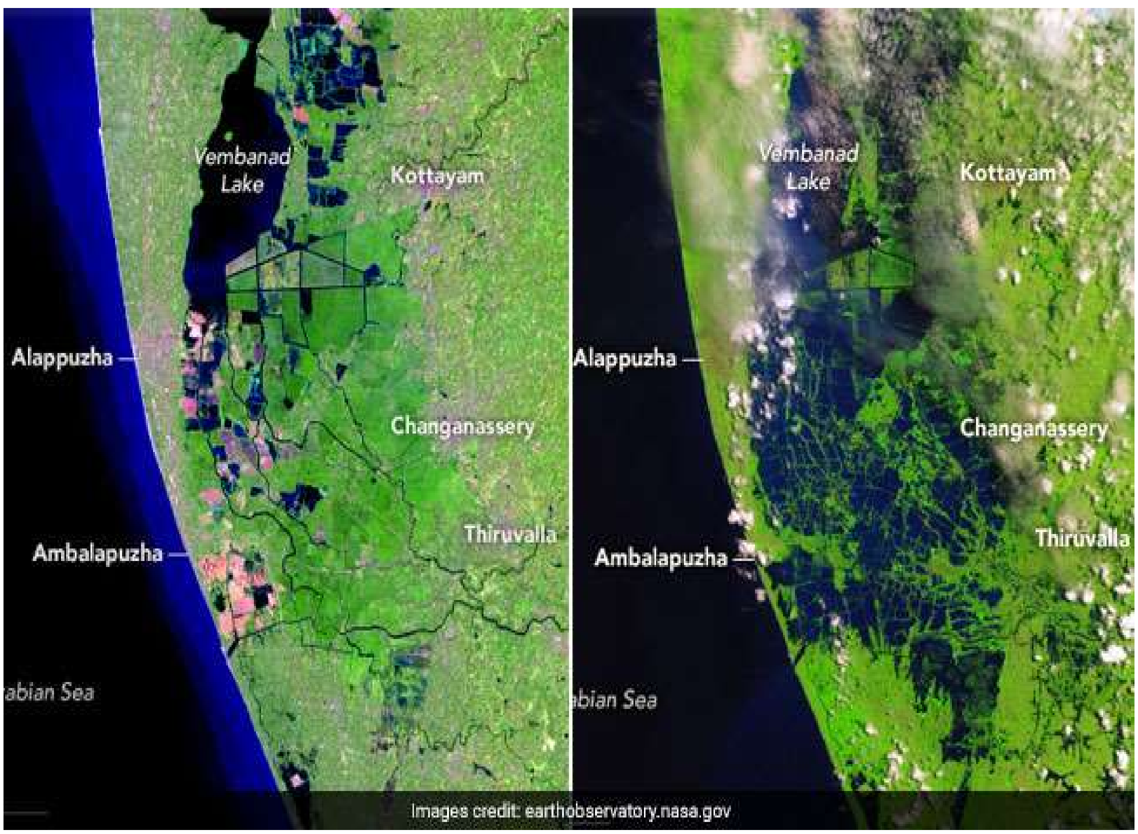
सत्यमेव जयते

REPORT ON
KERALA FLOOD & SOLUTIONS



Central Water Commission

December, 2018

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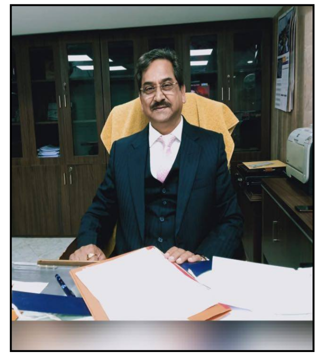

Kerala witnessed unprecedented floods in August 2018. Two back to back heavy rainfall events i.e. 08-10 & 15-17 in the month made the situation worst giving no opportunity to absorb the floods in major reservoirs. Despite a very long shore line, reasonable river bank height and presence of large number of reservoirs, the flood water could not be contained within the river banks and there was large spillage of water in lower reaches of river Periyar and low lying areas of other basins as well as Vembanad Lake.

In order to manage the floods of such magnitudes in future and help the State Government in formulating some strategies, CWC has carried out extensive model studies using state of art technology and available hydro-meteorological data. Through these studies, a hydrodynamic numerical model (both 1D & 2D) for Kerala has been setup and calibrated. This will assist in identification of areas vulnerable to flooding, demarcation of low, medium and high risk areas of inundation, flood guidance by relating forecasted excess rainfall with downstream river water levels depending on reservoir condition, reasonable flood control level to be adopted in some important reservoirs during the monsoon season and making available the three day advisory forecast to state government from incoming monsoon season based on IMD rainfall forecast and near real-time satellite rainfall estimates till actual real-time rainfall data is available from IMD/state government. In order to make it possible to provide a real time three day advisory forecast of any impending flood event in view of the available limited computational facilities so far at hand in CWC , a library of possible inundation scenarios have been generated to be kept ready beforehand for readily picking up a most likely scenario corresponding to the water level of the flood predicted for any point on the river at that potential location of inundation. The numerical model has been validated with successfully simulating the river flow data as observed at Neeleswaram on the river Periyar for past 35 years including the flood events of 2018.

Further, feasibility of providing conventional Statistical Level Forecast for Kumbidi on Bharathapuzha, Neeleswaram on river Periyar and Malakkara on river Pamba has also been studied. Flood Forecats for Kumbidi on Bharathapuzha and Neeleswaram on Periyar may be issued provided State Government agrees for the same from 2019 onwards.

I wish to place on record my compliments especially to Sh. Ritesh Khattar, Director and Sh. Mohd. Faiz Syed, Dy. Director with their team from FCA-II Directorate of CWC for bringing out this report and to the entire field unit team of CWC in Kerala for their assistance in providing the data. I hope this report shall be very useful for State Government to manage the floods in a more efficient manner in case such eventuality repeats again.

Yoginder Kumar Sharma
Member (River Management)
Central Water Commission

ACKNOWLEDGEMENT

Kerala in August, 2018 experienced a major flood disaster causing huge loss of life and property. In the wake of such an event prompt forecasting and issuing of flood warnings becomes necessary. Realizing the need effective flood management Central Water Commission has carried out this study to assist the State government in dealing such flood hazards. In this regard, Flood Management Organization (FMO) has done a comprehensive analysis of Kerala floods and has come out with solutions that can be valuable tool for such future events.

The study emphasises on various flood aspects in Kerala giving

- Return period based inundation maps for demarcating High, Medium and Low risk flooding areas.
- Return period identification of Aug, 2018 Kerala flood.
- Identification of flood vulnerable hot spots.
- WL prediction at the locations downstream of any dam based on Rainfall forecast in next 24 hours and initial reservoir level and operational conditions.
- Flood Control Levels in some important reservoirs

I, on behalf of the authors and project team of "Kerala Flood Study" acknowledge; valuable guidance provided by Shri Y.K. Sharma, Member (River Management) in overall steering the studies, identifying various scenarios of analysis, deriving their inferencesand providing perspective to the output ; Shri. N M Krishnamunni, Chief Engineer(CS&RO); ShriSharad Chandra, Director FFM; Shri Rishi Srivastava, Director RS; Shri. Ritesh Khattar, Director FCA-2; Shri. Mohd. Faiz Syed, Deputy Director FCA-2. Finally, our sincere thanks to Kerala field units of CWC and Kerala State Government for their valuable feedback and data sharing support.

(M.S.Dhillon)
Chief Engineer
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1.0 Background

Central Water Commission (CWC) in pursuance to OM-No.3/133/2018-FFM/2286-95 dated 17/09/2018 constituted a committee to carry out a study on Kerala flood, 2018 with following terms of reference.

1. To visit flood affected areas of Kerala and collect required data in coordination with state government.
2. To set up a mathematical model in FCA-II directorate of CWC and carry out the study
3. To prepare a report envisaging :
    a. The atlas of frequency based inundation plans
    b. Identification of return period of the recent flood of August, 2018.
    c. Study the feasibility of establishing flood forecasting network
    d. Setting up of model to provide flood forecast.
    e. Study of feasibility of integrated reservoir operations
    f. Any other issue related to the above.

The members of the committee are as follows.

1. Shri. N M Krishnamunni, Chief Engineer(CS&RO), CWC, Coimbatore
2. Shri. Rishi Srivastava, Director (RS), CWC, New Delhi
3. Shri. Sharad Chandra, Director(FFM), CWC, New Delhi
4. Shri. Ritesh Khattar, Director(FCA-II), CWC, New Delhi
5. Shri. Mohd Faiz Syed, Dy. Director(FCA-II), CWC, New Delhi

Using the available datasets, model studies have been carried out to provide solutions to State Government in management of floods in judicious manner. However, there is a scope of refinement subject to availability of historical data of reservoir outflow/inflow, river/reservoir bathymetry at finer resolution, high resolution terrain topography (DEM) and finer spatial and temporal resolution of rainfall data.

2.0 Study area

The members of committee visited some of the flood affected areas in the State during 25th – 27th September, 2018. These areas were mainly in the lower reaches of Periyar, Chalakkudy and Pamba basin and low lying areas adjoining Vembanad Lake. As per the State govt officers, these areas were worst affected during the 2018 flood. Major reservoirs like Idduki, Idamalayar & Mulla Periyar are existing upstream of these flooding areas. Therefore, these basins were selected for modeling purpose.

2.1 Periyar Basin

Periyar is the longest river with largest discharge potential in the state. The Periyar has a total length of approximately 244 Km and a catchment area of 5,398 sqkm of which 5,284 sqkm is in Kerala and 114 sqkm is in Tamil Nadu. It provides drinking water for several major towns and is of utmost significance to the state economy. It generates a significant proportion of Kerala's electrical power via the Idukki Dam and also provides water for irrigation and domestic use. Kochi city, in the vicinity of the river mouth draws its water supply from Aluva, an upstream site sufficiently free of seawater intrusion. Twenty five percent of Kerala's industries are along the banks of river Periyar. These are mostly crowded within a stretch of 5 km Inthe Eloor-Edayar region (Udhyogamandal), about 10 km north of Kochi harbor.

Figure 1: Periyar Basin

At Aluva, the river bifurcates into the Marthandavarma and the Mangalapuzha branches. The Mangalapuzha branch (primary) joins Chalakudy River and empties into the Sea and the Marthandavarma branch (secondary) flows southwards going through the Udhyogamandal area and finally draining into the Cochin backwater system (part of Vembanad Lake).

Two major reservoirs on the river are Idukki and Idamalayar with 1.46 BCM and 1.0 BCM storage capacity respectively.The MullaPeriyar dam is constructed at the confluence of the Periyar and Mullayar to create the Periyar Thekkady lake and reservoir, as well as the Periyar National Park. The average annual rainfall in Periyar basin is around 1933 mm. Neelaswaram and Vendiperiyar are the two CWC HO stations located on the river.

2.2 Pamba Basin

The Pamba River is the third longest river in Kerala. The river is 176 km long with the catchment area of 2,235 sqkm. The entire catchment lies within Kerala state. The basin is bounded on the east by Western Ghats and on the west by Arabian Sea. Sabarimala temple dedicated to Lord Ayyappa is located on the banks of the river Pamba. The river flows through Pathanamthitta District and the Kuttanad (an important rice cultivation area) area of Alappuzha District and few areas of Kottayam, which were major flood affected areas during the 2018 flood event. Kallopara, Malakkara and Thumpamon are three HO stations of CWC.

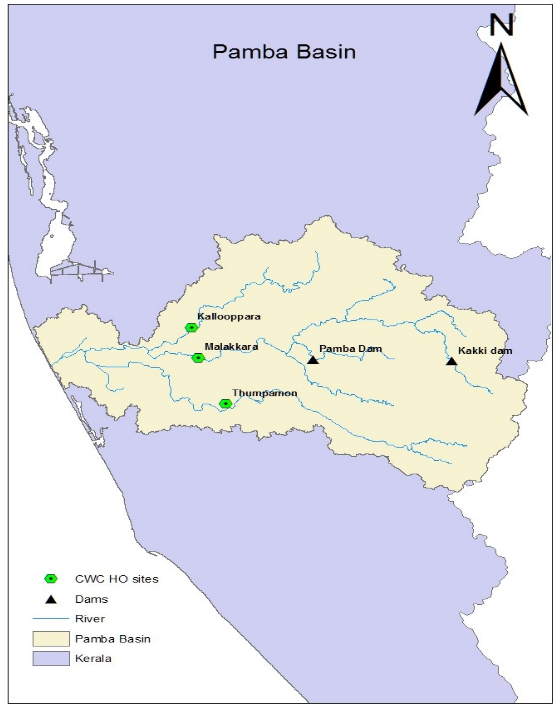


Figure 2: Pamba Basin

2.3 ChalakudyBasin

Chalakudy is the fifth longest river in Kerala which flows through Palakkad, Thrissur and Ernakulam District of the state. The river is 145.5 km long with total drainage area of 1704 km, out of this 1404 km² lies in Kerala and the rest 300 km² in Tamil Nadu. Though Chalakudy river in strict geological sense is a tributary of the Periyar river, for all practical purposes it is treated as a separate river by Government and other agencies. The River flows along the banks of the Chalakudy Town, the major settlement along the course of the river.Arangley is the CWC HO station located on this river. Arangley is CWC HO station in the basin.

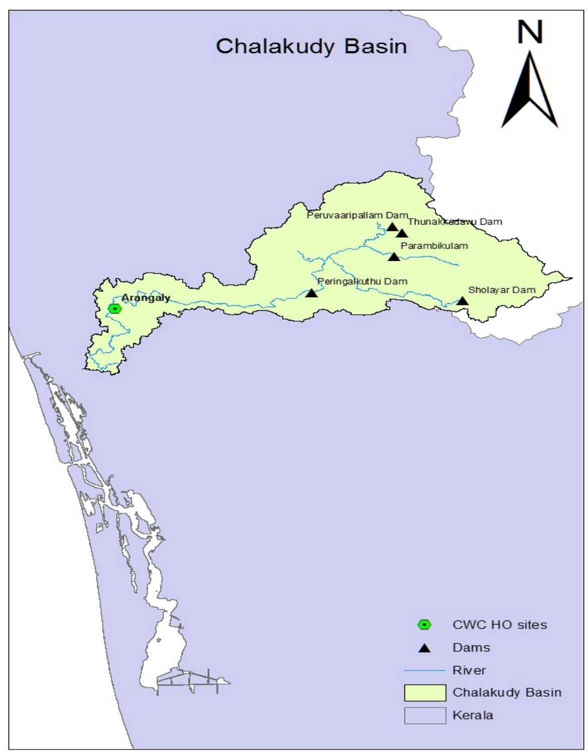


Figure 3: Chalakudy Basin

2.3 Vembanad Lake Catchment

Vembanad lake is the longest lake in India and has an area of over 2033.02 km² thereby making it the largest wetland system in the country. Of this, an area of 398.12 km² is located below the MSL and a total of 763.23 km² area is located below 1 m MSL. The lake is bordered by Alappuzha, Kottayam, and Ernakulam districts. It is situated at the sea level, and is separated from the Sea by a narrow barrier island. Canals link the lake to other coastal lakes in the north and south. The Vembanad Lake is approximately 14 kilometres wide at its widest point. The lake is fed by 10 rivers flowing into it including the six major rivers of central Kerala namely the Achenkovil, Manimala, Meenachil, Muvattupuzha, Pamba and Periyar. The total area drained by the lake is 15,770 km² which accounts for 40% of the area of Kerala. Its annual surface runoff of 21,900 Mm accounts for almost 30% of the total surface water resource of the state.Over 1.6 million people live on the banks of the Vembanadlake and are directly or indirectly dependent on it for their livelihoods.

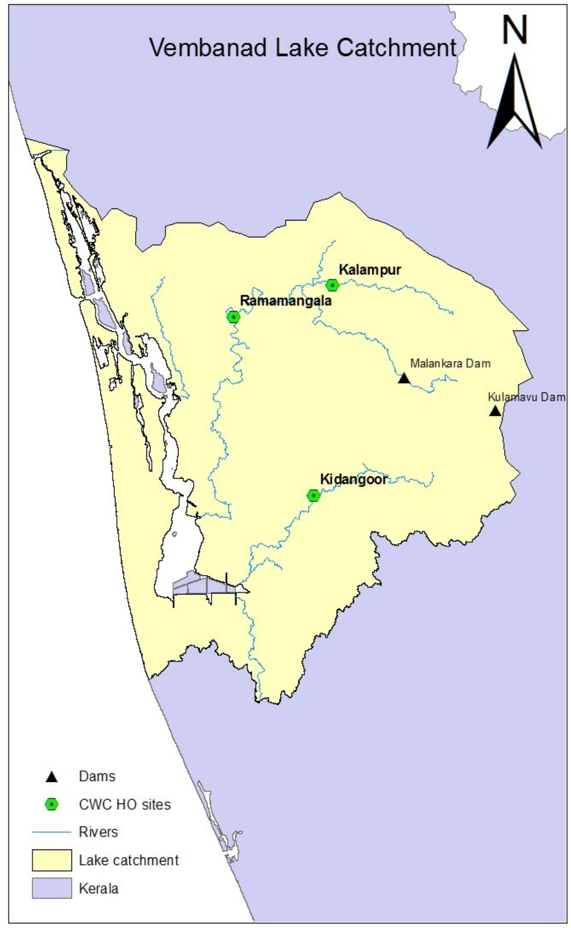


Figure 4: Vembanad Lake Catchment

The port of Kochi (Cochin) is located at the lake's outlet to the Sea. The town of Alappuzha (also known as Allepey), sometimes called the "Venice of the East" for its large network of canals that meander through the town - is sandwiched between the lake and the sea.

3.0 Methodology

The methodology adopted to carry out the flood study is shown in the figure below. To start with, IMD gridded historical rainfall of 35 years at country scale was first processed and brought to sub-basin scale for the study area in the gridded format. This sub-basin rainfall was then given as an input to the rainfall-runoff model and further routed through a hydrodynamic model (MIKE 11) to obtain the levels and flows at various identified locations in the channel. Based on the historical observed time series of levels and flows (CWC data) for various locations the MIKE 11 model was calibrated.

Further, the same sub-basin historical rainfall data from IMD was used to do the frequency analysis and obtain the rainfall inputs corresponding to 2, 5, 10, 25, 50 & 100 year return periods.

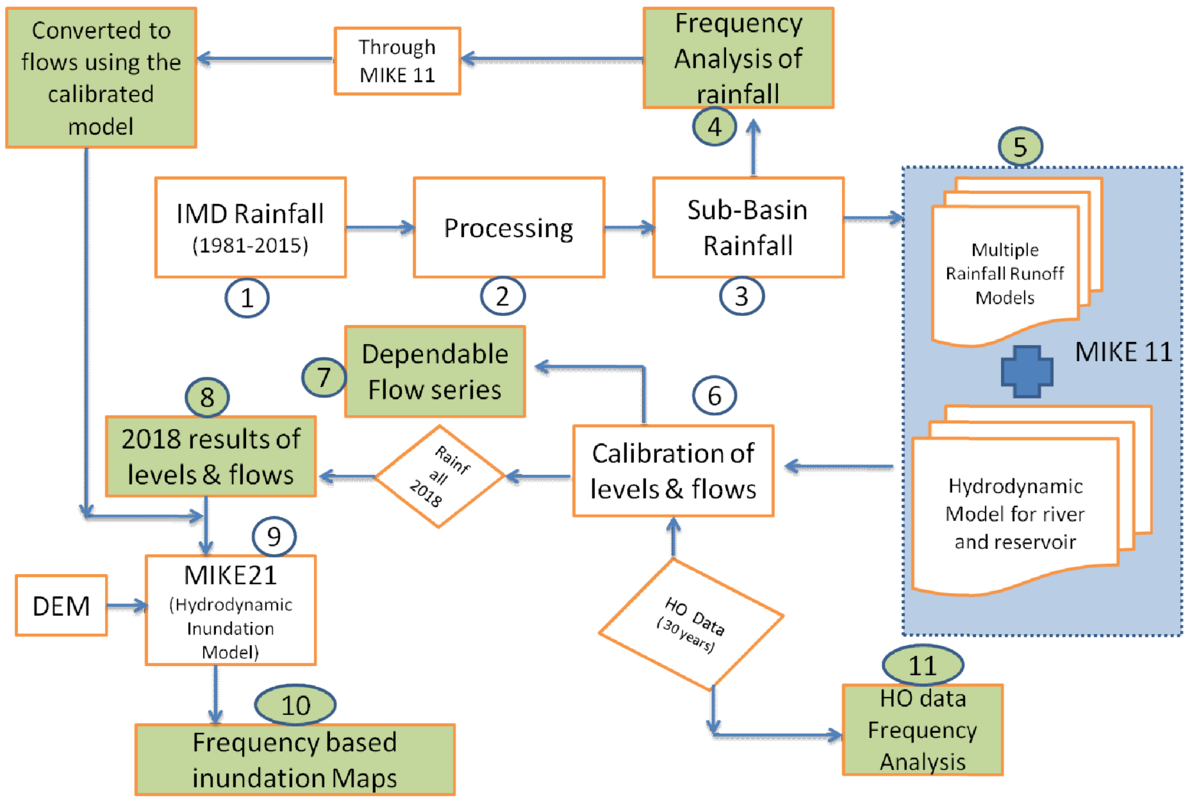


Figure5: Methodology

The calibrated MIKE 11 model is further used to generate the following outputs

1. 2, 5, 10, 25, 50 & 100 year return periods flows based on corresponding rainfall return periods for various HO stations.
2. Flows and levels of 2018 flood event based on the observed rainfall of 2018 flood event for various locations.

Finally, a 2D model (MIKE 21) is set up using a DEM to convert the output flows into inundation extent and depths. Therefore we get inundation maps for 2, 5, 10, 25, 50 & 100 year return periods floods and inundation maps corresponding to 2018 flood event for the region. The inundation maps are further validated using available satellite imagery.

4.0 Data Used

During the visit to Kerala the committee submitted a comprehensive list of data required in the study to the state government. The state government assured to make the data available as soon as possible. Unfortunately the desired data was not received. Subsequently CWC decided to go ahead with the study with the data available from its own resources. The data used in the study is mentioned below.

- 90m Digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) of United States. The river geometry analyzed using satellite imagery of various seasons was described in the SRTM DEM so that the conveyance of water in the river channel is represented to a reasonable degree of accuracy.
- Gridded historical rainfall data for past 35 years from IMD.
- Historical (35years) annual peak discharge and water level data of CWC HO sites in Kerala
- CWC river cross section data at Neeleswaram, Kallopara, Malakkara, VendiPeriyar, Arangley and Thumpamon.
- Area capacity curves for Idukki, Idamalayar, Kakki, Kalada, MullaPeriyar, Malamphuza reservoirs were established using reservoir data available with water management directorate of CWC.
- Satellite images of flood events from open source Landsat and Sentinel-1

5.0 Software Used

5.1 MIKE Flood

It includes a wide selection of specialized 1D and 2D flood simulation engines, enabling to model any flood problem - whether it involves rivers, floodplains, flooding in streets, drainage networks, coastal areas, dams, levee and dike breaches, or any combination of these. MIKE FLOOD is capable to generate dynamic flood depth maps and velocity distribution (spatially) maps of flood water propagation.

There are several advantages of applying models like MIKE FLOOD. It provides more reliable and accurate flood maps and flood hazard maps, than simpler methods like superimposing static water level maps on topographic maps. It simulates water levels accurately taking into account backwater effects from e.g. obstructions on the flood plain, and simulates correctly pathways, which may not necessarily be the shortest and direct distance between e.g. the river and the point of concern.

This technique requires a fine resolution land terrain model. The land terrain model, HD model are dynamically linked in MIKE FLOOD, and generate flood depth map and flood velocity map in every time step of its computation process.

5.2 ARCGIS

It is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

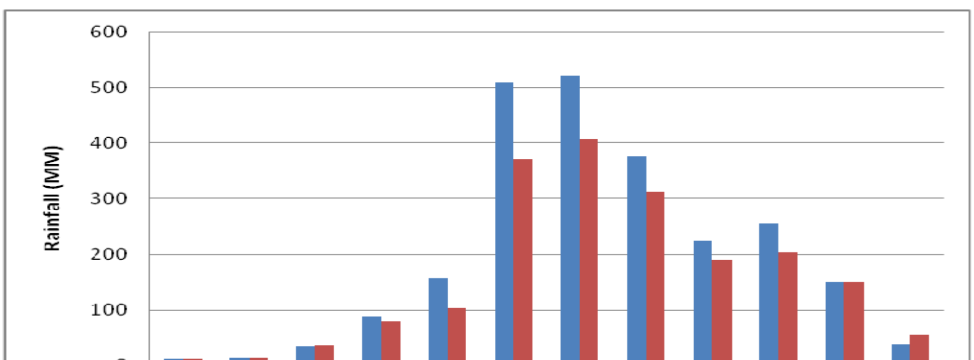
5.3 Google Earth Engine (GEE)

Google Earth Engine(GEE) is a tool that combines a multi-petabyte catalogue of satellite imagery and geospatial datasets with planetary-scale analysis capabilities to detect changes, map trends, and quantify differences on the Earth's surface. In the study, the GEE has been used to accurately detect the river channel for the purpose of representing it accurately on the DEM. It has also been use for verifying the model inundation results against the satellite image data.

Besides above software, Python and Vbscript applications have been used to carry out background processing of hydro-meteorological data.

6.0 Rainfall Analysis

Based on the IMD Gridded rainfall data available from 1981-2015, the rainfall distribution both seasonal as well as annual has been analyzed for the state. The seasonal analysis shows June-July are the wettest months and January-March are the driest months. It also indicates Kerala experiences prolonged rainfall season as compare to rest of country. This is due to the fact that both types of monsoon i.e. South-West & North-east are active over the state of Kerala.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kerala	11.0	14.6	33.7	88.3	156	508.	519.	374.	223	253.	149.	38.7
Periyar	13.4	13.9	35.5	78.4	103.	369.	407.	312.	190.	203.	149.	55.3

Figure 6: Seasonal Variation in Rainfall

The annual analysis shows that mean annual rainfall in the state of Kerala is 2370 mm with variability of +/- 366 mm. It also shows 2001- 2003 has been bad monsoon years particularly for Periyar basin.

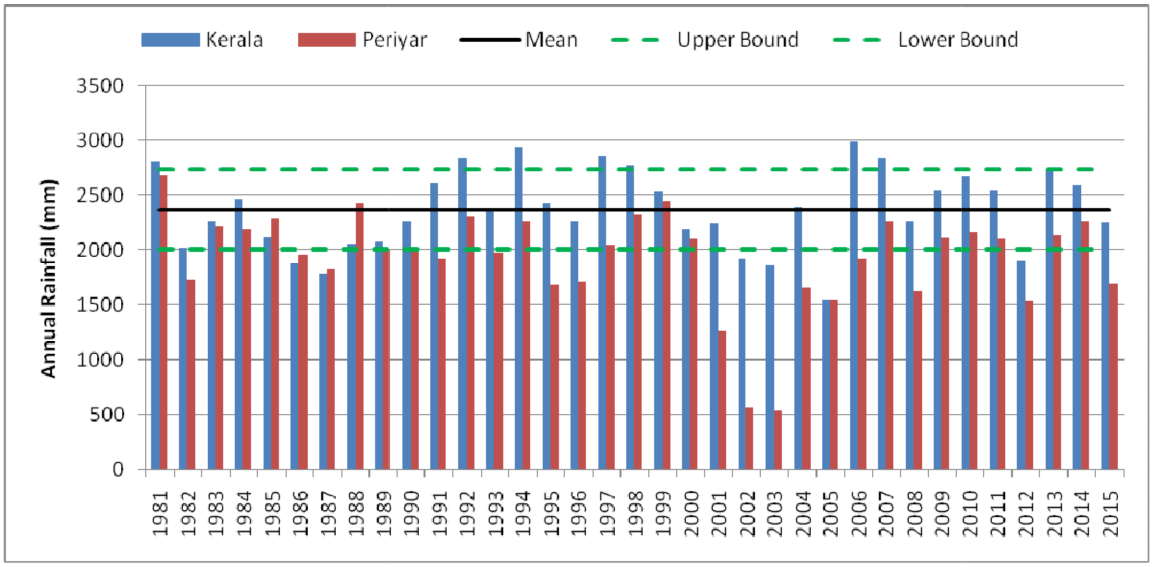


Figure 7: Annual Variation in Rainfall

7.0 *Model Calibration & Validation*

Both one dimensional(1D)&two dimensional (2D) hydrodynamic models were setup and run on the data available and the results were obtained. The 1D MIKE 11 model was calibrated on historaical flow data and validated by 2018 flood event at Neeleswaram and Malankara stations for Periyar and pamba basins respectively. Further, the 2D MIKE 21 model was validated by 2018 flood inundations extents obtained through sentinel 1 satellite imagery which is a microwave derived product.

7.1 MIKE 11 Model Calibration at Neeleswaram Site

The figure below shows the simulated and observed water level at Neeleswaram site in Periyar river basin. The corelation coefficient obtained between the observed and the simulated water levels was found to be 0.93.

Following infrences can be drawn form it:

1. Model is able to capture the actual flows from rainfall data
2. Two back to back severe events in very short period of time.
3. Rainfall event of (15th – 17th Aug, 2018) was nearly two times stronger than the rainfall event of (08th -10th Aug, 2018), therefore flood peaks attained were much higher.
4. Very little space left for absoption of flood resulting in passage of majority of incoming flood..

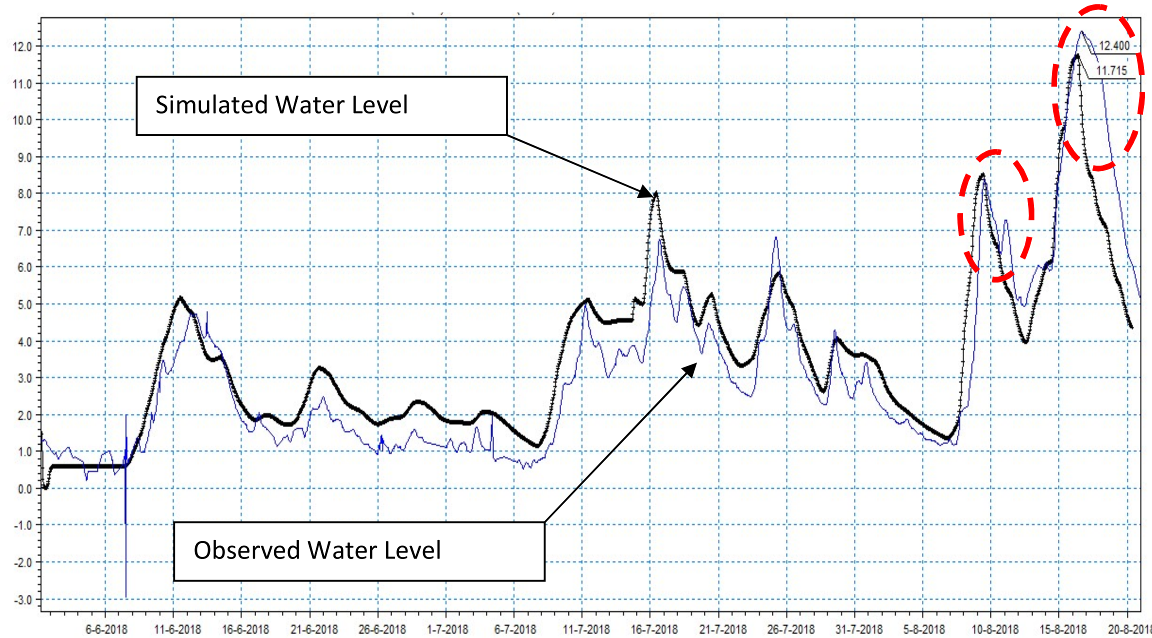


Figure 8: Model Calibration at Neeleswaram

7.2 MIKE 21 Model Validation for Kochi and Vembanad lake area

Model's 2D inundation results were validated by Sentinel-1 microwave satellite image data which was available only for 21st August, 2018 and not for 15th – 20th Aug, 2018 when the maximum flooding occurred. This is the reason why model inundation extent appears to be larger than the satellite extent as the flood may have receded from many areas by 21st Aug, 2018.

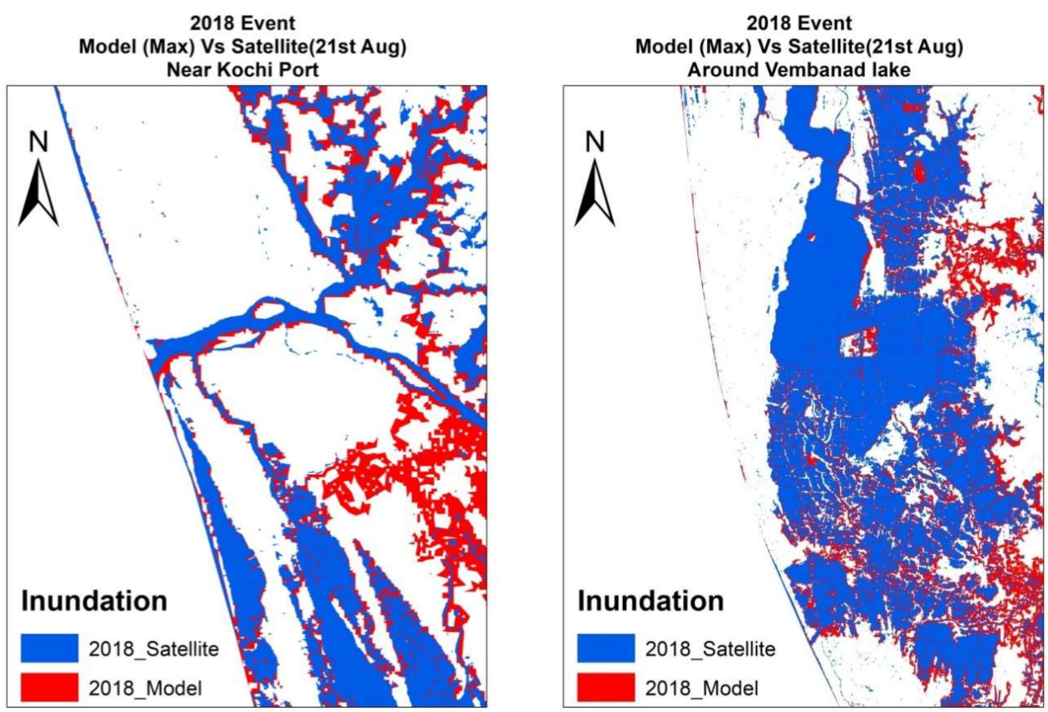


Figure 9: Satellite Verification

8.0 *Kerala Flood Solutions*

The study envisages giving following solutions with respect to flood problem in Kerala.

1. Return period based inundation maps for demarcating High, Medium and Low risk flooding areas.
2. Return period identification of Aug, 2018 Kerala flood.
3. Identification of flood vulnerable hot spots.
4. WL prediction at the locations downstream of any dam based on Rainfall forecast in next 24 hours and initial reservoir level and operational conditions.
5. Dependable Flows into the some important reservoirs
6. Flood Control Levels in some important reservoirs

8.1 *Return Period Based Inundation Maps For Demarcating High, Medium And Low Risk Flooding Areas.*

Past 35 years rainfall data from IMD was processed and frequency analysis using Gumble method was carried out. Rainfall intensity corresponding to 2, 5, 10, 25, 50 and 100 year return period was calculated. Further these different return period rainfalls were given input to the calibrated 1D model to determine the corresponding return period flows. Finally these flows routed through 2D model to obtain the respective return period inundation maps.

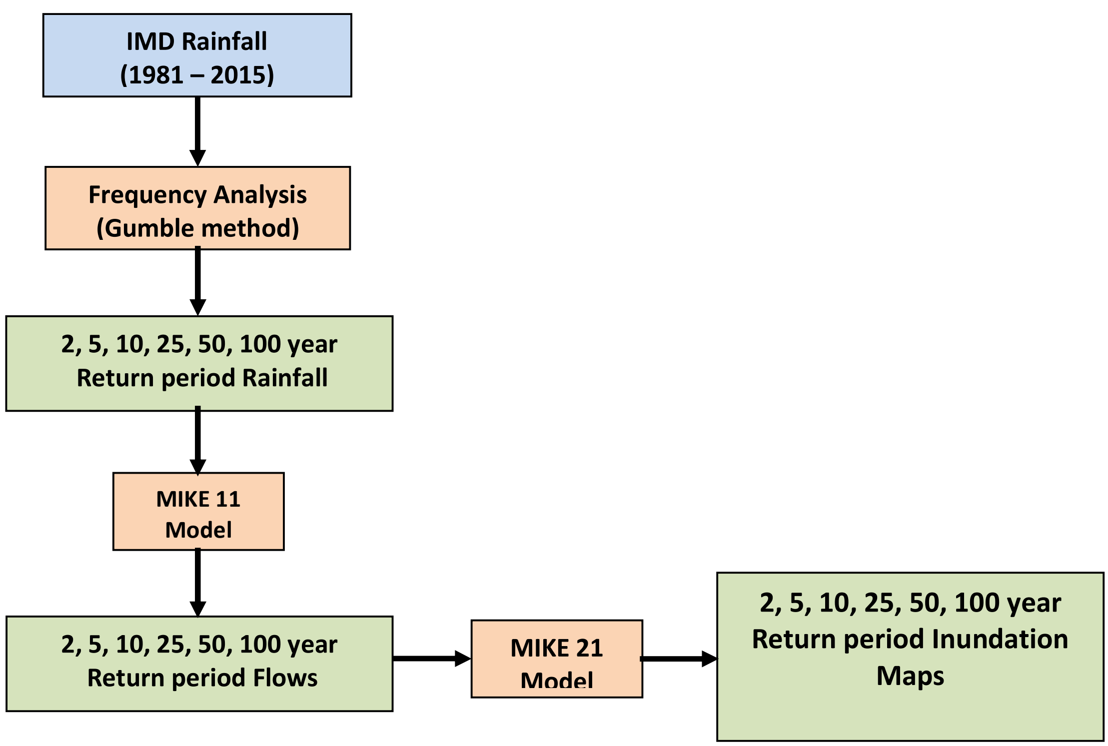


Figure 10: Flow Chart of Return Period Based Inundation Maps

2-Year Return Period Flood Inundation Map

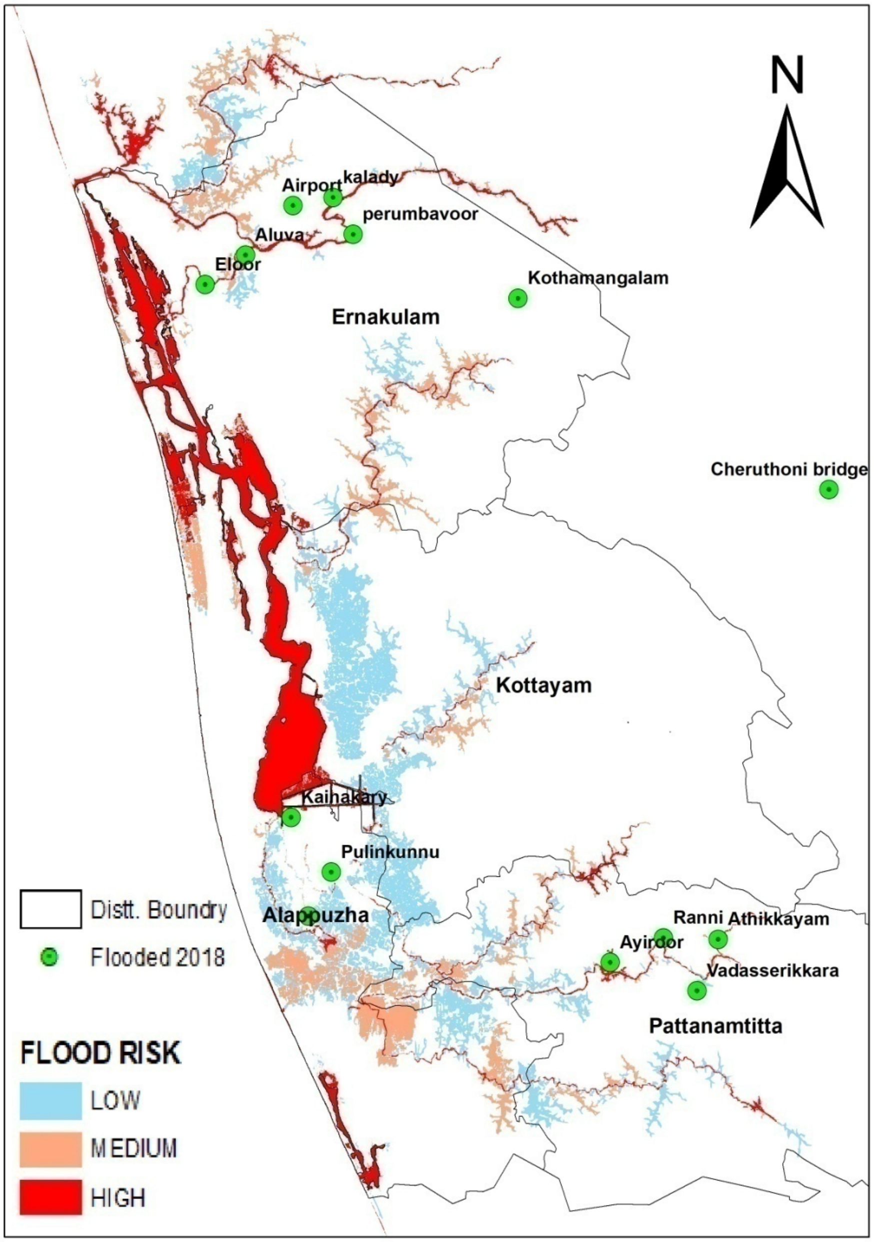


Figure 11: 2-Year Return Period Inundation Map

Flood Return Period	Inundation Area (Sqkm)	
	Increase from non-flood condition	% Increase from non-flood condition
Normal	0	
2-Year Flood	77.38	6.4 %

5 –Year Return Period Flood Inundation Map

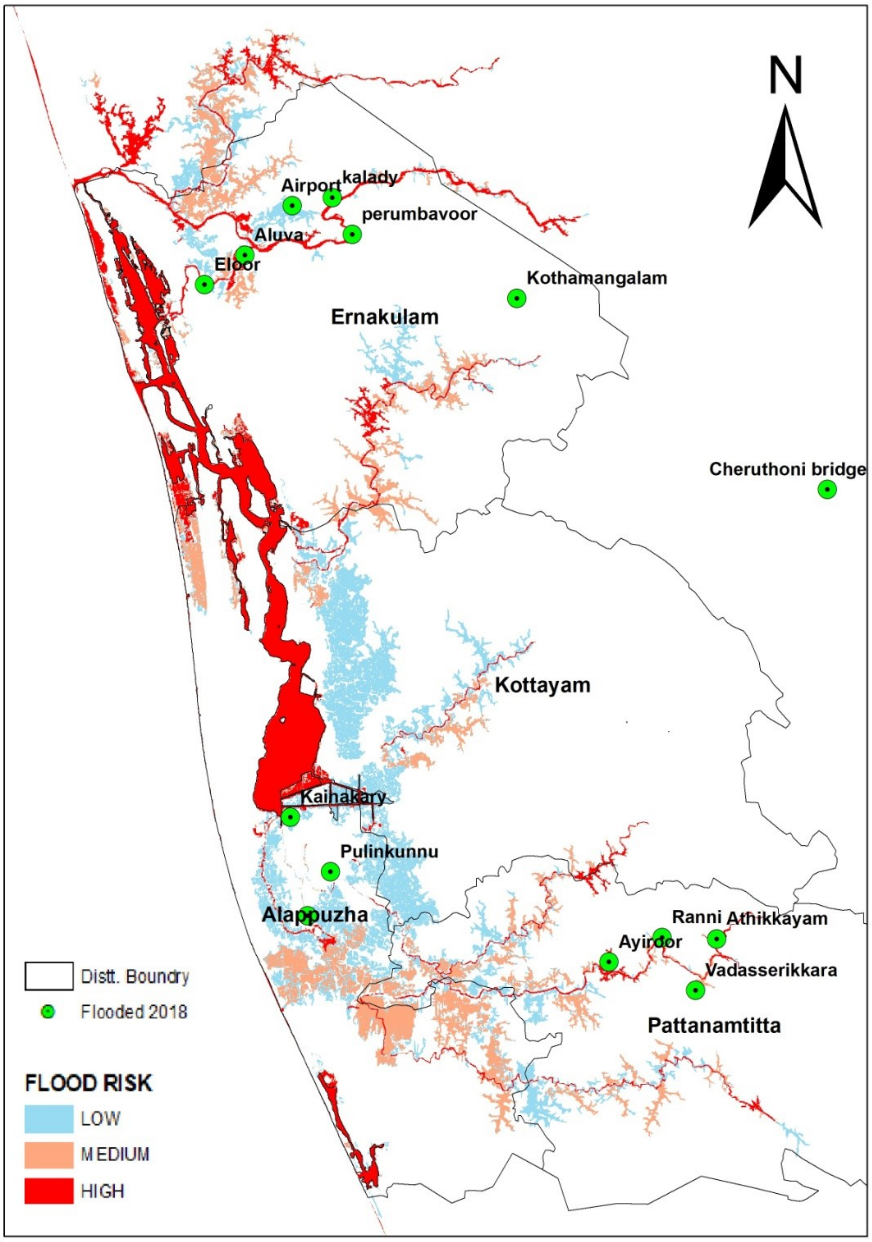


Figure 12: 5-Year Return Period Inundation Map

Flood Return Period	Inundation Area (Sqkm)	
	Increase from non-flood condition	% Increase from non-flood condition
Normal	0	
5-Year Flood	195.04	16.1 %

10 –Year Return Period Flood Inundation Map

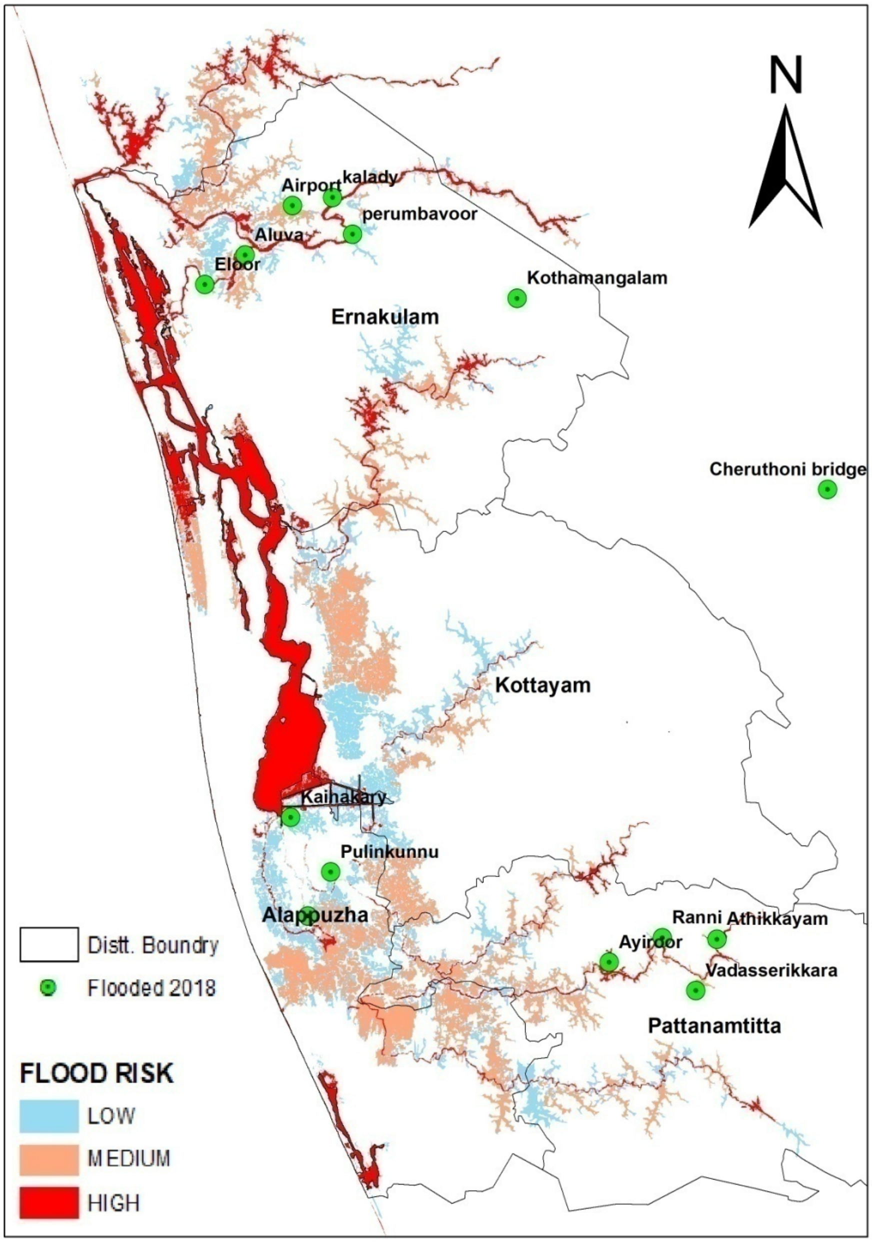


Figure 13:5-Year Return Period Inundation Map

Flood Return Period	Inundation Area (Sqkm)	
	Increase from non-flood condition	% Increase from non-flood condition
Normal	0	
10-Year Flood	283.95	23.34 %

25 –Year Return Period Flood Inundation Map

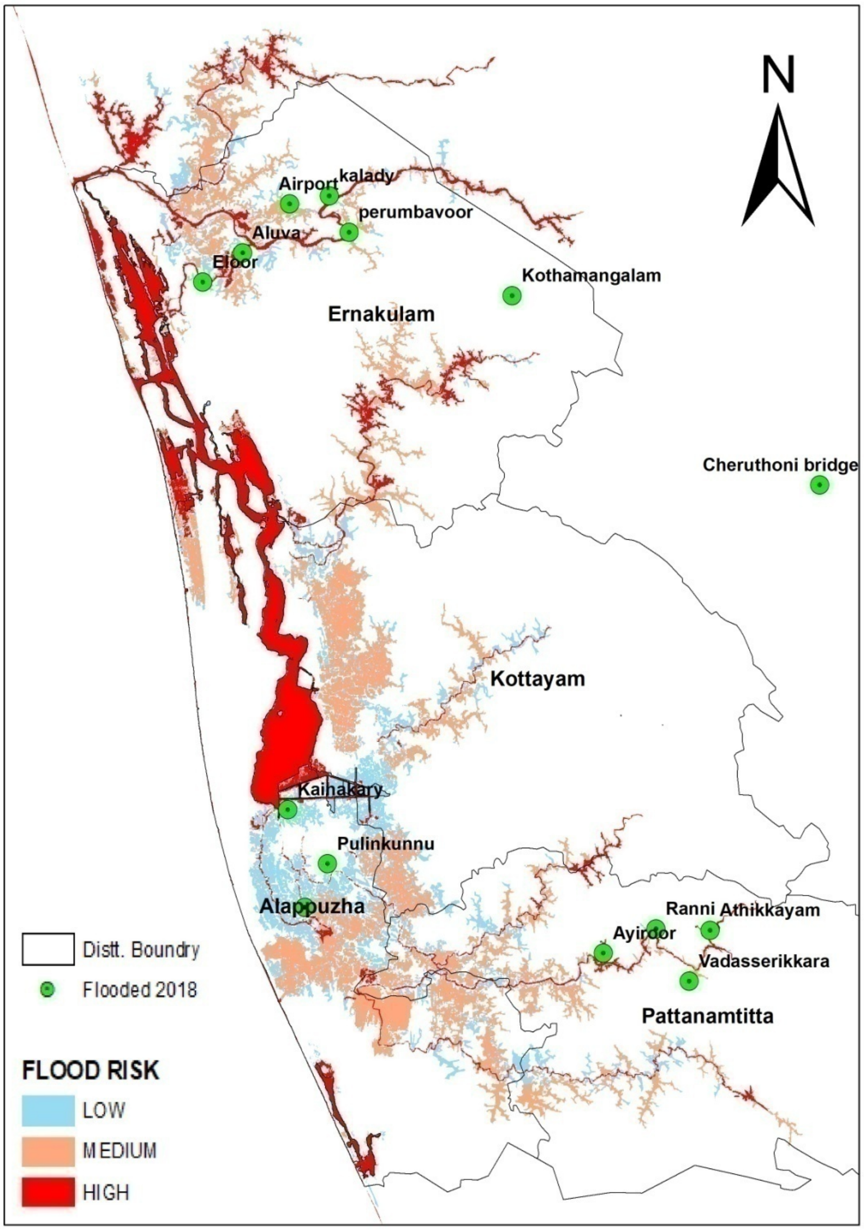


Figure 14: 25-Year Return Period Inundation Map

Flood Return Period	Inundation Area (Sqkm)	
	Increase from non-flood condition	% Increase from non-flood condition
Normal	0	
25-Year Flood	378.19	31.1 %

50 –Year Return Period Flood Inundation Map

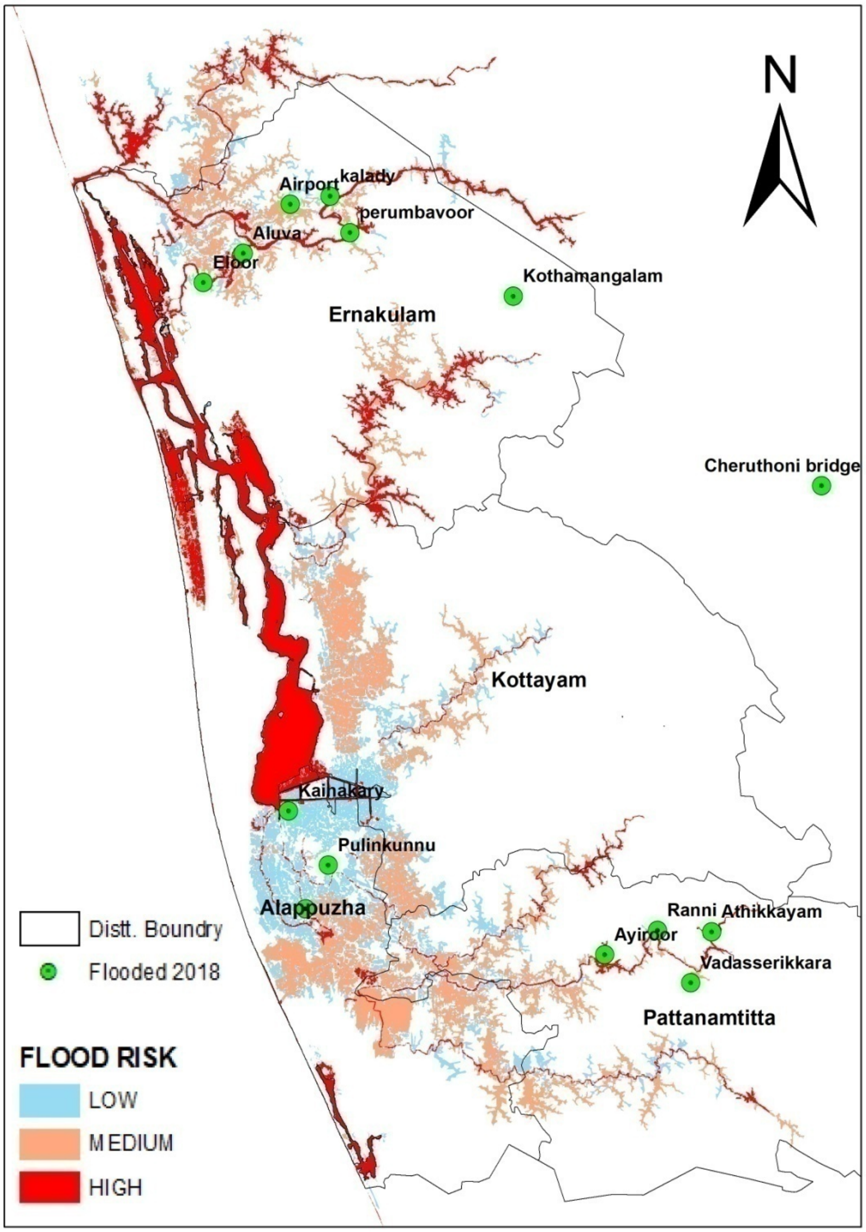


Figure 15:50-Year Return Period Inundation Map

Flood Return Period	Inundation Area (Sqkm)	
	Increase from non-flood condition	% Increase from non-flood condition
Normal	0	
50-Year Flood	445.01	36.6 %

100 –Year Return Period Flood Inundation Map

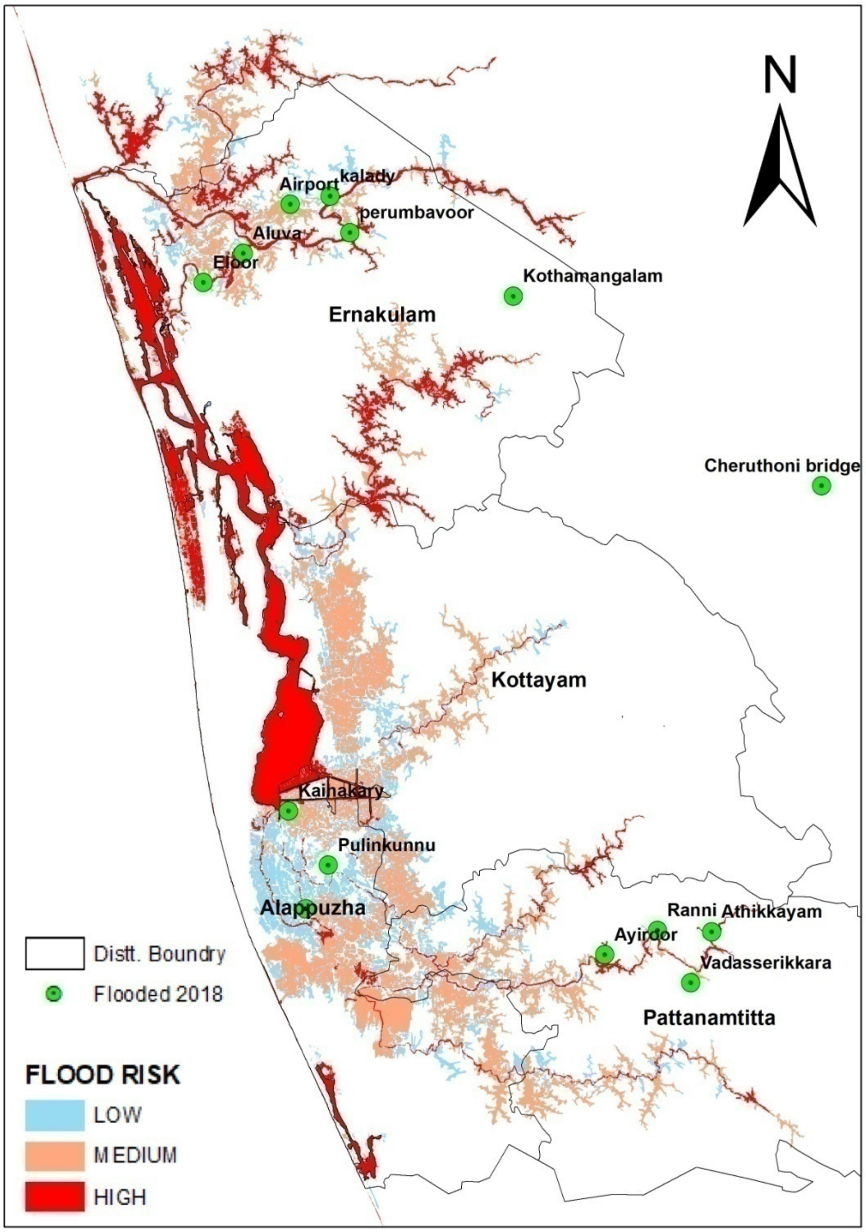


Figure 16:100-Year Return Period Inundation Map

Flood Return Period	Inundation Area (Sqkm)	
	Increase from non-flood condition	% Increase from non-flood condition
Normal	0	
100-Year Flood	484.79	39.9 %

Inundation Area Based on Water Depth (Sqkm)				
Flood condition	LOW RISK	MEDIUM RISK	HIGH RISK	TOTAL
Normal (No Flood)	533.61	280.53	402.30	**1216.45**
2-Year Flood	536.74	335.12	421.97	**1293.83**
5-Year Flood	547.72	410.80	452.96	**1411.49**
10-Year Flood	457.33	587.91	455.166	**1500.40**
25-Year Flood	448.11	672.71	473.81	**1594.64**
50-Year Flood	475.68	674.68	511.39	**1661.46**
100-Year Flood	432.03	717.55	551.64	**1701.24**
2018 Flood	423.00	724.34	689.63	**1836.97**

Table 1: Inundation Area Based on Risk

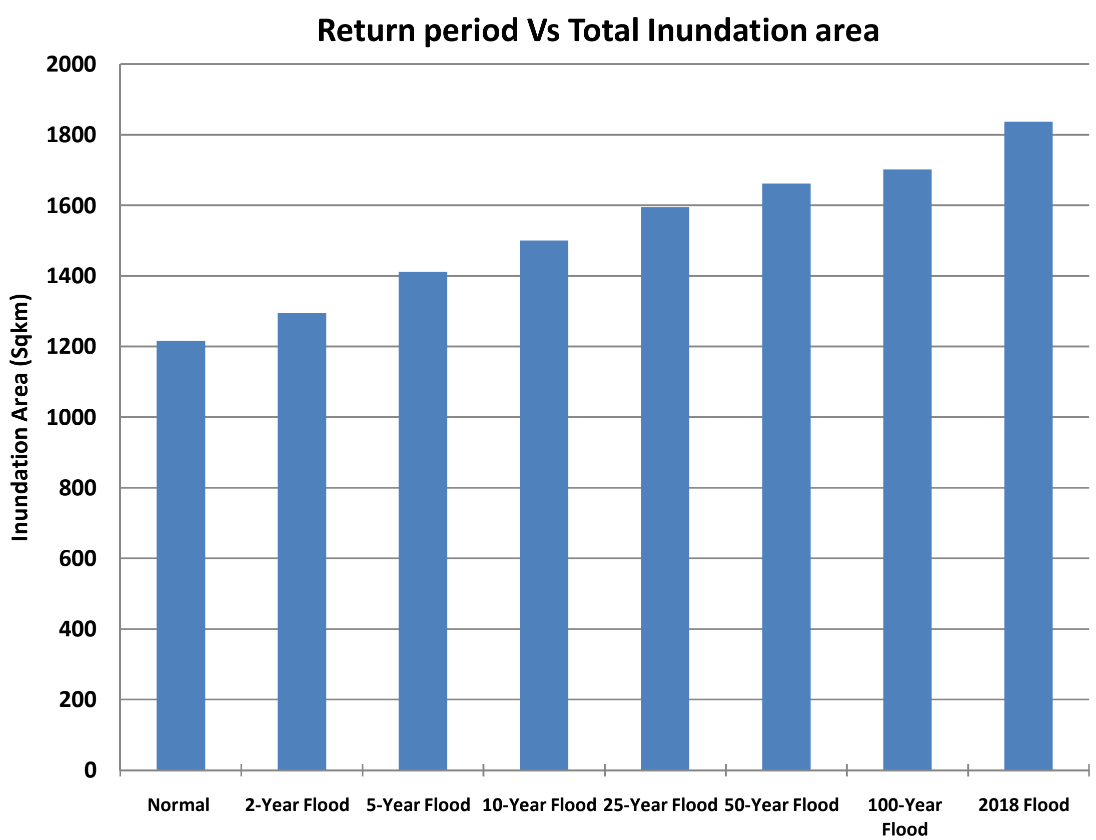


Figure 17: Return Period VsTotal Inundation Area

8.2 Return Period Identification of Aug, 2018 Kerala Flood

Following methodology was adopted to do this analysis.

I. **A** – Increase in inundation area from non-flood condition by using Aug, 2018 rainfall as input to model : **620.52 Sqkm**

II. **B** – Increase in inundation area from non-flood condition by using 100 year return period rainfall as input to model:**484.79 Sqkm**.

III. **A – B** ie. **135.73 Sqkm** is the additional area over 100 year return period inundation that got inundated in the 2018 flood event, it is therefore concluded that the **return period of 2018 Kerala flood was definitely above 100 years**.

Also, from the hydrological analysis carried out by CWC in September 2018 it was found that the August 2018 storm was almost comparable with the severest storm of July 1924 of Devikulam.

The figure below shows the comparison of inundation extent corresponding to 100 year return period flood and 2018 flood event.

100 year return period inundation **2018 inundation**

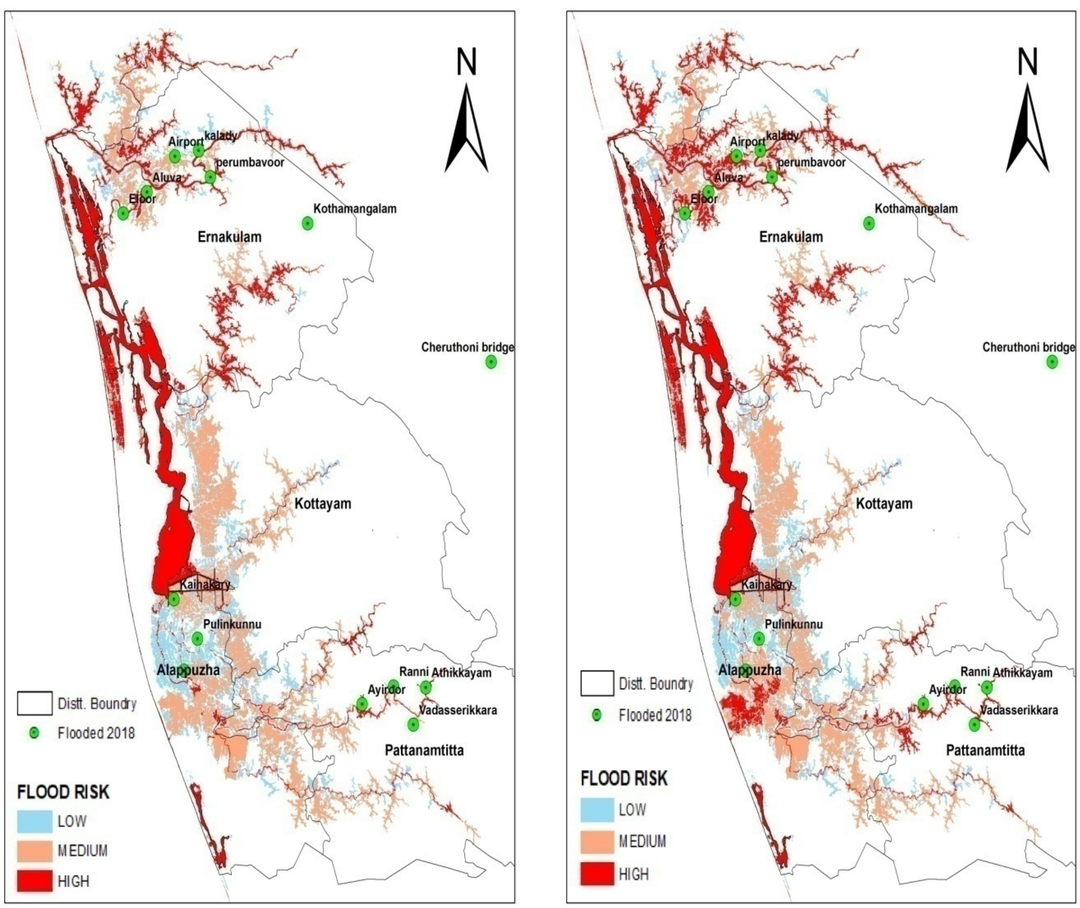


Figure 18: 100 YearVs 2018 Inundation Map

8.3 *Identification of Flood Vulnerable Hotspots atTaluk level*

For identification of flooded areas in flood vulnerable taluks lean period (non-flooded) inundation extent was subtracted from the 2018 flood inundation extent as shown in the figure below.

I. **A**: 2018 inundation extent
II. **B**: Non-flood (lean period) inundation extent
III. **A – B** = Flood vulnerable areas. (derived at Taluk level)

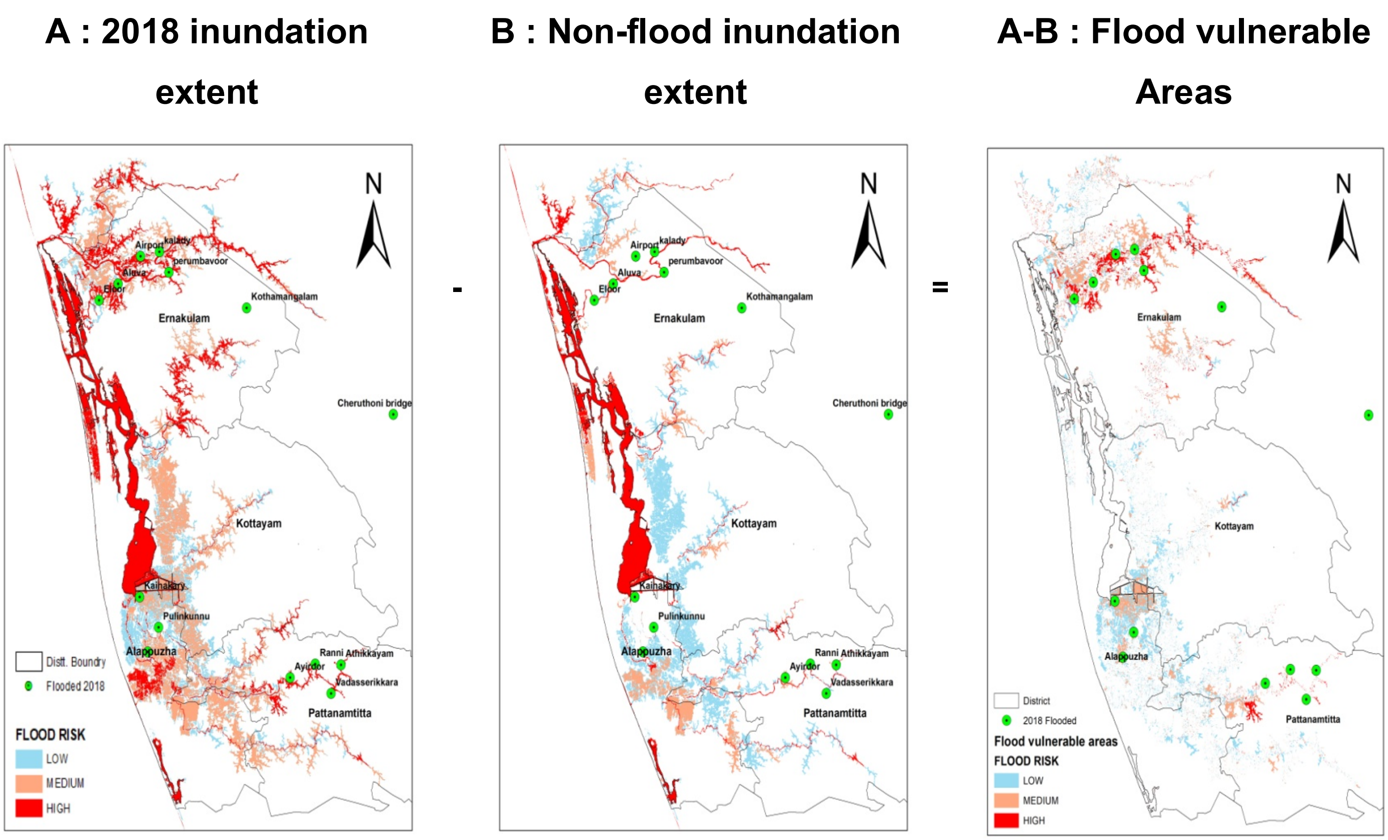


Figure 19: Flood Vulnerable Areas

Taluk-wise identification of flood vulnerable areas was further done to give more detail information, classifying the areas according to flood risk based on the inundation depths obtained from the model. Following are the inundation maps of the vulnerable taluks of the state.

SNo.	Taluk :	ALWAYE	District :	ERNAKULAM
1				

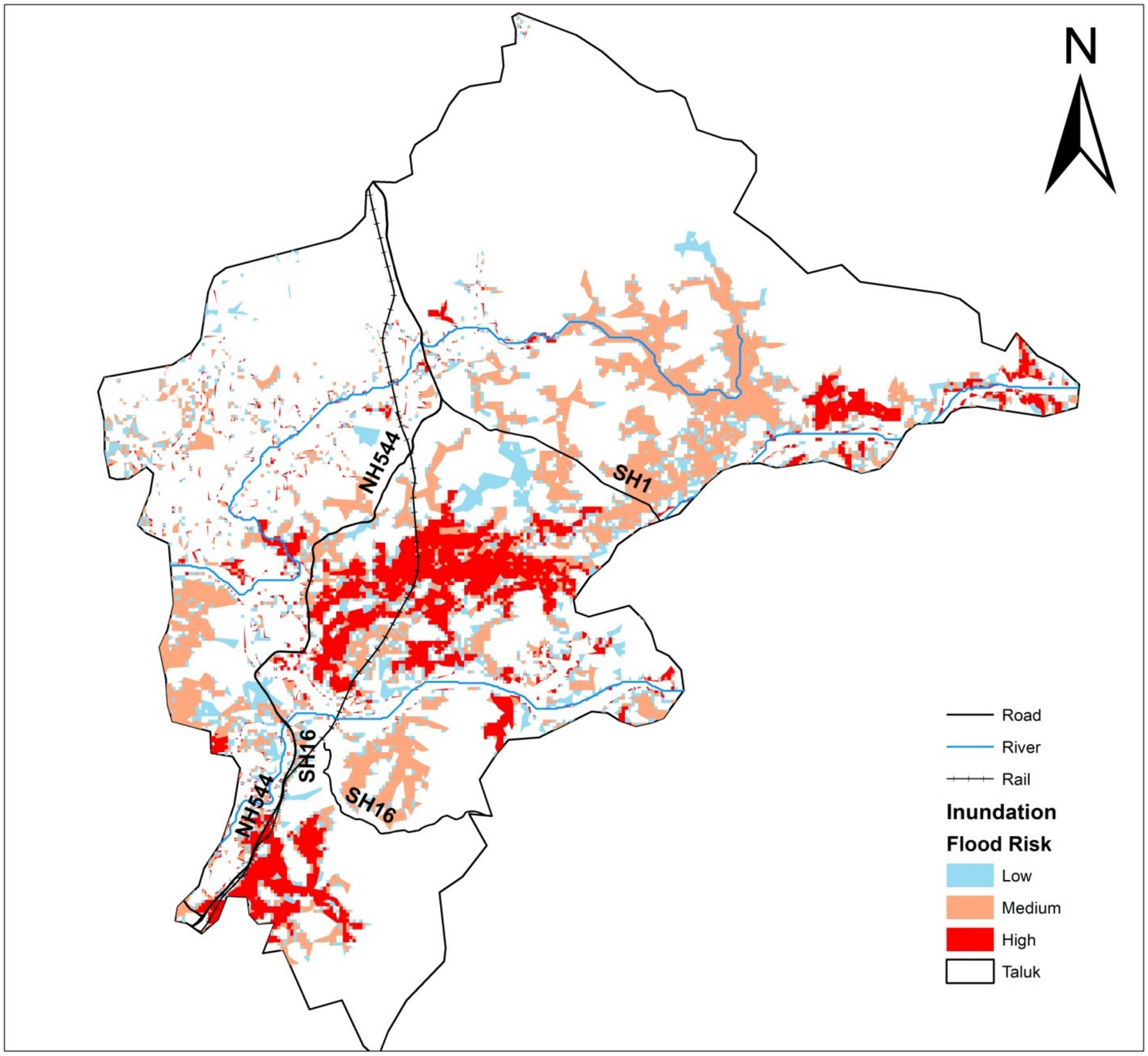


Figure 20:Hotspots in ALWAYE

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
332.17	**86.83**	**26.14**

SNo.	Taluk :	CHANGANACHERI	District :	KOTTAYAM
2				

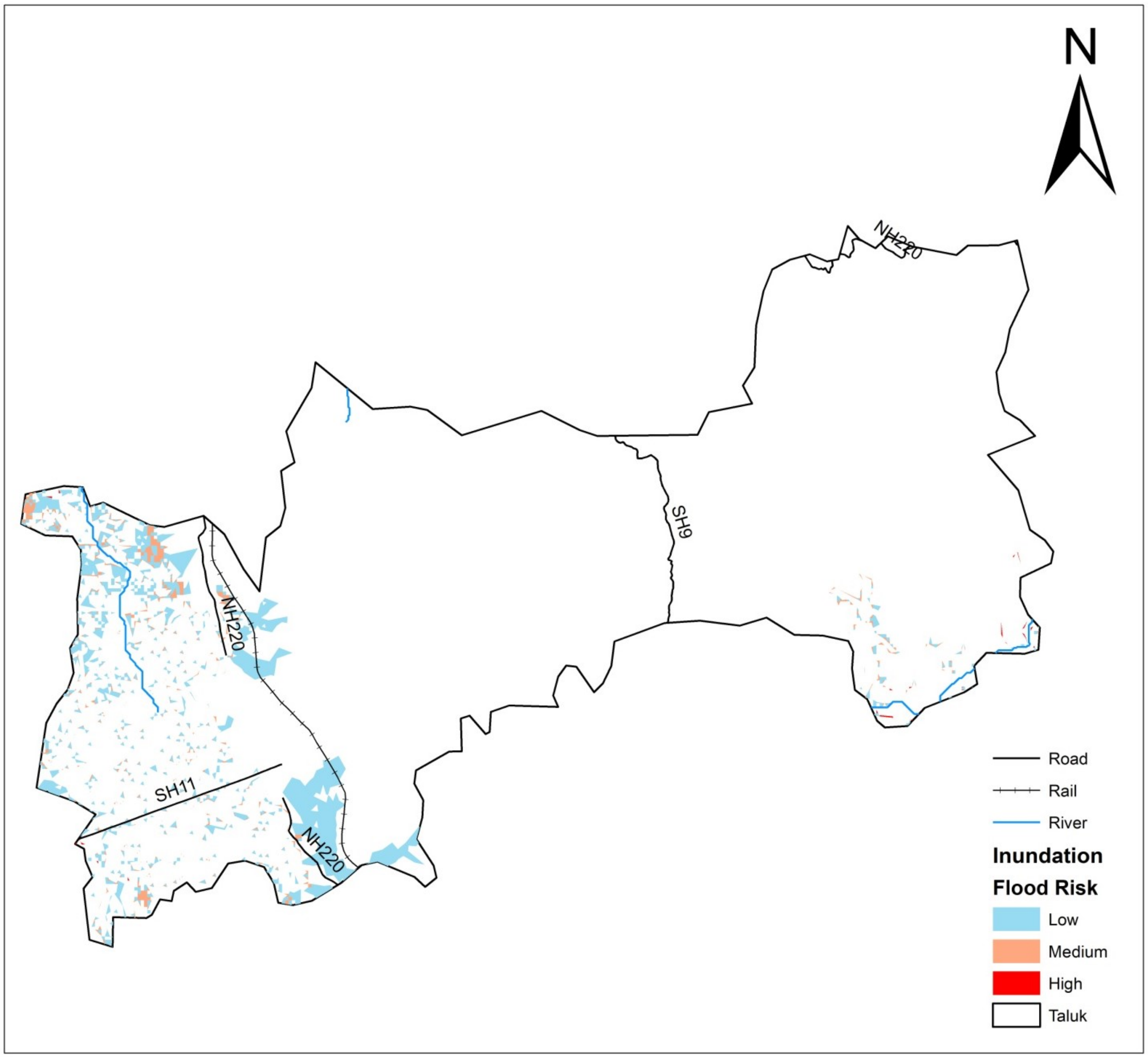


Figure 21:Hotspots in CHANGANACHERI

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
266.3	**13.22**	**4.96**

SNo.	Taluk :	CHENGANNUR	District :	ALLAPUZHA
3				

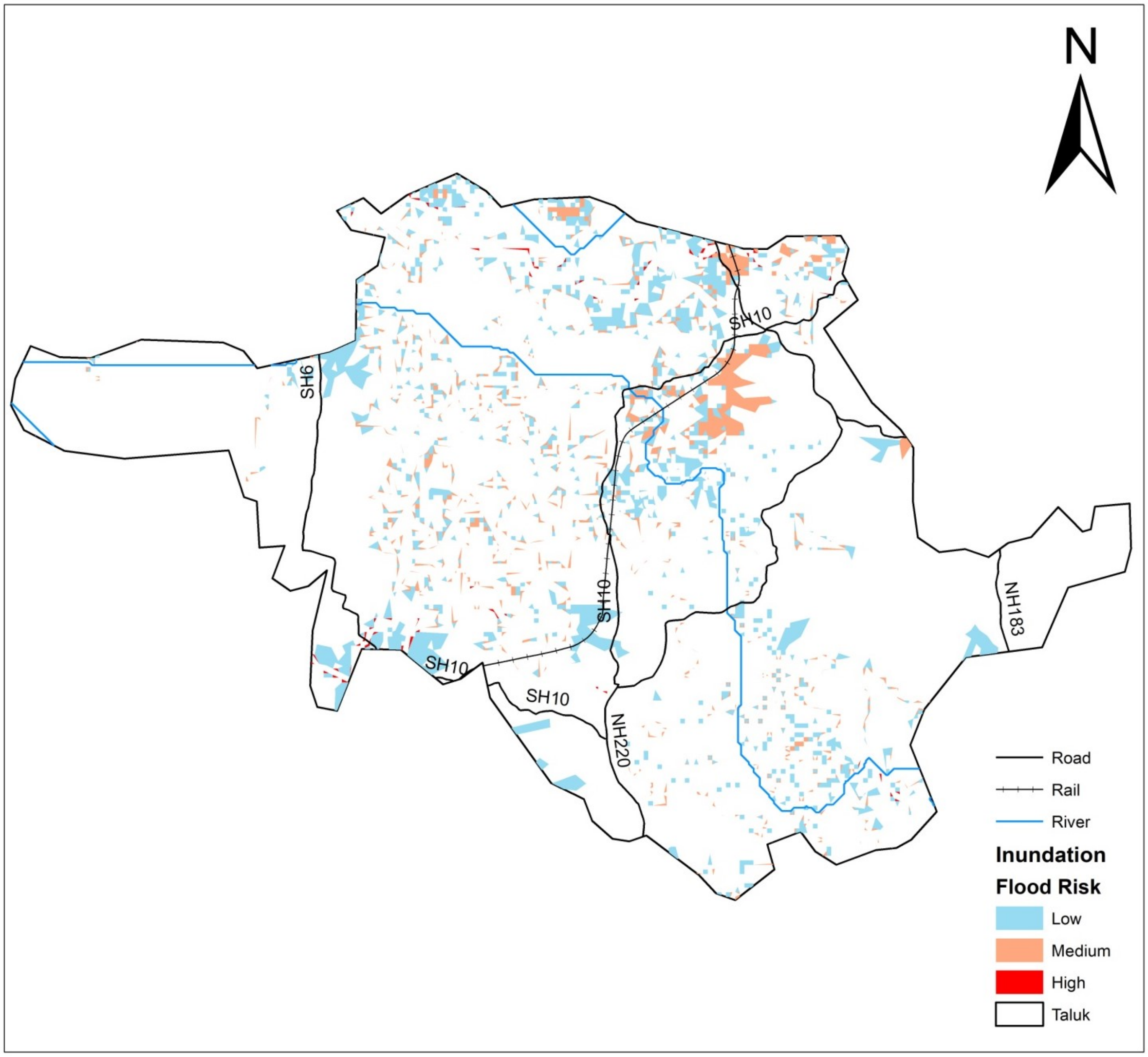


Figure 22: Hotspots in CHENGANNUR

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
153.98	**15.5**	**10.06**

SNo.	Taluk :	HARIPAD	District :	ALLAPUZHA

4

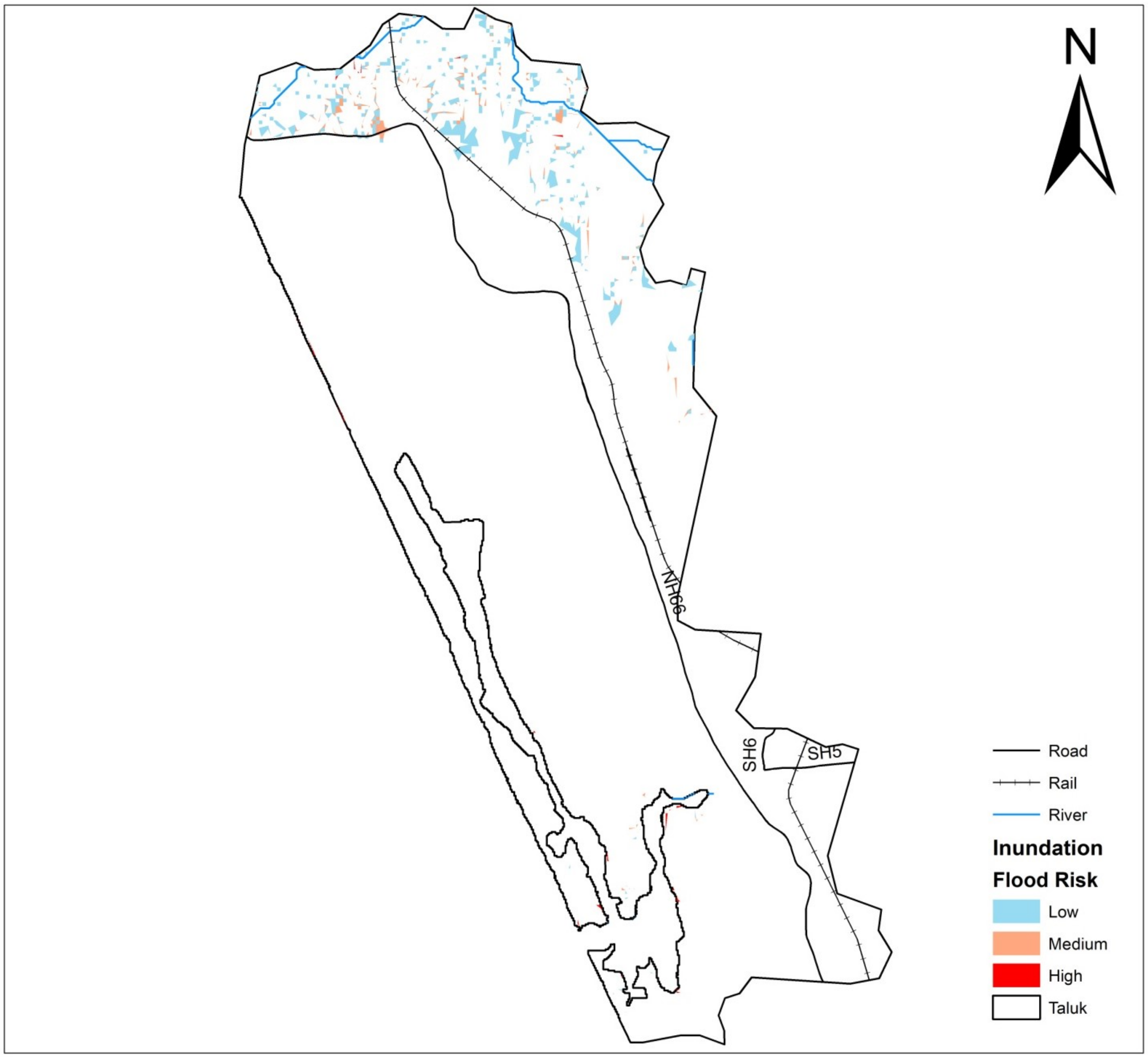


Figure 23: Hotspots in HARIPAD

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
186.84	**3.71**	**1.98**

SNo.	Taluk :	IRINJALAKUDA	District :	THRISSUR
5				

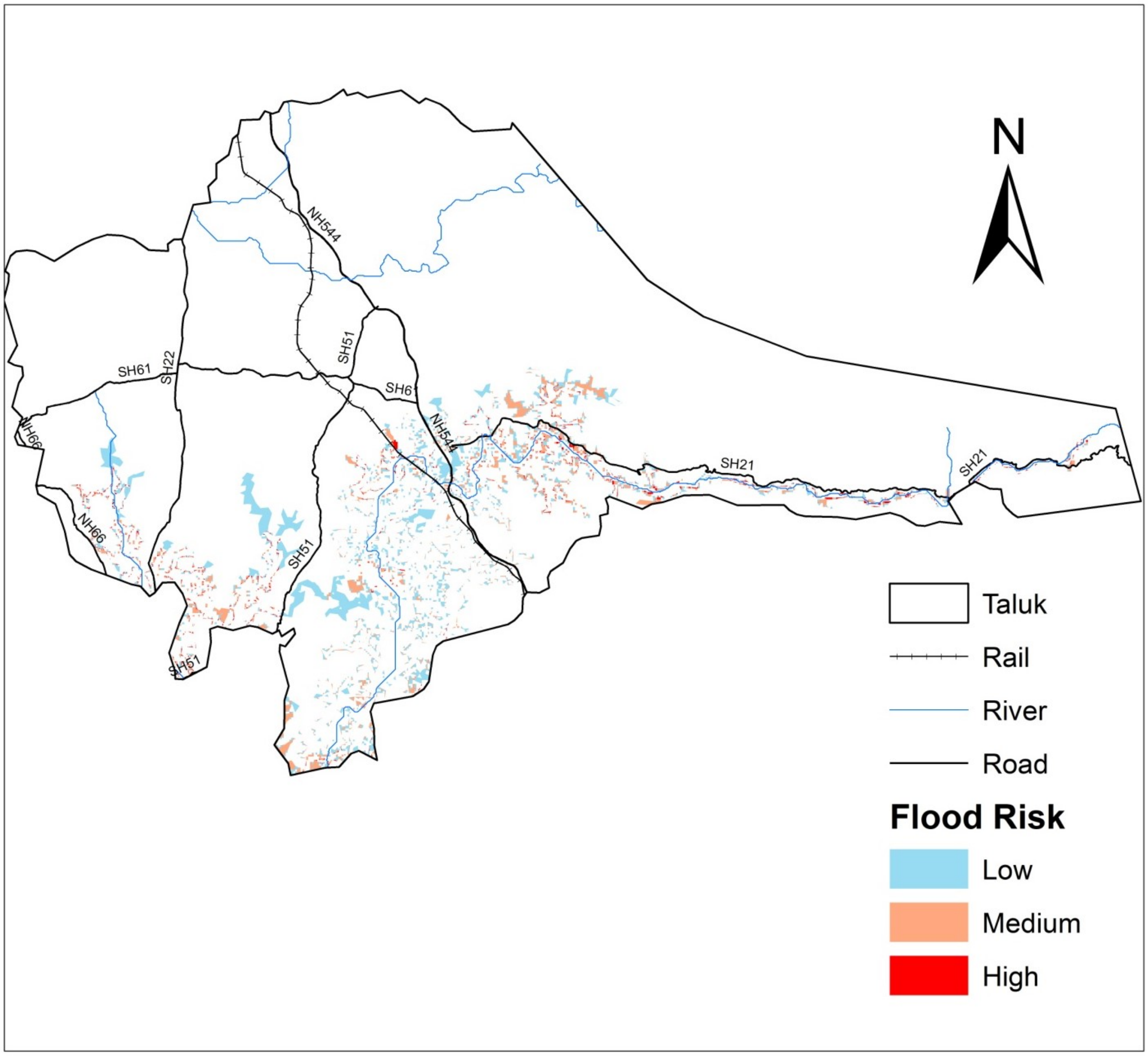


Figure 24: Hotspots in IRINJALAKUDA

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
856.1	**38.24**	**4.46**

SNo.	Taluk :	KOTTAYAM	District :	KOTTAYAM

6

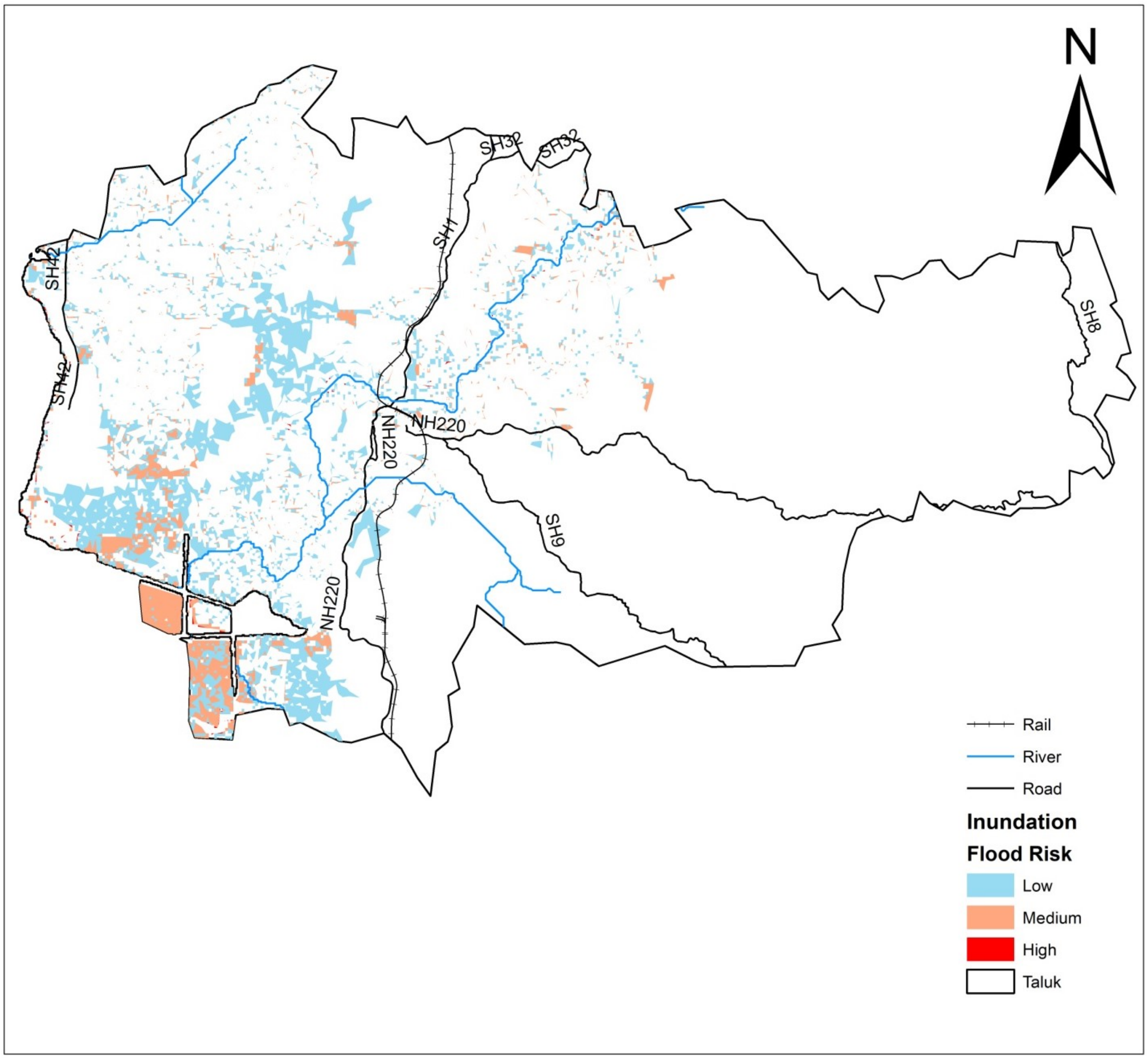


Figure 25:Hotspots in KOTTAYAM

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
514.14	**47.64**	**9.26**

SNo.	Taluk :	MALLAPALLI	District :	PATTANAMTITTA
7				

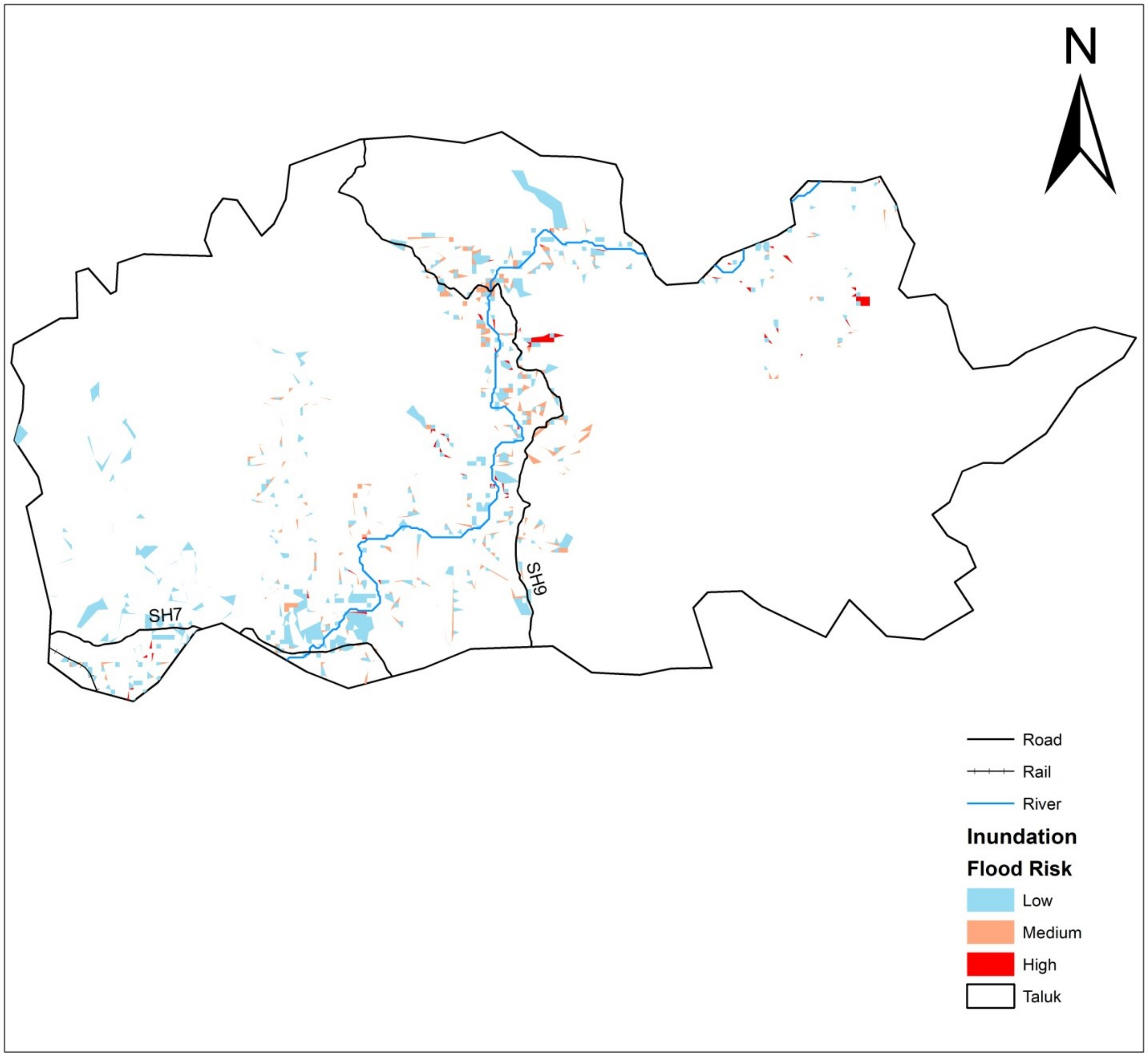


Figure 26: Hotspots in MALLAPALLI

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
168.58	**5.63**	**3.34**

SNo.	Taluk :	KUTTANAD	District :	ALLAPUZHA

8

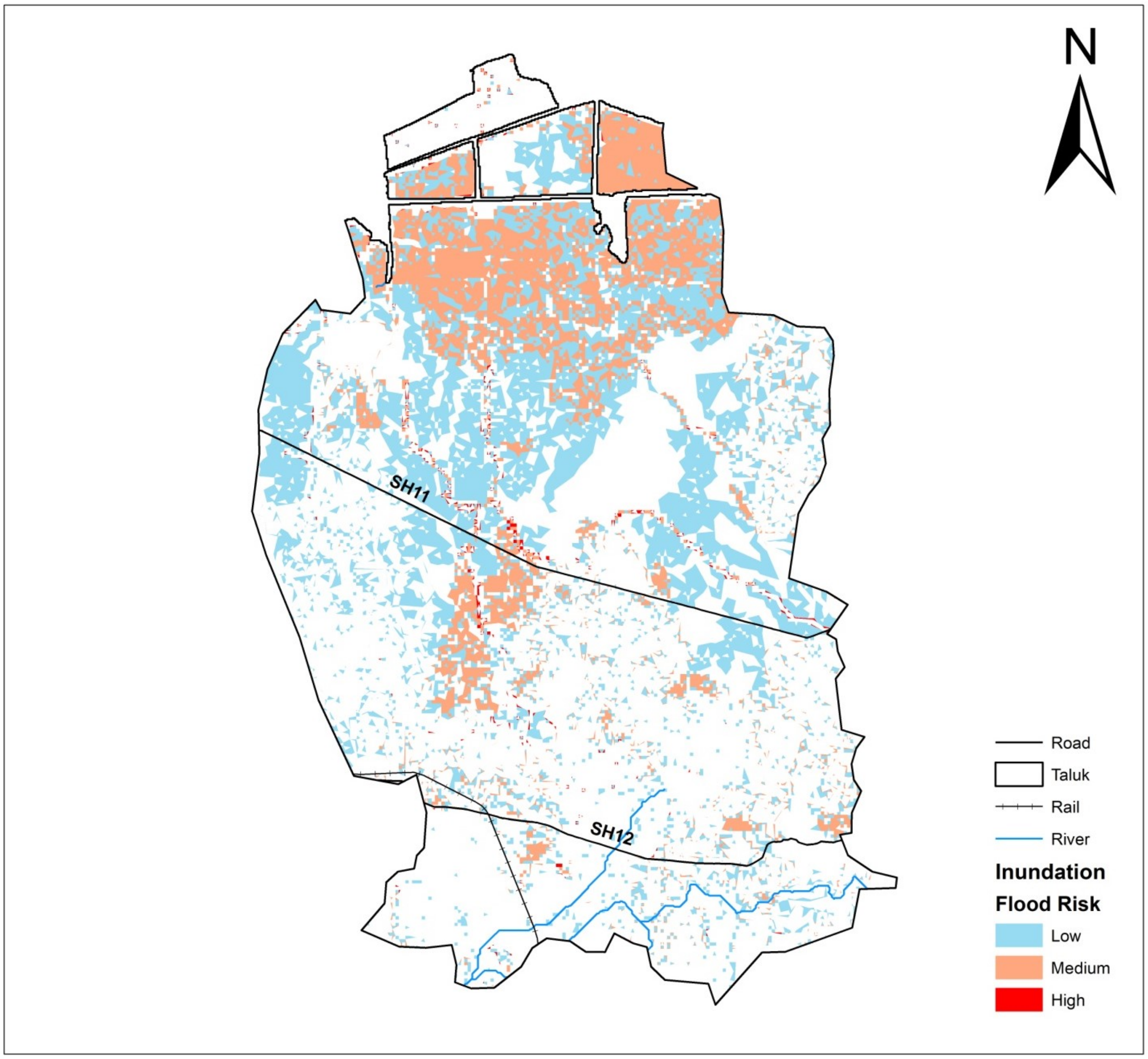


Figure 27:Hotspots in KUTTANAD

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
311.71	**111.6**	**35.8**

SNo.	Taluk :	MAVELIKARA	District :	ALLAPUZHA
9				

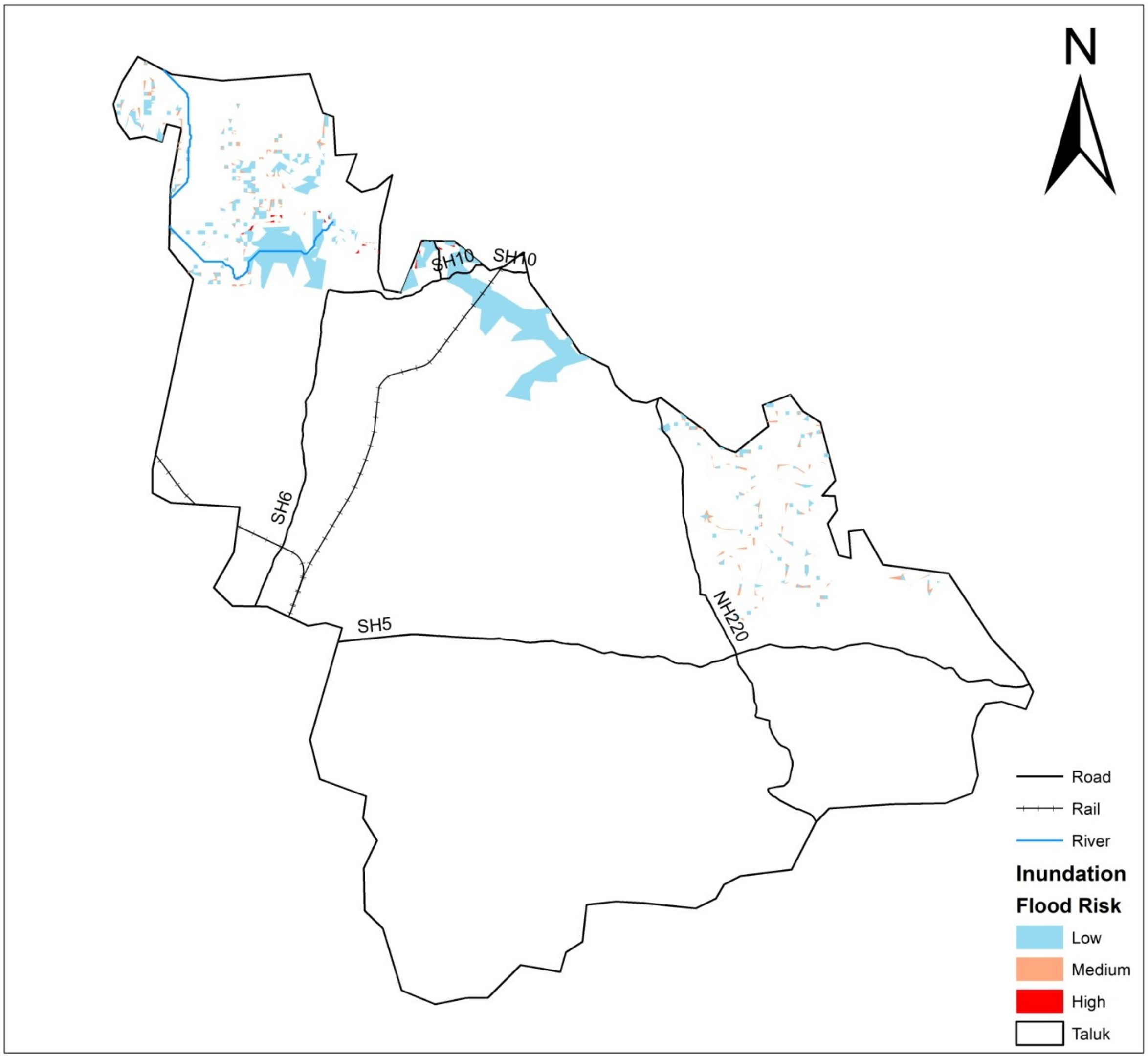


Figure 28: Hotspots in MAVELIKARA

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
234.42	**6.8**	**2.9**

SNo.	Taluk :	MUVATTUPULA	District :	ERNAKULAM

10

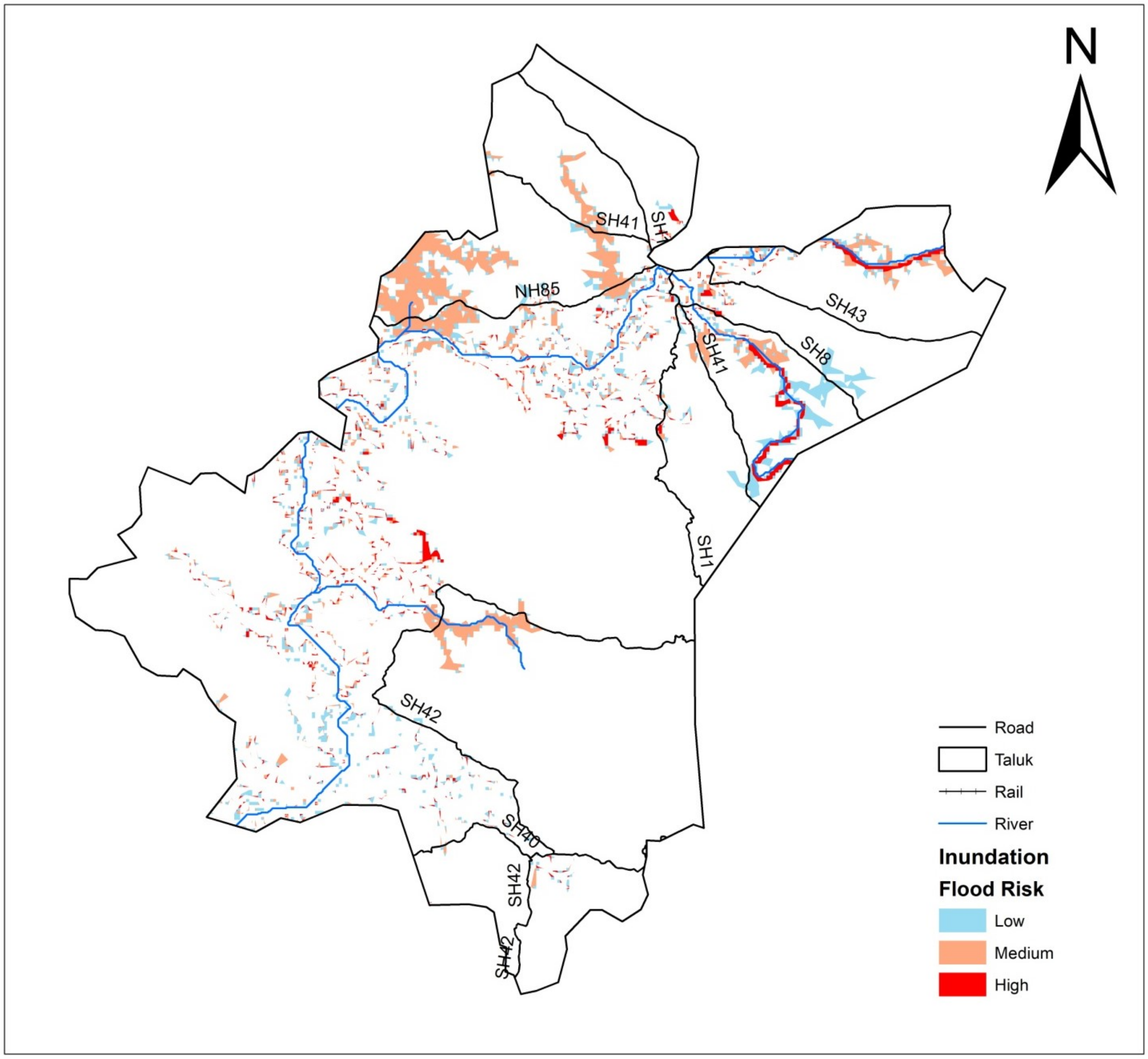


Figure 29:Hotspots in MUVATTUPULA

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
358.34	**29.51**	**8.23**

SNo.	Taluk :	PATTANAMTITTA	District :	PATTANAMTITTA
11				

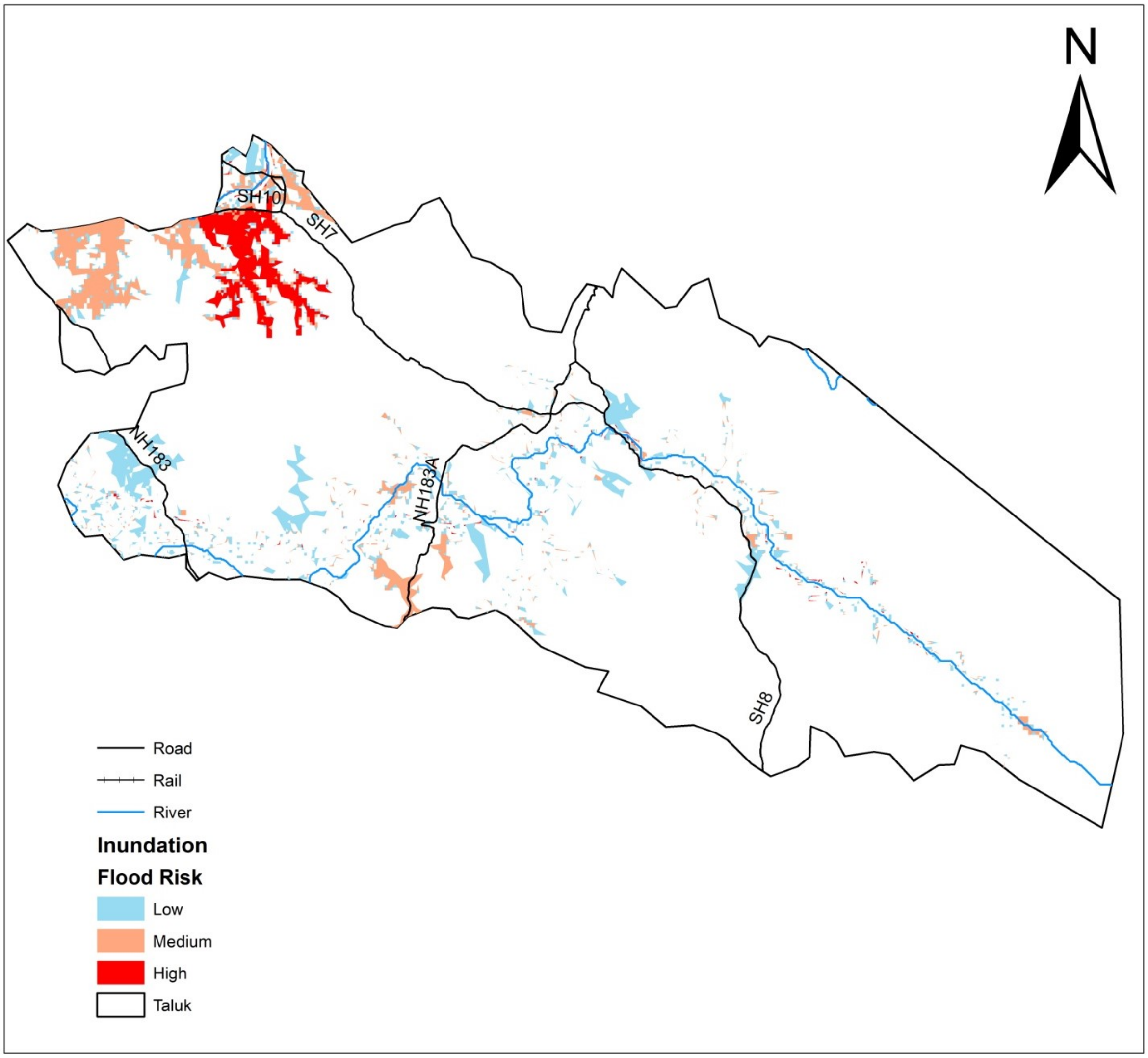


Figure 30:Hotspots in PATTANAMTITTA

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
434.34	**33.31**	**7.67**

SNo.	Taluk :	PALA	District :	KOTTAYAM

12

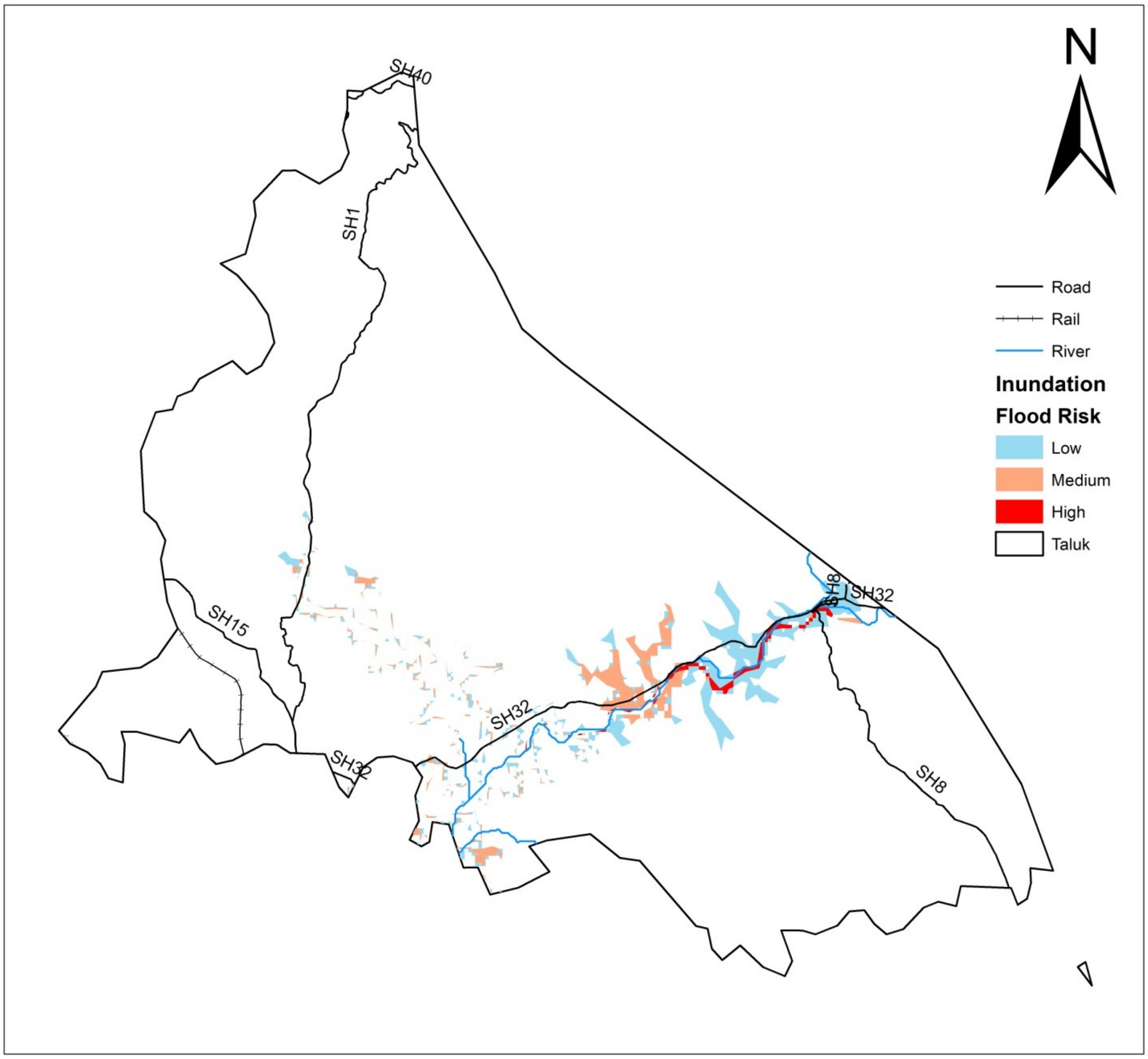


Figure 31: Hotspots in PALA

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
282.17	**9.88**	**3.5**

SNo.	Taluk :	PARUR	District :	ERNAKULAM
13				

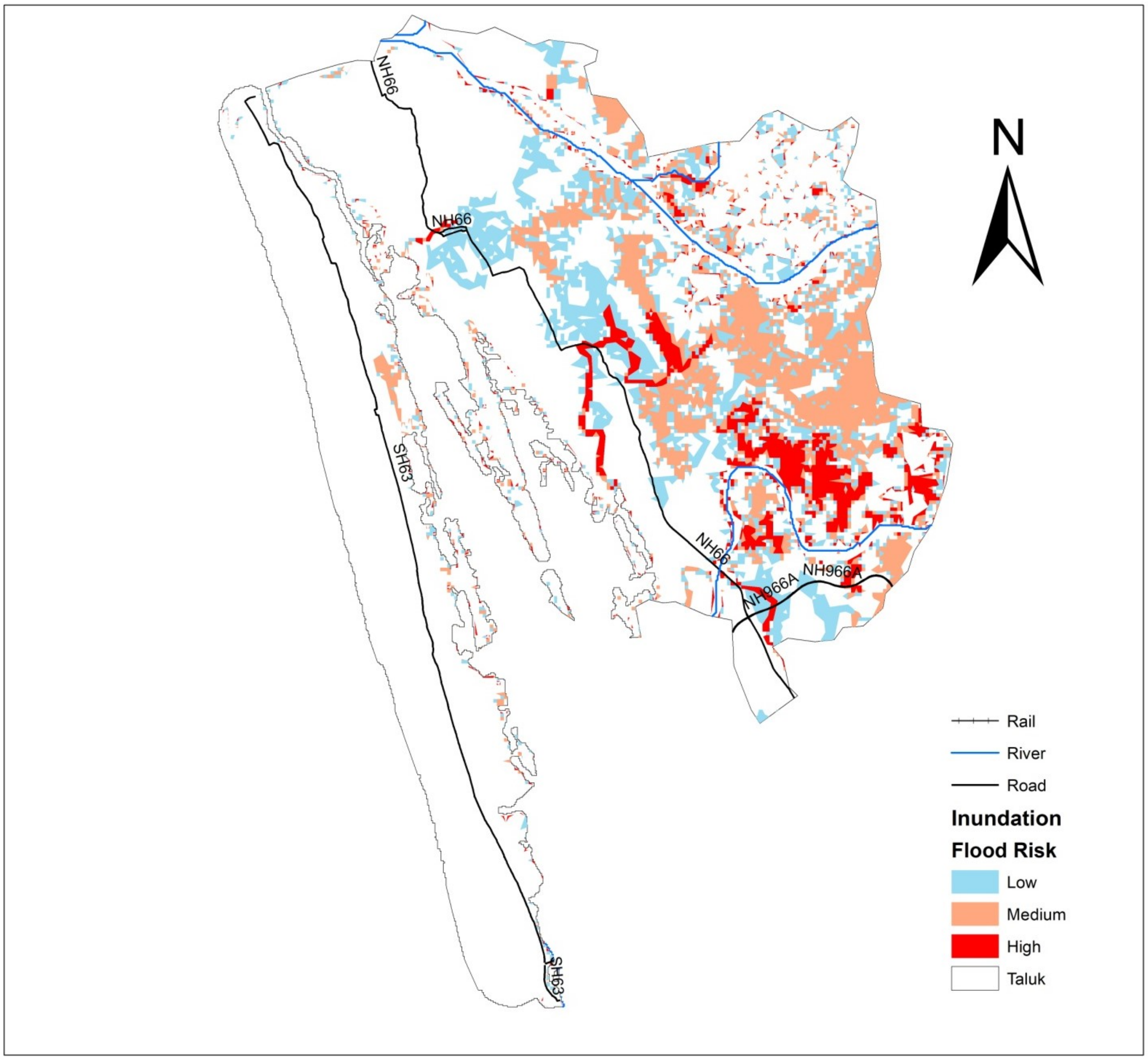


Figure 32:Hotspots in PARUR

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
217.8	**57.69**	**26.48**

SNo.	Taluk :	PERUMBAVUR	District :	ERNAKULAM
14				

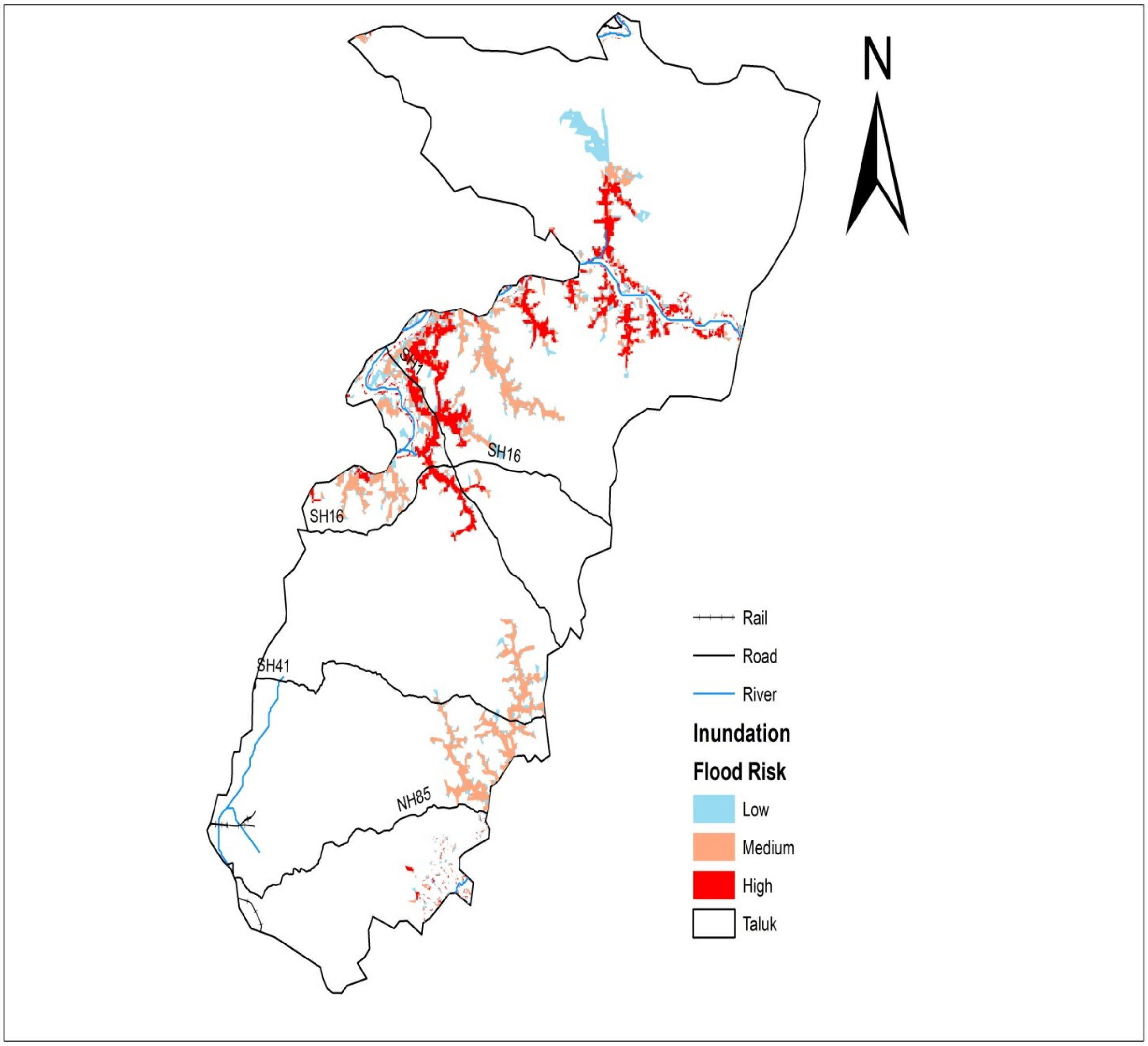


Figure 33:Hotspots in PERUMBAVUR

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
713.7	**60.43**	**8.46**

SNo.	Taluk :	RANI	District :	PATTANAMTITTA
15				

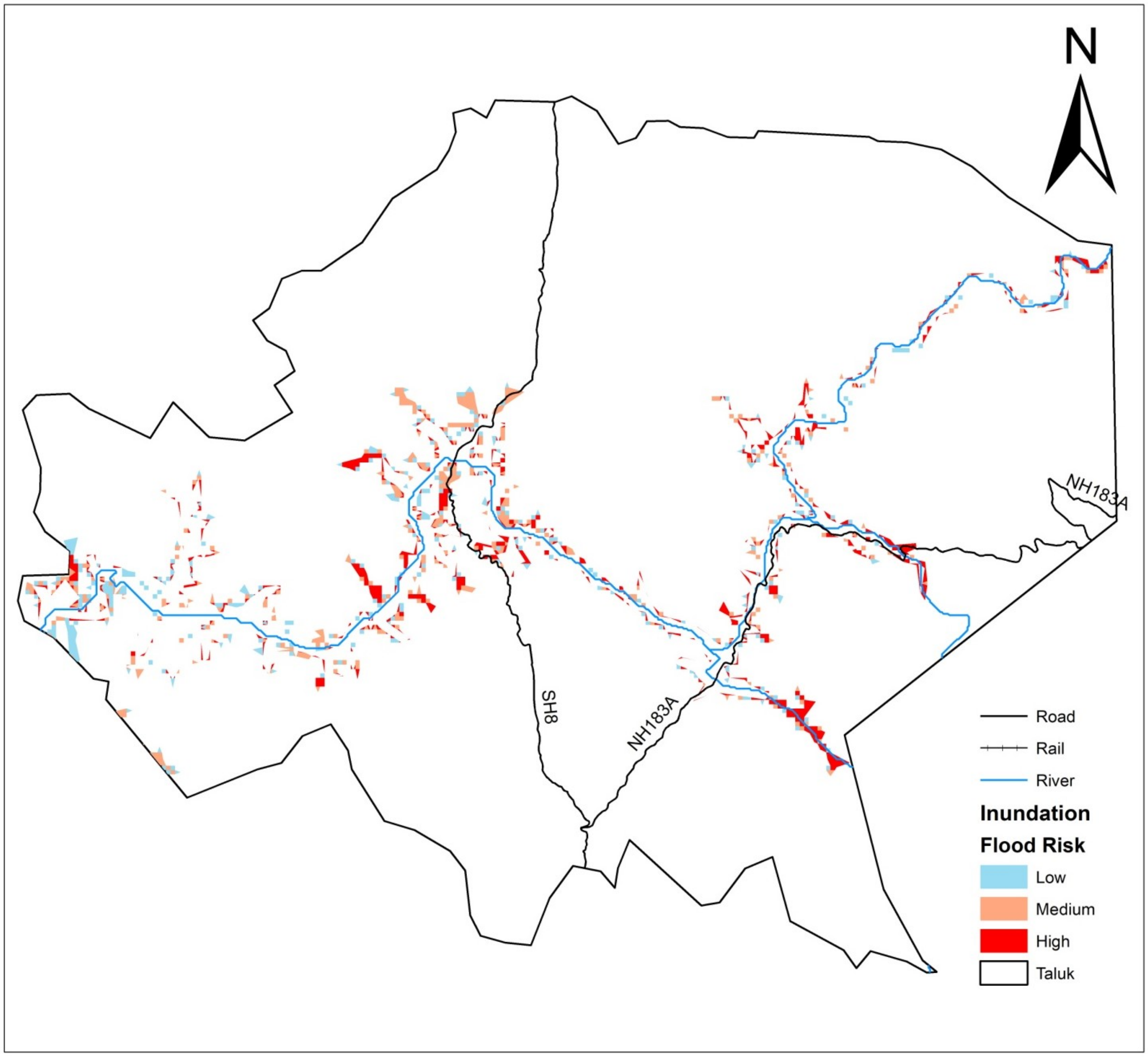


Figure 34: Hotspots in RANI

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
261.76	**7.96**	**3.04**

SNo.	Taluk :	TIRUVALLA	District :	PATTANAMTITTA
16				

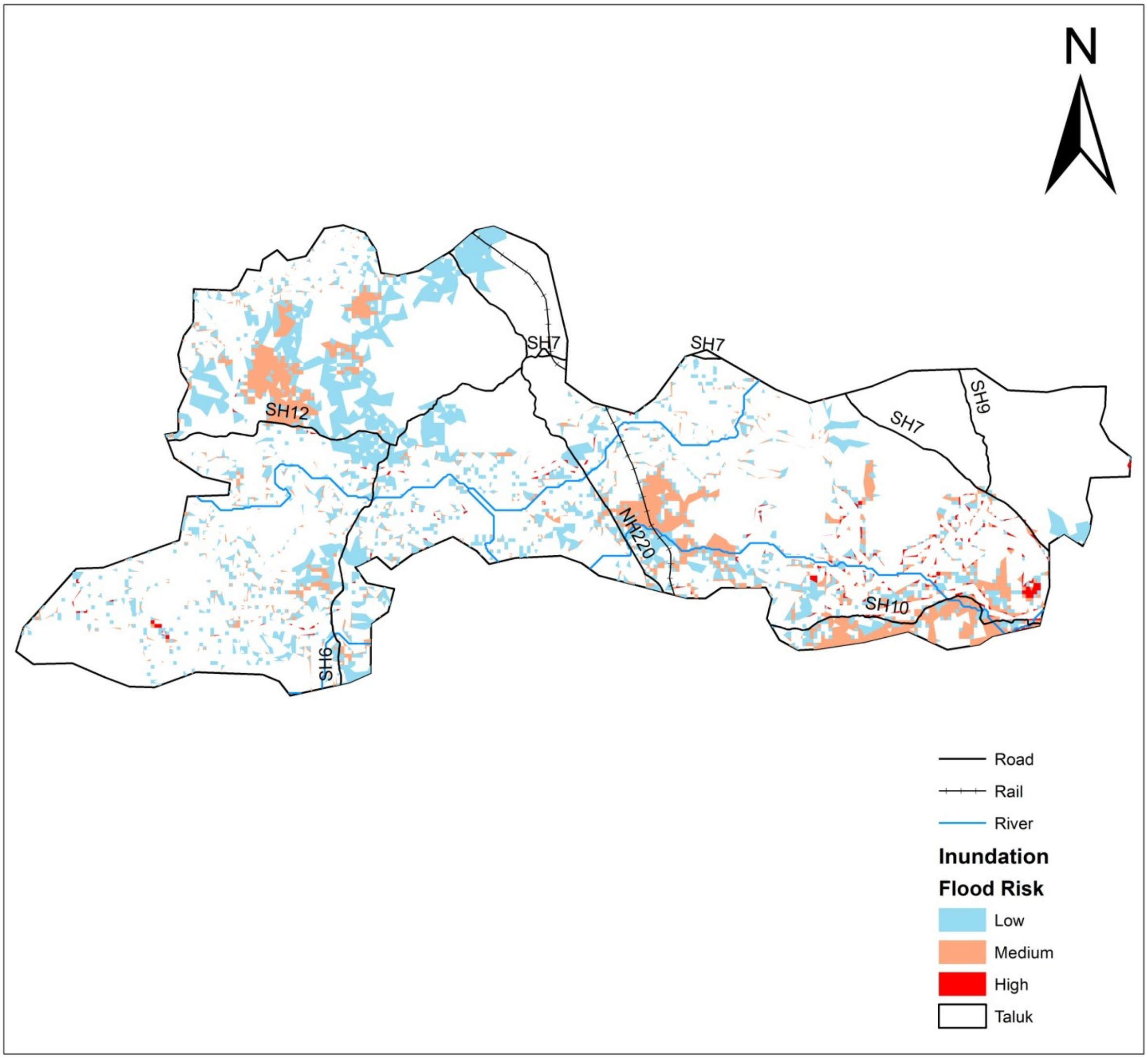


Figure 35: Hotspots in TIRUVALLA

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
165.69	**33.58**	**20.26**

SNo.	Taluk :	VAIKAM	District :	KOTTAYAM
17				

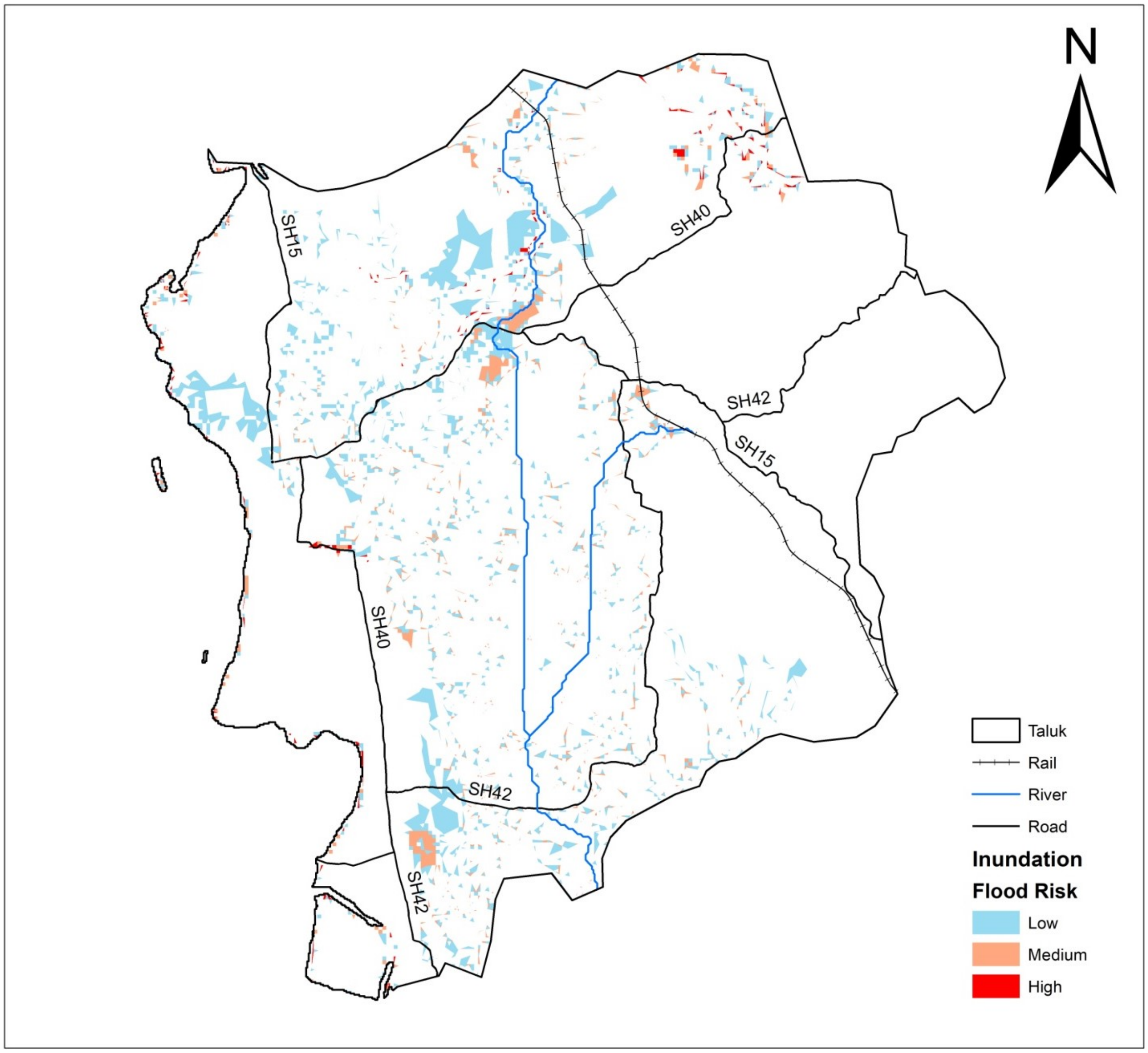


Figure 36: Hotspots in VAIKAM

Taluk Area (Sqkm)	Inundated area (Sqkm)	Inundated Area (%)
280.58	**17.15**	**6.12**

Taluk Name	**Taluk Area** (Sqkm)	**Inundated Area** (Sqkm)	**Inundated Area** (%)
KUTTANAD	311.71	111.6	**35.8**
PARUR	217.8	57.69	**26.48**
ALWAYE	332.17	86.83	**26.14**
TIRUVALLA	165.69	33.58	**20.26**
CHENGANNUR	153.98	15.5	**10.06**
KOTTAYAM	514.14	47.64	**9.26**
PERUMBAVUR	713.7	60.43	**8.46**
MUVATTUPULA	358.34	29.51	**8.23**
PATTANAMTITTA	434.34	33.31	**7.67**
VAIKAM	280.58	17.15	**6.12**
CHANGANACHERI	266.3	13.22	4.96
IRINJALAKUDA	856.1	38.24	4.46
PALA	282.17	9.88	3.5
MALLAPALLI	168.58	5.63	3.34
RANI	261.76	7.96	3.04
MAVELIKARA	234.42	6.8	2.9
HARIPAD	186.84	3.71	1.98

Table 2: Summary of Inundation Hotspots in Vulnerable Taluks

8.3 *Conventional Flood Forecasting*

There are 44 rivers in Kerala. 41 rivers are west flowing and 3 are east flowing. The rivers of Kerala are small and flow faster, owing to the hilly terrain and due to the short distance between the Western Ghat and the sea. There are 34 lakes in Kerala out of these 27 are connected with Arabian sea and 7 are inland lakes. The map of West Flowing River Basin from Tadri to Kanyakumari is at Fig. 37. It also shows the hydrological observation (HO) stations maintained by CWC.

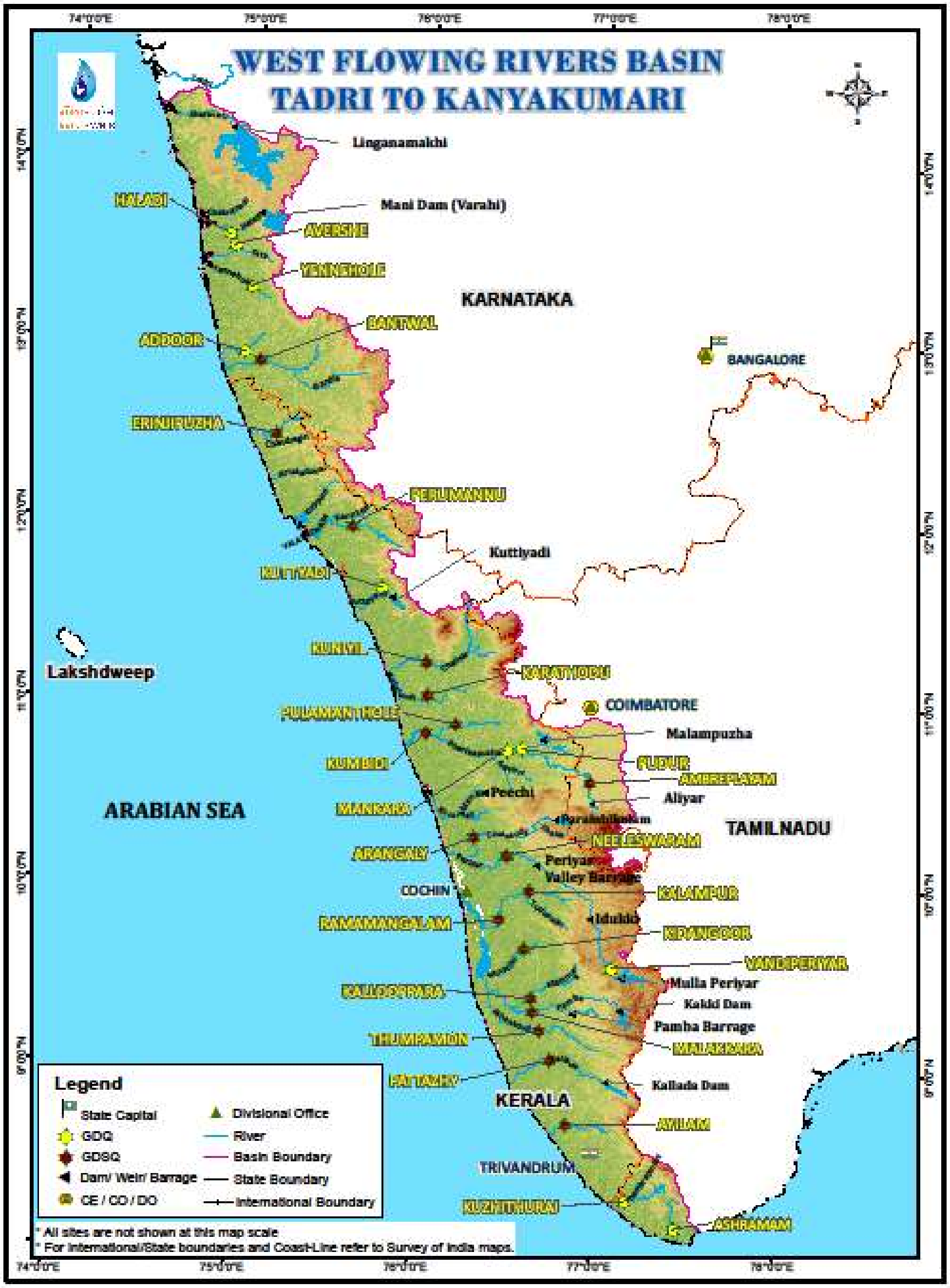


Figure 37: West Flowing Rivers Basin from Tadri to Kanyakumari

There is no Flood Forecasting network in Kerala till date as the rivers in Kerala are having small catchments and very steep slope and the water reaches terminal points in less than 6 to 8 hours in most of the cases. While preparing the EFC memorandum for XII Plan during 2011, CWC requested various State Governments to identify additional flood forecasting stations, so that the Flood Forecasting Network of CWC can be expanded to uncovered areas also. Many of the States requested for establishing/ expansion of the new/ existing flood forecasting network. There was no request from Kerala for any flood forecasting network in their State.

The committee constituted to study Kerala floods has tried to study the feasibility of the opening of flood forecasting network in various river basins of Kerala. As already explained, the lead/ response time to issue conventional level forecast for any station with respect to any base station upstream based on statistical correlation is very less and hence, no effective forecast can take place. Worthwhile forecast/ early warning system for these rivers can only be issued based on rainfall-runoff and hydrodynamic mathematical modeling, which has been discussed in the report separately in preceding paras.

There are two west flowing river systems in Kerala which are inter-state namely, Periyar and Bharathapuzha which have sufficiently large catchment and have warning time of 12 to 15 hours. Further, river Pamba also was affected severely by the August 2018 flood and hence, it was decided that three of the existing HO Stations in Kerala namely, Neeleswaram on Periyar, Kumbidi on Bharathapuzha and Malakkara on Pamba can be tried for conventional flood forecasting.

8.3.1 Data Requirement

In order to forecast the incoming floods, the conventional method use Correlation between upstream and downstream gauges, stage discharge relation between upstream and downstream gauges, river outflow from dams to flow at the downstream stations which can be converted to stage by a stable rating curve and unit hydrograph for rainfall runoff from intervening catchment area. The warning and danger levels can be indirectly fixed by seeing the cross-section of the river at the forecasting station.

For drawing a correlation curve using the above mentioned parameters the following data are required:

a) Hourly water level data for Level forecasting sites (Last 15 years)
b) Inflow discharge for reservoir sites (Last 20 years)
c) Outflow discharge from reservoirs
d) Rule Curves
e) X- Section data

8.3.2 *Development of Correlation Curves, Unit Hydrographs and S-D Curves*

The hourly stage data in respect of HO Stations in Bharathapuzha, Periyar and Pamba were furnished by RDC-2 Dte as well as from field office. However, the hourly dam inflow/ outflow through rivers were not yet received from the project authorities. With the readily available data an attempt was made to create a conventional model for the three identified Flood Forecast locations.

8.3.2.1 *Correlation Diagram for Kumbidi*

The cross-section at Kumbidi (Fig. 38) on the river Bharathapuzha indicated that the Danger Level at Kumbidi is around 9 m and the warning level is 8 m.

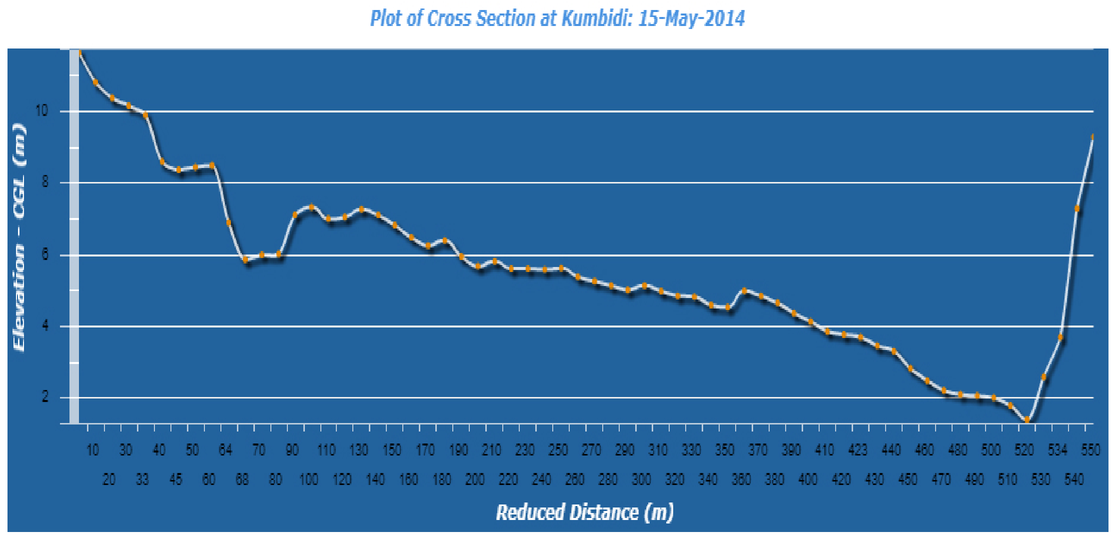


Figure 38: X- section at Kumbidi

The study of the available data from 2015 to 2018 at upstream station Mankara on Bharathapuzha indicated that floods of above Warning level magnitude have occurred only during 2018 and near warning level have occurred between 2015 and 2017. Taking all these data and the corresponding Kumbidi data, a travel time curve was drawn using Stage at Mankara in Y-axis and Travel Time in X-axis. Travel Time Curve (Fig. 39) and the travel time table (Table – 3) are shown below.

Travel Time for different base station levels	
Level (m)	**TT(hrs)**
47	3
48	5
49	11
50	21
51	31
52	37
53	38

Table 3: Travel Time

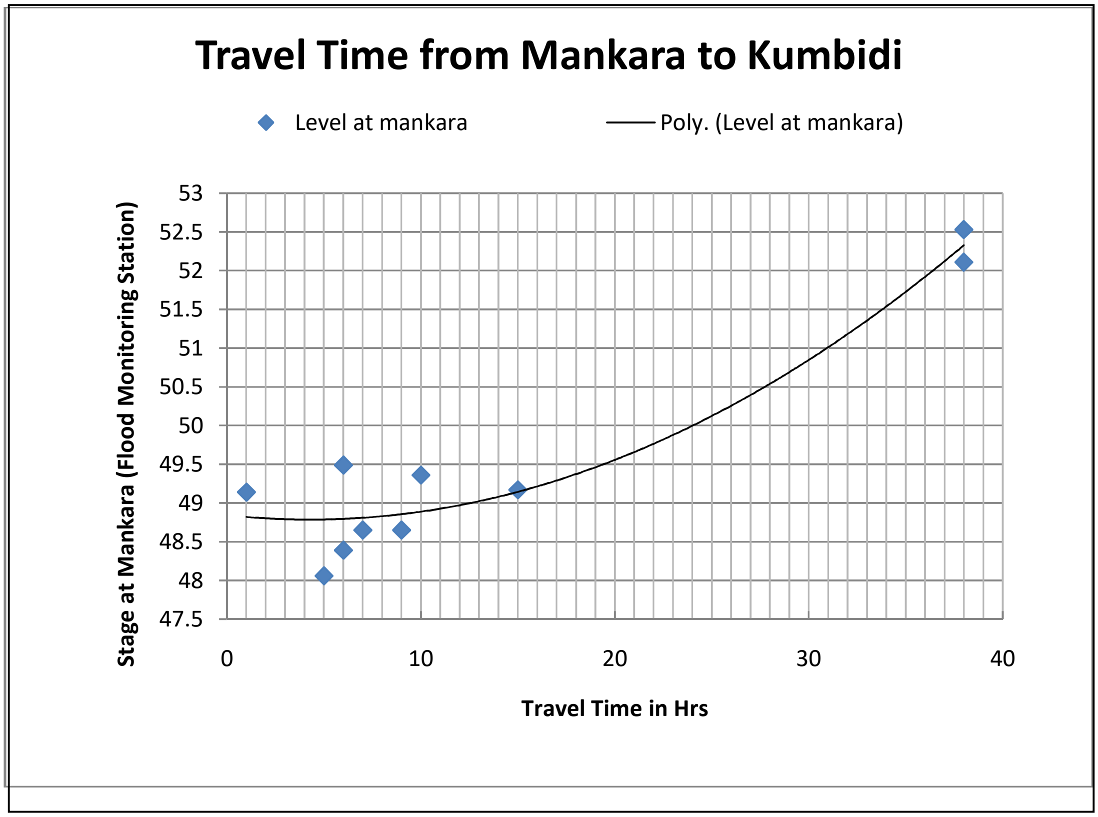


Figure 39: Travel Time curve between Mankara and Kumbidi

For these travel time, a correlation diagram based on rise/ fall at Mankara with the Stage at Kumbidi was attempted. Since the number of points above 10 m Stage at Kumbidi and for differences >1 m at Mankara was less (<10), the correlation diagram was restricted upto 11 m stage for all cases. The correlation diagram is shown in **Fig.11.4**.

The statistical correlations were well correlated with r^2 values for no Change was as high as 0.98 and that for >1m it was 0.884, while in falling stages, the value was between 0.867 and 0.75. So as a first approximation, this correlation curve can be readily used for formulation of flood forecast to Kumbidi. Since the number of days of flooding above Danger Level is very less, the improvement for first quadrant correlation can be done by using unit hydrographs for intervening catchment area rainfall and accounting the effect of tributary River Pulanthodu (Site Pulamanthole) further.

8.3.2.2 Stage vs Discharge, Dam releases & Unit Hydrograph for Periyar Basin

The river Periyar is an inter-state river with catchment area of 2% in Tamilnadu and 98% in Kerala. Major Dams such as MullaPeriyar, Idukki and Idamalayar Dams are situated in this basin. CWC is having a HO Site at Neeleswaram on river Periyar in Ernakulam District of Kerala.

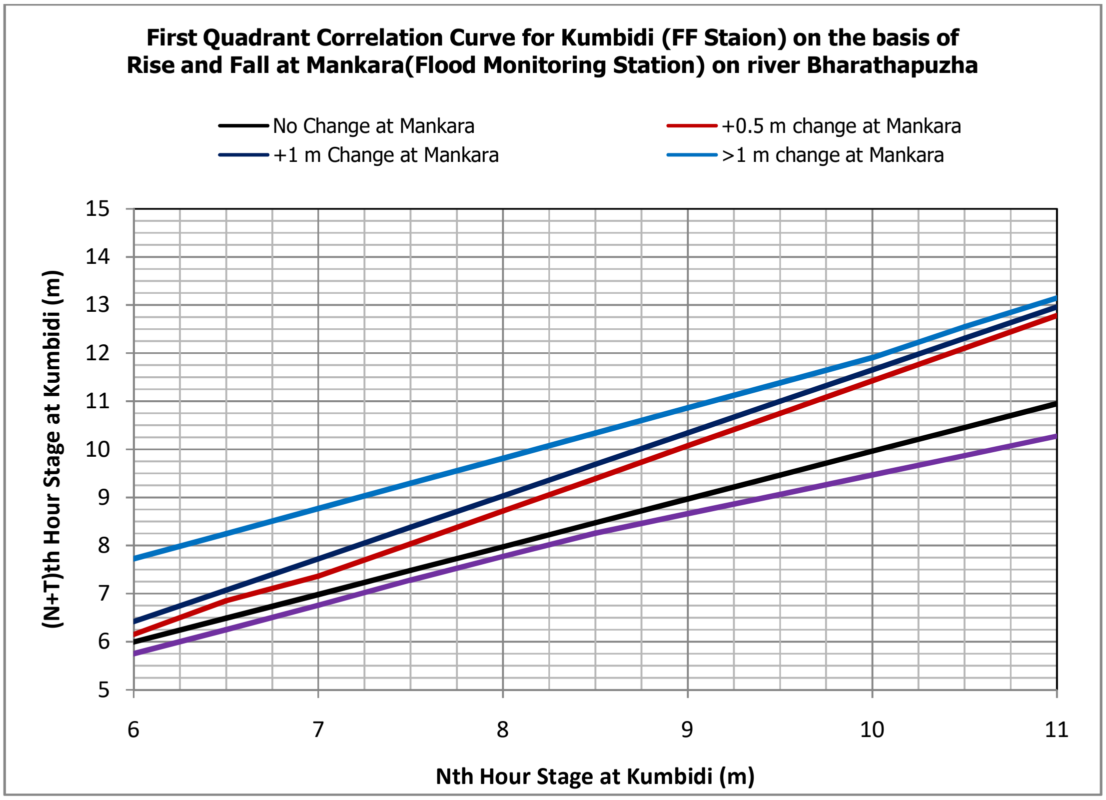


Figure 40: Correlation curves for Kumbidi

It is proposed to issue level flood forecast for Neeleswaram using dam discharges of the Idukki Dam and Idamalayar Dam. The Stage vs Discharge curve (Fig. 41) and the Cross-section (Fig. 42) at Neeleswaram is shown below. Based on this cross-section, Warning Level of 9 m and Danger Level of 10 m have been approximately fixed. Since the dam discharges are involved, the stage discharge curve of Neeleswaram was used for corresponding discharge values of combined inflow from both the dams and the stage corresponding to this combined discharge at Neeleswaram. Since hourly discharge from these project authorities were not available, the outflow hydrograph as generated by Mike-11 model was used as outflow from these dams. Further, it was seen that Idukki dam has released water only on three occasions viz. in 1988, 1992 and 2018; hence, these cannot give a clear picture of available flow at Neeleswaram. In order to account for the rainfall in the intervening catchment a unit hydrograph was developed using the daily rainfall at around 12 stations in the catchment as given by IMD and the daily discharges at Neeleswaram.

The analysis was done only for 2018 using the outflow hydrograph from calibrated Mike-11 model at Idukki and Idamalayar dams and the difference in discharge at Neeleswaram and combined discharge at both dams with a travel time of 8 hours.

This excess discharge on daily basis was used for developing the unit hydrograph for the free catchment area of 2329 sq.km.

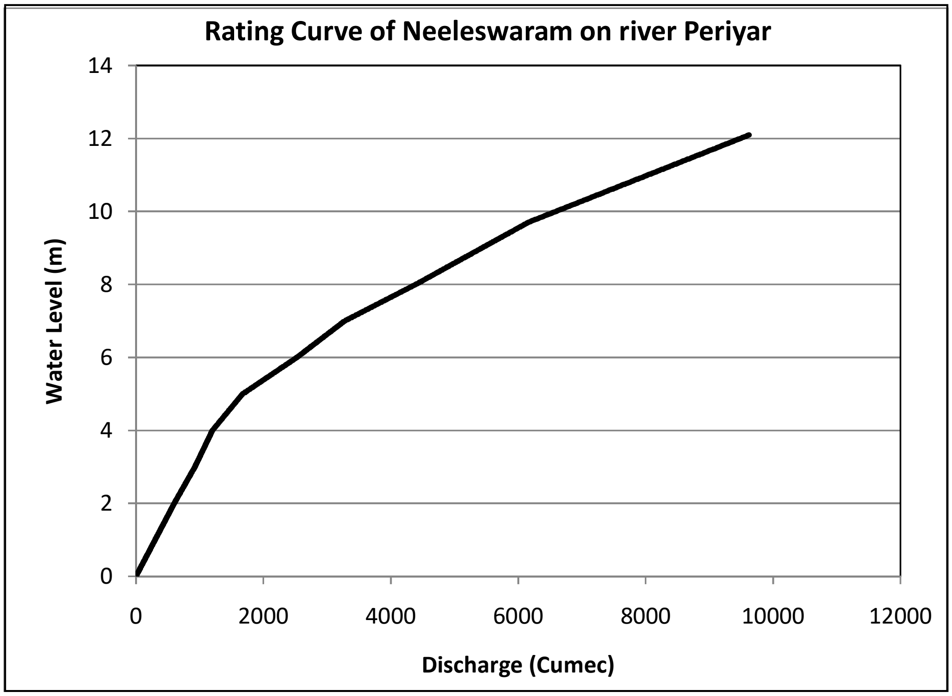


Figure 41: S-D curve for Neeleswaram

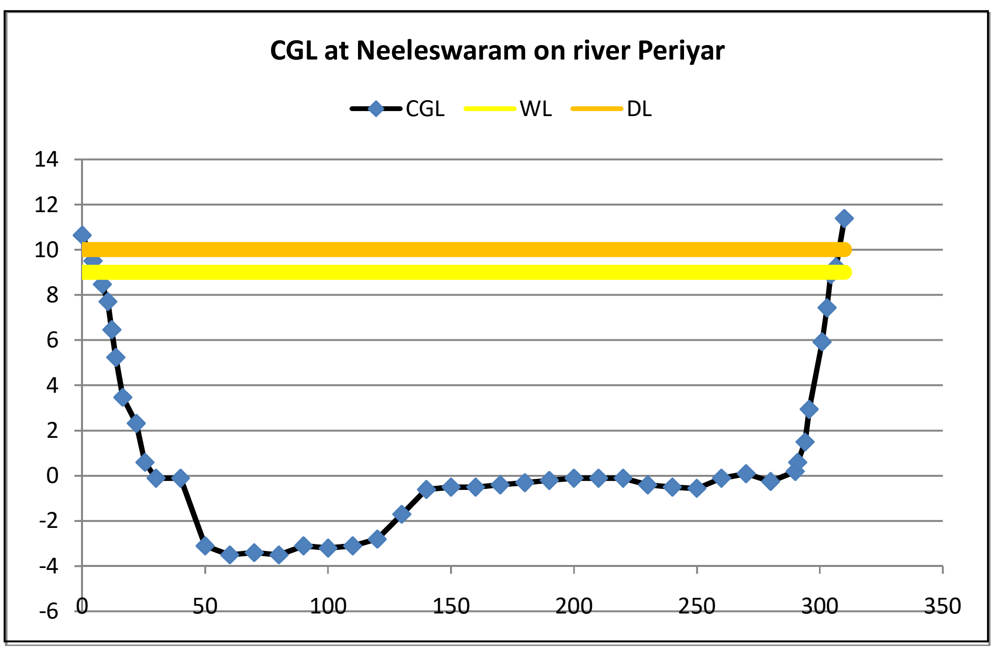


Figure 42: X- Section at Neeleswaram

The base flow separated hydrograph for Neeleswaram excess flow is given as under (Fig. 43):

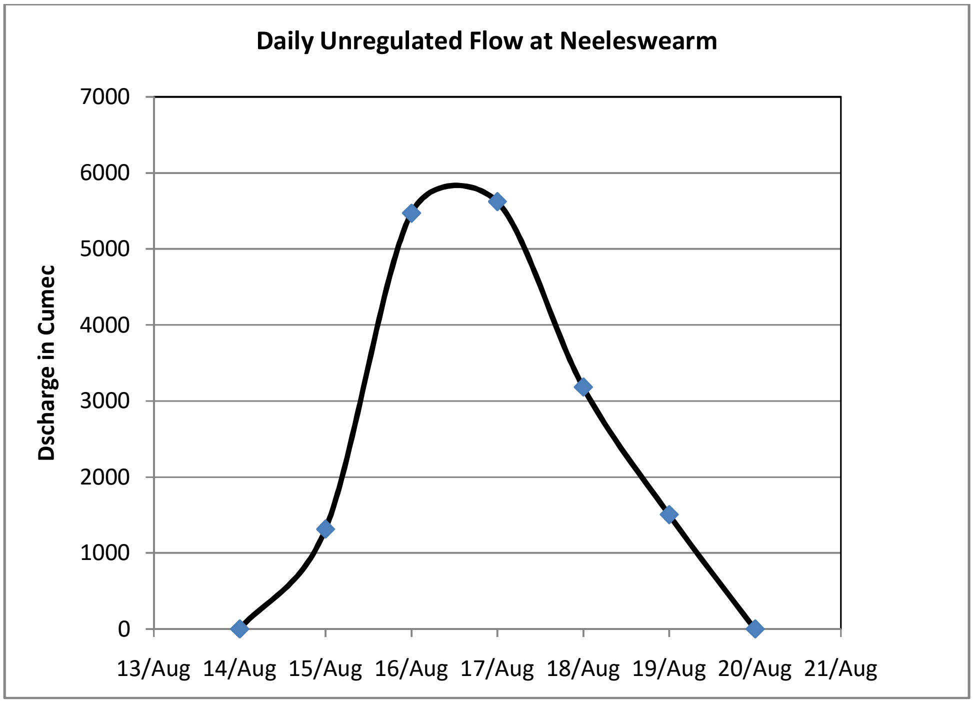


Figure 43: Hydrograph at Neeleswaram for free catchments

The ordinates of Unit Hydrograph for the daily rainfall and daily discharge for a free catchment area of 3042 sq.km are as given below (Fig. 44).

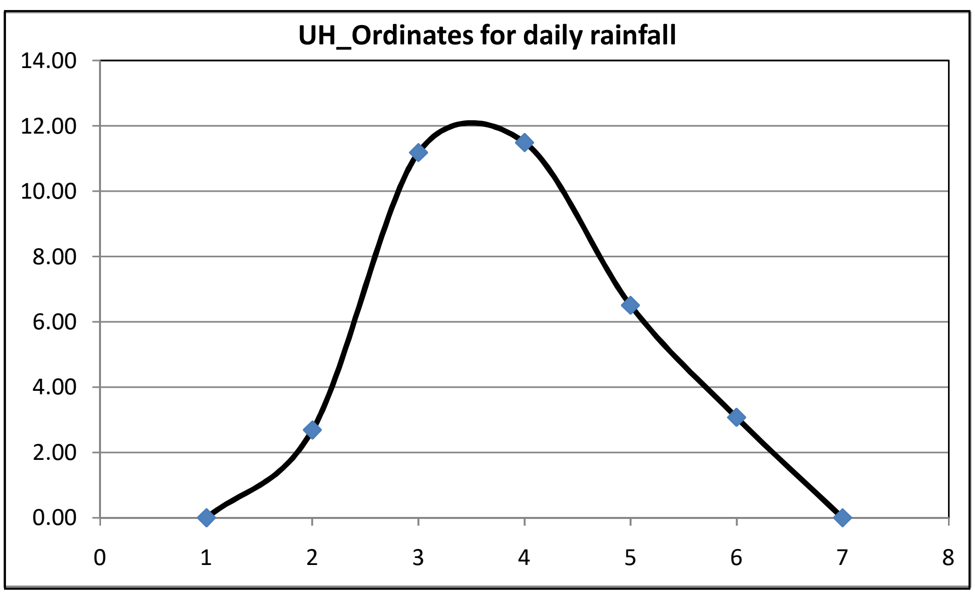


Figure 44: Unit hydrograph at Neeleswarm for free catchments

Based on this unit hydrograph ordinates and daily rainfall for any day, the total runoff available can be calculated by adding the base flow and the combined discharges from dams. This flow can be converted to Stage using the Stage Discharge curve at Neeleswaram and a level forecast can be given for Neeleswaram. Since the dams are not discharging any outflow for many of the years, the forecasts can be issued based on the unit hydrograph for daily rainfalls being received on real time basis.

8.3.2.3 Level Forecast For Malakkara on Pamba

Level Forecast is proposed for Malakkara on Pamba. The cross-section of Malakkara is as given below (Fig. 45). Based on this cross-section a Warning Level of 6 m and Danger Level of 7 m is fixed approximately for issue of Level Forecast. Since the dam releases from Kakki Dam is one of the main contributors for flow in Pamba, the dam hourly discharge from Pamba is main input for the conventional model. Since outflow data on hourly basis is not available, it is not possible to do the conventional model. The unit hydrograph generated by Mike 11 model can be used as an input to the model and with daily rainfall, the discharge generated can be converted to level with Stage Discharge curve of Malakkara.

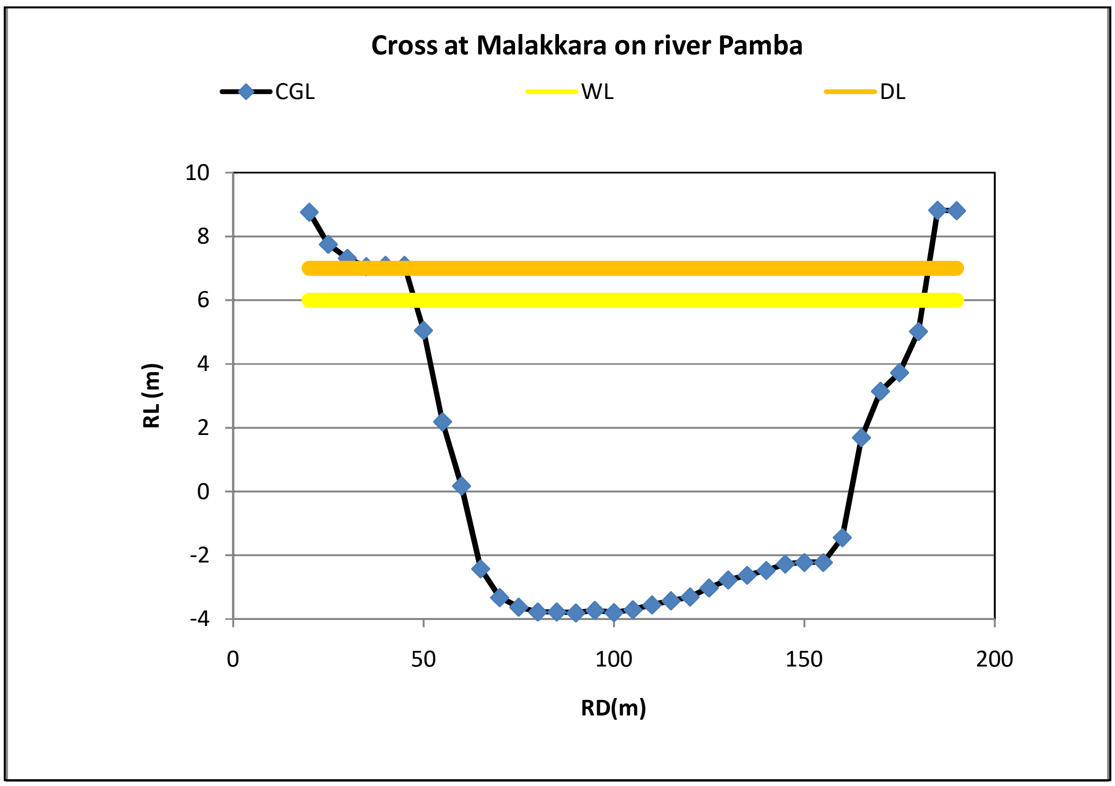


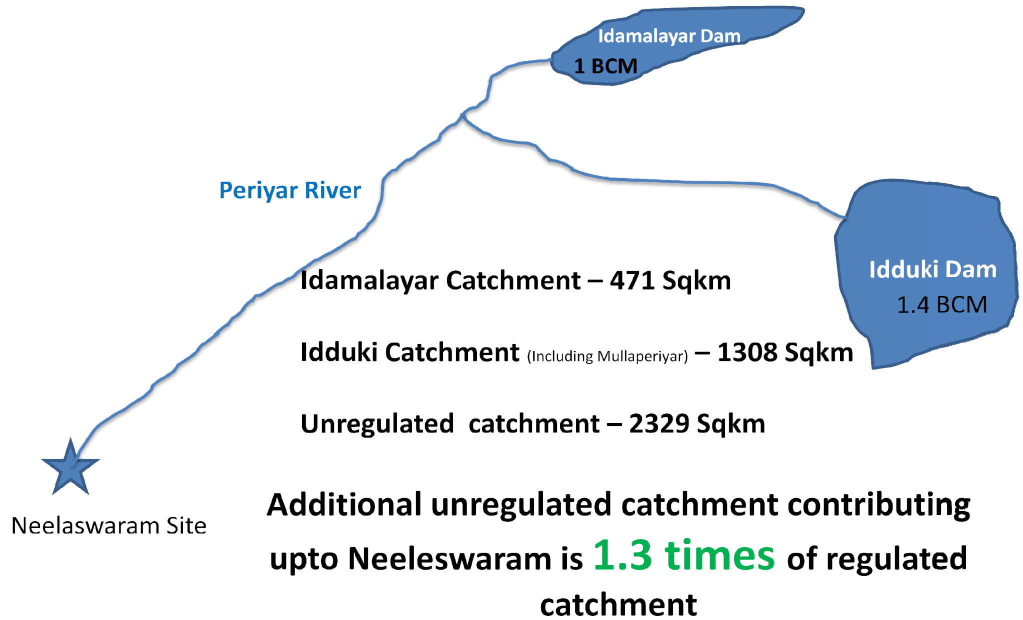
Figure 45: X-Section at Malakkara

8.3.3 Limitations of Conventional Method

1. The conventional correlation based studies depend on the availability of long time series data. In the case of Kerala, it is seen that floods are very rare occasion and the availability of flood data to correlate with upstream and downstream stations are very little which reduces the length of the time series.
2. Non-availability of real–time dam outflows in short intervals such as hourly or three-hourly is a major limitation for developing correlation.
3. Non-availability of hourly rainfall either through IMD/CWC is a major limitation in generating unit hydrographs.

8.4 WL Prediction At The Locations Downstream Of Any Dam Based On Rainfall Forecast In Next 24 Hours And Initial Reservoir Level Conditions.

This is a flood guidance reckoner, which will help in estimating river water levels at Neeleswaram site on river Periyar based on forecasted rainfall issued by IMD for next 24 hours and initial reservoir conditions at Idamalayar and idukkidam. In the analysis it was found that if both the reservoirs are 75% full then all incoming flood for excess rainfall upto 300 mm will be absorbed by reservoir and there will be no need for releases. However, reservoir will have to be brought to safe operating levels as and when downstream conditions are favourable, so as to pass subsequent flood events during the monsoon season.



Here, excess rainfall means that amount rainfall which is likely to be converted into overland flow. If top soils is fully saturated the all the rainfall fallen will be excess rainfall.

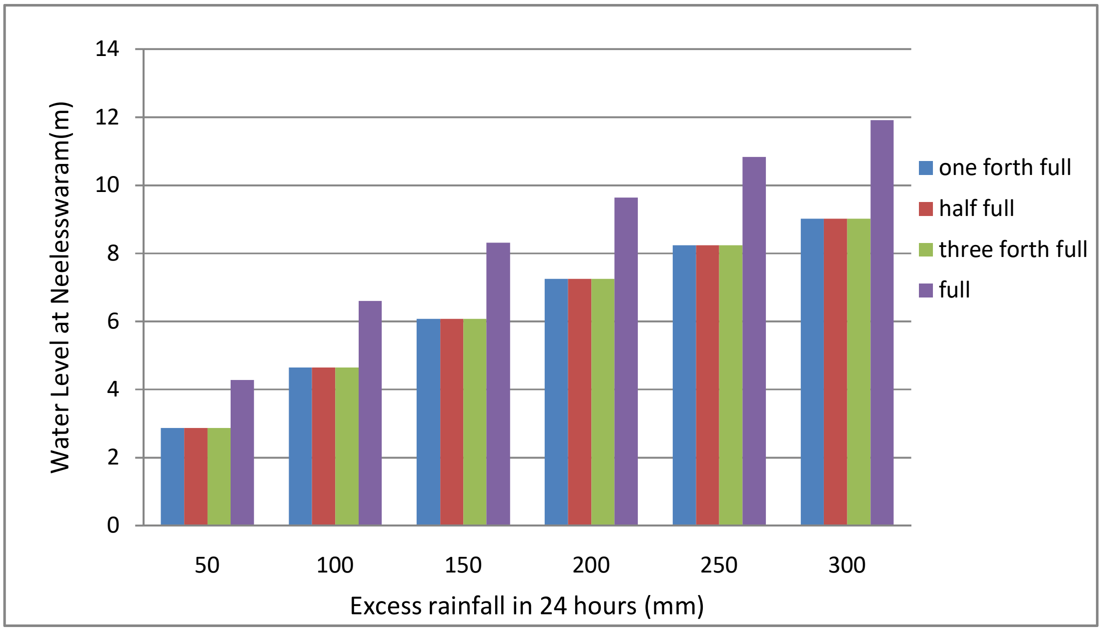


Figure 46: Water Level Prediction at Neeleswaram

MANDATORY RELEASES FROM RESERVOIRS TO MAINTAIN FRL

Excess 24hr	Idamalayar Releases (Cumec)			
Rainfall	25% full	50% full	75% full	100% full
50	0	0	0	242.46
100	0	0	0	519.20
150	0	0	0	783.89
200	0	0	0	1044.23
250	0	0	0	1304.05
300	0	0	0	1563.80

Table 4: Mandatory Releases from Idamalayar at FRL

Excess 24hr	Idukki Releases (Cumec)			
Rainfall	25% full	50% full	75% full	100% full
50	0	0	0	621.42
100	0	0	0	1396.00
150	0	0	0	2150.69
200	0	0	0	2885.19
250	0	0	0	3610.22
300	0	0	0	4331.50

Table 5: Mandatory Releases from Idukki at FRL

8.5 Flood Control Levels at Important Reservoirs

The IMD gridded rainfall was analyzed from 1981-2015 to derive yearly max accumulated rainfall in consecutive three days and thereafter using Gumble distribution, probability of rainfall was calculated. These excess rainfall were further feed into model to compute inflows and derive impinging flood control levels at Idamalayar and idukki dam.

Flood Control Level at Idukki Based on Probability of Excess Rainfall in Next Three Days

Excess Rainfall In consecutive three days (mm)	Probability of Excess Rainfall in Consecutive three days in a year (%)	Expected Inflow Volume (MCM)	Initial storage (BCM)	Initial Impinging Level (m)	Initial Reservoir Filling (%)
150	Above 50	189	1.271	728.88	87
200	50 to 16	251	1.209	727.72	83
250	16 to 4	313	1.147	726.55	79
300 **(08-10 Aug 2018)**	4 to 1	375	1.085	725.39	74
400	less than 1	499	0.961	722.95	66
500	less than 1	623	0.837	720.37	57
600 **(15-17 Aug 2018)**	less than 1	747	0.713	717.38	49

Table 6: Flood Control Level at Idukki Dam

Flood Control Level at Idamalayar Based on Probability of Excess Rainfall in Next Three Days

Excess Rainfall In consecutive three days (mm)	Probability of Excess Rainfall in Consecutive three days in a year (%)	Expected Inflow Volume (MCM)	Initial storage (BCM)	Initial Impinging Level (m)	Initial Reservoir Filling (%)
150	Above 50	71	0.947	166.52	93
200	50 to 16	93	0.925	165.75	91
250	16 to 4	115	0.903	164.98	89
300 **(08-10 Aug 2018)**	4 to 1	138	0.88	164.17	86
400	less than 1	183	0.835	162.6	82
500	less than 1	228	0.79	161.1	78
600 **(15-17 Aug 2018)**	less than 1	273	0.745	159.46	73

Table 7: Flood Control Level at Idamalayar Dam

The reservoirs have to be brought back to initial impinging level as and when downstream conditions become favourable and there is no heavy rainfall forecast in near future.

Disclaimer: *The flood control recommendations are based solely upon the disaster management point of view. However, any operational decision should be taken only after taking into account the prevailing flood condition as well as other conservational / consumptive uses it has to perform till that time and at the end of hydrological year.*

8.6 Integrated Reservoir Operation

A number of reservoirs have been planned and constructed in Kerala for conservation and utilisation of the water resources for deriving various benefits including flood control. In the initial stages of development, the projects were generally planned to serve single purpose such as irrigation, hydropower generation, flood control, municipal and industrial supply etc. In the past few decades, the country has witnessed immense urbanisation and industrialisation. These economic developments, compounded with increase in population have resulted in perceivable increase in demand for water. The ever increasing demands for sufficient quantity and quality of water distributed in time and space, have resulted in contemplation and implementation of even more comprehensive, complex and ambitious plans for water resources system. The operation of reservoir(s) in the wake of conflicting nature of conservation demands and flood moderation becomes very complex. In many reservoirs, a delicate balance is always needed, whether to keep the reservoir empty for absorbing the incoming flood or fill it to cater to the demands in leaner months. What if the reservoir does not fill up later? What if the forecasted flood does not come? Such apprehensions, in the mind of reservoir manager or the project authorities, make the reservoir operation quite tricky in real time.

The integrated operation of reservoirs is concerned with maximisation of benefits while trying to minimise the adverse effects on society, land, soil, general health, ecology etc.

The decision regarding releases generally depends upon the state of the reservoir at that instant, inflow forecasts, penalties for deviation from target storage and the flood conditions downstream. The release decisions on the basis of these conditions have to be made relatively quickly, based on short term information. For flood management operations, it may be daily or even hourly, whereas for conservational benefits, the short term may be a week, 10 day, or a month.

8.6.1 Reservoir Operation for Conservational Benefits

The operation schedule of a reservoir / system of reservoirs for conservational purpose is first derived first. The operation schedule would usually consist of two parts – the lower bound and upper bound. For each project it will be necessary to prepare rule curves separately for the filling period and for the depletion period. The rule curve (lower bound) for conservational benefits will be derived from long term historical inflow series (typically 30-40 years), various types of demands to be met by the reservoir(s), losses from the reservoirs / instream losses, and the storage characteristics of the reservoir(s). The upper bound for meeting the conservational demands is derived from the point of view of probability of filling of the reservoir. The reservoir is supposed to be operated between the two bounds throughout the year, i.e. the lower bound and the upper bound. In case, of system of reservoirs, the modelling requires a number of iterations to achieve a reasonable level of acceptability. The process requires number of trial runs.

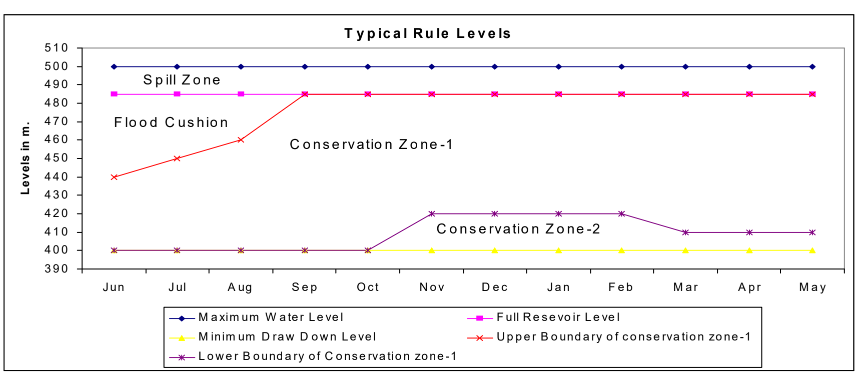
8.6.2 Reservoir Operation For Floods

The upper bound for reservoir(s) derived in the previous para was from the point of view of probability of filling up of the reservoir. This upper bound may or may not be adequate from the point of view of flood moderation to a desired level. This upper bound, then, needs to be tested against various flood hydrographs such as flood having return period of 1 in 25/50/100 year, SPF or PMF. The spillway capacity, dedicated flood storage space, downstream river channel discharge capacity, and flood inundation areas play a vital role in fixing the upper bound of rule levels. This requires reservoir routing studies, channel routing studies, 2-dimensional hydro-dynamic modelling of flood wave.

If the reservoir has permanent flood storage available between FRL and MWL, normally no extra flood cushion is needed, if the reservoir is to be operated as a single reservoir. However, the extra flood cushion might be needed in following cases:

- Inadequate flood space between MWL and FRL
- Reservoirs where FRL= MWL
- Very compelling downstream channel constraints
- Severely flood prone regions
- Integrated reservoir operation for moderation of flood in the system / sub-basin/basin

Based upon above, the upper and lower bound for a reservoir or a system of reservoirs are fixed. The typical Rule Levels for a multi-purpose reservoir is shown below:



The conservation zone-1 indicates that as long as water level in the reservoir is in this zone, all designated demands can be met at desired reliabilities. The conservation zone-2 implies that if water levels falls and enters this zone, then some pre-defined curtailment in some of the lesser priority demands may have to be made in order to meet the high priority demands in full.

The Flood Cushion zone indicates that the reservoir has to be filled gradually so that this zone can serve the purpose of providing extra flood moderation for floods of lower return periods.

The list of typical data required for formulation of operating rule levels is as under:

1. Ten-daily / monthly Inflow series from free catchment for each reservoir / barrage for 40 years (1977-2017) in cumecs in MS Excel format.

	1977-78	1978-79	…	….	….	….	2015-16	2016-17
Jun-I								
Jun-II								
June-III								
July-I								
…..								
…								
…								
…								
April-III								
May-I								
May-II								
May-III								

2. If the reservoir/ barrage did not exist in the period indicated above, then the ten daily / monthly river discharge in cumecs, close to the dam site for the period when it did not exist. (MS Excel)
3. Salient features of each reservoir (MWL, FRL, MDDL, Crest Level, latest Area (sq km)-Elevation (m)- Capacity (MCM) tables, spillway head (m)-discharge (cumec) relationship, canal / sluice gate head (m) versus discharge (cumec) relationship.
4. Salient features of each barrage such as crest level, gate rating curve, water diverted from barrage during 1977-2017 for various usages on ten-daily / monthly basis in cumec, in MS Excel format
5. Consumptive / Non-consumptive / In-stream demands on ten-daily / monthly basis for each dam / barrage. Irrigation, Domestic, Municipal, Industrial, demands are consumptive demands. Non-consumptive demand is hydropower generation. In-stream demands are e-flows, minimum flows, navigation, flushing doses. (Cumecs)
6. Total Water spills / withdrawals from the identified dam/barrage during 1977-2017 on ten-daily / monthly basis in cumecs in MS Excel format.
7. Flood hydrographs (Design flood, PMF, 1 in /25/50/100 year return period floods, and any observed flood closer to design flood in magnitude)

8. Downstream river channel's discharge carrying capacity (cumecs), wherever available.
9. Any existing operation manual / guidelines for identified reservoirs.

8.6.3 *Status of Reservoir Operation studies*

The list of data requirement for formulation of Rule Levels for Idukki, Idamalayar, and Kakki reservoirs was sent to Water Resources Department, Govt of Kerala in September, 2018 i.e. after 2018 floods of Kerala. The Committee of officers from RM wing, WP&P wing and NHP under the chairmanship of CE (CSRO, CWC Coimbatore visited various flood hit regions of Kerala during 25-27 September, 2018 and held discussions with various officers from Kerala State Govt during the visit in Thiruvananthapuram and Kochi. The importance of prudent Reservoir Operation and the requirement of data was explained to them at length. The chairman of the Committee has been in constant touch with State Govt but, so far, the requisite data for Reservoir Operation studies have not been provided by the State Govt.

During the visit of the Committee, it was conveyed to State Govt that CWC will provide all possible guidance to them towards formulation of Rule Levels for reservoir operation. They were advised to visit CWC New Delhi with the data in required format (as in Annex-I) for about a fortnight and can develop Rule Levels under guidance of CWC. However, no such visit with data has been undertaken by Kerala State Govt officers, so far.

The Reservoir Operation studies are probability based simulation studies and thus they require historical observed inflows for at least 30-40 years to arrive at a certain operation policy at desired confidence level. In the absence of such data, it may not be fruitful to undertake reservoir operation studies based upon the synthetic inflows and the absence of demand data.

9.0 Assumptions and Limitations of Study

Models are limited to systems with the properties described by the governing equations, by the capability of the numerical algorithm solving the equations, and by the capacity of the computational system. These factors define the ability of the model to represent a physical system in its numerical framework and require that a user understand the limitations of the modeling approach.

The rainfall based flood forecast model development requires huge data of catchment characteristics, river network and their cross sections at regular interval, hydraulic structures on the river, actual rainfall and forecasted rainfall etc. Such huge is hardly available at the desired accuracy and reliability or requires huge resources to capture the data. Thus the performance of three day advisory flood forecast is subject to the uncertainties involved in the satellite rainfall data, forecasted rainfall data and uncertainties of the model itself.

Main issues limiting/affecting the performance of the current model may be attributed to:

(i) Inaccuracies in representation of river topography due to limited number of cross sections also add to result uncertainty. Presently, the river cross sections available at CWC gauging sites have been used which are normally available at very coarse interval.

(ii) The details of various hydraulic structures like flood embankments, roads, bridges& barrageswhich can influence the flows in the river by storage or diversions were not incorporated in the current model. Non availability of data like reservoir releases, their operation schedule etc. hamper the performance of the model.

(iii) Limitations of topography i.e. 90m SRTM DEM

(iv) River channel and floodplain assumed to be part of DEM

(v) Manning's n value of 0.032 was adopted uniform throughout the flood plains as well as river channel in 2D model.

(vi) Constant flood wave conditions for a period of 20 hrs were assumed in the 2D model setup to generate return period based inundation maps.

(vii) Satellite images used for verification were from open domain at moderate resolution and their availability was on 21st August 2018 only after the peak flood event had passed.

(viii) Limitations of IMD Gridded Rainfall due to moderate temporal and spatial resolution.

(ix) One dimensional model does not account for river-floodplain interactions, storages in flood plains, flood losses due to overtopping of embankments as well as breaching of embankments, which sometime affect the quantum of floods.

10.0 Conclusion& Recommendations

The key conclusions of study are as under:

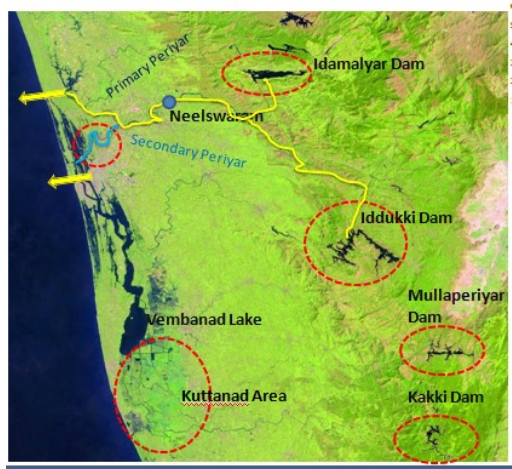
(i) Return period of flood event from 15th to 17th was above 100 year return period flood i.e. having probability less than 1%, while the flood event from 08th to 10th was above 25 year return period flood i.e. having probability more than 4%.

(ii) Initial Reservoir Level at Idukki and Idamalayar plays a key role in moderation of river water levels at Neeleswaram on river Periyar as well as managing the inundation risk.

(iii) Safe flood control Level at Idukki Dam for managing a rainfall event having a probability of 1 to 4% is in the order of 725.39m i.e. 74 % of FRL, whereas for managing a rainfall event having a probability less than 1% isin the order of 717.38 m i.e. 49% of FRL . The state Government should not exceed their reservoir level beyond 74 % of FRL during the monsoon season i.e. upto third week of August to cover a flood risk which has moderate probability of occurrence (1 to 4%).

(iv) Safe flood control Level at Idamalayar Dam for managing a rainfall event having a probability of 1 to 4% is in the order of 164.17m i.e. 86 % of FRL, whereas for managing a rainfall event having a probability less than 1% isin the order of 159.46 m i.e. 73 % of FRL . The state Government should not exceed their reservoir level beyond 86 % of FRL during the monsoon season i.e. upto third week of August to cover a risk which has moderate probability of occurrence (1 to 4%).

(v) As and when the river water level at Neeleswaram on river Periyar is upto in the order of 6.2m or discharge is upto in the order of 3200 cumecs ie. equivalent to 2 year return period flood, reservoir levels of Idamalayar and Idduki can be brought to initial impinging levels / safe operating levels, so that dams can withstand subsequent flood flows in monsoon season.



(vi) The flow in primary branch of Periyar during high flood suggest that it gets fully choked and is not able to discharge more than 50% resulting in huge spillage over the primary as well as secondary branch. Therefore, proper maintenance of river section in such critical reaches is required. The river encroachment, if any in such reaches should be removed.

(vii) Level Flood Forecasting can be started at Kumbidi on Bharathapuzha in Palakkad District and Neeleswaram on river Periyar in Ernakulam district from the next flood season onwards with following infrastructures

a. 24x7 control room at Executive Engineer, CWC, Kochi
b. Good Communication channel
c. Identification of user agencies and their contact details
d. Training in use of correlation curves and Stage Discharge relation to the personnel.

(viii) Further improvements in developed correlation curves and unit hydrograph by using additional data as well as short duration data.

(ix) Usage of 3-day QPF in Unit hydrographs

(x) Opening of new monitoring stations downstream of reservoirs to monitor the outflows and use these stations for developing correlation curves instead of using reservoir releases.

(xi) Installation of more real-time reporting rainfall stations either by IMD or by CWC using Satellite based or GPRS based telemetry.

11.0 References

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