Flood Risk Assessment of Thiruvananthapuram City, Kerala

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ABSTRACT

Flood is one of the most dangerous and deadliest natural hazards in the world which devastates both life and economy to a very large extent. In Kerala, climate change induced floods are becoming an annual problem. In the midyear of 2018 and 2019, Thiruvananthapuram, the capital city of Kerala, witnessed heavy rainfall and strong winds which resulted in widespread damage in various parts of the City. Flood risk assessment study provides a comprehensive detail of geographic areas and elements that are vulnerable to the particular hazard. As far as Thiruvananthapuram is considered, most of the flood risk assessment studies available were found to be based only on a specific catchment or stream. This paper discusses the need of flood risk assessment study of Thiruvananthapuram City and also focuses on estimating the intensity of storm causing flood. In this work, the major natural drains and the places prone to drainage concentration are delineated from Digital Elevation Model of the study area. The drainage map and land use map are prepared using ArcGIS and ERDAS software respectively. The hydraulic modeling is done using HEC-RAS software and simulations for different rainfall intensities are carried out to estimate the magnitude of flood and to identify the major flood prone areas in the City. This study presents a systematic methodology that can be adopted for flood risk assessment of urban cities, especially when there is less available data.

Keywords: Flood risk assessment, Drainage, ArcGIS, HEC-RAS.

1 Introduction

Flood is one of the most dangerous and deadliest natural hazards in the world which devastates both life and economy to a very large extent. Flood occurs when the flow is relatively higher and it overflows the natural or artificial boundaries of a river, stream or any other water body. The nature and occurrence of floods are governed by diverse factors, including rainfall characteristics, properties of the drainage catchment and land and water use and management of resources in the catchment. The consequences of floods vary greatly depending on the location, extent of flooding, vulnerability and value of the natural and constructed environments that they affect. Flood Risk Assessment (FRA) is a report that outlines the main flood risks to a development site and presents recommendations for mitigating measures to reduce the impact of flooding to the site and surrounding area.

In Kerala climate change induced floods are becoming an annual problem and severe flood occurred due to heavy rainfall during midyear of 2018 and 2019. In Thiruvananthapuram, Thampanoor region was frequently getting flooded during rainy seasons. Severe damage to several areas of city including East Fort, Pazhavangadi, Uppilamoodu, Kannamoola etc occurred during the above-mentioned rainy season.

The objective of this work was to prepare a flood risk map of Thiruvananthapuram Corporation using GIS and to estimate the magnitude of flood in the flood prone areas using HEC-RAS software.

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1.1 Area of Study

The study area is Thiruvananthapuram City which is located at 8˚30ˈN and 76˚54ˈE. The City Corporation which is the largest City Corporation in Kerala, spreads over an area of 215.86 km^2 stretches over 35km of low-lying coastal belt and undulating terrain of midland. It also holds the highest number of population with average population density of 3808 persons/km^2.

2 Literature Review

In order to mitigate urban flooding it is important to first identify flood prone areas and to construct drainages that are correctly aligned along the natural flow routes. This is possible through flood risk mapping and flood frequency analysis. Flood prone areas can be determined by creating a flood hazard map in a Geographic Information Systems (GIS) platform, which is a framework designed to store, retrieve, manage, display and analyze all types of geographic and spatial data. ArcGIS is a geographic information system (GIS) for working with maps and geographic information maintained by ESRI (Environmental Systems Research Institute) (Sebastian et al., 2016).

Flood hazard maps can be created by one dimensional hydrodynamic simulation on the basis of digital elevation model (DEM) data. Digital Elevation Model is a 3D computer graphics representation of a terrain's surface which is created from a terrain's elevation data and is the most common basis for digitally produced relief maps (Mohamed et al., 2019). After acquiring the required satellite images, digital image processing techniques can be carried out for analysis of images in ArcMap and ERDAS IMAGINE software. ERDAS software is required for the generation of thematic maps and is an image processing software. It is integrated within other GIS and remote sensing applications and the storage format for the imagery can be read in many other applications (Basha et al., 2018, Shaji and Macwan, 2017).

For computing excess rainfall, curve number method is used in most of the hydrologic models. To assign curve number (CN), Hec-GeoHMS model can be used, which is a function of land use, soil type, soil moisture and watershed (Hayat, 2017). Another method of estimating flow hydrograph is to access the peak flood discharge using a rational method which estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, and mean rainfall intensity (Vinod et al., 2014).

Flood inundation models are prepared by using Hydraulic models like HEC-RAS and HEC-GeoRAS. HEC-GeoRAS is an ArcGIS extension that integrates GIS data with HECRAS. Hydrologic Engineering Centre River Analysis System (HEC-RAS) can be used to generate flooding limits for different flow rates. The geometric data can be created in the form of RAS layers. The RAS layer includes stream centerline, flow paths centerline, main channel banks, cross-section cut lines and the land use (Manning's *n* values) (Butt et al., 2019). The 1-D hydrodynamic model created using HEC-RAS is accurate for flow modeling of discharges with varying probability (Getahun et al., 2015). Furthermore, the model can be used to simulate real-time flood events to map flooded areas and accordingly decide combat strategy and adopt relief measures (Martina et al., 2018).

As far as Thiruvananthapuram is considered, most of the studies were based on a specific catchment or stream such as the Karamana river basin (Vinod et al., 2014) or the Thampanoor watershed (Parvathy, 2015). Flood inundation studies considering the entire Thiruvananthapuram Corporation were not identified from any of these publications. Also, very limited papers were found on flood risk assessment using both GIS and HEC-RAS. Hence this work focused on a comprehensive methodology to access the flood risk of Thiruvanathapuram Corporation area with the data that can be easily accessed from various sources.

3 Methodology

Methodology adopted for the study is shown in Figure 1 and is explained in subsequent sections.

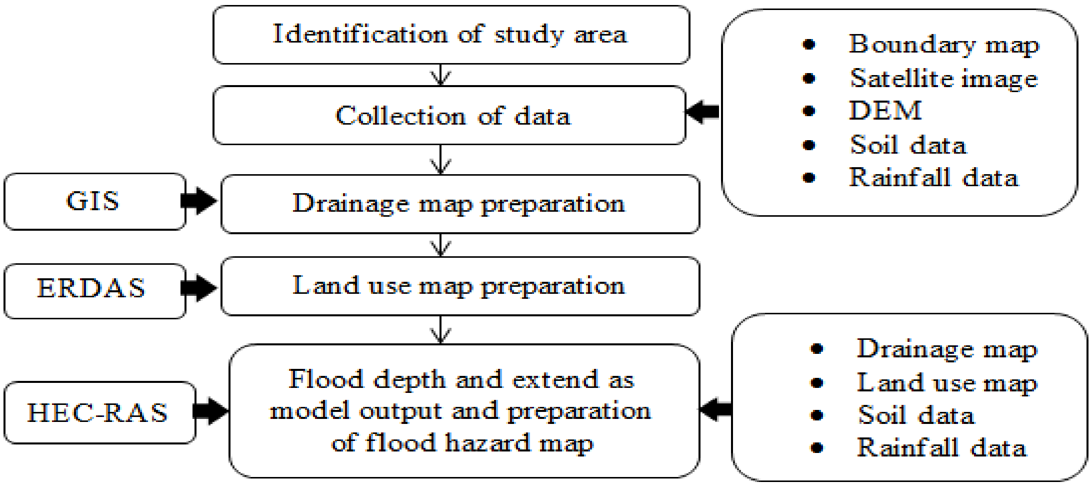


Figure 1. Flow chart showing methodology

3.1 Data Collection

The data required for the study was boundary map, soil data, satellite image of the study area, Digital Elevation Model and rainfall data. Geo-referenced boundary map of Thiruvananthapuram Corporation was collected from the Corporation office. Satellite image and Digital Elevation Model (DEM) of the study area were downloaded from the online portal, USGS Earth Explorer. Soil data was collected from Kerala State Land Use Board (KSLUB) located in Palayam, Thiruvananthapuram and rainfall data were collected from (IMD) Indian Meteorological Department. The daily rainfall data for four consecutive years from 2015 to 2018 was used for the study.

3.2 Drainage Map Preparation

ArcGIS software was used to prepare the drainage map. Digital Elevation Model downloaded from Earth Explorer was the input of ArcGIS and it was processed to generate a drainage map as shown in Figure 2. Using drainage map, water flow path can be identified.

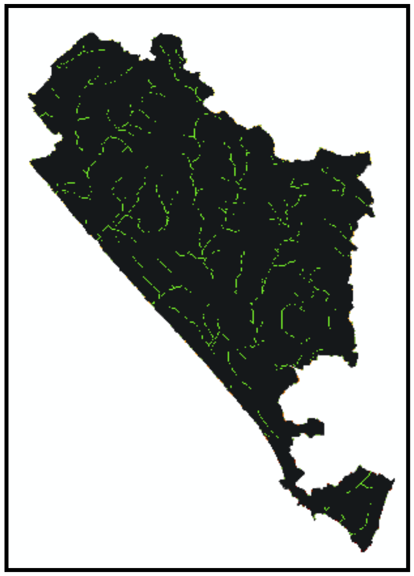


Figure 2. Drainage Network map of Thiruvananthapuram Corporation.

3.3 Land Use Map Preparation

Land use map was prepared using the software ERDAS IMAGINE which is raster based software designed specifically to extract information from images. The satellite images were downloaded from USGS Earth Explorer for the date 16/03/2020. Based on the pixel size classification, study area was classified into five categories such as barren land, agriculture, mixed vegetation, water body and built-up area and the land use map was generated.

4 Result and Discussion

4.1 Estimation of Peak Flood Discharge

Rational method was adopted to estimate the peak runoff rate for each watersheds. It is a function of the drainage area, runoff coefficient, and mean rainfall intensity for duration equal to the time of concentration. The rational formula proposed by Kuichling (1889) as expressed in equation (1) was used in the study for the estimation of the maximum rate of runoff.

$$Q = CIA/360 \quad (1)$$

where, Q = maximum rate of runoff (m^3/s)

C = runoff coefficient

I = average rainfall intensity (mm/hr)

A = drainage area (ac or ha)

360 = conversion factor for use only with metric measurements

From the runoff coefficient values of urban watershed area provided in the reference, 'Design and construction of sanitary and storm sewers' the runoff coefficient values of various land use classes were chosen as shown in Table 1 (ASCE and WPCF, 1970). From these values, the runoff coefficient (C) to be used in equation (1) was calculated using equation (2),

$$C = \Sigma C_i A_i / \Sigma A_i \quad (2)$$

where i = 1, 2, 3…. n types of land use patterns in the region. Land use raster was used to find the areas (A) under different land use class for each of the watershed.

Table 1. Run-off coefficient values (ASCE and WPCF, 1970).

Land use type	Run-off coefficient
Barren land	0.2
Water body	0
Built-up	0.9
Mixed vegetation	0.5
Agriculture	0.4

4.1.1 Estimation of Average Rainfall Intensity (I)

The annual maximum rainfall depths of 1, 2, 3, 7 and 10 days for a return period of 5 years were calculated from the daily hourly rainfall data for the years 2015-2018 from IMD as shown in Table 2. The precipitation depth, X is calculated for a given return period using the equation 3. Here, X_{mean} is the mean of annual extreme rainfall, SD is standard deviation, and K_t is the frequency factor.

$$X = X_{mean} + (K_t \times SD) \quad (3)$$

Table 2. Annual maximum rainfall depth in mm and intensity in mm/hr.

Year	Unit	1 day	2 day	3 day	7 day	10 day
2015	Mm	131.5	154.4	203.2	221.3	254.5
	mm/hr	5.47	3.216	2.82	1.317	1.064
2016	Mm	86.9	140.7	155	243.9	268
	mm/hr	3.675	2.93	2.152	1.45	1.116
2017	Mm	86.5	118.5	134.8	151	193.8
	mm/hr	3.604	2.468	1.87	.956	0.807
2018	Mm	117.7	170.5	200.5	283.7	355.2
	mm/hr	4.9	3.552	2.784	1.688	1.48
X_{mean}	mm/hr	4.41	3.04	2.41	1.35	1.12
SD	mm/hr	0.8	0.4	0.41	0.26	0.24
Precipitation depth for 5-year return period (X) mm/hr		4.99	3.33	2.7	1.54	1.29

From the rainfall intensities estimated, graphs were plotted with rainfall intensity in Y-axis and duration in X-axis, both in logarithmic scale. A Gumbel distribution is fitted to the annual maximum series for estimating rainfall of different durations and return periods. Intensity is denoted as I and time of concentration as t and from the graph,

$$\log I = m \times \log t + Constant \quad (4)$$

t = time of concentration is the time required for runoff to travel from hydraulically most distant point in the watershed to the outlet.

The calculated values of intensity, average runoff coefficient and area for each watershed were substituted in equation (1) to find the peak flow of the watershed. The peak flood discharge values obtained was shown in Table 3.

Table 3. Calculated peak flood discharge.

Sl. No.	Watershed/ Thodu	Time of concentration (hr)	Intensity (mm/hr)	Discharge (m^3/s)
1.	Medical College	0.498	48.47	47.37
2.	Pattom	0.679	40.49	87.09
3.	Ulloor	0.668	40.87	95.98
4.	Parvathyputhanar	0.556	45.47	72.38
5.	Sub-Thettiyar	0.715	39.29	95.40
6.	Thettiyar Thodu	0.506	48.02	49.37
7.	Kochupalam Thodu	0.615	42.88	69.36
8.	Thampanoor Thodu	0.438	52.21	46.16
9.	Akkulam	0.713	39.36	109.28
10.	Killiar	0.947	33.38	259.54

4.2 Hydraulic Modelling

Hydraulic modelling simulates rainfall runoff flow to predict the extent of creek and river water levels and flooding and to test ways to reduce the flooding without actually constructing the project. Hydraulic modelling was done with the help of HECRAS program used for modelling water flowing through systems of open channels and computing water surface profiles.

4.2.1 Flood Modelling

The drainage area map and stream network of Thiruvananthapuram city which was delineated using ArcGIS was imported to HEC-RAS. The stream networks selected for the flood modelling were Akkulam Lake, Medical College thodu, Thampanoor thodu, Pattom thodu, Ulloor thodu, Parvathyputhanar, Thettiyar, Killi river and Kochupalam. Rivers were identified and their centerlines were traced using the imported stream network as shown in Figure 3. Manning's roughness coefficient can be defined for each cross-section in the main channel, left bank and right bank. To define roughness select Manning's table for each reach, values used are 0.035 for left and right bank and 0.03 for channels.

After entering values for steady state conditions, run the steady flow analysis and compute. The flood inundated areas can be then identified by importing this to the Arc-GIS software. Thus, the areas that will be covered by flood can be identified in the Arc-GIS software.

The flood hazard assessment map was produced by flood generating HEC-RAS model for 5-year return period of peak rainfall data from 2015 to 2018 of Thiruvananthapuram City. The peak discharge flood data was used in HEC-RAS model for water surface profile calculation in subcritical flow regime. An example of water surface profile is given in Figure 4. The flood depth data obtained from selected watershed area are enlisted in Table 4.

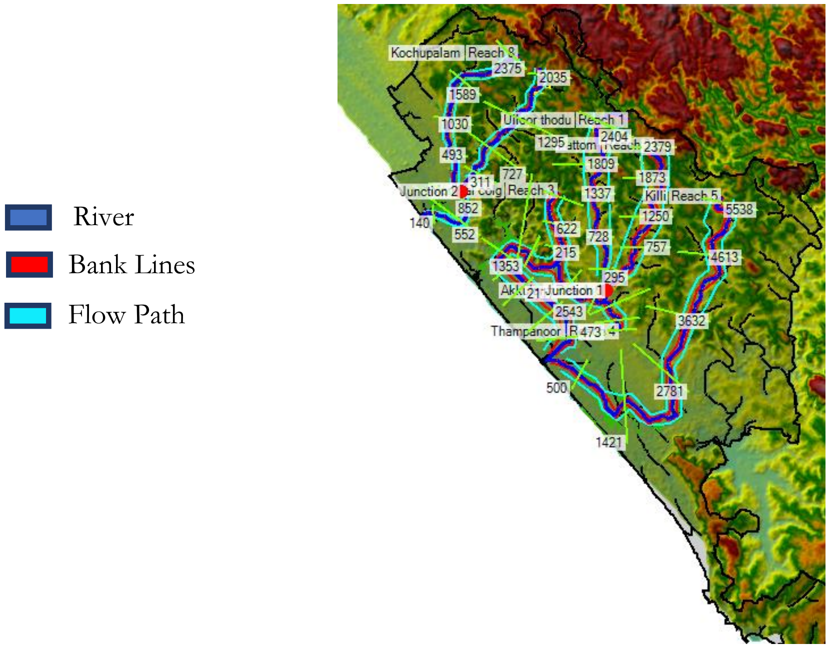


Figure 3. River cross-section.

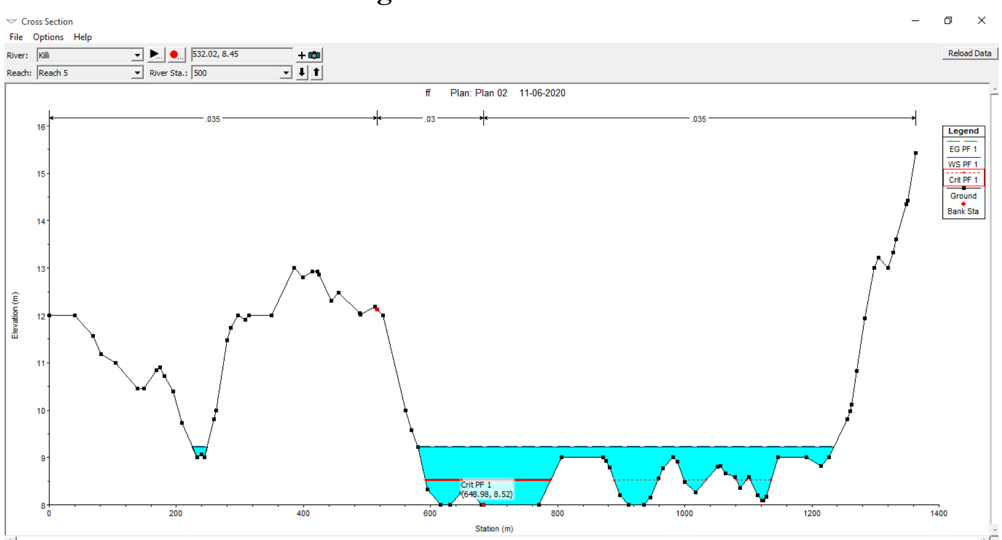


Figure 4. Water surface profile data of a cross-section at Killi river.

Table 4. Flood depth in critical regions of watershed area.

Sl. No.	Watershed	Overflow flood depth (cm)
1.	Medical College	96
2.	Pattom	48
3.	Ulloor	127
4.	Parvathyputhanar	55
5.	Sub-thettiyar	63
6.	Thettiyar Thodu	46
7.	Kochupalam Thodu	44
8.	Thampanoor Thodu	43
9.	Akkulam	86
10.	Killiar	73

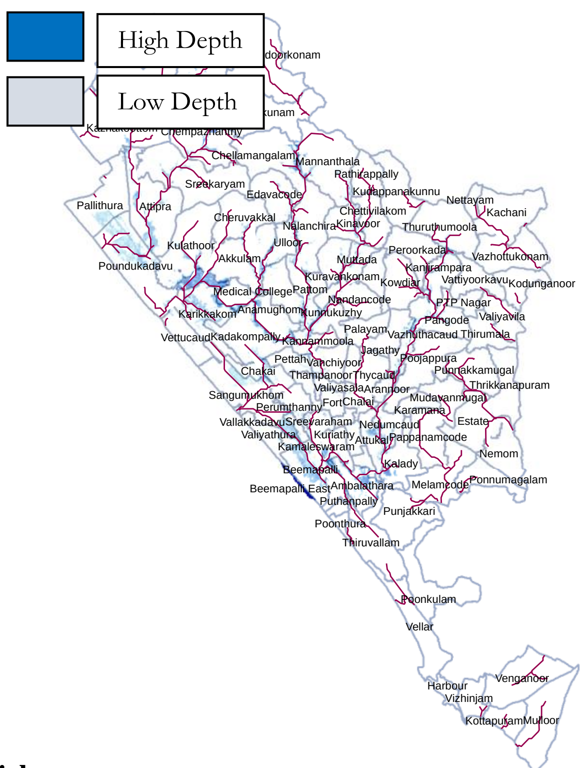
4.2.2 Flood Map in ArcGIS

The final flood plain delineation and inundation depth is shown in Figure 5.

Figure 5. Map of Thiruvananthapuram Corporation Inundation.

5 Conclusions

Using one dimensional steady flow analysis in HEC-RAS flood hazard map for 5 year return period was prepared using annual peaks flow of 4 years from 2015 to 2018, which was calculated using rational method. In the water surface profile generated, when the water level is above the critical profile flow, flood occurs. From the result obtained, it was observed that the wards namely Kattayikonam, Chanthavila, Sreekaryam, Pondukadavu, Medical College, Edavacode, Mannanthala, Kinavoor, Karikkokom, Shangumukham, Bheemapalli, Vanchiyoor, Kadakampalli and Chakai are highly prone to flood. As a flood control measure one can adopt innovative concepts such as "Sponge City". This refers to a city where its urban underground water system operates like a sponge to absorb, store, leak and purify rainwater and release it for reuse when necessary. So, it can be used as a sustainable drainage system on an urban scale to reduce floods.



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