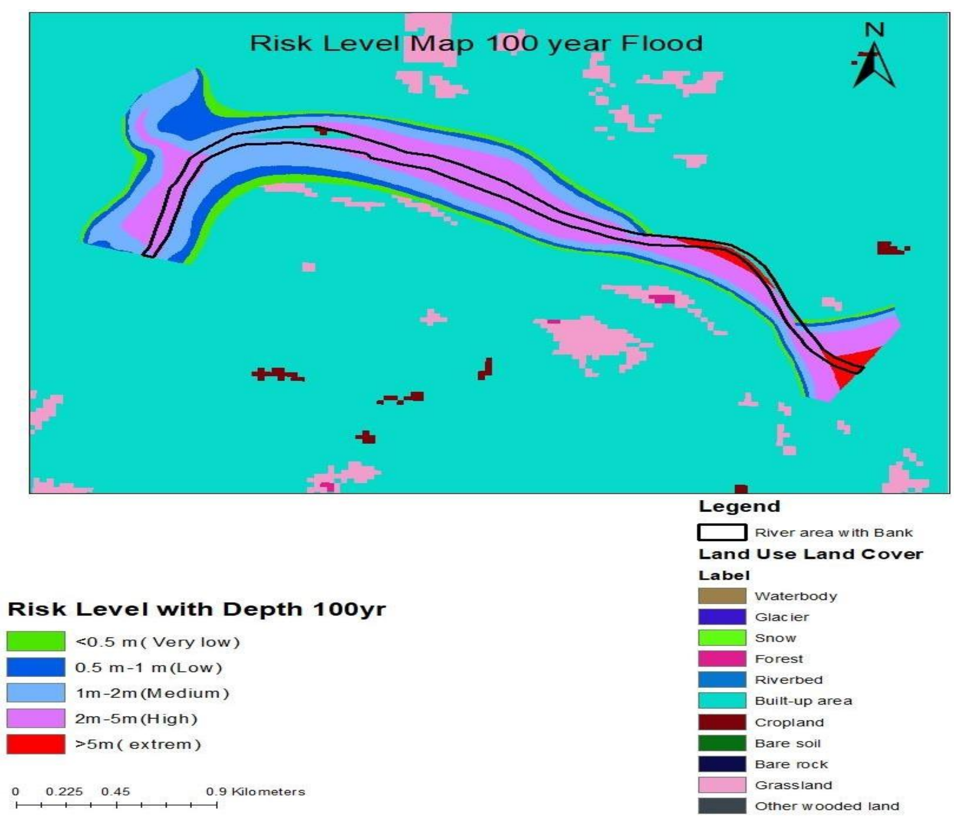

Figure 16: Risk Map of Settlement of Bagmati River 0f 100 Year Return Period

4. Conclusion

Settlement of Kathmandu valley had their impoverished living conditions, highly congested spaces and an absence of public facilities such as education, health, safe drinking water, sanitation and waste management. Residents of these settlements are also highly vulnerable to flood disaster. The study shows the systematic process of preparation of hazard maps of Bagmati River and flood vulnerability settlement living at the bank of river with the application of one-dimensional model HEC RAS and Arc Map GIS. The application of this models and procedure provide effective results within less time consumption and little resources. The result obtained as graphical output (maps) from the model for different return period of flood can help in decision making of flood risk analysis of settlement for disaster preparedness and mitigation activities.

Flood hazard assessment was also done according to different return periods. The relation between flood discharge and flooded area shows that there is increment of flooded area with increase in discharge. Total flooded Area is 1.835575 and 1.879375 km2 of 50 years and 100-year flood respectively. One of the biggest challenges remain here is the generation of the precise DEM. In this study DEM of 5m resolution has been used whichis not sufficient for hydrological modelling in a small catchment. Thus, availability of high resolution DEM is necessary to get higher accurate results. This kind of models is very useful and important for preplanning of disaster and also planning for proper land use, land development and settlement planning.

The flood vulnerability was assessed with regard to number of household in the flood plain of the study area. It showed that 31391 and 32141 Population of settlement are vulnerable to flood of 50yr and 100yr of flood respectively from Shankhamul to Balkhu. For 50-year flood and 100 flood are high risk population are 11278 and 12134 respectively. All building types vulnerable to structural damage. The result of this reportis very important as a preliminary information guide for settlement planning, decision making in preparedness and mitigation of flood disaster to settlement.

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