Final Report

Forecasting of Flash flood and management for east flowing rivers of India's Sub-zone 4(A)

NATIONAL INSTITUTE OF

HYDROLOGY JAL VIGYAN BHAWAN

ROORKEE- 247 267

2017-2020

ABSTRACT

The east flowing rivers between Mahanadi and Godavari Rivers (zone 4(A)) are typical in their flow regime. They all originate in high grounds of Eastern Ghats descend down to the east coastal plain and empty into the Bay of Bengal and none of them forming any deltaic or estuarian conditions. Flow in most of these rivers are seasonal, very flashy in nature and in lower reaches owing to their restricted flood plain may inundate urban built up lands and rural crops lands, on their banks often cause lot of disruption to the communication network like railways, road, telecom etc. Flooding of areas used for socio-economic activities produces a variety of negative impacts. The magnitude of adverse impacts depends on the vulnerability of the activities and population and the frequency, intensity and extent of flooding. Providing warning for these types of situations can be a challenging due to the combination of meteorological and other factors. A flood forecasting indicating reservoir inflows could lead to overtopping of dams. Similarly, climate change impact assessments of extremes such as floods are of particular interest because floods usually have the greatest and most direct impact on our everyday lives, community and environment. Changes in the frequency of flooding events are expected and projected changes will have serious implications for planning, operation and design of water resources systems. However, quantifying the changes in extremes is subject to various sources of uncertainty and hence requires further investigation. Main objectives of the study on flood modeling for east flowing rivers of Zone 4(A), Analyze existing quantitative precipitation forecast estimates from IMD as input to such rainfall-runoff models for flood forecasting and Assessment of climate change on runoff/flood pattern in the region Zone 4(A).

In the proposed study hydrological model HEC HMS with hydrodynamic model HEC-RAS model would be integrated by employing IMD forecast rainfall as input. ASTER 30 m resolution digital elevation model (DEM) downloaded from Earth Explorer (USGS WEB site) and delineation study basin, sub-catchments and drainage network using with terrain processing in HEC-GeoHMS environmental. Basin, sub-catchments and stream characteristics was determined in basin processing. Land use and land cover (LU/LC) were performed with January 2018 landsat 8 image downloaded from USGS web site. Discharge data collected from India-WRIS and WRD AP and rainfall collected from IMD (0.5 degree gridded) and WRD, AP of three basins. Analyse the design storm for various return periods using simple Gumble distribution. Estimated all the input parameters of the HEC HMS model and simulated the runoff for peak flood years. The simulated runoff is calibrated with observed flow data of Nagavali and Vamsadhara river basins. Model calibrated results well mach with observed flood peak. Image classification performed (2009, 2016, 2019) and examine the land use changes impact on peak flood. It is observed that the not significant changes peak flood due LU/LC. HEC HMS model output results are used in the hydrodynamic model (HEC-RAS) to forecast the flash flood. HEC RAS model simulated using hourly runoff depth/excess rainfall and calibrated with observed data. Develop the IDF curves using CHRS hourly data and use this IDF curves for developed the flood maps for different return periods.

CONTENETS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

The east flowing rivers between Mahanadi and Godavari Rivers (zone 4(A)) are typical in their flow regime. They all originate in high grounds of Eastern Ghats, descend down to the east coastal plain and empty into the Bay of Bengal. None of them is forming any deltaic or estuarian conditions. Some of them form catchment areas of about 15000 km^2 and others about 1500 km^2 only, which can be considered medium to small as per the size of Indian rivers. Flow in most of these rivers are seasonal, very flashy in nature and in lower reaches owing to their restricted flood plain inundation urban built up lands and rural crops lands, on the banks often cause a lot of disruption to communication network like railways, road, telecom etc. Most of the medium sized dams constructed across the rivers also support in irrigation supplies and are inadequate to accommodate the water storage during flash flood, which sometimes risk the dam safety as well.

Flash floods, with little or no warning time, cause more deaths than slow-rising riverine floods. Flooding of areas used for socio-economic activities produces a variety of negative impacts. The magnitude of adverse impacts depends on the vulnerability of the activities and population and the frequency, intensity and extent of flooding. Providing warning for these types of situations can be challenging due to the combination of meteorological and other factors. Similarly, climate change impact assessments of extremes such as floods are of particular interest because floods usually have the greatest and most direct impact on our everyday lives, community and environment. Changes in the frequency of flooding events are expected and the projected changes will have serious implications on planning, operation and design of water resources systems.

In the real world system rainfall runoff process is influenced by each and every physical characteristics of the catchment and to generalize all physical characteristics of the catchment is really a difficult task. Consider the infiltration phenomenon which has direct influence on the runoff process but when we observe the infiltration rate at different sites in the catchment it varies widely. In case of lumped hydrological model representation of such a wide range of values is difficult because parameter values are to be averaged for the particular catchment. Hydrologic models are useful to simulate the rainfall-runoff process and hydraulic models for analysis of the runoff flow in a river and its distributries. The aim of this objective is to use the two well-known hydrological models, firstly, for calibrating models and making sure that the models work properly; secondly, for modelling the past flooding events and analyzing the hydraulic response by looking at river discharge, flow velocity and stage; thirdly, for running the models in forecast mode using rainfall data and comparing the model outputs with the observed information.

However, quantifying the changes in extremes, is subject to various sources of uncertainty and hence requires further investigation.

1.1 Objectives of the Study

- Study on flood modeling for east flowing rivers of Zone 4(A)
- Analyze existing quantitative precipitation forecast estimates from IMD as input to such rainfall-runoff models for flood forecasting.

Chapter 2

LITERATURE REVIEW

The high variability of precipitations (Moussa et al., 2007) along with topography influence and spatial distribution of soil and land use properties makes hydrological processes largely variable both in time and space (Pilgrim et al., 1988). Flash floods are extreme catchment responses with high peak discharge often produced by severe localized thunderstorms. They are one of the most destructive hazards in the Mediterranean region and have caused casualties and billions of euros of damages in France over the last two decades (Gaume et al., 2009). These events often reveal aspects of hydrological behaviour that were either unexpected on the basis of weaker responses or highlight anticipated but previously unobserved behavior (Delrieu et al., 2005). Characterizing the response of a catchment during flash flood events thus may provide new and valuable insight into processes for extreme flood response and their dependency on catchment properties and flood severity (Borga et al., 2008). In the literature, several approaches are proposed for flash flood events modeling and/or prediction, each with its specificities depending on perception and parameterization of the dominant hydrological processes (Moussa et al., 2007; Saulnier and le Lay, 2009; Braud et al., 2010; Roux et al., 2011). These models often take advantage of available data in order to assign spatially distributed forcing as well as distributed catchment parameters. However, increasing model complexity can lead to overparameterization and equifinality problems because of high dimensionality and multi-modal response surface. As a result, parameter values might not be identifiable in the calibration process (Beven, 1989). Sieber and Uhlenbrook (2005) have highlighted that sensitivity analysis (SA) can not only identify the most important parameters but also contribute to understanding and improving the structure of hydrologic model.

The literature contains many works that summarize the level of understanding of the complex physics governing the transformation of rainfall into runoff (Dunne, 1978). Many efforts have been made to schematize the whole process so as to develop mathematical models (Todini, 1989). These range from the simple lumped calculation of design discharge to the distributed representation of the various processes based on the conservation of mass, energy and momentum. Taken together, such models form the broad category of distributed differential models (Todini, 1986); they are frequently referred to as 'physically based models' to highlight the fact that their respective parameters are (or should be) reflected in the field measurements (Beven, 1989). Given their nature, such models are appropriate for studying the effects of land use changes, soil erosion, surface groundwater interactions, etc., but are less suitable for conventional rainfall-runoff applications at catchment scale.

Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation. It allows to predict the hydrologic response to various watershed management practices and to have a better understanding of the impacts of these practices (Kadam, 2011). It is evident from the extensive review of the literature that the studies on comparative assessment of watershed models for hydrologic simulations are very much limited in developing countries including India (Kumar and Bhattacharya, 2011; Putty and Prasad, 2000), There is bare necessity to undertake study on hydrologic simulation through development of a suitable watershed model. The Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) is a popularly used watershed model to simulate rainfall runoff process. Several studies have been conducted using the HEC-HMS model in different regions under different soil and climatic conditions. Chu and Stenman (2009) used HEC-HMS model for both event and continuous hydrological modeling in Monalack watershed in West Michigan. HEC-HMS model has also been used to simulate rainfall-runoff process with geo-informatics and atmospheric models for flood forecasting and early warnings in different regions of the world (Abed et al., 2005; Anderson et al., 2002; Clay et al., 2005; Hu et al., 2006; Knebl et al., 2005; McColl and Aggett, 2006; Yusop et al., 2007; Yener et al., 2012; Arekhi, 2012; Majidi and Shahedi, 2012; Halwatura and Najjim, 2013; Majidi and Vagharfard, 2013, Ali et al., 2011; Dzubakova, 2010). It was also used for watershed management in different parts of India (Putty and Prasad, 2000; Shrestha, 2006; Kumar and Bhattacharya, 2011; Bhatt et al., 2012; Kadam, 2011). The model was found accurate in spatially and temporally predicting watershed response in event based and continuous simulation as well as simulating various scenarios in flood forecasting and early warnings. For prediction of the floods in Romagna river basin in Italy, Pistocchi and Mazzoli (2002) completely integrated HEC- HMS and HEC-RAS model as a part of the decision support system. Use of Artificial Neural Networks (ANNs) was made by Kamp and Savenije (2007) coupling of the 4 models: ecological model, a rainfall run- off model, an estuarine salt intrusion model, and a river channel routing model. Hydraulic modeling approach and integrated hydrological approach was used for assessment of risks associated with the extreme flood events of a thermoelectric power plant, as explained by Anselmo *et al.* (1996).Various flood-forecasting systems also make use of integrated hydraulic and hydrologic models. For instance, MIKE11's flood forecasting systems constitutes of 3 modules: Updating Procedure (FF), Hydro- dynamic (HD model), and Rainfall-Runoff (NAM Model) developed by DHI (2003). HEC-RAS is used world over and is public domain software. Mike 11, however, is proprietary software which needs a registration key for using the software.

Yener*et al.*, (2006) used HEC-HMS hydrological model for rainfall-runoff simulation in Yuvacik basin and the resultant outflow hydrographs are used for the development of flood model required for the management of floodplains around the basin and for studies of assessing the flood damage. The results of this work reported gaps in data and bad quality of data. So the developed model is to be trained with periodical data to avoid errors recorded in discharge and rain gauge stations.

Bhatt *et al.,* (2012) performed rainfall-runoff simulation using HEC-HMS for 11 years of daily rainfall data for a period of 1992-2002. Stream flow data observed at the outlet point of Tehri Dam in Bhagirathi basin was considered. Shuttle Radar Topography Mission (SRTM), Digital Elevation Model (DEM) and Topographic Parameterization (TOPAZ) are used for the extraction of basin boundary from the flow accumulation. Historical daily discharge data recorded at the outlet point of the basin is considered for model calibration and validation purposes.

Phu Nguyen., et.al (2015) HiResFlood-UCI was developed by coupling the NWS's hydrologic model (HL-RDHM) with the hydraulic model (BreZo) for flash flood modelling at decametre resolutions. The coupled model uses HL-RDHM as a rainfall-runoff generator and replaces the routing scheme of HL-RDHM with the 2D hydraulic model (BreZo) in order to predict localized flood depths and velocities. Omeon.T., et.al (2020) to demonstrate the advantages of the proposed framework, a commonly used conceptual model was applied over the same catchment for comparison. Results show the framework to be robust, with the uncalibrated PDE-based model matching stream flow observations reasonably.

Chapter 3

STUDY AREA

Turning attention to the other side of the peninsular triangle, this group covers the east-flowing rivers between Mahanadi and Godavari and extends over an area of 49,570 km^2 which lies between longitudes 81^{0}15' E to 85^{0}30' E and latitudes 16^{0}55' N to 20^{0}18'N. The basin lies at the east coast of the peninsular India and covers large areas in the States of Orissa and Andhra Pradesh. Total drainage area is about 49,570 Sq Km (Odisha 25,665 Sq Km and AP 23,905 Sq Km). The basin of rivers in this zone is bounded on the north, the west and the south by the various ranges of the Eastern Ghats and on the east by the Bay of the Bengal. The basin, which is irregular in shape, has a maximum length of about 182 km in the northwest-southeast direction and a maximum width of 476 km in the northeast-southwest direction. The basin can be divided into two major topographical divisions: the hilly ranges of the Eastern Ghats and the coastal plains as shown in figure 1. The hilly ranges are well-forested and the plains extending from the eastern slopes of the Ghats slope gently towards the Bay of Bengal.

Flash floods represent forecast and detection challenges because they are not always caused simply by meteorological phenomena. Flash floods result when specific meteorological and hydrological conditions exist together. Although heavy rainfall is usually a factor, a given amount and duration of rainfall may or may not result in a flash flood, depending on the hydrologic characteristics of the watershed where the rain is occurring. Therefore it is proposed to forecast the flash floods and management for east flowing rivers of India’s Sub-zone 4(A) in Andhra region as shown in figure 1.

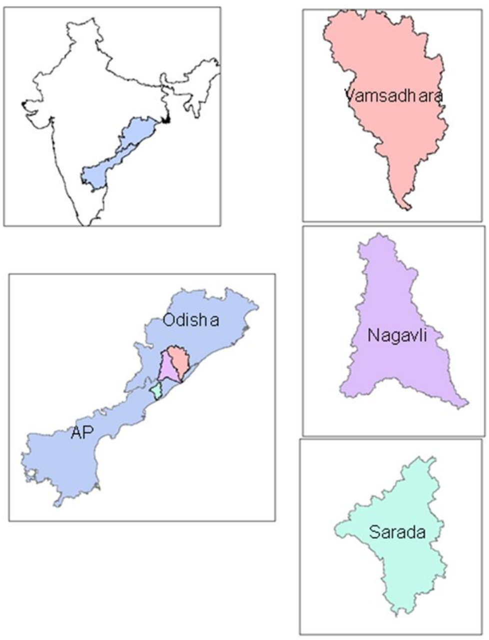


Figure 1. East flowing rivers of India’s sub-zone 4(A) in Andhra region

Chapter 4

METHODOLOGY

Flash floods (FF) occur in medium and smaller basins, rivers, streams and are linked to short, but extreme rainfall events. However, they have been categorized into fatal and costly natural disasters. Sub zone 4(a) is one of the region's that is most affected by FF and likely to suffer more frequently due to the impacts of climate change. Thus, there exists an urgent requirement for FF forecast-related studies. Much previous research has suggested approaches to mitigate the impacts of FFs through the early identification of FF occurrences (time and location) or their forecast. This is a crucial information for the local people, as such information will help them to protect themselves from these floods. The current study proposes by coupling the hydrological model HEC HMS (the Hydraulic Engineering Center hydrological model System) with hydrodynamic model HEC-RAS (the Hydraulic Engineering Center River Analysis System) model as shown in the figure 2.by employing IMD forecast rainfall as input.

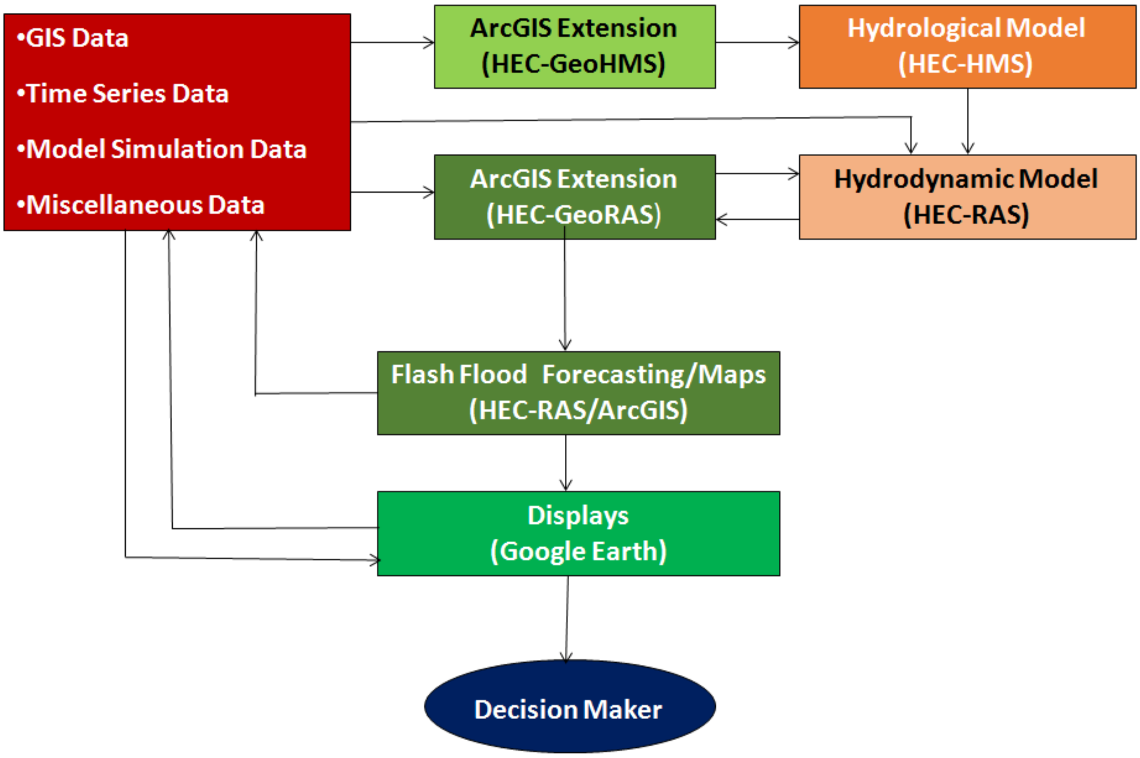


Figure 2. Model flow chart of flash flood forecasting and management

The geospatial Hydrological Modeling Extension (HEC geoHMS) uses ArcGIS and spatial Analyst to develop a number of hydrological inputs, Analysing digital terrain information, HEC GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that presents the watershed response to precipitation. Rainfall-runoff modelling would be performed using the HEC HMS model by importing results from HEC-GeoHMS. The physical representation of watershed would be accomplished with a basin model.

Flood forecasts are typically based on a two-step process in which a hydrological model is first used to route the flood and determine expected flow hydrographs at the site of interest. The peak flow from this flood routing analysis is then typically input into a steady flow hydraulic model, such as the U.S. Army Corps of Engineers HEC-RAS model, to determine the corresponding flood levels that would be expected along river reaches extending through populated areas. U.S. Army Corps of Engineers' public domain HEC-RAS (River Analysis System) model now offers flood forecasters such a modelling capability. Specifically, HEC-RAS has been expanded to include an unsteady flow modelling component which, although not capable of handling highly dynamic flows such as dam break and ice jam release events, is more than adequate for the application of open water flood forecasting. Because HEC-RAS is so widely used in practice, virtually all water resources engineers have some familiarity with it. Furthermore, as it is the standard tool for floodplain delineation studies, most government agencies responsible for flood forecasting already have HEC-RAS models of the river reaches affecting the populated areas within their jurisdiction. For anyone who has used HEC-RAS in this capacity, the unsteady modelling component will be an easy extension. HEC-RAS is a hydraulic model that is composed of three 1D hydraulic examination modules designed for 1) steady flow water surface profiles, 2) Unsteady flow simulation, and 3) Sediment transport, movable boundary computations. Ordinary geometric data modeling and geometric and hydraulic calculation sub-modules are implemented in all three of these models. Apart from these three models for hydraulic research, the model also includes many hydraulic planning utilities that can be used after the fundamental water surface contours are programmed.

This can deal with the full dynamic St. Venant equations in order to reproduce 1D flow through single branch or looped system of open channels. It also simulates break- downs in levees; impedance and other changes encountered by the river while passing through dams, barrage, weir overflow structures, bridges and culverts and pumped diversions. The boundary conditions of upstream are needed at the up-stream region of all the catchments that are disconnected from other basins or reservoirs in the form of a current hydrograph of total flow against time. Similarly the status, the boundary conditions of downstream are needed at the downstream region of all the basins not in contact with other basins or reservoirs. There are four distinct kinds of the boundary conditions of downstream: stage hydrograph of water elevation against time, current hydrograph, one-value rating curve and normal depth.

To accomplish the study objective of forecasting flash flood, the flow velocity, the water levels and the peak flow (all related to peak discharge) are considered to be influential with respect to flash flood occurrence. In the investigation, HEC HMS model will be calibrated and validated, and the outputs will be used for HEC-RAS. Subsequently, adequacy of HEC RAS model in flash forecasting will be investigated by analysing flood characteristics using different indices. Furthermore, the model would be used to forecast river stage by using forecasted discharge from HEC HMS model. HEC-RAS also offers a module to map the flood plains.

Chapter 5

RESULTS AND DISCUSSION

In the proposed study hydrological model HEC HMS (the Hydraulic Engineering Center hydrological model System) with hydrodynamic model HEC-RAS (the Hydraulic Engineering Center River Analysis System) model would be integrated by employing IMD forecast rainfall as input. As per CWC report three basins fall in the flood prone area sub zone 4(A) of the Andhra region namely Vamsadhara, Nagavali and Sarada river bains. Accordingly ASTER 30 m resolution digital elevation model (DEM) downloaded from Earth Explorer (USGS WEB site) as shown in figure 3 and delineation study basin, sub-catchments and drainage network using with terrain processing in HEC-GeoHMS environmental are shown in figure 4. Basin, sub-catchments and stream characteristics was determined in basin processing. Land use and land cover (LU/LC) were performed with January 2018 landsat 8 image downloaded from USGS web site shown in the figure 5. Soil maps of the river basins generated using NBSS, Nagapur is shown in the figure 6. Daily discharge data collected from India-WRIS and WRD AP and rainfall data collected from IMD (0.5 degree gridded), CHRS hourly rainfall data and WRD, AP of three basins. Analysed the design storm for various return periods using simple Gumble distribution and estimated all the input parameters of the HEC HMS model and simulated the runoff for peak flood year. The simulated runoff was calibrated with observed flow data of Vamsadhara, Nagavali and Sarada river basins. River basin simulated runoff and model calibrated results are shown in figure 7-14. Travel time for each sub catchment is computed as shown in table 1 and 2 of Nagavali and Vamsadharaa river basins.

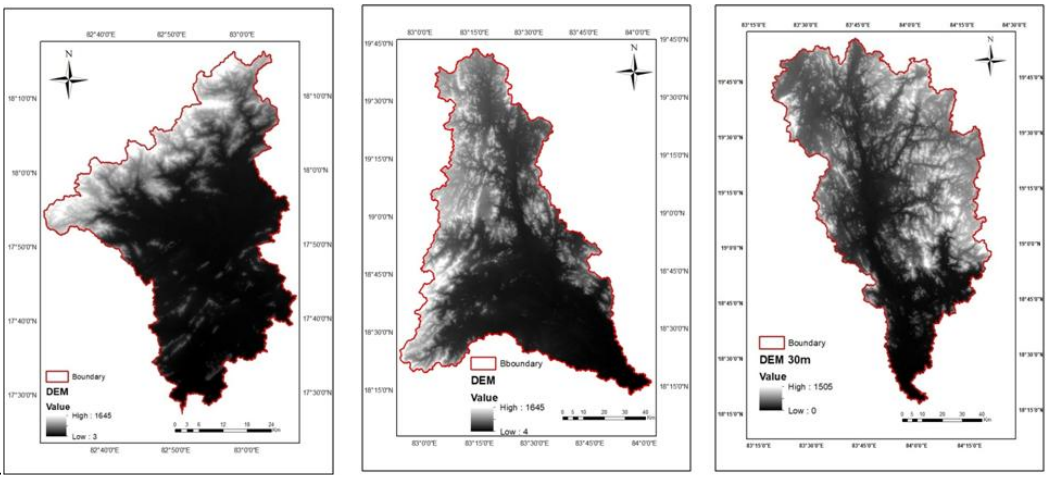


Figure 3. ASTER 30 m resolution digital elevation model (DEM) of the Sarada, Nagavali and Vamsidgara river basins.

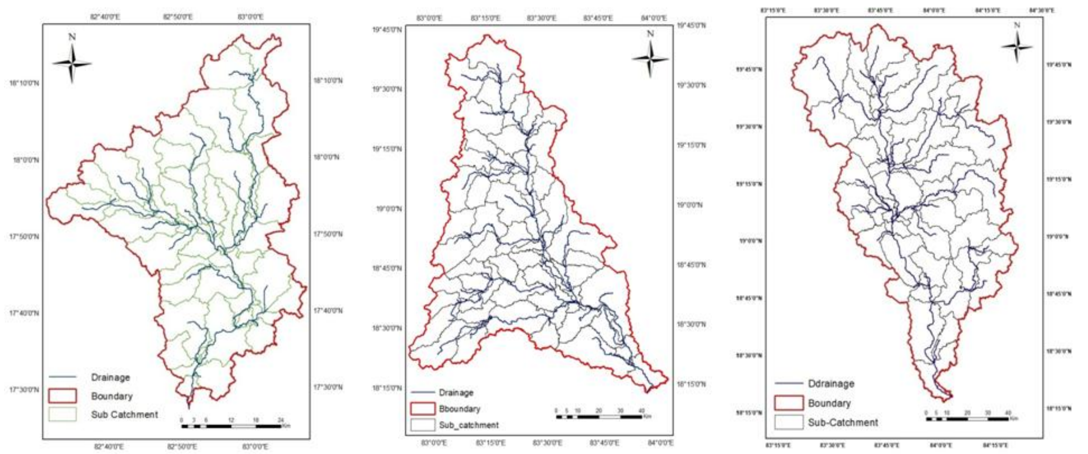


Figure4. Watershed, drainage and sub-watershed delineation of the Sarada, Nagavali and Vamsadharaa river basins.

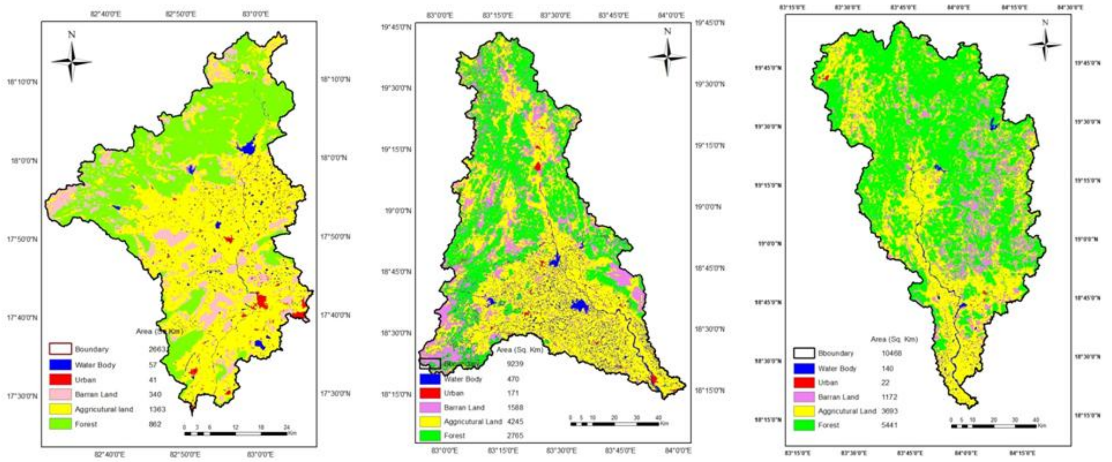


Figure 5. Land use/land cover (LU/LC) of the Sarada, Nagavali and Vamsidgara river basins Using landsat 8 image January 2018.

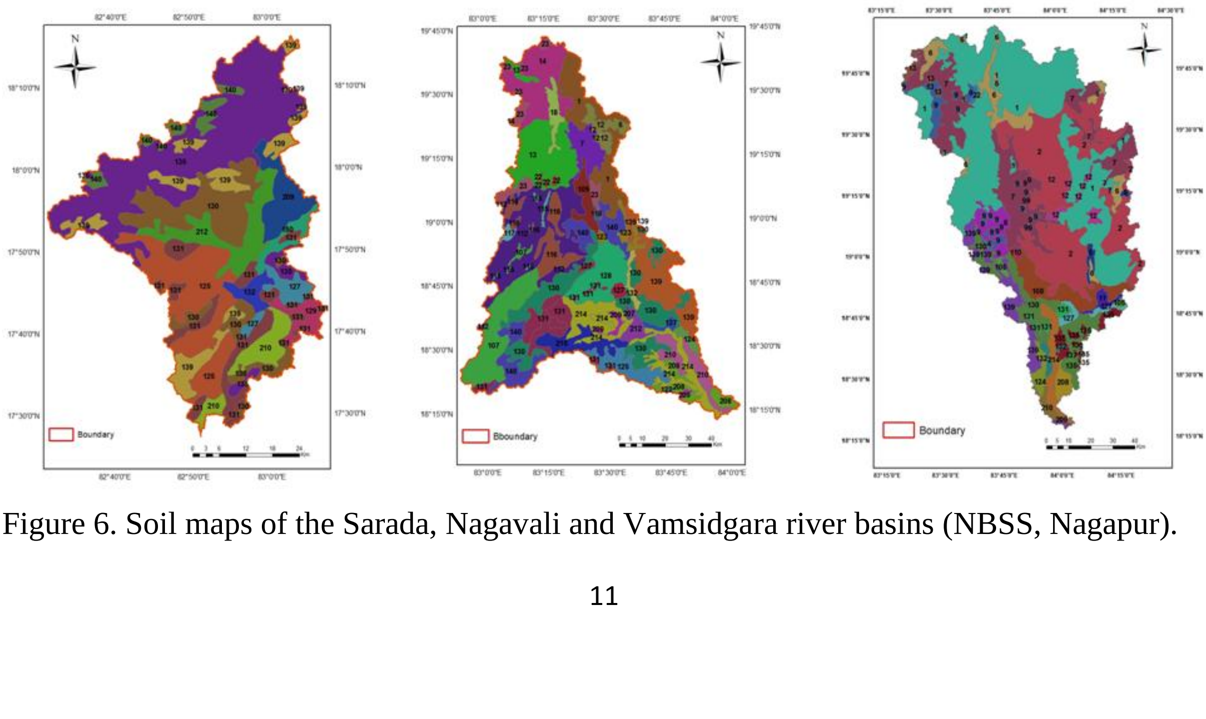


Figure 6. Soil maps of the Sarada, Nagavali and Vamsidgara river basins (NBSS, Nagapur).

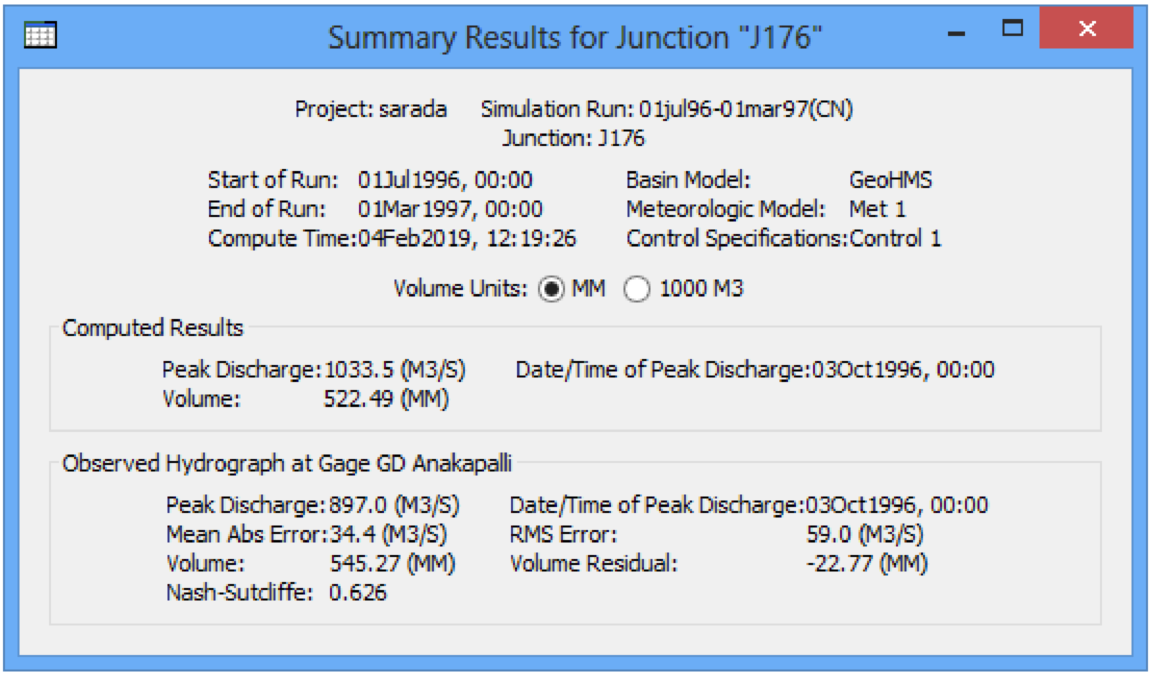


Figure 7. Calibration summary results of the Sarada river basin.

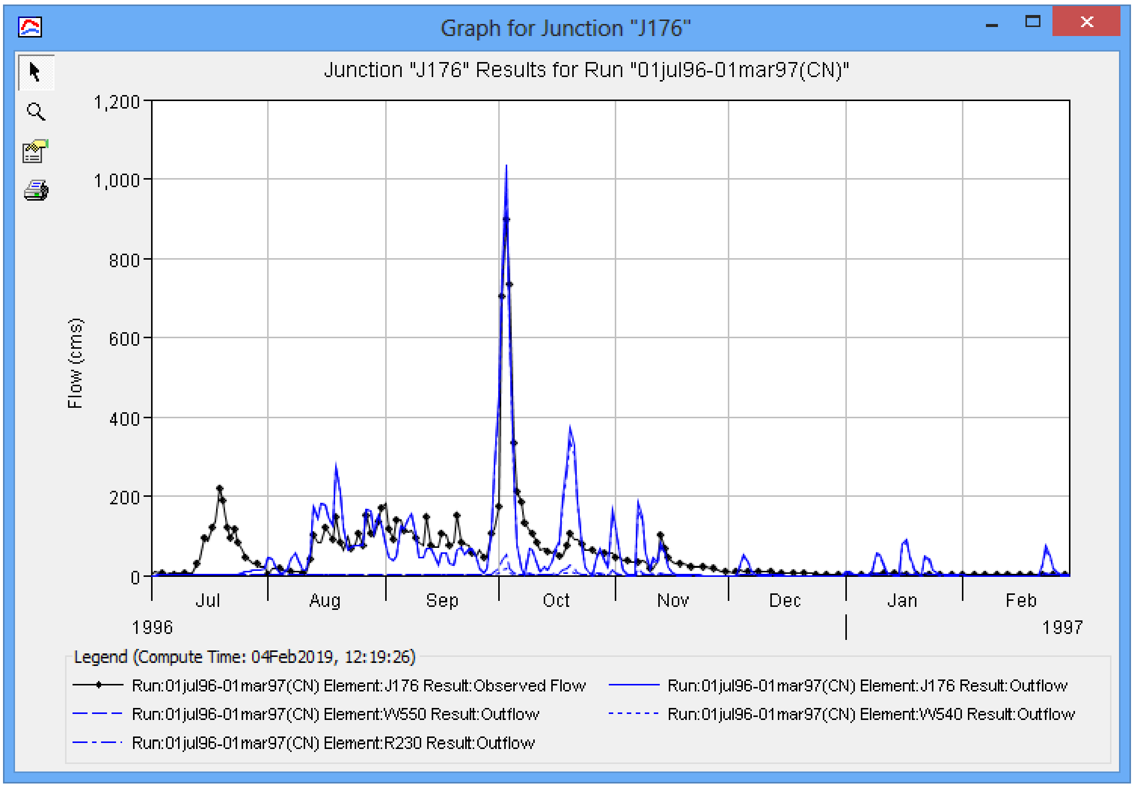


Figure 8. HMS simulated results comparison with observed flow of the Sarada river basin.

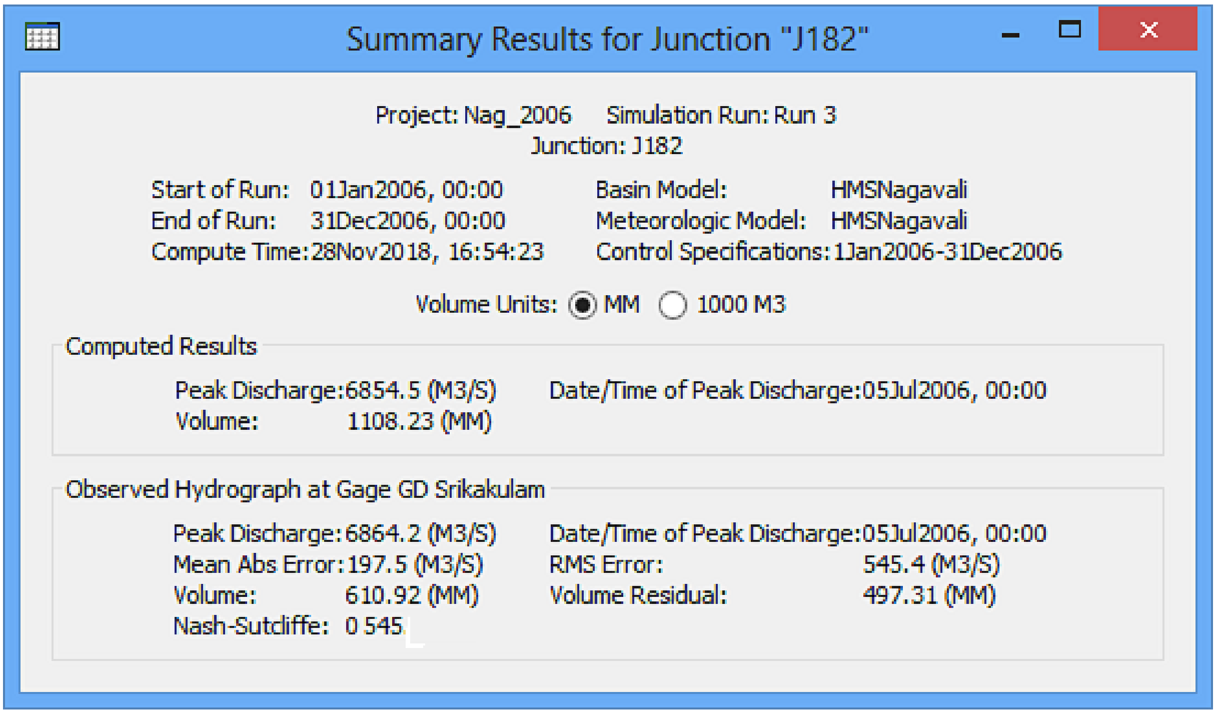


Figure 9. Calibration summary results of the Nagavali river basin.

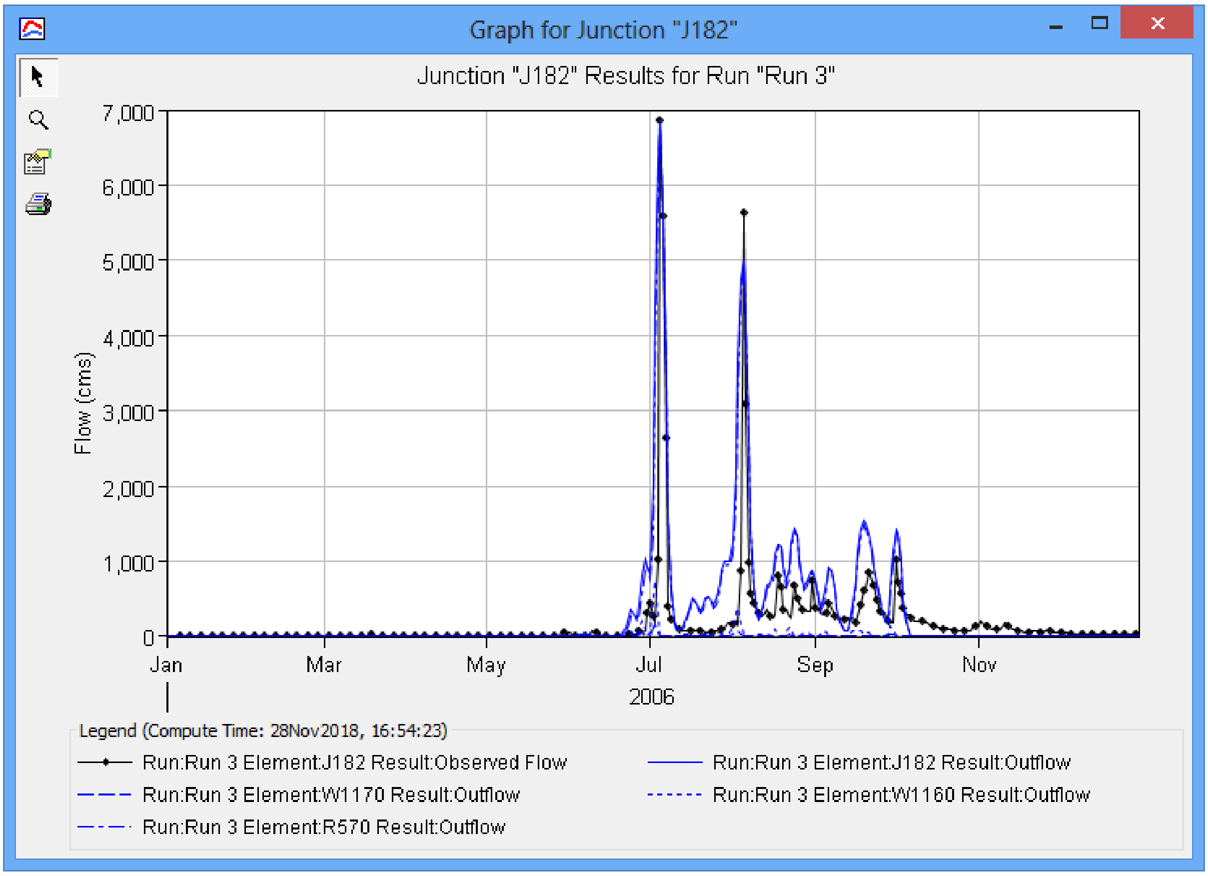


Figure 10. HMS simulated results comparison with observed flow of the Nagavali river basin.

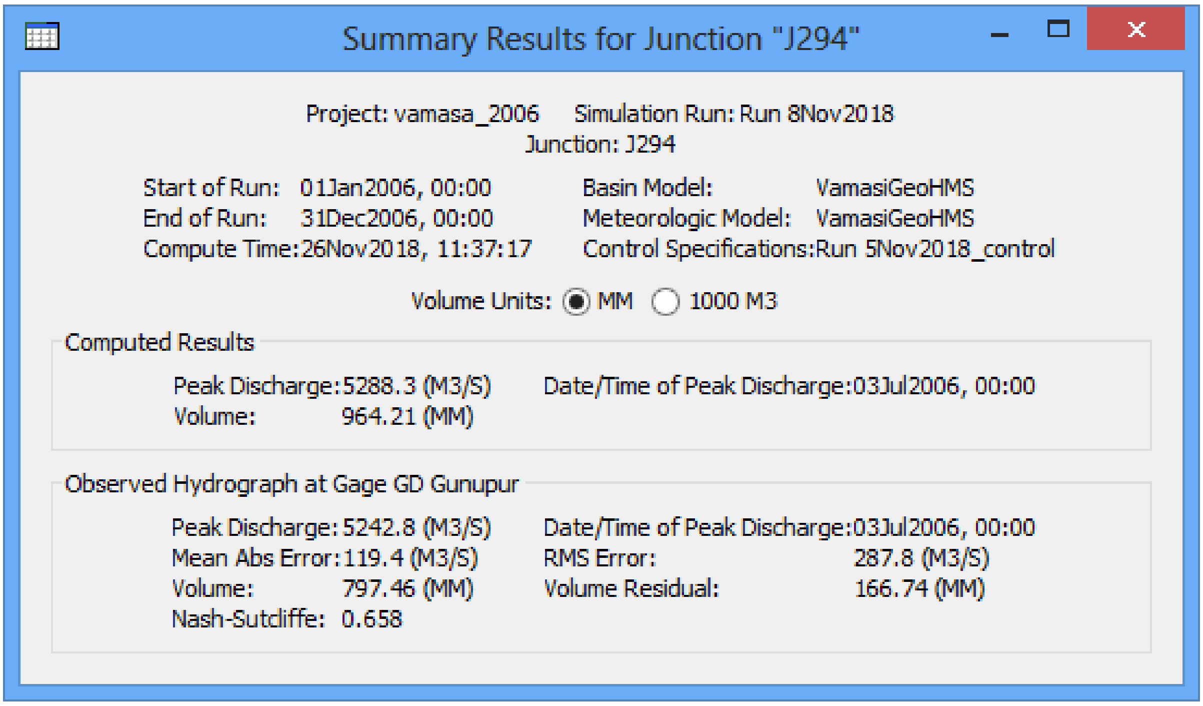


Figure 11. Calibration summary results of the Vamsadhara river basin at Gunupur GD site.

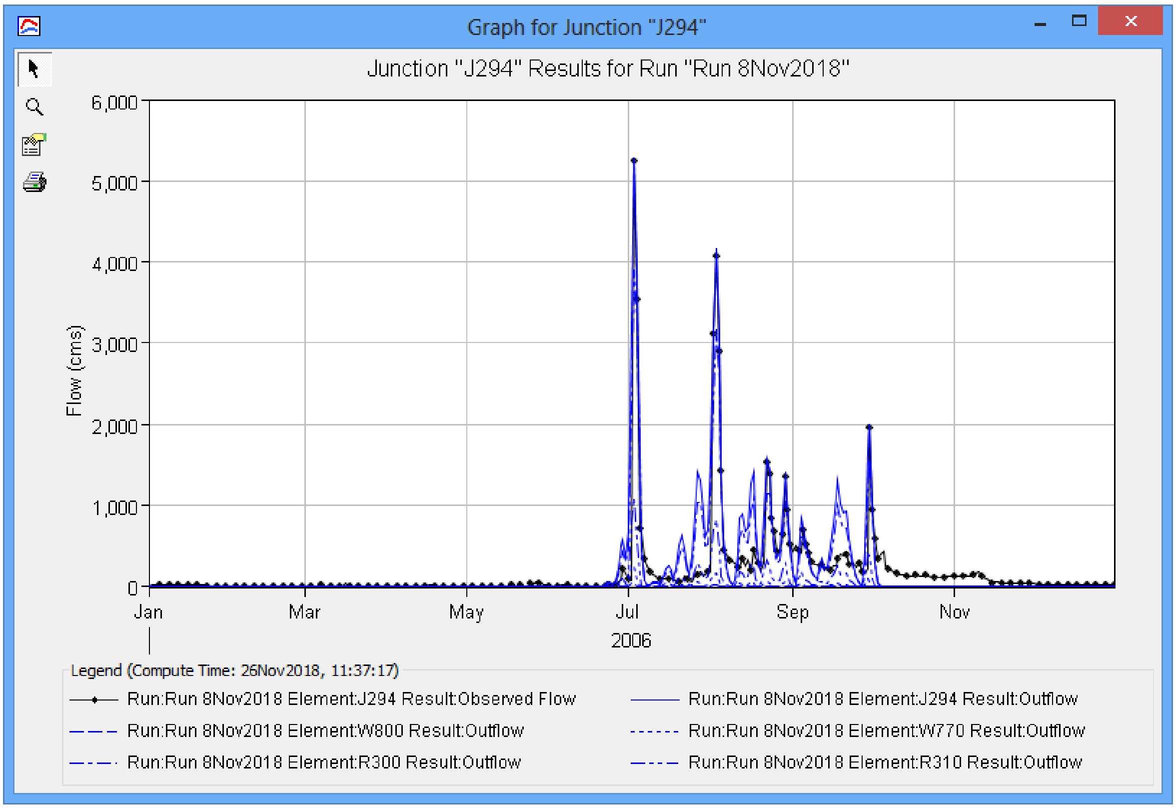


Figure 12. HMS simulated results comparison with observed flow of the Vamsadhara river basin at Gunupur GD site.

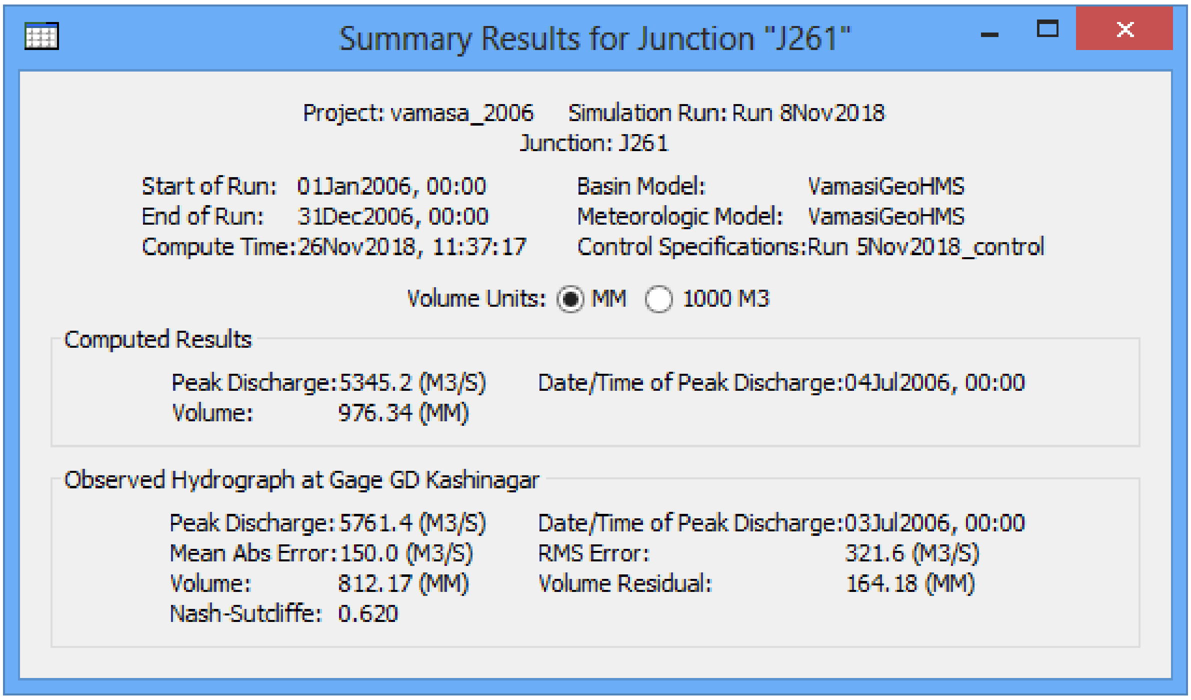


Figure 13. Calibration summary results of the Vamsadhara river basin at Kahinagar GD site.

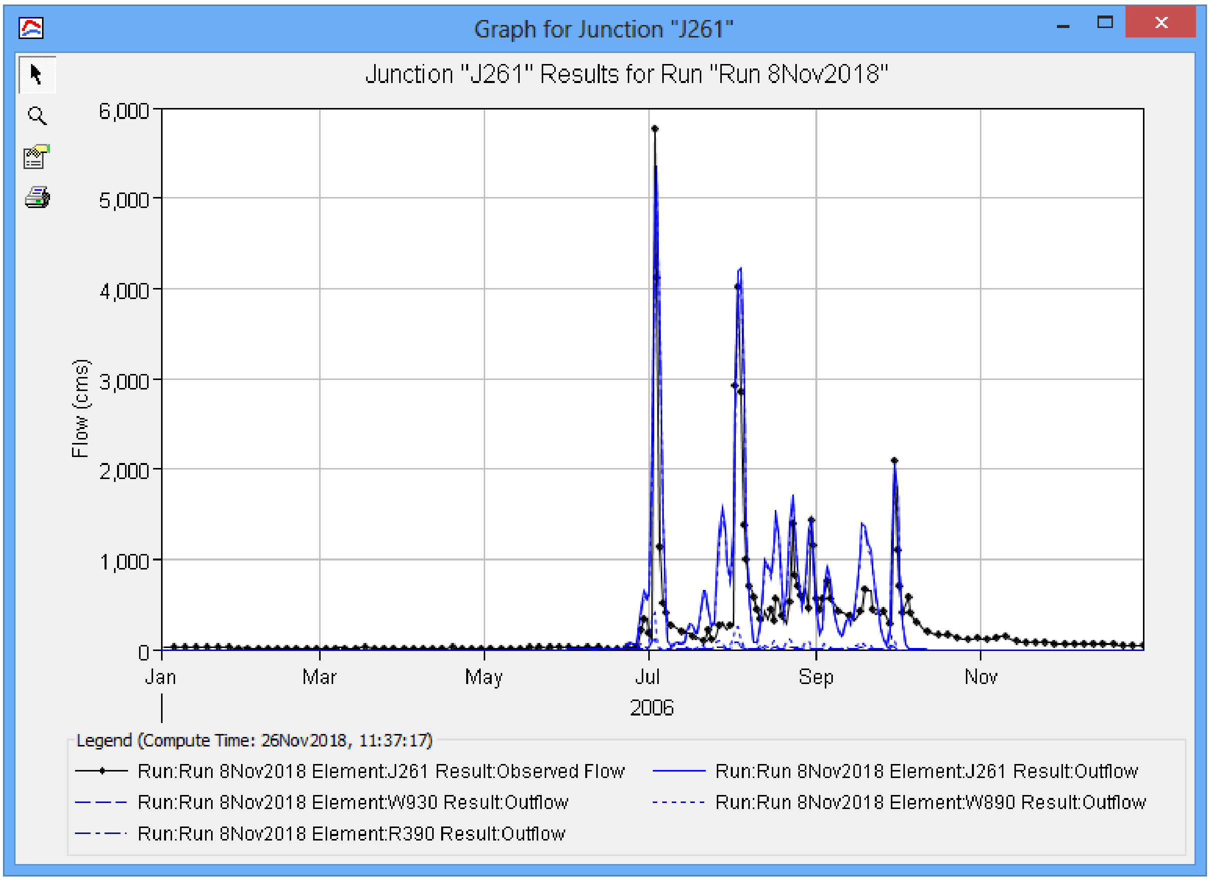


Figure 14. HMS simulated results comparison with observed flow of the Vamsadhara river basin at Kashinagar GD site.

Table 1. Sub catchment travel time for Nagavali river basin.

Nagavali River Basin					
Sl.No	**Sub catchment Name**	**Sub catchment Time of travel (hr)**	**Sl.No**	**Sub catchment Name**	**Sub catchment Time of travel (hr)**
1	W600	10.13	30	W890	9.63
2	W610	5.29	31	W900	7.89
3	W620	4.84	32	W910	7.00
4	W630	5.77	33	W920	8.70
5	W640	5.27	34	W930	12.72
6	W650	10.10	35	W940	4.88
7	W660	8.22	36	W950	10.96
8	W670	6.04	37	W960	5.73
9	W680	2.84	38	W970	12.88
10	W690	8.02	39	W980	7.22
11	W700	1.50	40	W990	3.96
12	W710	8.04	41	W1000	1.87
13	W720	0.52	42	W1010	6.52
14	W730	1.80	43	W1020	24.22
15	W740	8.06	44	W1030	5.44
16	W750	8.31	45	W1040	10.08
17	W760	3.93	46	W1050	7.15
18	W770	5.93	47	W1060	7.23
19	W780	1.77	48	W1070	1.78
20	W790	4.37	49	W1080	1.29
21	W800	2.83	50	W1090	23.01
22	W810	9.50	51	W1110	8.69
23	W820	2.47	52	W1120	6.29
24	W830	5.94	53	W1130	9.68
25	W840	5.07	54	W1140	5.57
26	W850	5.20	55	W1150	5.71
27	W860	2.11	56	W1160	18.44
28	W870	8.32	57	W1170	3.93
29	W880	8.15	58	W1180	11.64

Table 2. Sub catchment travel time for Vamsadharaa river basin.

Vamsadhara River Basin					
Sl.No	**Sub catchment Name**	**Sub catchment Time of travel (hr)**	**Sl.No**	**Sub catchment Name**	**Sub catchment Time of travel (hr)**
1	W500	7.69	26	W750	1.26
2	W510	8.87	27	W760	4.81
3	W520	4.91	28	W770	8.69
4	W530	7.27	29	W780	6.54
5	W540	6.52	30	W790	0.68
6	W550	1.86	31	W800	2.85
7	W560	5.69	32	W810	6.74
8	W570	8.59	33	W820	2.46
9	W580	9.96	34	W830	5.48
10	W590	2.02	35	W840	8.27
11	W600	9.64	36	W850	5.28
12	W610	3.99	37	W860	5.92
13	W620	0.19	38	W870	4.76
14	W630	6.41	39	W880	2.14
15	W640	4.70	40	W890	5.63
16	W650	8.01	41	W900	10.58
17	W660	10.99	42	W910	7.80
18	W670	6.46	43	W920	5.05
19	W680	7.55	44	W930	7.42
20	W690	2.54	45	W940	5.31
21	W700	5.10	46	W950	2.21
22	W710	2.50	47	W960	8.92
23	W720	9.15	48	W970	11.24
24	W730	2.94	49	W980	5.12
25	W740	8.32			

5.1 Image classification and impact assessment on peak flow

In this study, totally five LULC classes were established as forest, agriculture, barren, water body and urban. Description of these land cover classes are presented in Table 3. Three dated Landsat images were compared using supervised classification technique. In the supervised classification technique, three images with different dates are independently classified. Accurate classifications are imperative to ensure precise change-detection results. A Supervised classification method was carried out using training areas and test data for accuracy assessment. Maximum Likelihood Algorithm was employed to detect the land cover types in Arc GIS 10.5 as shown in figure 15 to 20.

Table3: Description of different LULC categories.

Land use/Land cover	Description
Water	Rivers and lakes
Urban	Residential, commercial, industrial, transportation and facilities
Agriculture	Almost all type of crop’s
Forest	Land with tree canopy density more than 40%
Barren land	Areas devoid of vegetation; e.g., sediments, exposed rocks, landslide zones, degraded forest area

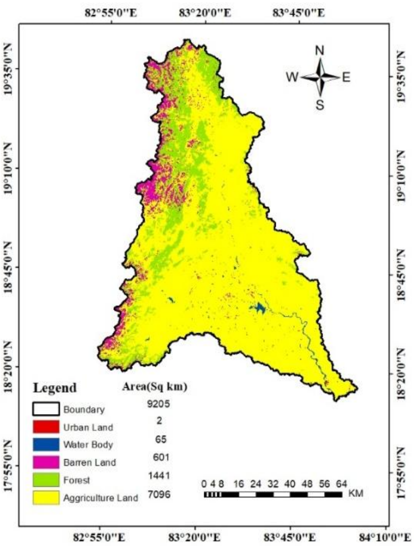


Figure 15. Land use Land cover for 2009 of Nagavali river basin.

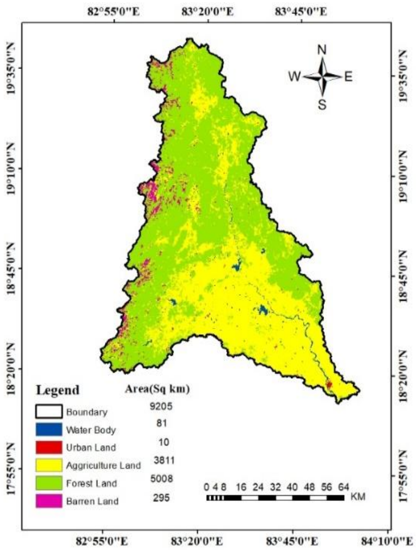


Figure 16. Land use Land cover for 2016 of Nagavali river basin.

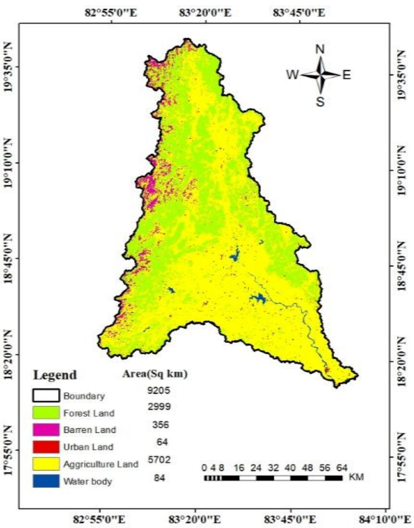


Figure17. Land use Land cover for 2019 of Nagavali river basin.

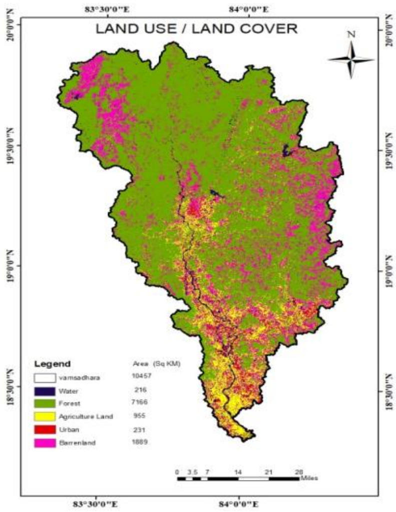


Figure 18. Land use land cover for 2009 of Vamsadharaa river basin.

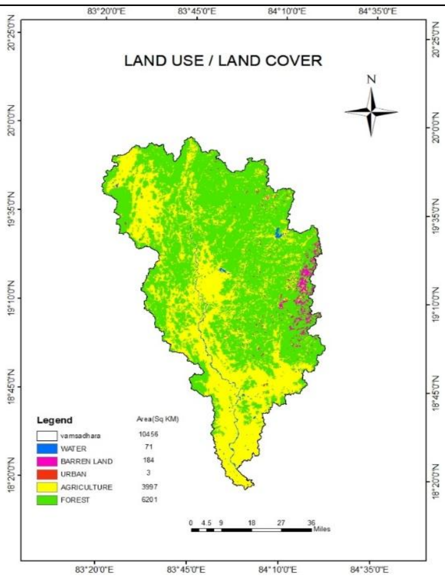
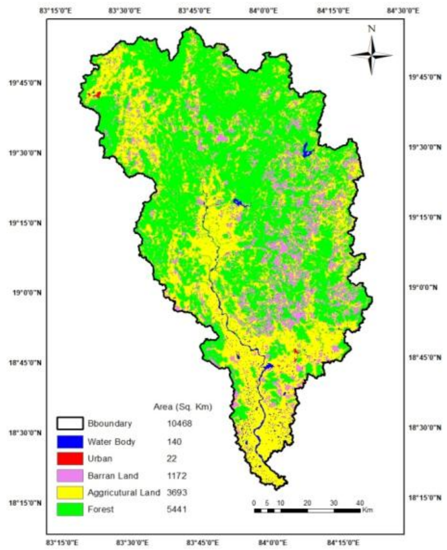
	

Figure 19. Land use land cover for 2016 of Vamsadharaa river basin.	Figure 20. Land use land cover for 2019 of Vamsadharaa river basin.

Accuracy assessment was critical for a map generated from any remote sensing data. Error matrix is the most common way to present the accuracy of the classification results. Overall accuracy, user's and producer's accuracies, and the Kappa statistic were then derived from the error matrices. The Kappa statistic incorporates the off-diagonal elements of the error matrices and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance.

In this analysis we used 3 years of satellite images of Landsat 4-5 for 2009 and Landsat 8 for the 2016, and 2019 performed as shown in figure 15 to 17 with five different types of classifications as mansion hear Forest Land, Urban Land, Agriculture Land, Barren Land and Water body. The overall accuracy of classification image dated 2009, 2016 and 2019 was 87%, 86% and 86% and the Kappa coefficient was 83.2%, 79.1% and 81.3% as shown in the table 5 to 6 for Nagavli river basin. The accuracy assessment and kappa coefficient was calculated using formulas notified below.

Percentage of accuracy assessment $= \dfrac{\text{sum of true values}}{\text{total number of values}} \times 100$

Kappa coefficient $= \dfrac{\{(TS \times TCS) - \sum(column\ total \times Row\ total)}{TS^2 \times \sum(column\ total \times Row\ total)} \times 100$

TS=Total number of values and TCS=Sum of true values

Table 4 : Accuracy assessment for supervised classification of Landsat 4-5 for 2009 of Nagavali river basin

True value							
Predict	**Forest**	**Barren land**	**Urban Land**	**Agriculture**	**water**	**sum**	**Percentage %**
Forest	**31**	0	0	6	0	37	84
Barren	0	**39**	0	3	0	42	93
Urban	0	0	**6**	0	0	6	100
Agriculture	0	0	11	**68**	7	86	79
Water	0	0	1	0	**52**	53	98
Sum	31	39	18	77	59		
Percentage%	100	100	33	88	88		

Overall accuracy = 87% and Kappa coefficient = 83.2%

Table 5 : Accuracy assessment for supervised classification of Landsat 8 for 2016 of Nagavali river basin

	True value						
Predict	**Forest**	**Barren land**	**Urban Land**	**Agriculture**	**water**	**sum**	**Percentage %**
Forest	**46**	0	0	21	0	67	69
Barren	0	**46**	0	0	0	46	100
Urban	0	0	**20**	0	0	20	100
Agriculture	0	5	0	**86**	2	93	92
Water	0	2	0	0	**64**	66	97
Sum	46	53	20	107	66		
Percentage%	100	87	100	80	97		

Overall accuracy = 86% and Kappa coefficient = 79.1%

Table 6 : Accuracy assessment for supervised classification of Landsat 8 for 2019 of Nagavali river basin

	True value						
Predict	**Forest**	**Barren land**	**Urban Land**	**agriculture**	**water**	**sum**	**Percentage %**
Forest	**47**	0	0	9	0	56	84
Barren	0	**29**	0	0	0	29	100
Urban	0	10	**27**	0	0	37	73
Agriculture	0	6	18	**123**	0	147	84
Water	0	0	0	0	**48**	48	100
Sum	47	45	45	132	48		
Percentage%	100	64	60	93	100		

Overall accuracy = 86% and Kappa coefficient = 81.3%

For Vamsadharaa river basin Landsat 4-5 for 2009 and Landsat 82016 LU/LC was performed as shown in the figure 18 and 20 and computed the overall accuracy for 2009 and 2016 is 87% and 83%. The kappa coefficient is 82% for 2009 and for 2016 as shown in table 7 to 9.

Table 7: Accuracy assessment for supervised classification of Landsat 4-5 for 2009 of Vamsadharaa river basin.

Predict	**True value**					**sum**	**Percentage%**
	Water	**Forest**	**Agriculture**	**Urban**	**Barren**		
Water	**40**	0	0	2	3	45	88
Forest	0	**64**	1	0	0	65	98
Agriculture	0	0	**43**	0	0	43	100
Urban	0	0	1	**5**	5	11	45
Barren	0	0	0	10	**1**	11	9
Sum	40	64	45	13	8	170	
Percentage%	100	100	95	38	12		

Overall Accuracy = 87% and Kappa Coefficient = 82%

Table 8: Accuracy assessment for supervised classification of Landsat 8 for 2016 of Vamsadharaa river basin.

Predict	**True value**					**sum**	**Percentage%**
	Water	**Forest**	**Agriculture**	**Urban**	**Barren**		
Water	**83**	0	0	9	0	92	90
Forest	21	**81**	0	18	4	124	65
Agriculture	6	0	**103**	5	0	114	90
Urban	0	0	0	**41**	0	41	100
Barren	0	0	0	0	**6**	6	100
Sum	110	81	103	73	10	377	
Percentage%	75	100	100	56	6		

Overall accuracy = 83% and Kappa coefficient = 77%

Table 9: Accuracy assessment for supervised classification of Landsat 8 for 2019 of Vamsadharaa river basin.

Predict	**True value**					**sum**	**Percentage%**
	Water	**Forest**	**Agriculture**	**Urban**	**Barren**		
Water	**80**	0	0	9	0	89	90
Forest	24	**81**	0	18	4	127	64
Agriculture	6	0	**103**	5	0	114	90
Urban	0	0	0	**41**	0	41	100
Barren	0	0	0	0	**6**	6	100
Sum	110	81	103	73	10	377	
Percentage%	75	100	100	56	6		

Overall accuracy = 83% and Kappa coefficient = 77%

Impact of the LU/LC HMS results are shown in table 10 and the results show that there is no significant change in the peak flow.

Table 10. HMS simulated peak flood Impact of LU/LC.

LU/LC	Observed peak flow (M^3/S)	Simulated peak flow (M^3/S)	Percentage of deviation
Nagavali			
2009	6864.20	6215.32	10.11
2016	6864.20	6894.50	00.43
2019	6864.20	7056.52	02.72
Vamsadhara			
2009	5761.40	5285.31	09.01
2016	5761.40	5645.20	02.05
2019	5761.40	5701.36	01.06

5.2 HEC RAS 2-D Results

Imported terrain data was used for creating the 2D flow area within geometry editor and total number of cells 9,18,700 was created over the 2D river flow area within the river basin as shown in the figure 21 forecast the flash flood. Each cell size 100m x 100m was used for the analysis with a computational time interval of one hour and with a output interval of one hour. Small time interval and small cell size selection is better for getting good result though the simulation takes more time to complete. For the unsteady flow analysis in HEC-RAS, initial conditions of river were assumed to be wet even though default mode of HEC-RAS simulation is dry. Assuming this condition, at first HEC-RAS will fill up the mesh till the warm-up time and then simulation will be done with that filled cells of river as open channel flow using diffusion wave equation considering the finite volume approximation. Before doing analysis in HEC-RAS, hydraulic properties of each cell should be assigned. HECRAS has capability of creating hydraulic properties of each computed cell mesh. Those hydraulic properties are based on the provided geometric terrain data as well as the manning’s n value of LULC (Water body=0.001, Urban= 0.0404, Barren= 0.010, Agriculture = 0.037 and Forest = 0. 32) as per NLCD and Chow.

5.2.1 Nagavali River Basin

Calibration of the model was done by comparing the simulated flow value of river with the observed maximum flood flow at Srikakulam gauging station of Nagavali river basin for the period of 15th June 2006 to 15th October 2006 by using output of HEC HMS simulated runoff depth or precipitation depth boundary condition over the mesh and downstream boundary condition as stage data in HEC RAS 2D model as shown in Figure 22. From the observed and simulated data coefficient of determination (R^2) was found to be 0.625 as shown in Figure 23. From the analysis, the correlation between the observed and simulated data was found to be satisfactory.

From the HEC-RAS analysis for forecast the flash flood, the time variation of result of unsteady flow analysis was obtained the water depth and water surface elevation within the time series is found to be maximum when there was maximum flow though the location of maximum value of each cell result got varied over the reach with time as shown in figure 24, depth of water over the basin of flood inundation and flow hydrograph water surface profile at Srikakulam GD station(SKL) shown are in figure 25 and 26.

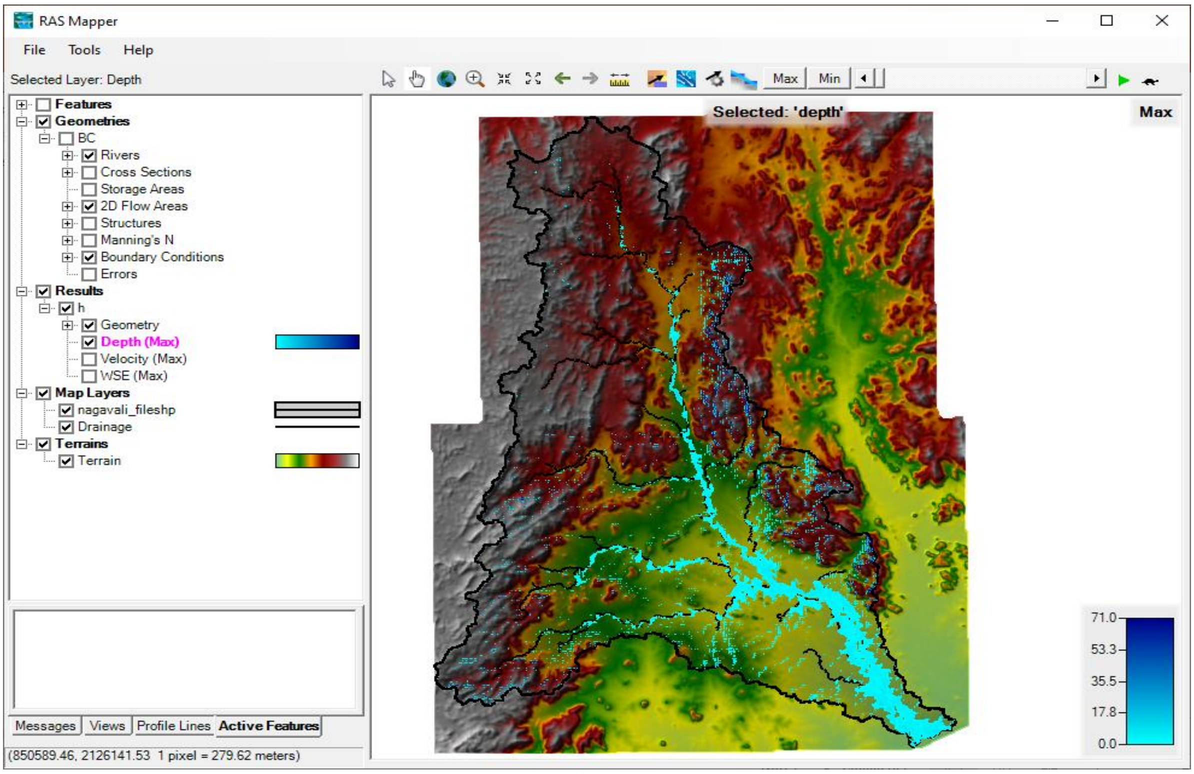


Figure 21. RAS 2D flow area mesh of Nagavali river basin for forecast the flash flood.

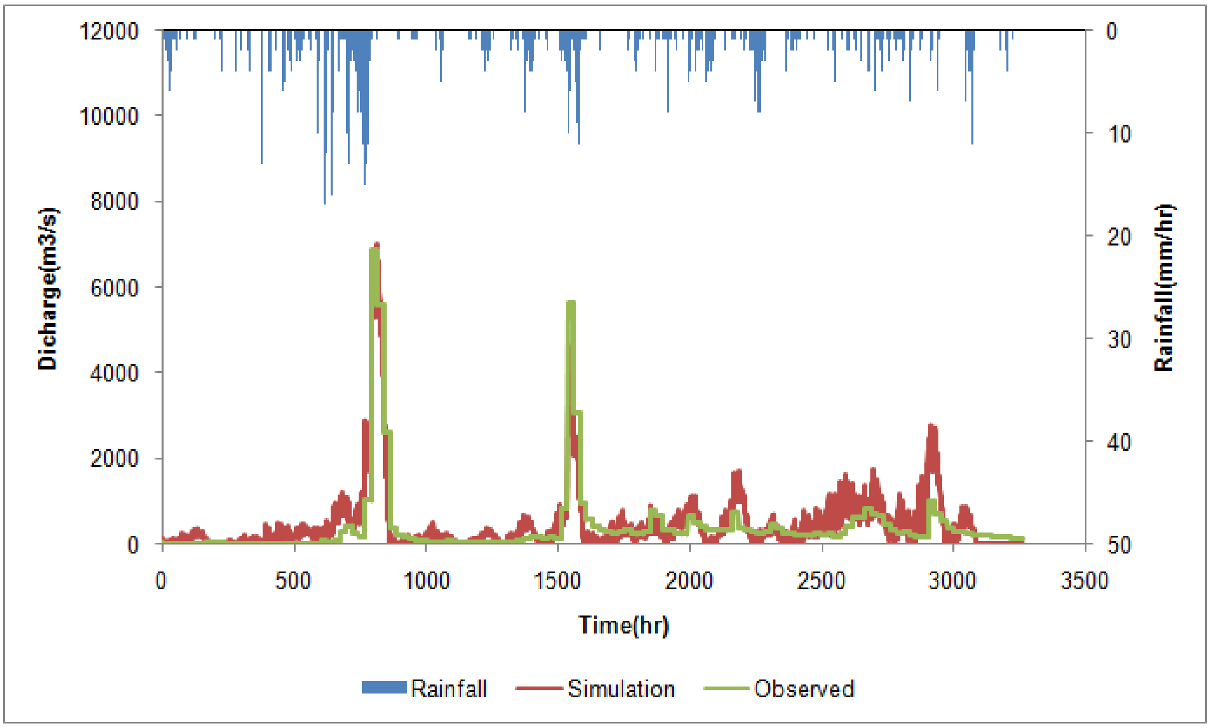


Figure 22. RAS 2D model simulated forecasted flow comparison with observed flow of the Nagavali river basin.

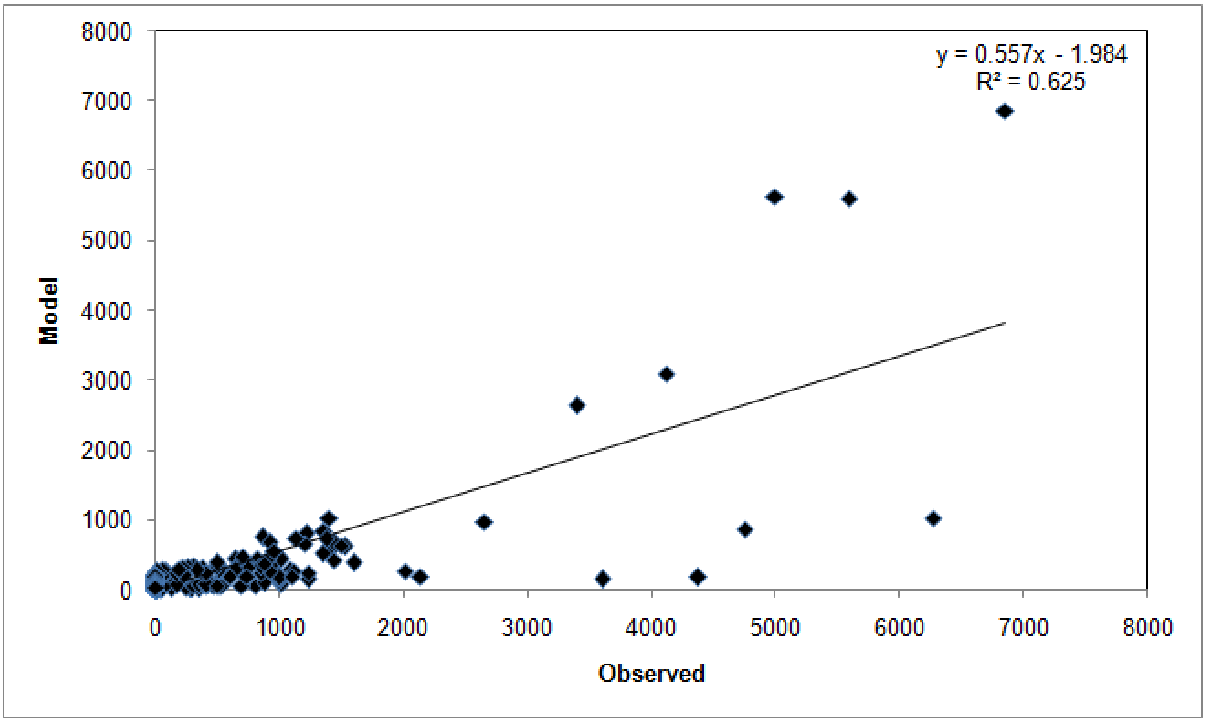


Figure 23. Scattered graph between RAS 2D model simulated flow and observed flow of the Nagavali river basin.

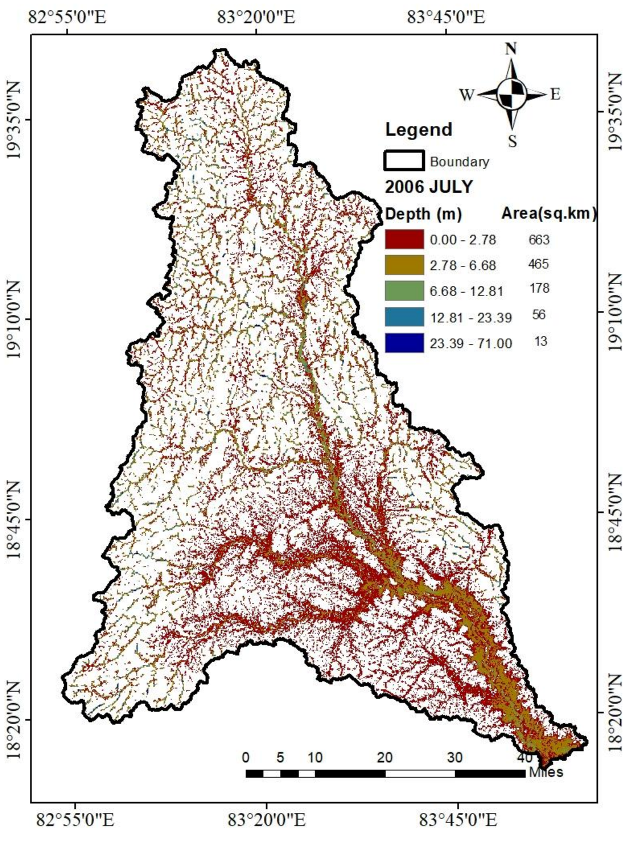


Figure 24. Maximum water depth flow with time variable of the Nagavali river basin during 2006 monsoon period.

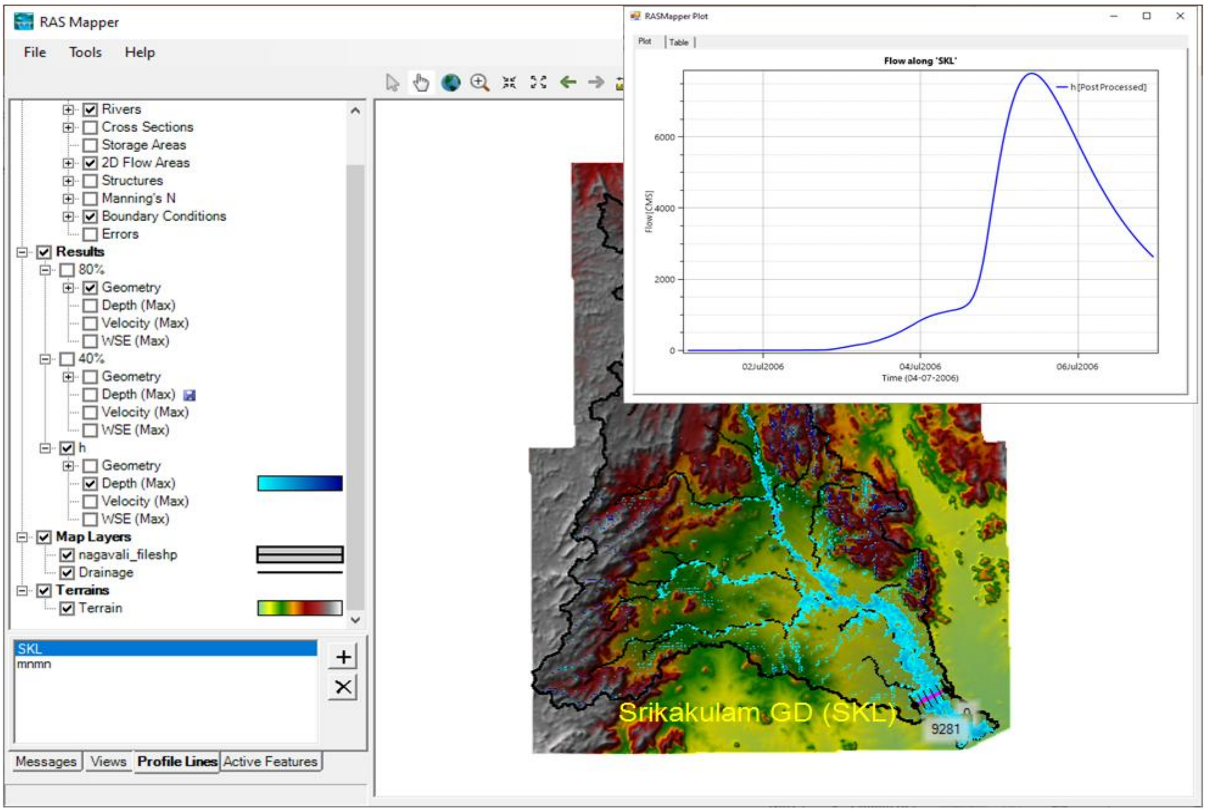


Figure 25. Flash flood forecast at Srikakulam GD (SKL) site location maximum flow.

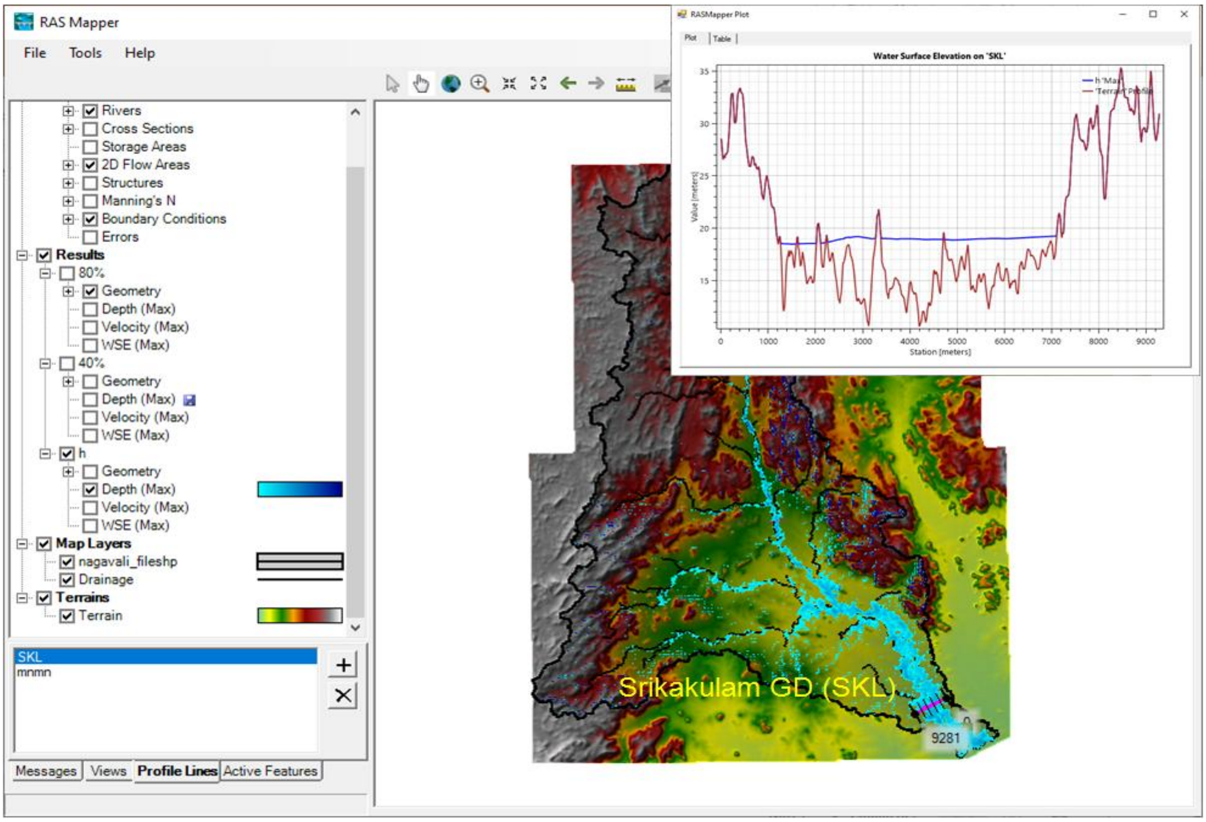


Figure 26. Flash flood forecast at Srikakulam GD (SKL) site location water surface profile maximum flow.

5.2.2 Frequency analysis

Information on the frequency of heavy rainfall is often required by engineers and hydrologists involved in the water management and design of drainage systems. Though many frequency distributions are reported in the literature, for the present study, it was decided to test the applicability of Extreme Value Type 1 (EV1) distribution to the available rainfall data. A brief description of the EV1 distribution follows (Chow *et al.*, 1988, Cunnane, 1989) the probability distribution function for EV1 is given by

$$F(q) = P(Q \leq q) = e^{-e^{-(q-u)\alpha}} \quad (1)$$

where, u and α are location and scale parameters of the distribution and q is the threshold value. The parameters of u and α are given by

$$u = P_m - 0.5772\alpha \quad (2)$$

$$\alpha = \frac{\sqrt{6}}{\pi} s \quad (3)$$

where, P_m and s are sample mean precipitation and sample standard deviation respectively. In the present study plotting position for the EV1 distribution as proposed by Gringorten (1963) was used.

$$F_i = \frac{i - 0.44}{N - 0.12} \quad (4)$$

where, i is the plotting position, N is the sample size and i is the rank with i =1, indicating the smallest sample member. The reduced variant of EV1 can be defined as

$$y_i = -\ln(-\ln(F_i) \quad (5)$$

$$y_{T_r} = -\ln(-\ln(1 - \frac{1}{T_r}) \quad (6)$$

where, T_r is the return period. Using the method of frequency factors, the expected value of P can be obtained from the relation (Eq. 7).

$$P_{T_r} = P_m + K_{T_r} s \quad (7)$$

where, K_{T_r} is the frequency factor given by (Eq. 8).

$$K_{T_r} = -\frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\left\{-\ln\left(1 - \frac{1}{T_r}\right)\right\}\right) \quad (8)$$

5.2.2.1 Design Storm

Useing the above method the IDF curves were developed as shown in the figure 27 using hourly data and using alternative block methods estimate the hyetographs and simulated hydrographs are shown in the figure 28 for different return periods from IDF curves. The hyetograph was used to simulate the depth of runoff/ excess rainfall as input to RAS model to develop the flood maps of maximum depth water with time variable of the basin as shown in figure 29 to 34 for different return periods

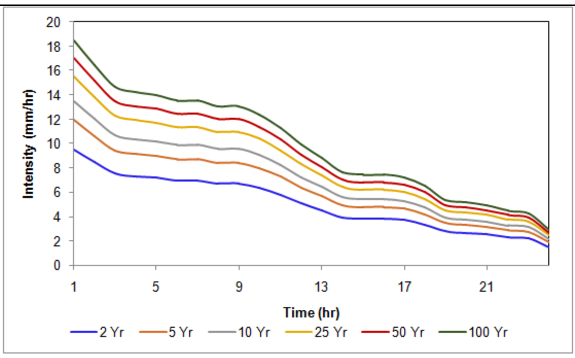


Figure 27. IDF curves for different return periods of Nagavali river basin.

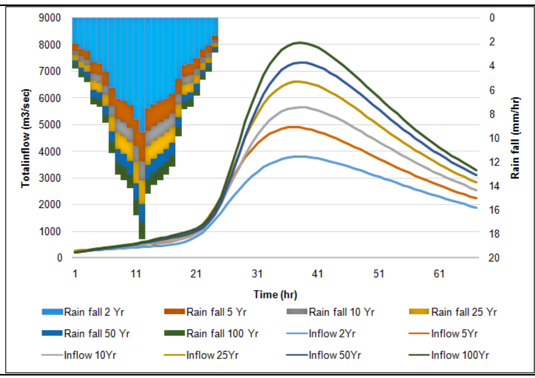


Figure 28. Design storm hydrographs for different return periods of Nagavali river basin.

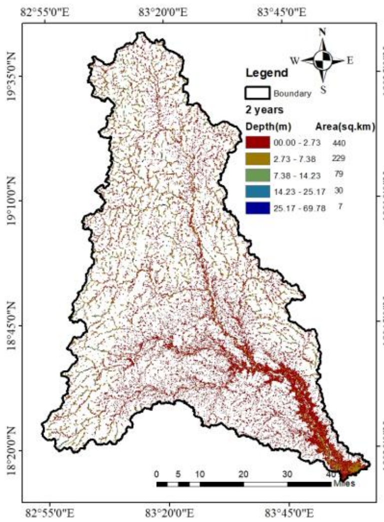


Figure 29. 2 Year return period Maximum water depth flow with time variable of the Nagavali river basin.

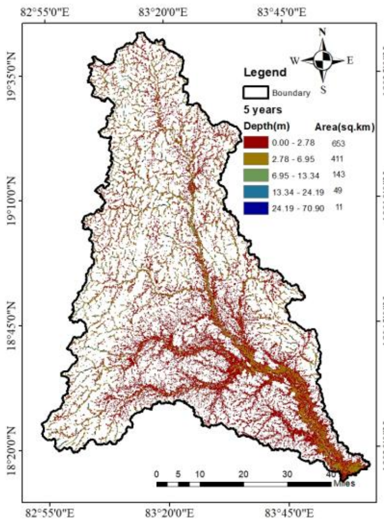


Figure 30. 5 Year return period Maximum water depth flow with time variable of the Nagavali river basin.

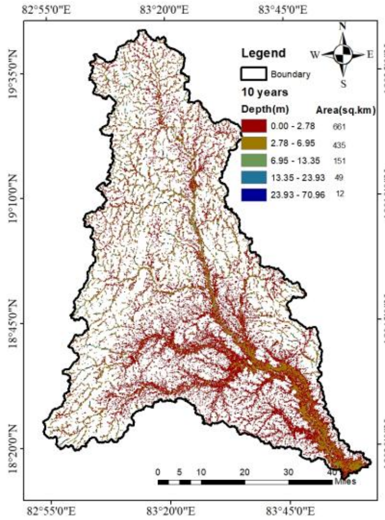


Figure 31. 10 Year return period Maximum water depth flow with time variable of the Nagavali river basin.

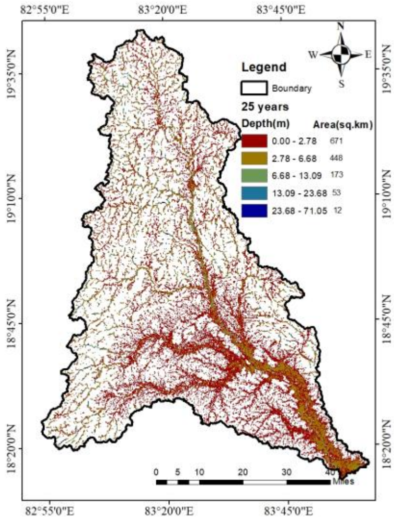


Figure 32. 25 Year return period Maximum water depth flow with time variable of the Nagavali river basin.

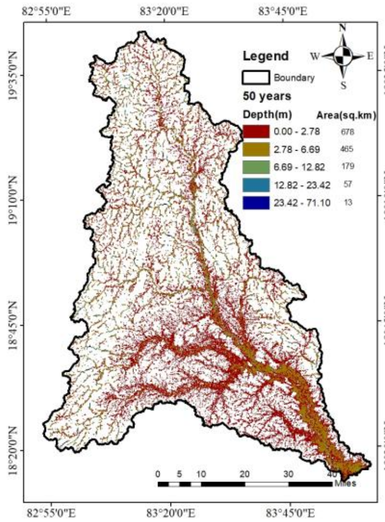


Figure 33. 50 Year return period Maximum water depth flow with time variable of the Nagavali river basin.

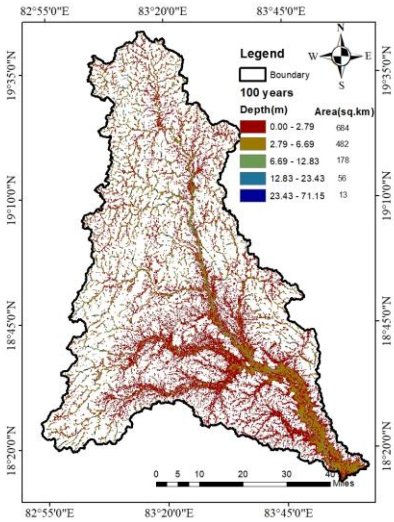


Figure 34. 100 Year return period Maximum water depth flow with time variable of the Nagavali river basin.

5.2.3 Vamsadharaa River basin

2D model setup is shown in figure 35 to forecast the flash flood of Vamsadharaa river basin mesh size 10,05,000 and with cell size 100m x 100m. Calibration of the model was done by comparing the simulated flow value of river with the observed maximum flood flow at Gunupur and Kashinagar gauging station of Vamsadharaa river basin from the period of 15th June 2006 to 15th October 2006 by using the output of HEC HMS simulated runoff depth or precipitation depth boundary condition over the mesh and downstream boundary condition as stage data in HEC RAS 2D model as shown in Figure 36 and 37. From the observed and simulated data the coefficient of determination (R^2) was found to be 0.766 and 0.777 as shown in Figure 38 and 39. From the analysis, the correlation between observed and simulated data was found to be satisfactory. From the HEC-RAS analysis for forecast the flash flood, the time variation of result of unsteady flow analysis was obtained, the water depth and water surface elevation within the time series is found to be maximum when there was maximum flow though the location of maximum value of each cell result got varied over the reach with time as shown in figure 40, depth of water over the basin of flood inundation and flow hydrograph water surface profile at Gunupur GD station are shown in figure 41 to 43.

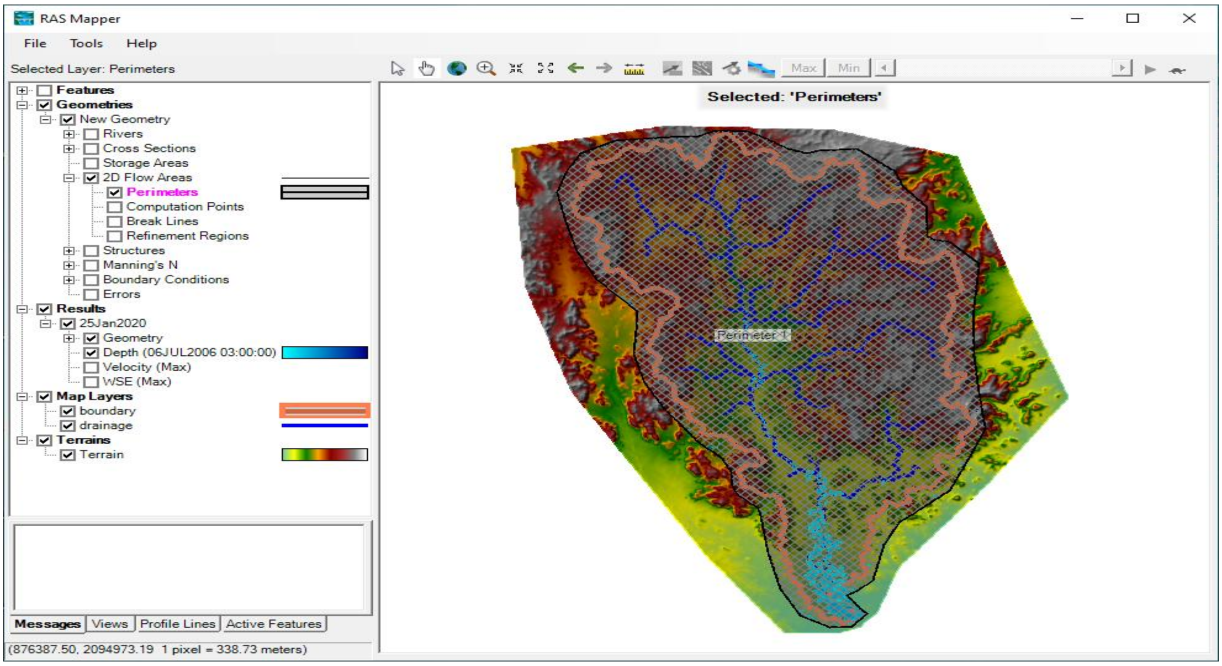


Figure 35. RAS 2D flow area mesh of Vamsadharaa river basin for forecast the flash flood.

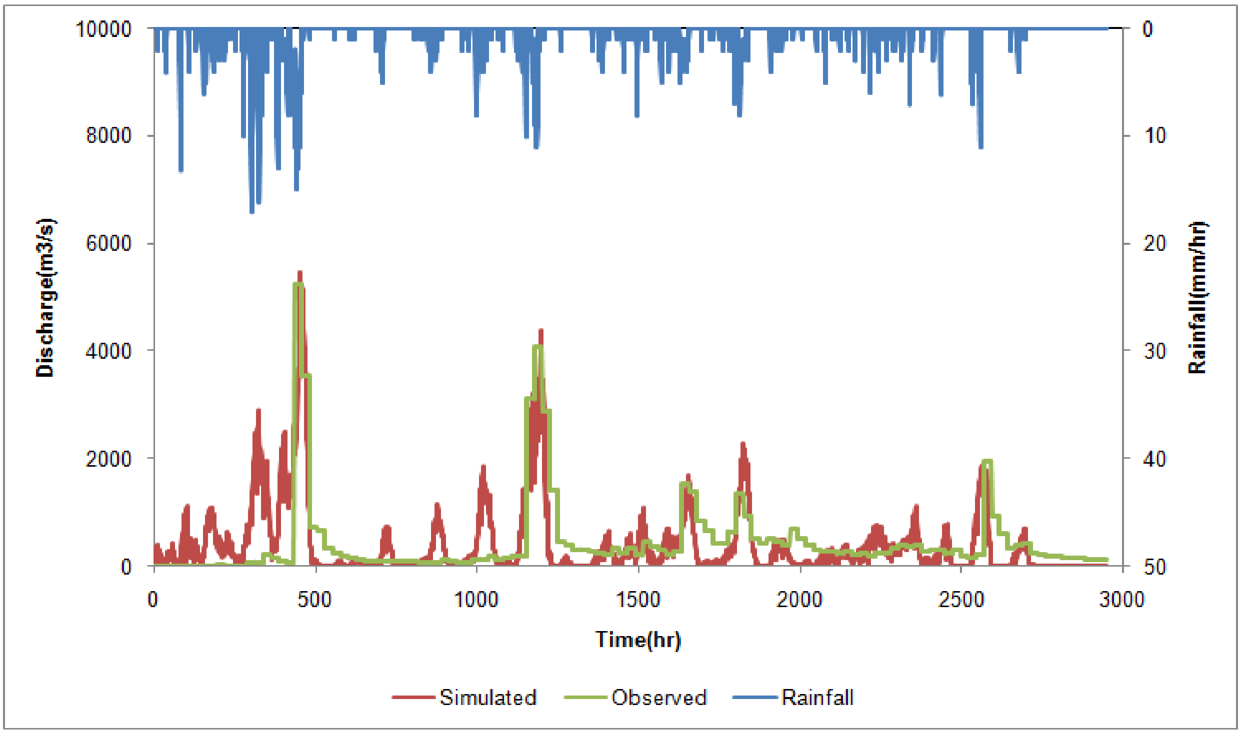


Figure 36. RAS 2D model simulated forecasted flow comparison with observed flow period

from 15th June 2006 to 15th October 2006 at Gunupur gauge station of the Vamsadharaa river basin.

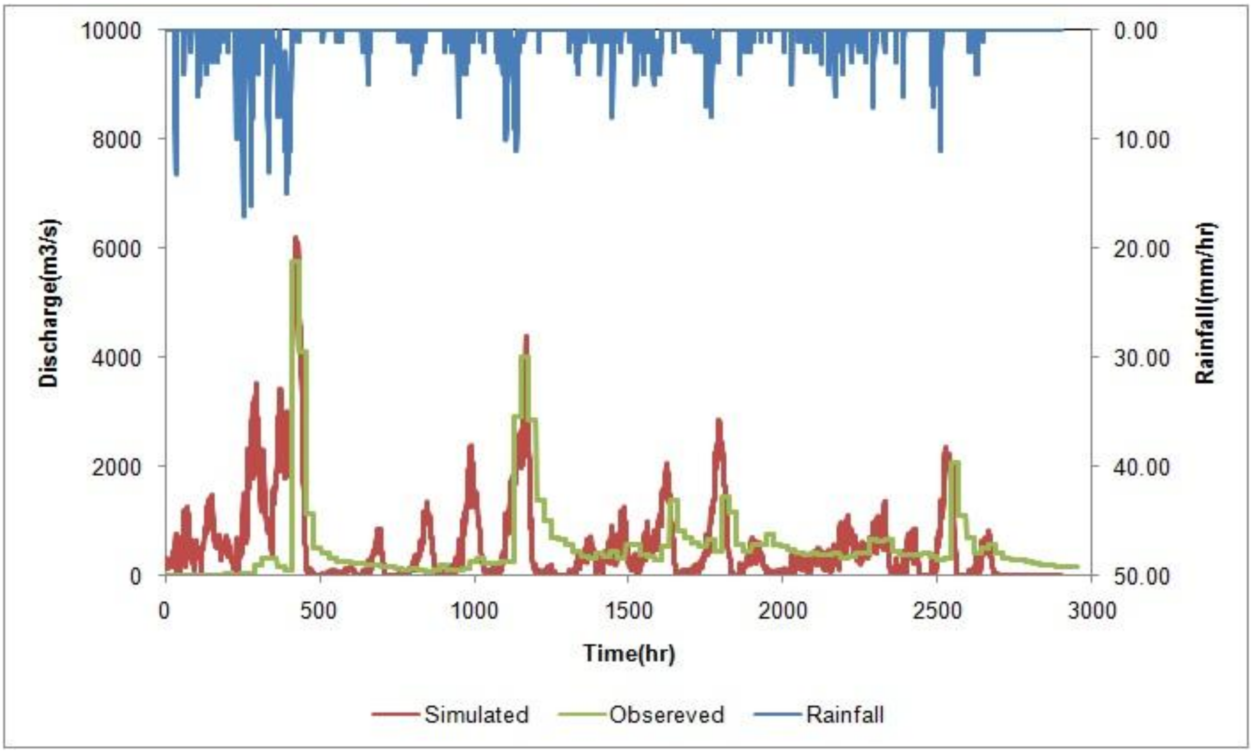


Figure 37. RAS 2D model simulated forecasted flow comparison with observed flow period from 15th June 2006 to 15th October 2006 at Kashinagar gauge station of the Vamsadharaa river basin.

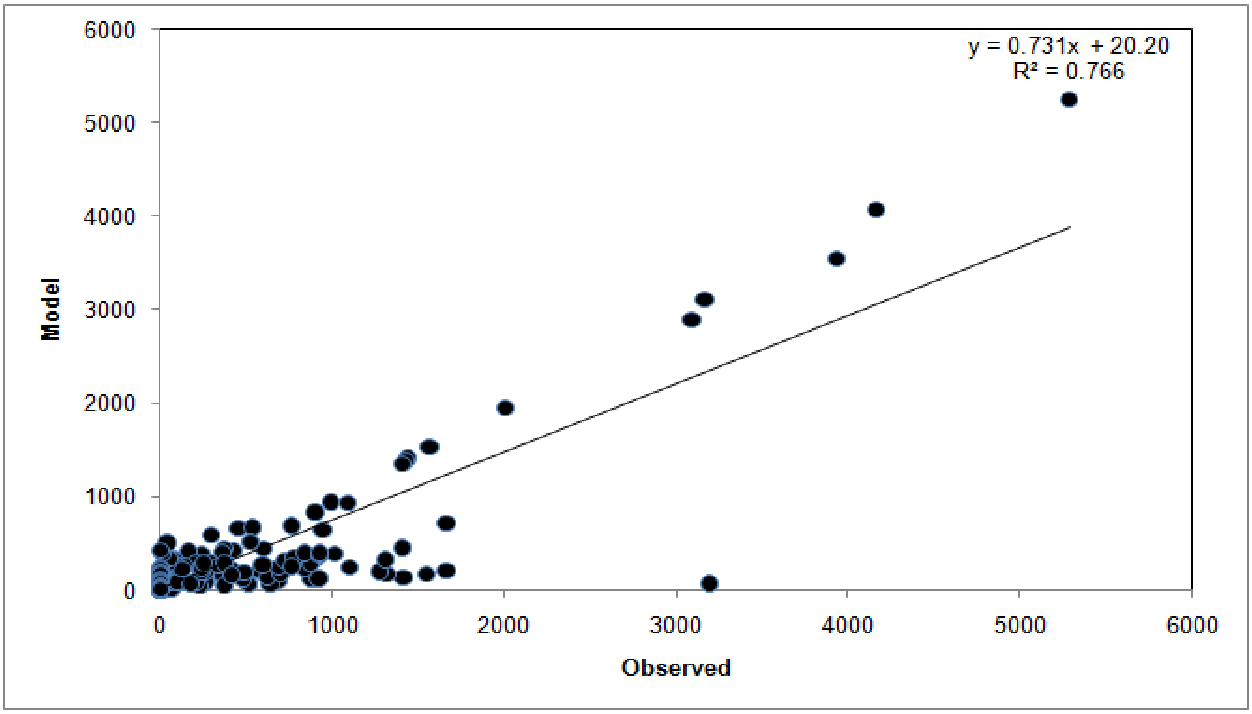


Figure 38. Scattered graph between RAS 2D model simulated flow and observed flow at Gunupur gauge station of the Vamsadharaa river basin.

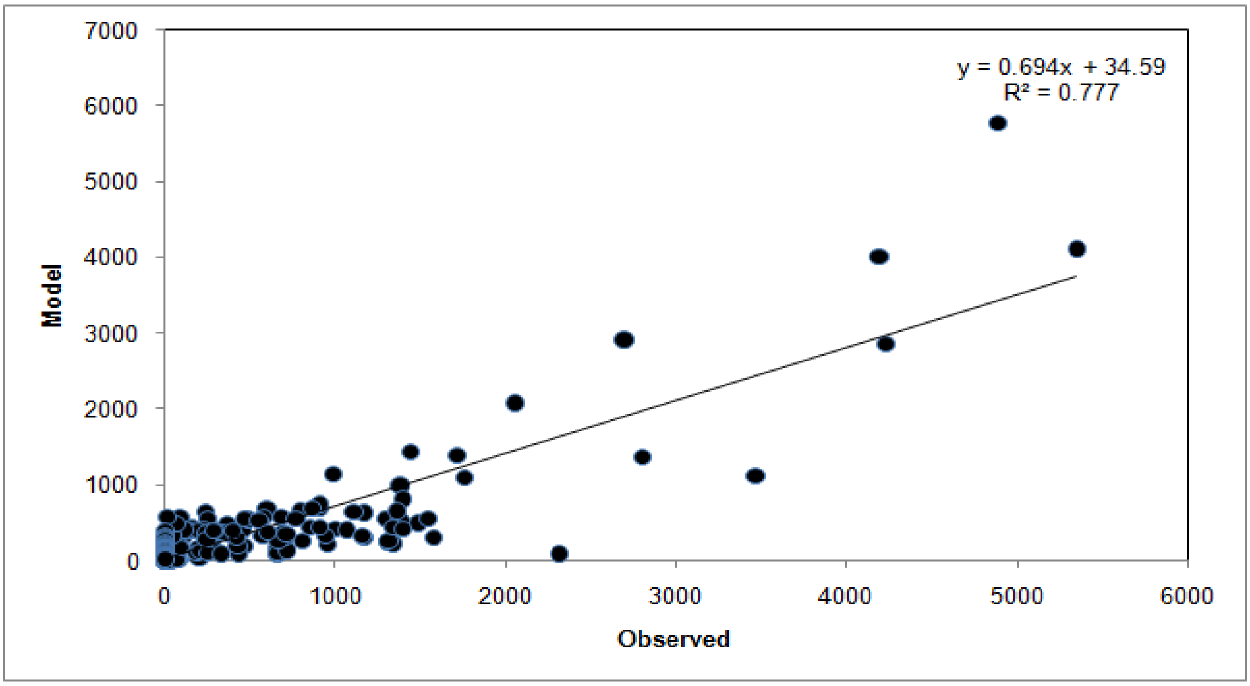


Figure 39. Scattered graph between RAS 2D model simulated flow and observed flow at Kashinagar gauge station of the Vamsadharaa river basin.

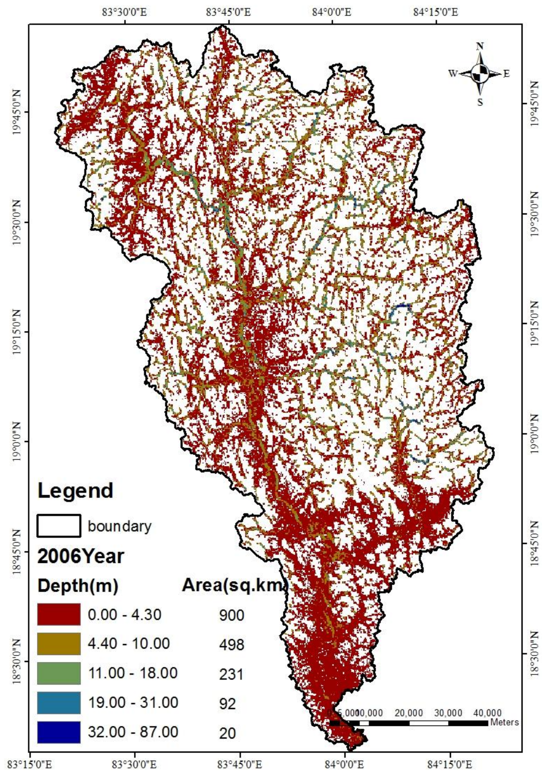


Figure 40. Maximum water depth flow with time variable of the Vamsadharaa river basin for maximum flood during 2006 monsoon period.

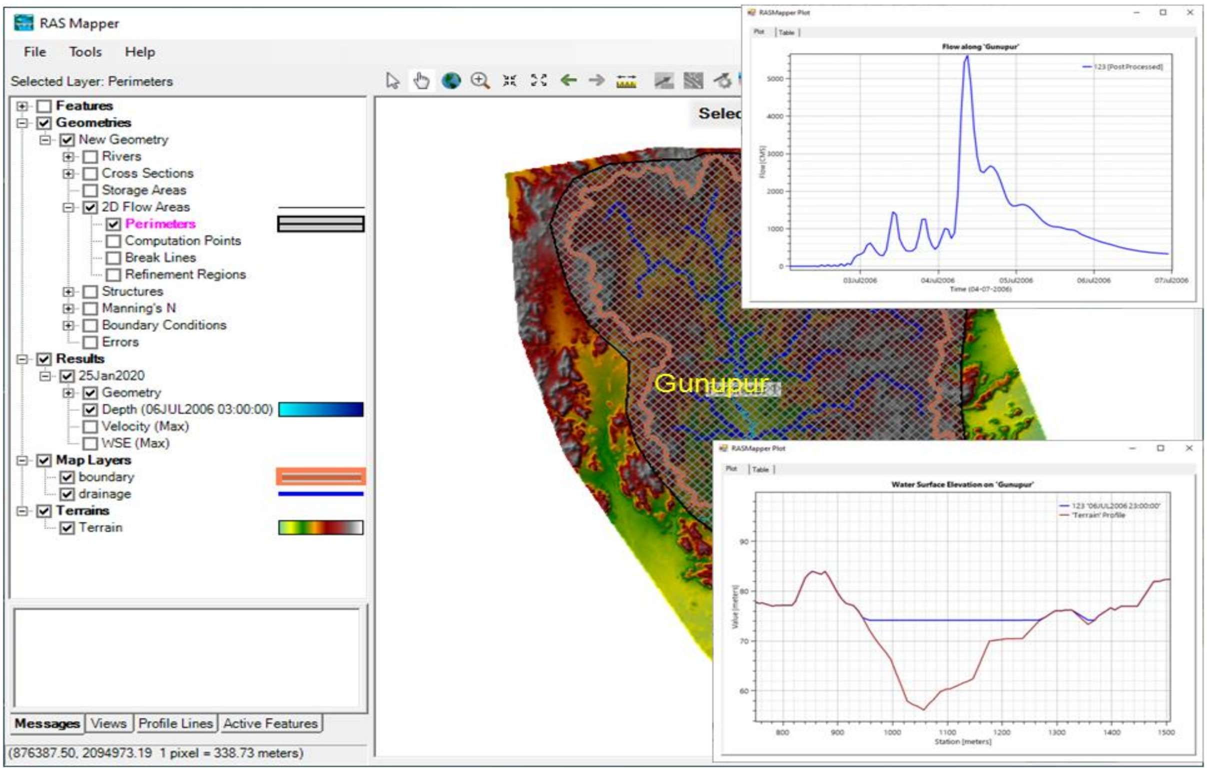


Figure 41. Flash flood forecast at Gunupur GD site location flow and water surface profile maximum flow.

.

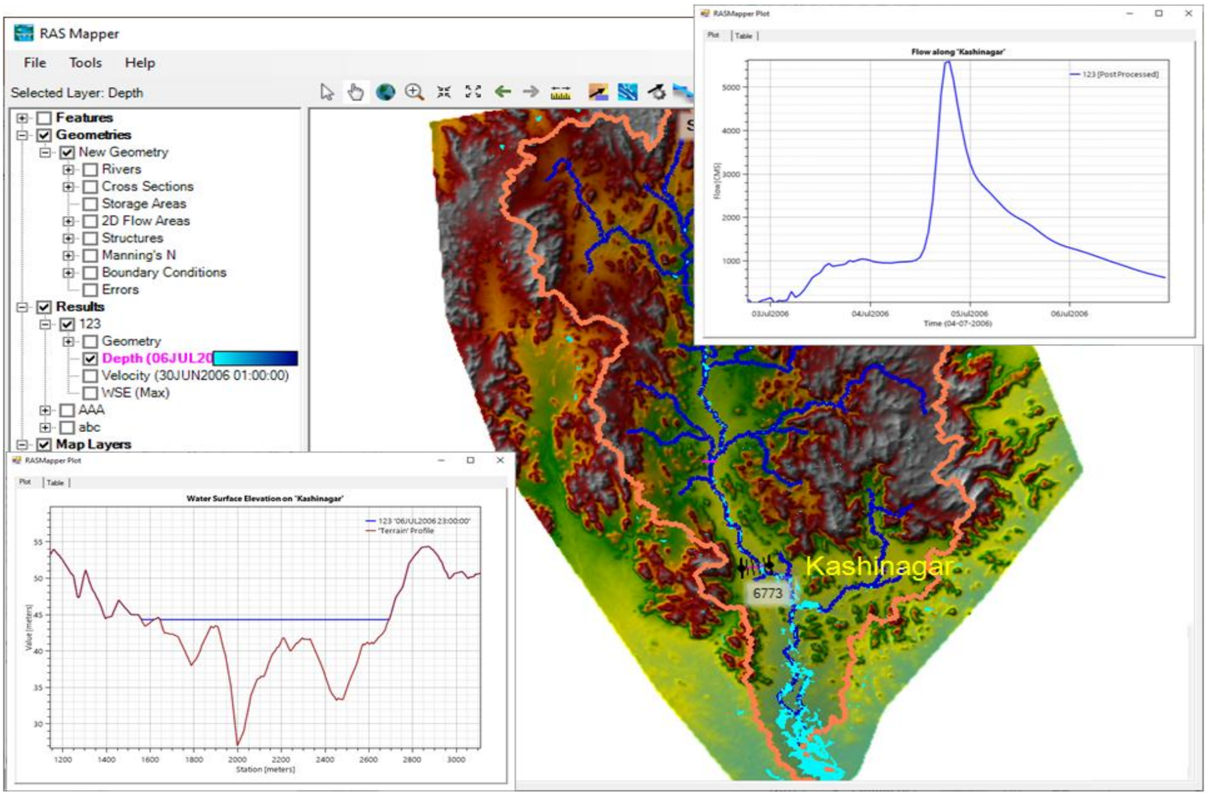


Figure 42. Flash flood forecast at Kashinagar GD site location flow and water surface profile maximum flow.

5.2.3.1 Design Storm

Using Extreme Value Type 1 (EV1) distribution developed the IDF curves as shown in figure 43 using hourly data and using alternative block methods to estimate the hyetographs and simulated hydrographs as shown in the figure 44 for different return periods from IDF curves. Using the hyetograph simulated the depth of runoff/ excess rainfall as input to RAS model to develop the flood maps of maximum depth water with time variable of the basin as shown in figure 45 to 50 for different return periods

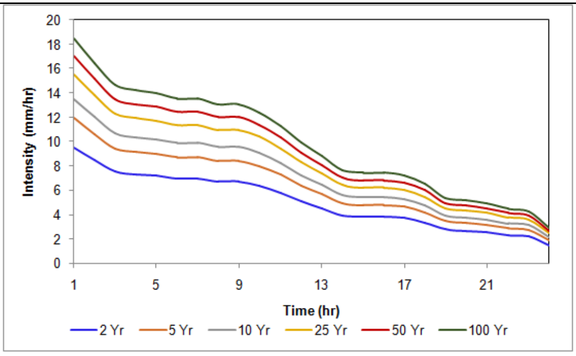


Figure 43. IDF curves for different return periods of Vamsadharaa river basin.

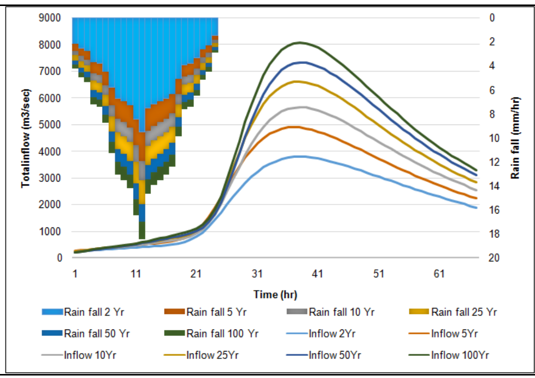


Figure 44. Design storm hydrographs for different return periods of Vamsadharaa river basin.

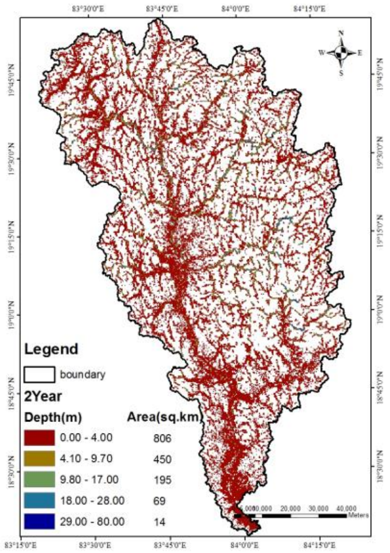


Figure 45. 2 Year return period Maximum water depth flow with time variable of the Vamsadharaa river basin.

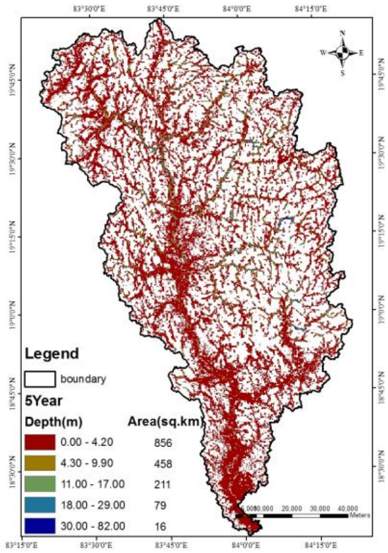


Figure 46. 5 Year return period Maximum water depth flow with time variable of the Vamsadharaa river basin.

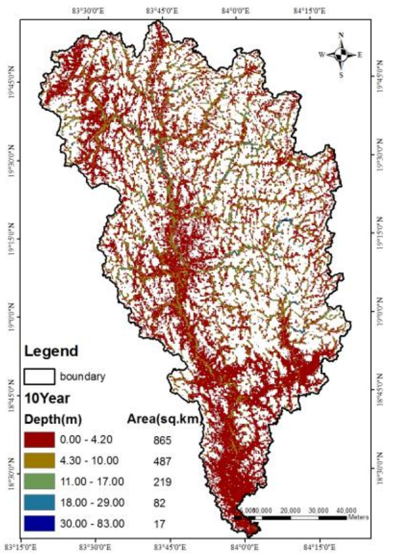


Figure 47. 10 Year return period Maximum water depth flow with time variable of the Vamsadharaa river basin.

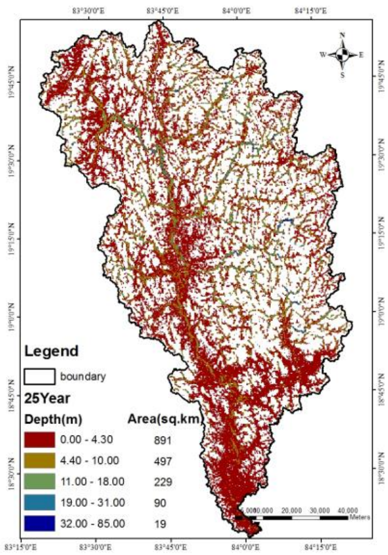


Figure 48. 25 Year return period Maximum water depth flow with time variable of the Vamsadharaa river basin.

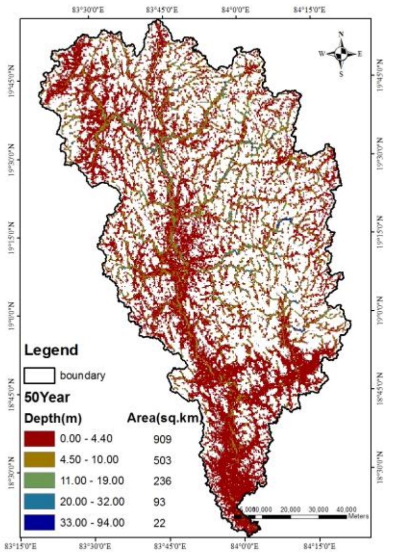


Figure 49. 50 Year return period Maximum water depth flow with time variable of the Vamsadharaa river basin.

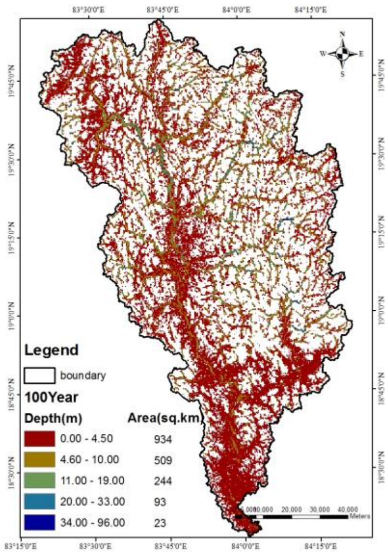


Figure 50. 100 Year return period Maximum water depth flow with time variable of the Vamsadharaa river basin.

5.2.4 Data Driven Model

Best hydrologic models are linear stochastic model autoregressive (AR) and nonlinear models Artificial neural network (ANN) and Wavelet neural network (WNN) in flash flood forecasting daily stream flow in rivers. Wavelet neural network (WNN) is hybrid modelling approach for the forecasting of river flow using daily time series data. A discrete wavelet multi-resolution method was employed to decompose the time series data of river flow into sub series with low (approximation) and high (details) frequency, and these sub series were then used as input data for the artificial neural network (ANN). WNN model with *db3* wavelet decomposition level was employed to forecast the flash flood ahead of time. Daily flow data was collected from India-WRIS and rainfall from IMD from 1971 to 2013.

Data used was 60% for calibration and 40% for validation for each gauge station in the model. The performance of various models during calibration and validation were evaluated by using the statistical indices: the Root Mean Squared Error (RMSE), Correlation Coefficient (R) and Coefficient of Efficiency.

The original time series was decomposed into Details and Approximations to certain number of sub-time series {D_1, D_2.... D_p, A_p} by wavelet transform algorithm. These play different role in the original time series and the behavior of each sub-time series is distinct (Wang and Ding, 2003). So the contribution to original time serie varies from each successive approximations being decomposed in turn, so that one signal is broken down into many lower resolution components, tested using different scales from 1 to 10 with different sliding window amplitudes. In this context, dealing with a very irregular signal shape, an irregular wavelet, the Daubechies wavelet of order 3 (DB3), has been used at level 3. Consequently, D_1, D_2, D_3 were detail time series, and A_3 was the approximation time series.

An ANN was constructed in which the sub-series {D_1, D_2, D_3, A_3} at time t are input of ANN and the original time series at $t + T$ time are output to ANN, where T is the length of time to forecast. The input nodes for the WNN are the decomposed subsets of antecedent values of the rainfall and runoff are presented in Table 11. The Wavelet Neural Network model (WNN) was formed in which the weights are learned with Feed forward neural network with Back Propagation algorithm. The number of hidden neurons for BPNN was determined by trial and error procedure. The performance of various models estimated to forecast the river flow was presented in Table 12.

Table 11. Model Inputs for WNN

Model	Input Variables
I	Q(t) = f (Q [t-1])
II	Q(t) = f (Q [t-1], R [t-1])
III	Q(t) = f (Q [t-1], Q [t-2], R [t-1])
IV	Q(t) = f (Q [t-1], Q [t-2], R [t-1], R [t-2])
V	Q(t) = f (Q [t-1], Q [t-2], Q [t-3], R [t-2], R [t-1])
VI	Q(t) = f (Q [t-1], Q [t-2], Q [t-3], Q [t-4], R [t-3], R [t-2], R [t-1])

Note: Q is discharge and R is Rainfall/precipitation

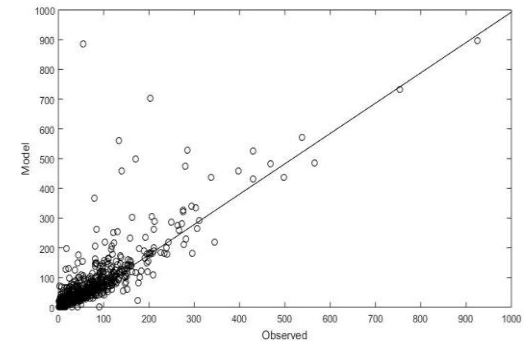
Table 12. Goodness of fit statistics of the calibration and validation for flood forecast.

Model	**Calibration**			**Validation**		
	RMSE	**R**	**COE**	**RMSE**	**R**	**COE**
Sarada (Anakapalli)						
AR						
	23.8584	0.8477	71.6003	75.3502	0.6813	42.5863
ANN						

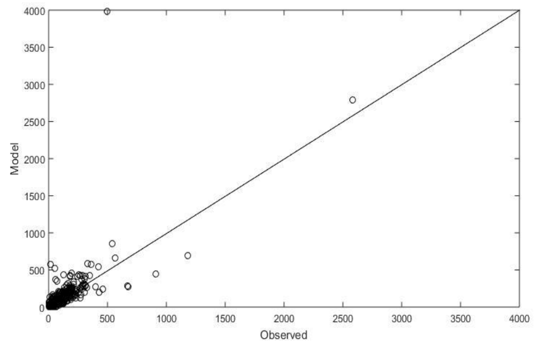
Model	I	23.3762	0.8528	72.7179	75.8293	0.6619	41.869
Model	II	23.5743	0.851	72.2536	88.7815	0.6128	20.3353
Model	III	21.8142	0.8734	76.242	81.2646	0.5837	33.2717
Model	IV	21.6969	0.8747	76.4968	82.1069	0.5693	31.8989
Model	V	21.0126	0.883	77.9559	71.8458	0.7021	47.8705
Model	VI	21.0095	0.88314	77.9625	65.3786	0.75577	56.8329
Model	VII	21.0419	0.8829	77.8945	80.868	0.5854	33.9902
WNN							
Model	I	14.59	0.9457	89.3723	87.0687	0.7161	23.3597
Model	II	12.2218	0.9623	92.5423	79.0013	0.6127	36.9204
Model	III	9.0993	0.9794	95.8662	73.9154	0.6864	44.7951
Model	IV	7.3412	0.9866	97.3093	79.8172	0.6456	35.6442
Model	**V**	**6.34691**	**0.99**	**97.9888**	**48.9945**	**0.87103**	**75.7576**
Model	VI	5.8926	0.9914	98.2664	84.6235	0.6063	27.6979
Nagavali (Srikakulam)							
AR							
		84.4542	0.806	64.2654	141.749	0.7601	56.6646
ANN							
Model	I	79.7041	0.825	68.0576	138.163	0.7729	58.8411
Model	II	61.9024	0.899	80.7317	143.409	0.7524	55.6691
Model	III	59.8557	0.9055	81.9838	129.571	0.803	63.8221
Model	IV	62.0606	0.8983	80.6311	130.906	0.796	63.0837
Model	V	61.3149	0.9007	81.0936	122.309	0.825	67.7824
Model	VI	59.373	0.9074	82.2717	127.591	0.8062	64.9498
Model	VII	59.8907	0.9057	81.9608	132.541	0.7893	62.1881
WNN							
Model	I	52.5906	0.9282	86.1009	119.336	0.8328	69.294
Model	II	37.7359	0.9637	92.8435	110.447	0.8589	73.7058
Model	III	27.7318	0.9805	96.1348	86.1893	0.9184	83.992
Model	**IV**	**26.6424**	**0.982**	**96.4323**	**69.3069**	**0.9479**	**89.6521**
Model	V	23.4544	0.9861	97.235	96.767	0.8937	79.8334
Model	VI	22.974	0.9867	97.3471	120.34	0.8861	68.8204
Vamsidhara (Gunupur)							
AR							
		230.465	0.5774	31.4296	80.5468	0.8033	57.7296
ANN							
Model	I	216.499	0.6287	39.5062	76.9465	0.803	61.3207
Model	II	166.039	0.8043	64.429	90.3716	0.7752	46.5047
Model	III	157.693	0.8244	67.9168	84.9136	0.7972	52.7449
Model	IV	142.432	0.8345	68.9562	86.7892	0.7862	54.6781
Model	V	149.176	0.7869	61.9107	90.6754	0.7589	57.5539
Model	VI	151.75	0.7312	53.4505	86.0059	0.6922	47.8594

WNN							
Model	I	103.645	0.9282	86.1356	59.5191	0.8781	76.8573
Model	II	70.1224	0.9679	93.6556	62.1344	0.8651	74.7119
Model	III	50.5531	0.9835	96.7028	57.4773	0.8861	78.3485
Model	IV	40.6531	0.9893	97.8677	51.0849	0.9131	82.8954
Model	**V**	**40.6419**	**0.9894**	**97.8688**	**48.0763**	**0.9272**	**84.8564**
Model	VI	32.3385	0.9933	98.6506	48.9779	0.9203	84.2914
Vamsidhara (Kashinar)							
AR							
		139.784	0.6975	47.6003	155.982	0.6483	40.4824
ANN							
Model	I	131.75	0.7312	53.4505	146.006	0.6922	47.8594
Model	II	125.519	0.7601	57.7493	140.525	0.7191	51.7075
Model	III	121.913	0.7755	60.1415	140.811	0.7214	51.5179
Model	IV	119.984	0.7836	61.3927	136.122	0.7398	54.6993
Model	V	119.176	0.7869	61.9107	131.773	0.7589	57.5539
Model	VI	117.553	0.7934	62.9407	142.946	0.7106	50.0577
WNN							
Model		76.7682	0.9179	84.1957	87.655	0.9063	81.2073
Model	II	59.6406	0.9513	90.461	88.2994	0.9148	80.9328
Model	III	44.262	0.9735	94.7461	61.1728	0.9574	90.8499
Model	**IV**	**43.0368**	**0.975**	**95.0329**	**59.4632**	**0.9595**	**91.3554**
Model	V	37.7801	0.981	96.1722	79.9264	0.929	84.3842
Model	VI	35.833	0.9827	96.5565	81.9237	0.9223	83.5963

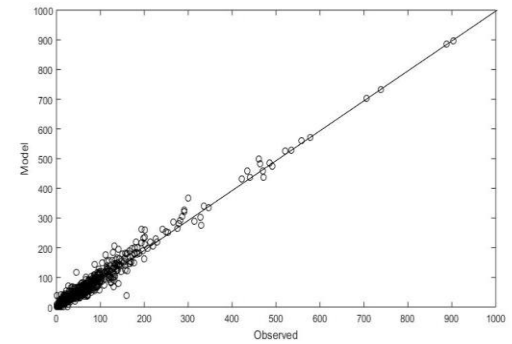
From Table 10, it is found that low RMSE values of Vamsadhara basin GD sites of Kashinagar (87.6550 to 59.4632 cums) and Gunupr (59.5191 to 48.0763 cums), Nagavali basin GD site of Srikakulam (119.3360 to 69.3069 cums) and Sarada GD site of Anakapalli (87.0687 to 48.9945 Cums) for WNN models when compared to ANN and ARMA models. It has been observed that WNN models estimated the peak values of discharges to a reasonable accuracy. Further, it is observed that the WNN model having three antecedent values of the time series, estimated minimum RMSE of Vamisidhara GD sites Kashinagar(0.9595Cums) and Gunupur(0.9272 cums),Nagavali basin GD site of Srikakulam (0.9479 cums) and Sarada basin GD site of Nagavali(0.8711 cums) high correlation coefficient and highest percentage of efficiency (Kashinagar>91, Gunupur>84 , Srikakulam>89 and Sarada>75) during the validation period. The model IV and V for Vamisidhara GD sites of Kashinagar and Gunupur, Model IV for Nagavali basin GD site of Srikakulam and Model V for Sarada basin GD site of Anakapalli of WNN was selected as the best fit model to forecast the river flow one-day in advance. Sarada river basin model results, not performed well due to data inconsistence. Figure 51 shows the scatter plot between the observed and modeled flows by WNN and ANN. It was observed that the flow forecasted by WNN models were very much close to the 45 degrees line. From this analysis, it is worth to mention that the performance of WNN was much better than ANN and AR models in forecasting the river flow in one-day advance.



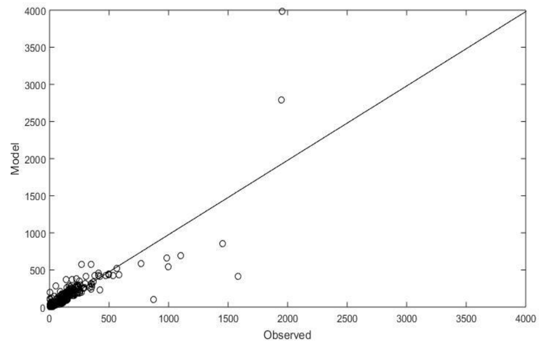
Anakapalli ANN calibration



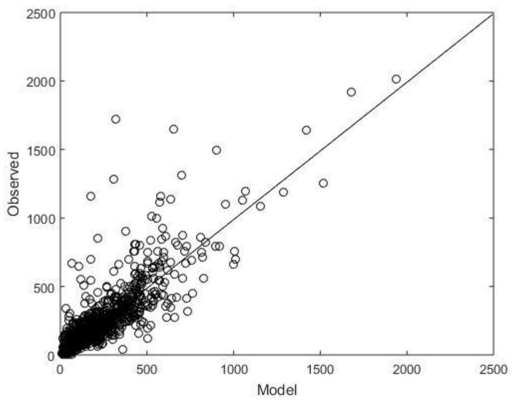
Anakapalli ANN validation



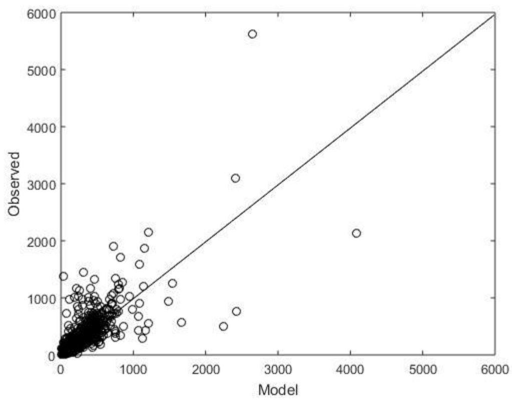
Anakapalli WNN calibration



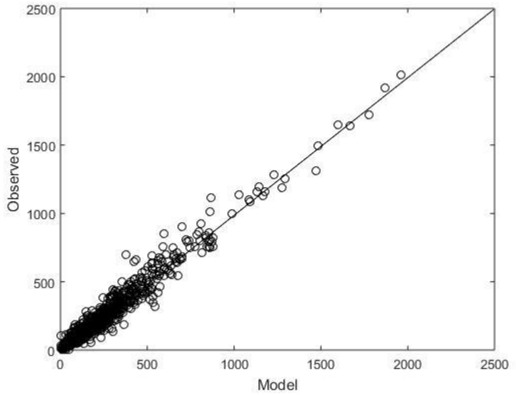
Anakapalli WNN validation



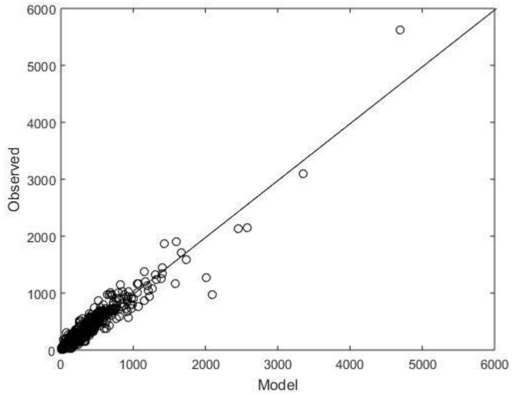
Srikakulam ANN calibration



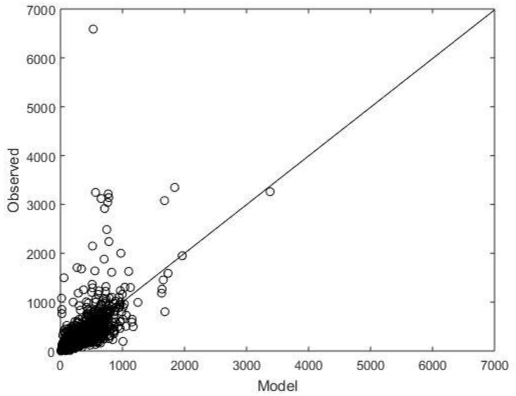
Srikakulam ANN validation



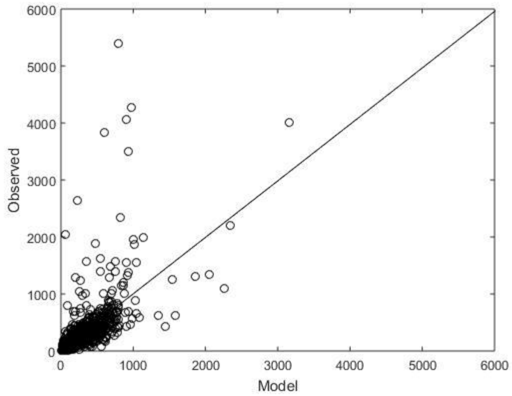
Srikakulam WNN calibration



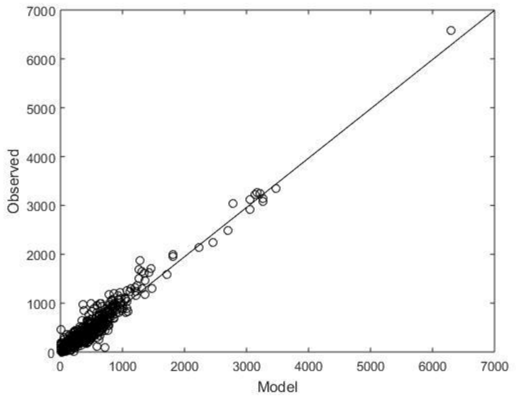
Srikakulam WNN validation



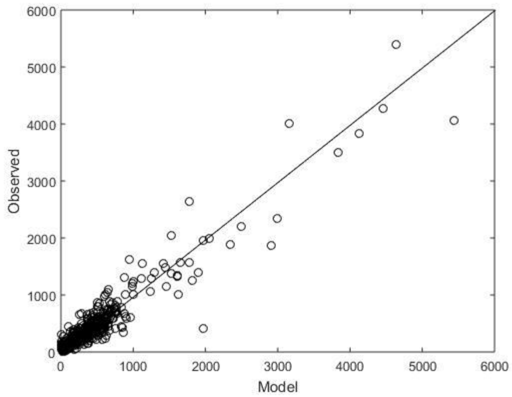
Kashinagar ANN calibration



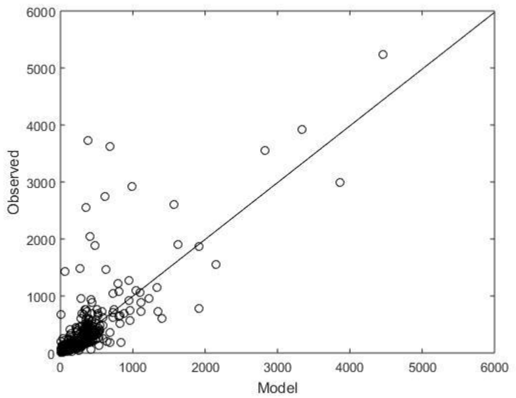
Kashinagar ANN validation



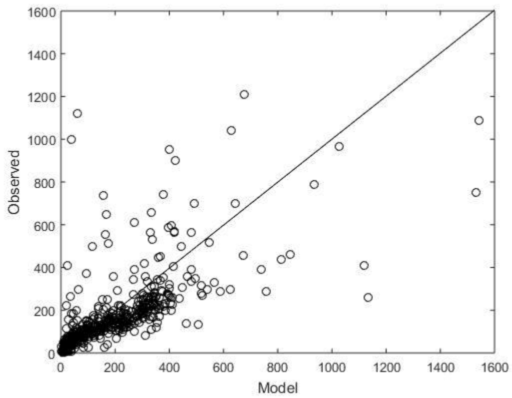
Kashinagar WNN calibration



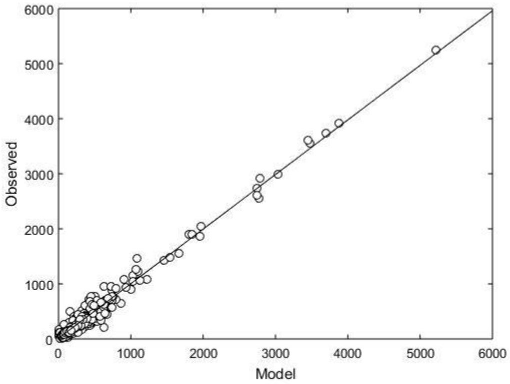
Kashinagar WNN validation



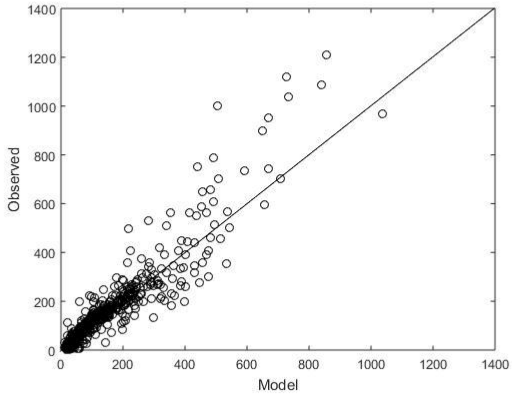
Gunupu ANN calibration



Gunupur ANN validation



Gunupur WNN calibration



Gunupur WNN validation

Figure 51. Scatter plot between the observed and modeled flows by WNN and ANN

Chapter 6

CONCLUSION

In this study, hydrological model HEC-HMS (Hydraulic Engineering Center - Hydrological Model System) and hydrodynamic model HEC-RAS (Hydraulic Engineering Center - River Analysis System) model is proposed to be integrated to forecast flash flood using rainfall as input.

For the purpose of the study, the ASTER 30 m resolution Digital Elevation Model (DEM) have been downloaded from Earth Explorer (USGS) and basin/sub basin and drainage network have been delineated using terrain processing in HEC Geo HMS model. Land use and land cover (LU/LC) maps have been prepared using Landsat-8 satellite data. Daily discharge data have been collected from India-WRIS and rainfall data have been collected from IMD (0.5 degree gridded data) and CHRS hourly rainfall.

The input parameters of the HEC-HMS model have been estimated and the runoff for flood years has been simulated. The simulated runoff has been calibrated with observed flow data of Nagavali and Vamsadharaa river basins. HEC-HMS model output results (Runoff depth) have been used as input in the 2D hydrodynamic model (HEC-RAS) to forecast the flash flood. The simulated HEC-RAS Model results compared with the observed flow data and the correlation coefficient (R^2) is around 0.63 at Srikakulam gauge station of Nagavali river basin and 0.766 and 0.776 at Gunupur and Kashinagar gauge station of Vamsadharaa river basin.

Frequency Analysis was performed with Extreme Value-I(Gumble) utilizing 15 years notable precipitation data (2003-2019) and simulated the runoff hydrographs for various return periods (2, 5, 10, 25, 50 and 100 years). Developed the flood maps for design storm runoff hydrographs for Nagavli and Vamsadharaa river basins

LU/LC maps have been prepared for the years 2009, 2016, and 2019 and used as inputs to the model to examine the impacts of land use changes on peak flood. No significant impact on flood peak due to LU/LC changes has been observed.

Also developed the data driven models (AR, ANN and WNN) to flood forecast model using daily discharge rainfall of Sarada, Nagavali and Vamsadhara river basins in sub zone 4A in the Andhra region. It is observed that the Nagavali and Vamsadhara river basin models were good in predictions and Sarada river basin model was poor in prediction due inconsistence in observed flow data with rainfall data.

Notwithstanding challenges, restrictions and uncertainties related with getting the observations and measured parameters, this study ended-up with simulated design storm flood hydrographs. The model can assist with setting aside time and cash in acquiring the overflow information as opposed to estimation of runoff in the watershed. Also, it might assist is simulating runoff where no gauging system are available.

Reference:

Abed, N. A., Abdulla, F. and Khyarah, A. A. (2005), GIS-hydrological models for managing water resources in the Zarqa River basin, Environmental Geology, 47, pp 405–411.

Anderson, M. L., Chen, Z. Q., Kavvas, L. and Feldman, A. (2002), Coupling HECHMS with Atmospheric Models for Prediction of Watershed Runoff, Journal of Hydrologic Engineering, July/August 2002, 7, pp 312-318.

Anselmo V., Galeati G., Palmieri S., Rossi U. and Todini E. (1996) "Flood Risk Assessment Using an Integrated Hy-drological and Hydraulic Modelling Approach: A Case Study," Journal of Hydrology, Vol. 175, No. 1-4, pp. 533-554. doi:10.1016/S0022-1694(96)80023-0

Arekhi, S. (2012), Runoff modeling by HEC-HMS Model (Case Study: Kan watershed, Iran), International Journal of Agriculture and Crop Sciences, 4(23), pp 1807-1811.

Beven, K.: Changing ideas in hydrology – The case of physicallybased models, J. Hydrol., 105, 157–172, 1989.

Borga, M., Gaume, E., Creutin, J. D., and Marchi, L.: Surveying flash floods: gauging the ungauged extremes, Hydrol. Process., 22, 3883–3885, 2008.

Braud, I., Roux, H., Anquetin, S., Maubourguet, M.-M., Manus, C., Viallet, P., and Dartus, D.: The use of distributed hydrological models for the Gard 2002 flash flood event: Analysis of associated hydrological processes, J. Hydrol., 394, 162–181, 2010.

Clay, H. E., Welty, C. and Traver, R. G. (2005), Watershed-Scale Evaluation of a System of Storm Water Detention Basins, Journal of Hydrologic Engineering, 10, pp 237-242.

Delrieu, G., Ducrocq, V., Gaume, E., Nicol, J., Payrastre, O., Yates, E., Kirstetter, P.-E., Andrieu, H., Ayral, P.-A., Bouvier, C., Creutin, J.-D., Livet, M., Anquetin, S., Lang, M., Neppel, L., Obled, C., Parent-du-Chˆatelet, J., Saulnier, G.-M., Walpersdorf, A., andWobrock,W.: The Catastrophic Flash-Flood Event of 8–9 September 2002 in the Gard Region, France: A First Case Study for the C´evennes–Vivarais Mediterranean Hydrometeorological Observatory, J. Hydrometeorol., 6, 34–52, 2005.

DHI (2003), "A Modelling System for Rivers and Channels," Reference Manual, in DHI Software 2003, DHI Water & Environment, Hørsholm.

Dunne T, Black R.D., 1970, 'Partial area contributing to storm runoff in a small New England watershed', Water Resources Res 6(5):1286-1311.

Gaume, E., Bain, V., Bernardara, P., Newinger, O., Barbuc, M., Bateman, A., Blaskovicov´a, L., Bl¨oschl, G., Borga, M., Dumitrescu, A., Daliakopoulos, I., Garcia, J., Irimescu, A., Kohnova, S., Koutroulis, A., Marchi, L., Matreata, S., Medina, V., Preciso, E., Sempere-Torres, D., Stancalie, G., Szolgay, J., Tsanis, I., Velasco, D., and Viglione, A.: A compilation of data on European flash floods, J. Hydrol., 367, 70–78, 2009.

Halwatura, D. and Najjim, M. M. M. (2013), Application of the HEC-HMS model for runoff simulation in a tropical catchment, Environmental Modeling and Software,46 (2013) pp 155-162.

Hu, H. H., Kreymborg, L. R., Doeing, B. J., Baron, K. S. and Jutila, S. A. (2006), Gridded Snowmelt and Rainfall-Runoff CWMS Hydrologic Modeling of the Red River of the North Basin, Journal of Hydrologic Engineering, March/April 2006, 1,

Kamp. R. G. and Savenije. H. H. G.(2007) "Hydrological Model Coupling with ANNs," Hydrology and Earth System Sci-ences, Vol. 11, No. 6, , pp. 1869-1881. doi:10.5194/hess-11-1869-2007

Knebl, M. R., Yang, Z. L., Hutchison, K. and Maidment, D. R. (2005), Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin Summer 2002 storm event, Journal of Environmental Management, 75, 4, 325–336.

Majidi, A. and Shahedi, K. (2012), Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran),International Journal of Hydraulic Engineering, 1(1), pp 5-9.

McColl, C. and Aggett, G. (2006), Land-use forecasting and hydrologic model integration for improved land-use decision support, Journal of Environmental Management, 84(4), pp 494–512.

Moussa, R., Chahinian, N., and Bocquillon, C.: Distributed hydrologicalmodelling of a Mediterranean mountainous catchment –Model construction and multi-site validation, J. Hydrol., 337,35–51, 2007.

Moussa, R., Chahinian, N., and Bocquillon, C.: Distributed hydrological modelling of a Mediterranean mountainous catchment – Model construction and multi-site validation, J. Hydrol., 337, 35–51, 2007.

Pilgrim, D. H., Chapman, T. G., and Doran, D. G.: Problems of rainfall-runoff modelling in arid and semiarid regions, Hydrolog.Sci. J., 33, 379–400, 1988.

Pistocchi and Mazzoli. P.,(2002) "Use of HEC-RAS and HEC-HMS Models with ArcView for Hydrologic Risk Management," iEMSs2002 Congress Proceedings, Lugano.

pp 91-100.

Roux, H., Labat, D., Garambois, P.-A., Maubourguet, M.-M., Chorda, J., and Dartus, D.: A physically-based parsimonious hydrological model for flash floods in Mediterranean catchments, Nat. Hazards Earth Syst. Sci., 11, 2567–2582, doi:10.5194/nhess-11-2567-2011, 2011.

Saulnier, G.-M. and le Lay, M.: Sensitivity of flash-flood simulations on the volume, the intensity, and the localization of rainfall in the C´evennes-Vivarais region (France)Water Resour. Res., 45, W10425, doi:10.1029/2008WR006906, 2009.

Todini E (1989) Flood forecasting models. Excerpta 4:117-162
Todini, E., (1996), "The ARNO rainfall-runoff model", *Journal of Hydrology*, **175**, 339-382.

Yener, M. K., Sorman, A. U., Sorman, A. A., Sensoy, A. and Gezgin, T. (2012), Modeling Studies with HEC-HMS And Runoff Scenarios in Yuvacik Basin, Turkiye, International Congress on River Basin Management, pp 621-634.

Yusop, Z., Chan, C.H. and Katimon, A. (2007), Runoff characteristics and application of HEC-HMS for modelling stormflow hydrograph in an oil palm catchment, Water Science and Technology, 56(8), pp41–48.

Begnudelli, L., Sanders, B.F.(2006). Unstructured grid finite-volume algorithm for shallow-water flow and scalar transport with wetting and drying. J. Hydraulic Eng. 132 (4), 371–384.

Bates, P.D., Horritt, M.S., Fewtrell, T.J (2010) . A simple inertial formulation of theshallow water equations for efficient two dimensional flood inundation modelling. J. Hydrol. 387, 33–45.

Horritt, M.S., Bates, P.D (2002). Evaluation of 1-D and 2-D numerical models for predicting river flood inundation. J. Hydrol. 268 (1–4), 87–99.

Nguyen, P, A. horstensen, KL Hsu, S. Sorooshian (2015). A high resolution coupled hydrologic-hydraulic model (HiResFlood-UCIfor flash flood modeling, Journal of Hydrology HYDROL18995R2, doi:10.1016/j.jhydrol.2015.10.047.

Poméon,T.,N. Wagner,C.Furusho, S. Kollet, and R. Reinoso-Rondinel. (2020). Performance of a PDE-based hydrologic model in a flash flood modeling framework in sparsely-gauged catchments. *Water*, **12**, 2157, https://doi.org/10.3390/w12082157.

Director	**J. V. Tyagi**
Co-ordinator	**J. V. Tyagi**
Head	**Y. R. Satyaji Rao**

Study Group

R. Venkata Ramana	**PI**
Y. R. Satyaji Rao	**Co-PI**
V. S. Jeyakanthan	**Co-PI**
T. Vijay	**Co-PI**
P. C. Nayak	**Co-I**