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Event-Based Rainfall-Runoff Modeling Using HEC-HMS

Jarugu Anjanee Prabha[1], Mahesh R Tapas[2]
[1, 2]*(M. Tech,Department of Civil Engineering, National Institute of Technology Warangal, Telangana, India)*

Abstract:
Flood is one of the most common natural catastrophes. Therefore, it is essential to estimate the runoff caused due to rainfall. Hydrological modeling is required to estimate the runoff. Simulation is the best solution for rainfall-runoff modeling and to estimate approximate runoff. By taking all these facts into consideration, the present study is carried out with the specific objectives. HEC-HMS hydrological model is utilized to simulate the rainfall-runoff process and "Event-based flood modeling." A sub-basin was generated using a discharge location, which is a part of the Godavari basin, and its name is Ambabal. Every year in India, discharge is high during monsoons. So, modeling of extreme events during monsoon time in that particular study area with modeling losses, modeling direct runoff is done. Modeling methods are chosen in such a way that it suits to the study area. Here in this process, the Green and Ampt method for the infiltration process (modeling losses) and SCS unit hydrograph for modeling direct runoff is applied. Calibration and validation of the model are done. Skill metrics like Nash-Sutcliffe efficiency is used to check the suitability of the model. Optimization is done by taking Nash-Sutcliffe Efficiency as an objective function.

***Keywords**:Event-based rainfall-runoff modeling, HEC-HMS, hydrological modeling, Nash-Sutcliffe Efficiency.*

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I. Introduction

1.1 Contextual

Water is the primary natural resource on the earth, which is essential for all human beings. The main focus of this subject is the hydrological cycle, which has neither beginning nor end, and its processes occur continuously. Hydrology deals with the circulation of water on the earth, which is very important for living beings and their type of habitat. The main important question this subject deal with is 'What happens to the rain?' Water that is precipitated may be intercepted by vegetation, become overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow and discharge into streams as 'surface runoff' and the water percolates deeper into the earth in order to recharge groundwater which is known as 'infiltration.' How much amount of infiltration, runoff is going to be produced, a contribution for base flow, amount of flood discharge produced during rainfall in a particular basin is significant. The study of all these questions involves 'Hydrology.India is a country where Monsoon climate plays a predominant role. Uneven distribution of rainfall leads to drought in some areas and floods in some areas. Flood is a natural catastrophe that has a lot of socio-economic impacts and human life. There are many reasons for floods. One of the main reasons is unexpected rainfall, which leads to the overflow of rivers and results in the inundation of banks. The discharge of the river increases drastically. So, modeling of flood events is significant for future predictions. In order to mitigate disaster, for designing hydraulic structures, flood modeling is significant. Rainfall in India is more during the monsoon that is during the period June-September. Therefore, discharge during this period is also very high. The modeling of flood events during this period is very important for future predictions. The consequence of Land use and Land cover (Such as agriculture land, vegetation land, urban land) on the surface runoff. The basin area, land use, land cover, type of soil on that particular basin, time-series data all these features are taken into consideration for the calculation of discharge.

1.2 Problem Statement

In India, from June to September, precipitation will be more because of the monsoon climate. Floods will occur more during this period. Hence, it is very important to model these extreme events and validate the events. Modeling of basin or sub-basin is a very complex task involving data availability, collection of data, basin knowledge, software to be used. Modeling is a tool that will help water resource managers to find out reasons for floods and changes in discharges in-stream gauge stations so that they can take necessary steps to mitigate the floods.

1.3 Significance of the problem

The primary significance of the problem is to identify the flood-prone watershed and calculate the discharge by giving inputs like loss parameters, transform parameters, base flow parameters. The discharge calculated can be further used in Stage calculation, and these results can be used in Hydraulic modeling software like HEC-RAS.

1.4 Different Models Available

1.4.1 Hydrological models

All hydrological models are the simplified representation of the real world. For a better understanding of hydrology processes and water resources availability, they have been used in different river basins. These models are fundamental in order to assess and predict water availability, which helps us in the development of strategies. The results of the hydrologic models are significant for better watershed planning, management of basins, construction of hydraulic structures, understanding climate change.

1.4.2 Hydrological system model

The study of the system operation and prediction of its output is the main objective of hydrologic system analysis. Its construction is a set of calculations linking the inputs and outputs, which are measurable hydrologic variables. System transformation is the central concept of Model structure.

1.4.3 Types of hydrological models

Depending upon randomness, there are two types of hydrological models. Deterministic models can use the data as it is while the stochastic models use the statistical nature of data available for predicting rainfall-runoff.

Deterministic models-based on spatial variation are of three types. They are the lumped model, semi-distributed model, distributed model. In lumped, the total area is considered a single entity while in semi-distributed or distributed model parameters are given based upon the characteristics of the land.

Stochastic models-Statistical dependence will be there, and uncertainty will be there.

Empirical models-Models based on various relations derived from various studies of a particular area.

Physical-based models-defines fluid motion (e.g. Kinematic wave theory).

C**onceptual models-**These are commonly used to represent the essential components like features, events, processes that relate hydrological inputs to outputs. Examples are the Nash conceptual model, Clark model.

1.4.4 Rainfall-runoff modeling

It is one of the essential applications in hydrology. Its primary purpose is to simulate the hydrograph or the peak river flow induced by rainfall. The rainfall-runoff models will describe part of the water cycle. They are implicitly or explicitly are based on the laws of physics. Principles like conservation of mass, conservation of energy, conservation of momentum are taken into consideration. Simulation of flood hydrographs, estimation of peak river flow, simulation, and estimation of synthetic river flows for a certain extended period. Water resource managers can further use this for developing strategies. Some of the examples of rainfall-runoff models are SWAT, HEC-HMS. We will see what the advantages and disadvantages of both the software are.

1.5 SWAT

Soil and water assessment tool is a basin-scale model. The impact of land management practices in large and complex watersheds can be quantified in the Soil and Water assessment tool. It can be considered as a watershed hydrological transport model. It is a continuous-time model that operates on a daily time step at the basin scale. The prediction of long-term impacts in large basins is the main objective of the model. Management and timing of agricultural practices within a particular year. SWAT uses a two-level dis-aggregation scheme. Soil type, land use, topographic criteria are taken into consideration for identifying and discretizing preliminary sub-basin.

A fundamental computational unit known as hydrologic response unit is formed with the same soil type and land use. It is assumed to be homogenous in hydrologic response to land cover change.

1.6 HEC-HMS

The comprehensive hydrologic procedures of dendritic watershed systems can be simulated by HEC-HMS (hydrologic modeling system). HEC-HMS is a product of the Hydrological Engineering Center within the U.S Army Corps of Engineering. It is designed to be applicable in solving a wide range of problems for a more full geographical area. There is no constraint on the geographical zone. It includes flood hydrology, river basin water supply, small urban or natural watershed runoff.HEC-HMS is a generalized modeling system that has the capacity to represent many different watersheds. A model of the watershed can be constructed by taking the part of a hydrological cycle and constructing boundaries around the watershed of interest. Mass or energy flux within the cycle can then be represented with a mathematical model. The program for the mathematical model is included in such a way that it is suitable for different environments under different conditions. Therefore, users must require the knowledge of watershed and the goal of the hydrological study for making choices and usage of the software.

Features of HEC-HMS software:

1. **Physical description of the watershed,** which includes losses, base flow, routing, transform. Loss parameters, base flow parameters, transform parameters must be taken into consideration for getting hydrograph.
2. **Meteorological Description:** Here, we have to give precipitation as input data. Time series data must be given as input by adding precipitation gages and discharge gage for giving discharge data as an input. It considers hourly data.
3. **Control specification model:** Time step for the simulation run must be given in the control specification model.

HEC-Geo HMS: It is a spatial analyst extension for ArcGIS. It is used to develop the hydrologic modeling inputs required for HEC-HMS. It transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the drainage network. Basin characteristics, spatial analysis performance, delineation of sub-basins, and drainage network, HMS links can be done in HEC-Geo HMS.

1.6.1 HEC-HMS versus SWAT software

HEC-HMS can be mostly used as a hydrologic design tool, whereas SWAT concentrates mainly on the analysis of the effectiveness of agricultural practices. HEC-HMS is an event-based model, and hourly runoff can be simulated by HEC-HMS.SWAT is a water-balance model. Daily, monthly, annually runoff can be simulated by SWAT but not on hourly based events. Therefore, the main focus is on Event-based flood modeling; hence, we are using HEC-HMS hydrologic software.

1.6.2 Limitations of HEC-HMS software

Because of the choices made in the development and design of the software, every simulation system has it is own limitations. Simplified model formulation and simplified flow representation are the main limitations in the design of a program of HEC-HMS software.

Formulation of model: The program included in the HEC-HMS software is deterministic. That is, all the mathematical models in the program are deterministic. The model assumes that the initial conditions, boundary conditions, and parameters are precisely known. Therefore, for every time if a simulation is computed, it will produce the same results as all previous times it was computed. Constant parameter values are used by the mathematical models which are included in the program. Parameters are assumed to be time stationery. Mathematical models are uncoupled.

Representation of flow: Flow in the basic model will be represented as dendritic stream networks. It is not possible to split the outlet of a hydrologic element into two different downstream outlets. Sometimes, in a real-world scenario, all the downstream hydrologic elements do not have a single outlet. Therefore, simulation for branching or looping network is not included in the program. Diversion of the network is not possible. A separate hydraulic model is required for the representation of such networks.

1.7 Event-based rainfall-runoff modeling

Event-based flood modeling is mainly useful for flood forecasting. The results of the Event based flood modeling are mainly used in flood risk assessment, the preparedness of a particular basin. It is advantageous to find out climate change and land-use change. Basin response to an individual rainfall event like peak time, total runoff, and peak discharge will be shown by event hydrological modeling.

1.8 Event-based versus Continuous based rainfall-runoff model

Event-based rainfall runoff modeling is useful for flood forecasting, while continuous based rainfall-runoff modeling is used to analyze future trends. Infiltration is considered as a significant loss in event-based rainfall-runoff modeling while evapotranspiration is considered as a significant loss in continuous rainfall-runoff modeling. Event-based rainfall-runoff can be simulated on the more excellent time scale, and continuous rainfall-runoff can be simulated on a coarser time scale. Therefore, peak flood discharge and time to the peak can be easily calculated. Therefore, in order to simulate peak discharges and extreme flood events of a particular watershed, we considered "Event-based rainfall-runoff modeling." Using HEC-HMS hydrological modeling software.

1.9 **Objective**

The primary aim of this thesis is to simulate, calibrate, and validate the extreme flood events of Ambabal sub-basin of Godavari basin using Event-based rainfall-runoff modeling in HEC-HMS software.

1.10 Critical appraisal of the literature review

Basin response to an individual rainfall event (peak discharge, total runoff, time to peak) will be revealed by Event hydrological modeling. Continuous hydrologic modeling synthesizes hydrologic processes and phenomena of the basin to several rain events and cumulative effects. Xuefeng Chu and Steinman (2009) performed joint Event and continuous hydrologic modeling using HEC-HMS and its application to the Mona Lake watershed in West Michigan and in doing so suggests that the fine-scale (5 min time step) event hydrologic modeling, supported by intensive field data, is useful for improvising the coarse-scale (hourly time step)continuous modeling by providing more accurate and well-calibrated parameters and concludes that for some small sub-basins, a larger computation time scale (such as an hourly time step) used in the continuous model and the critical implication drawn from this is model calibration can be done more accurately. Parameters can be identified by using event hydrological modeling which consecutively develops the continuous hydrological modeling over a much larger time scale.

Rainfall-runoff modeling is fundamental. H.K. Nandalal et al. (2010) used HEC-HMS in event rainfall-runoff modeling of the Kalu-Ganga river basin in Sri Lanka, and this was significant because it helps in forecasting floods and enables to take mitigation measures. They used lumped conceptual hydrological model and compared two different hydrological models one with four sub-basins and other with ten sub-basins and compared the results of the two models in doing so, and he reveals that there is no influence of the number of sub-basins taken in the modeling of the basin on the forecast of floods due to rainfall. The negligible difference was there, and there is no scale effect of the basin in calculating discharge of the basin.

M.M.G.T. De Silva et al (2014) concludes that the ability of HEC-HMS to generate stream flows in the basin to a high simulated river affirms that event-based hydrologic modeling assisted by intensive field data is useful to derive calibrated parameters for continuous hydrologic modeling and its application helps in disaster mitigation, flood control.

ZurainiBasarudin, Nor Aizam Adnan et al. (2014) illustrates that in order to quantify the influence of rainfall during the extreme rainfall events on the hydrological model in Kelantan River catchment, two dynamic inputs were used in the study which is known as rainfall and river discharge using semi-distributed HEC-HMS hydrological model and demonstrates that rainfall change has a distinctive impact in determining discharge to peak and runoff depth. However, his study was limited to quantify rainfall changes during the events 2004 and 2008 to simulate discharge and runoff values. Land use change was not considered in this study. He concludes that it has a further scope on changes in land use and its impact on the hydrograph.

To compute the runoff volume, peak runoff rate, base flow, and flow routing methods SCS curve number, SCS unit hydrograph, exponential recession, and Muskingum routing methods were chosen. Kishor Choudhari, Balram Panigrahi et al. (2014) conclude that statistical tests values like RMSE (root mean square error) and MARE (Mean Absolute Relative Error) after parameter optimization were reduced and this calibrated model with optimized parameter is used for validation.

A lumped continuous hydrological model was developed in order to estimate the runoff for different rainfall events in three sub-basins of the Tapi river using HEC-HMS. Praveen Rathod, Kalpesh Borse, V.L.Manekar (2015), and suggests that the comparison between SCS unit hydrograph and Synder unit hydrograph was made and the best suitable method is chosen for the study area. He defines his objective as to fit the peak flow discharges and maximizing the Nash-Sutcliffe coefficient, the correlation between simulated and observed discharge, and finally concludes that the HEC-HMS model can be used for the Tapi river basin.

An upsurge in urbanization centrals to an increase in impervious area and reduces infiltration. Vinay Ashok Rangari, N V Umamahesh et al.(2018) suggests that urban flood management is essential in order to reduce the intensity of damage caused due to flash floods. Therefore, in order to improve proper stormwater drains and sewerage network present land use pattern is considered for future development. HEC-HMS software was used for rainfall-run-off modeling of the urban catchment, and the study area is Hyderabad city and found the peak discharge by giving Green and Ampt loss parameters and Kirpich law for calculation of the time of concentration. However, observed data was not there because of this model results are not verified with real values.

1.11 Study area

Godavari basin is one of the largest basins in south India, as shown in Figure: 1. Based on the discharge location, a part of the Godavari basin was delineated using pour point watershed analysis. Events in the Ambabal watershed, which is a part of the Godavari basin, is being simulated.

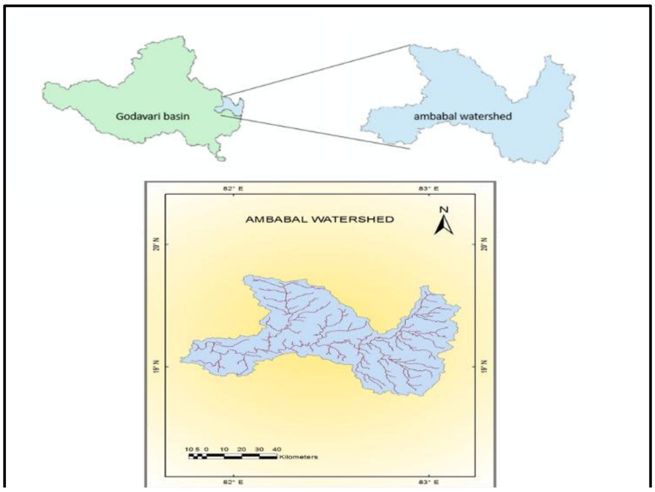

Figure:1 Study area (Ambabal)

1.12 Godavari basin location

The Godavari is the second largest river after Ganga. Its source is in Triambakeshwar, Maharashtra. Its location is 19.93, 73.5275. Its area is around 3,00,000 square kilometers. It flows east for 1,465 kilometers draining the states of Maharastra (48.6%), Telangana (18.8%), Andhra Pradesh (4.5%), Chhattisgarh (10.9%), Madhya Pradesh (10%), Odisha (5.7%), Karnataka (1.4%) and Pondicherry (Yanam) and its mouth is located inAntarvedi Andhra Pradesh and drains into the Bay of Bengal through its network of tributaries. It lies between 73°24' to 83°4 °E and 16°19' to 22°34'°N and accounts for nearly 9.5% of the total geographical zone of the country. This basin is categorized as having a risk of flooding with rising sea levels. Major discharge locations in the Godavari basin are Ambabal, Ashwin, Badrachalam, Bhaktakeda, Chass, Cherla, Chinndar, DawaleshwaramInjaram, Koida, Mancherial, Patnaude, Perur, Polavaram. Of these significant discharge locations, the Ambabal discharge location was selected as the study area for event-based flood modeling.

The ambabal study area is around 7000 square kilometers. A significant part of this is located in Orissa. Its elevation is around 920 meters. This watershed was delineated in ArcGIS10.4 based upon its gauge station location. It is stream network also delineated using the watershed delineation process (flow accumulation, flow direction) events in this area are modeled in HEC-HMS.

1.19 Acquisition of data

The data required for this Event based flood modeling are discharged location, precipitation gauge location, soil maps, land use the land cover map. Table 1 shows the source of various data required for calculating discharge.

Table 1. Source for data

SRTM 30M DEM	earthexplorer.usgs.gov
Precipitation data(rainfall)	IMD(Indian Meteorological Department)
Discharge gauge location and data	WRIS(Water Resources Information System)
Soil map and data	FAO(Food and Agricultural Organisation)
Land use the land cover map	daac.ornl.gov/VEGETATION/guides/Decadal_LULC_India.html, google earth

1.19.1 Precipitation and discharge locations:

Rainfall data, along with its location, is used for giving input as meteorological data. For the whole Ambabal sub-basin, only one rain gauge station was considered. Rain gauge station location is 82.25,19.75. From figure: 2, discharge and rainfall gauge station locations are shown

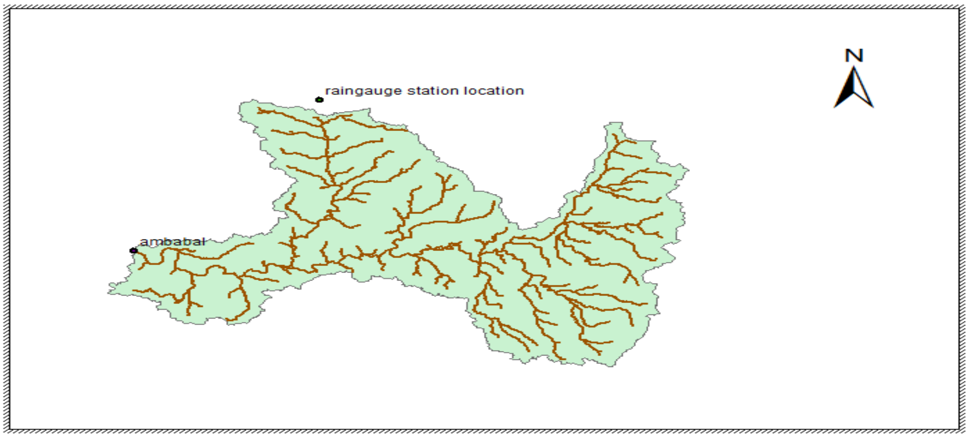

Figure: 2 precipitation gauge location

3.2.2 Soil map

In order to calculate infiltration parameters (green and empty), the nature and texture of the soil are required. Figure: 3 shows the data obtained from the FAO (Food and Agricultural Organisation). Sandy- loam, sandy-clay-loam, clay-loam.

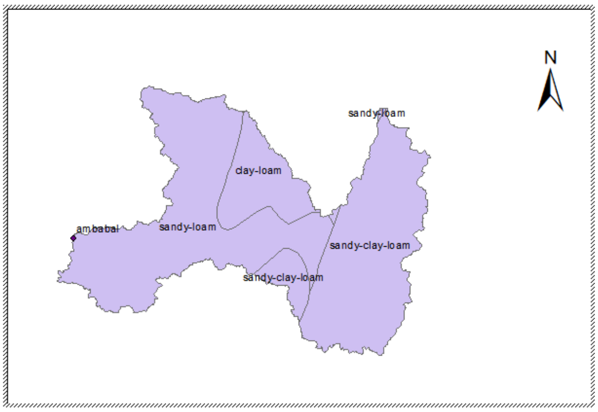

Figure: 3 Soil map (source FAO)

1.20 SRTM 30m DEM

SRTM 30m Digital elevation model for elevation. This is the basic data that we will use it for watershed delineation, generation of the stream network. It is the basic input in Hec Geo HMS, which is used in finding the longest flow path, basin slope, centroidal location of each subbasin, basin elevation, which will be useful in the calculation of loss parameters, transform parameters like green and Ampt parameters, time of concentration. It is also useful in the groundwork of a schematic view, which has reaches, junctions, outlet which we will further import into HEC-HMS.

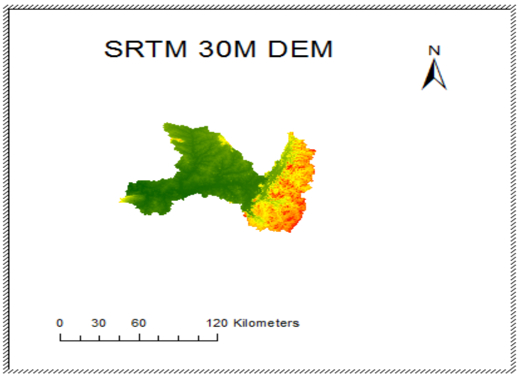

Figure: 4 DEM (earthexplorer.usgs.gov)

1.21 Land use the land cover map

Most of the area is covered with agricultural land. Almost 75-80%is agricultural land followed by vegetative land, forest and then followed by water bodies. Most of the area is located in the state of Orissa. Here we took two land use land cover maps, one in 2005 and the other in2010.

2005 Land use land cover map was already prepared, and 2010 land use land cover map was prepared in ArcGIS software by using unsupervised classification and maximum likelihood method. From figure 3.5, there are 11 classifications in the readymade map (2005), which downloaded from the daac.ornl.gov website. Figure 3.6 shows the classification of the LULC map of 2010, which was prepared in ArcGIS and downloaded from google earth. Only three classes are classified using unsupervised classification, which are predominant, i.e., cropland, water body, and vegetation land.

Land use land cover map helps in finding out the predominant area in that particular study area, which helps us to calculate the imperviousness of the area. Imperviousness ranges from 0.1% to 13% based on the year and the basin area. Imperviousness slightly increased with an increase in the year.

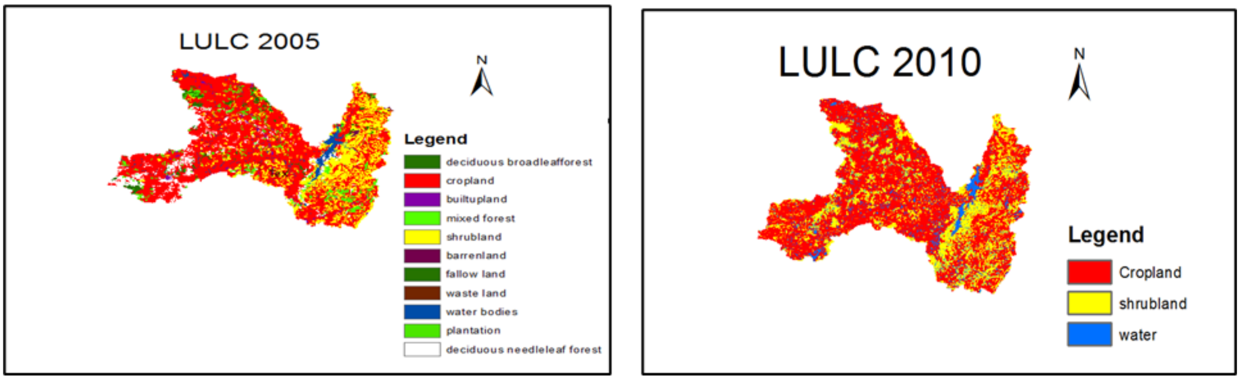

Figure: 5 LULC map for 2005& 2010

II. Methodology

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2.1 General

The methodology includes the preparation of the conceptual model in Hec-geo HMS. This model is then imported into HEC-HMS. In HEC-HMS, we have to give input time-series data, loss parameters, transform parameters, control specification, and then we have to run the model. Figure: 6 shows the methodology of the entire process.

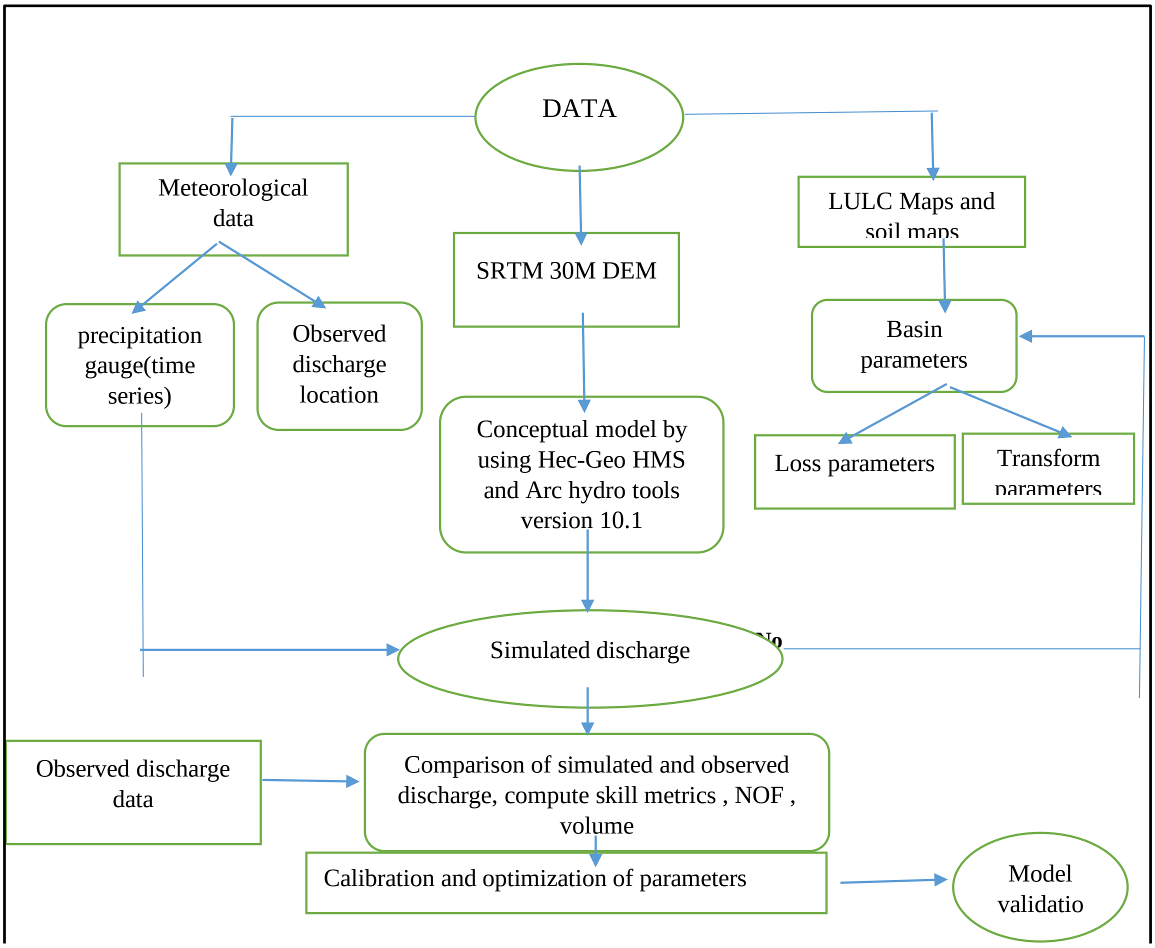


Figure: 6 flow chart for methodology

After getting the results, we have to compare the simulated results and observed results. If necessary, we need to optimize the parameters and increase the Nash Sutcliffe coefficient and compare the discharge values. In this way, model calibration and validation must be done.

2.2 Meteorological data

The basin is alienated into 7 sub-basins and for each sub-basin time series data is given along with the date. At outlet discharge, data will also be given.

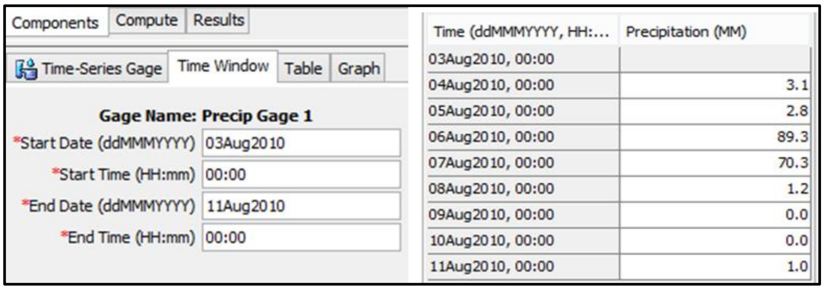


Figure 7: time series input in HEC-HMS

2.3 Control specification

Regulatorstipulations are one of the key components in a project, even though they don't contain much parameter data. The main requirement of control specification is to start and stop simulation and time from running the simulation. Without entering time in the simulation, we can't run the simulation process. At what time interval is used in the simulation.

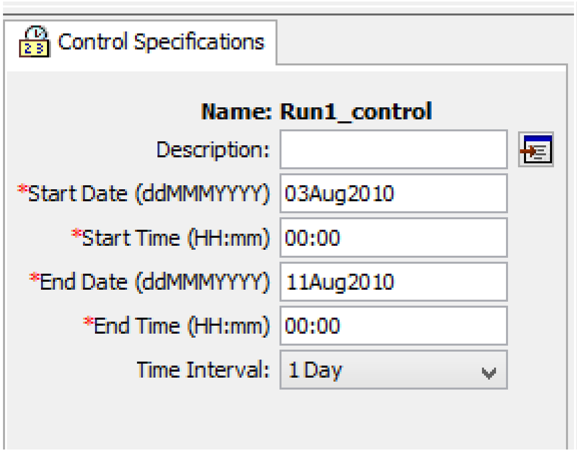


Figure 8: control specification input in HEC-HMS

III. Modeling and Analysis

3.1 Preparation of conceptual model

In order to simulate the discharge, we have to first prepare the basin model using HEC-Geo HMS and Arc hydro tools,as in Figure: 9 flow chart briefly gives information about sub-basin preparation.

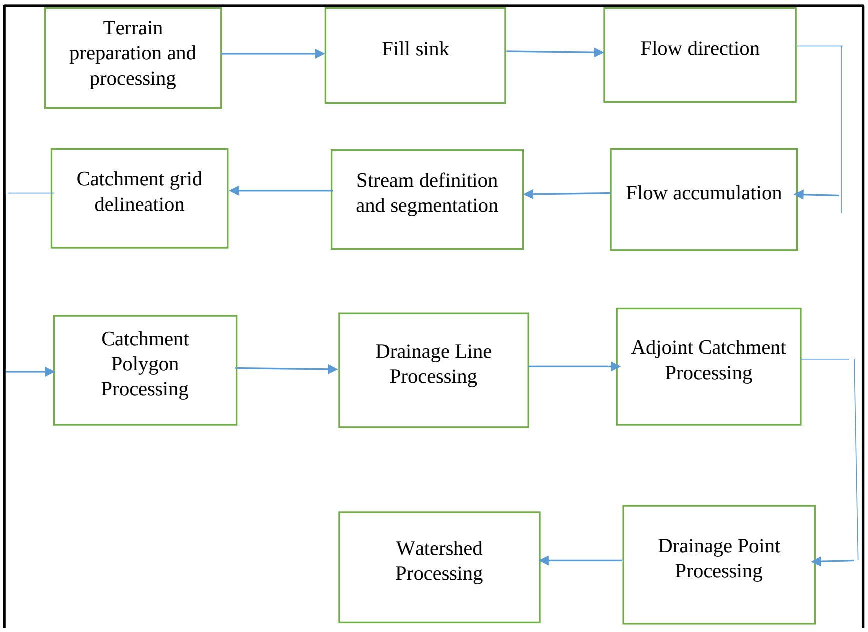


Figure 9: preparation of SUB-BASIN

After sub-basin preparation for calculation of physical characteristics of the basin like the longest flow path, basin slope, elevation. Figure: 10 shows the preparation of the basin model by using HEC-GeoHMS.

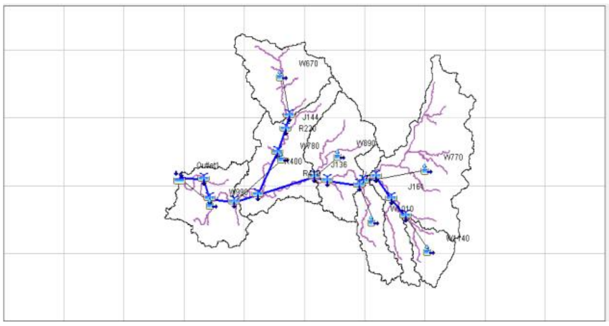


Figure 10: HEC-HMS basin model

By using Hec-Geo HMS, we divided basin into seven sub-basins, and there is no scale-effect regarding how many sub-basins we divided into. We calculated the basin parameters like longest flow path, basin slope, basin elevation, basin area, which further required to calculate loss parameters and transform parameters.

Table 2: Basin characteristics

Sub-basin	Longestflowpath(m)	Basinslope(%)	slope	Area(km2)	Elevation(m)
W670	73848.00324	6.603	0.066	1060.88	670
W780	113676.2662	29.064	0.29	1329.16	780
W990	88914.36547	45.737	0.45	977	990
W890	59266.35853	29.124	0.29	1142.73	890
W1010	63639.6288	42.985	0.42	632.42	1010
W770	91234.6718	30.687	0.30	2382.25	770
W1140	45234.12588	56.645	0.56	416.06	1140

3.2 Calculation of Loss parameters

After the preparation of the sub-basin, we have to give parameters as input. There are many methods to calculate loss parameters of these initial and constant rate method, SCS curve number method, Green and Ampt infiltration method. Out of these methods, we took the Green and Ampt method to calculate infiltration. In event-based flood modeling, infiltration is very important than evapotranspiration, and in continuous rainfall runoff modeling, evapotranspiration plays an important role. Therefore, here we are giving preference in order to calculate infiltration by using the Green and Ampt method.

Green and Ampt infiltration method is the explicit form of Richard's equation for unsteady water flow in soil. The Green and Ampt infiltration method assumes that the soil is originally at unvarying moisture content, and infiltration occurs with so-called piston displacement. It undertakes that the surface is in a ponding state. It is assumed to be a control volume.

The significant parameters in the Green and Ampt method are the initial water content, saturated water content, wetting front suction, hydraulic conductivity.

At the beginning of the simulation, initial saturation of the soil is given by the initial water content and is specified in terms of volume ratio.

The supreme water holding capacity in relations of volume proportion is given by the saturated water content of the soil. It is frequentlypresumed to be the total porosity of the soil.

Wetting front suction is a function of soil texture. From the field tests and by knowing the soil texture, hydraulic conductivity must be specified.

Imperviousness is calculated based on the land use land cover maps and based on the percentage of the basin area. Here most of the land is agricultural lands.

Therefore, four parameters defined in HEC-HMS to calculate loss are:

1. Initial content-initial saturation as a volume ratio-θi.
2. Saturated content- total porosity as a volume ratio-n.
3. Suction (mm)-wetting front soil suction head—ψ.
4. Conductivity (mm/hr)-hydraulic conductivity-k.
5. Impervious (%)-percentage of the basin with impervious cover.

Parameter 1 is computed by using equation 2

$$\boldsymbol{\theta_i = \theta_e\ (1 - S_e)}$$

Theta E is the effective porosity (from Green and Ampt table), and it is the relative saturation of the soil when the precipitationcommences (0<=se<=1). Here, we assumed 0.3.

$$\boldsymbol{\theta_i = 0.7\ \theta_e}$$

Based on texture and based on different studies, table 3 gives the details of the parameters for predominant soils.

Table 3: Predominant soils

S.NO	Texture	Porosity	Suction(mm)	Conductivity(mm/hr)	Theta E
1	**Sandy-Clayey-Loam**	**0.398**	**218.5**	**1.5**	**0.33**
2	**Sandy-Loam**	**0.453**	**110.1**	**10.9**	**0.412**
3	**Clay-Loam**	**0.464**	**208.8**	**1**	**0.309**

Table 4: Green and Ampt parameters calculated for predominant soils for each sub-basin

Calculated green and Ampt parameters	W770	W1140	W1010	W890	W670	W780	W990
Initial content	0.231	0.231	0.231	0.2163	0.2884	0.2884	0.2884
Saturated content	0.398	0.398	0.398	0.464	0.45	0.45	0.45
Suction(mm)	218.49	218.49	218.49	208.798	110.08	110.08	110.08
Conductivity(mm/hr)	1.5	1.5	1.5	0.998	10.9	10.9	10.9

3.3 Calculation of transform parameters

Transform parameters are nothing but direct runoff. This procedurementions to the alteration of rainfall excess into direct runoff. There are different models included for calibrating in HMS are Clark's model, Snyder's model, SCS-UH model.

Here, the SCS-Unit Hydrograph method was used in order to calculate direct runoff. It requires lag time as input. We need to develop the time of concentration for calculation of lag time. SCS has a relation between the time of concentration and lag time.

The Unit hydrograph by Soil Conservation Service (SCS) method represents a curvilinear unit hydrograph by first keeping the percentage of the unit runoff that occurs before the peak flow (NRCS, 2007). A curvilinear unit hydrograph is to be fit by the triangular unit hydrograph consequently the unit hydrograph's overall time base can be considered. The 37.5% of unit runoff is defined for the standard unit hydrograph, which occurs before peak flow.

Flow distance, ground slope, and additional properties of the watershed reflect the percentage of unit runoff that occurs before the peak flow, which is not uniform across all the watersheds. Therefore, the alternate unit hydrographs with varying topography and other conditions that affect runoff can be computed by changing the percentage of unit runoff before the peak. Peak Rate Factor (PRF) gives the percentage of runoff that occurs before the peak. For flat watersheds, PRF is very low, which is less than 100. For steeper basins, PRF is as high as 600. In the HEC-HMS software PRF factor is taken as 484 by default.

The standard lag is well-defined as the span of the time between the centroid of precipitation mass and the peak flow of resulting hydrograph. Based on the studies, lag time can be defined as 0.6 times of the time of concentration. Consequently, it is essential for us to calculate the time of concentration.

The time of concentration is based on many empirical formulae. Here the area of the watershed is very large and for large watersheds.

$$T_c = \frac{4\sqrt{A} + 1.5\,L}{0.8\,\sqrt{H}}$$

Table 5: Time of concentration and lag time

Basin	Time of concentration (hrs)	Lag time(hrs)
W670	25	15
W780	25.16	15.096
W990	15	9
W890	14.826	8.8956
W1010	11.22	6.732
W770	26.96	16.176
W1140	7.58	4.548

In the equation, A is the area in km2, L is the longest flow path (km), H is the difference between the mean basin elevation(m) and outlet elevation(m).

This empirical formula is based on 12 basins with drainage areas between 170 km2 to 70,000km2. Here our study area is around 7000km2. There is no area limitation in HEC-HMS software. Lag is given in minutes.

IV. Results and Discussion

4.1 General

Based on the collected data in the Ambabal watershed of Godavari basin, we calculated parameters and want to simulate the extreme events and compare it with observed events. For comparison, we use skill metrics such as Nash- Sutcliffe co-efficient. Four events are calibrated and then optimized the parameters, and two events are validated. The skill metrics used for the accuracy of the model are NSF.

$$NSE = 1 - \frac{\sum_{t=1}^{T} (Q_m^t - Q_0^t)^2}{\sum_{t=1}^{T} (Q_0^t - \bar{Q_0})^2}$$

From the equation, Q_o is the mean of observed discharges,
Q_m is modeled discharge,Q_o^t is observed discharge at time t
$-\infty$ to 1 can be the range for Nash-Sutcliffe efficiency. If the modeled discharge is equal to the observed data, then we can say that the model is perfect, i.e., if NSF=1, then it is a perfect model. If NSF=0, then the model predictions are as accurate as of the mean of the observed data. If it is less than 0, then the observed mean is a better predictor than the model. The ideal range for NSE could be 0.6<NSE<0.75. Then it is possible to accept the model. Now we see the results and analysis of modeled discharge and observed discharge.

4.2 Results

Based on many simulation trials, we will now see some of the selected events of the Ambabal discharge location for modeling, and we will see the compatibility between observed discharge and modeled discharge.

For finding the extreme events rainfall during the period June to September are considered, and from the continuous daily rainfall data, extreme rainfall data was considered. From figures, 11, 12, 13, 14photographs of heavy rainfall were taken for calibration that particular watershed and for these hyetographs, extreme discharge was simulated and are compared with observed hydrographs. Five rainfall events are considered for calibration in Aug2000, Aug2001, Aug 2004, Aug2007.

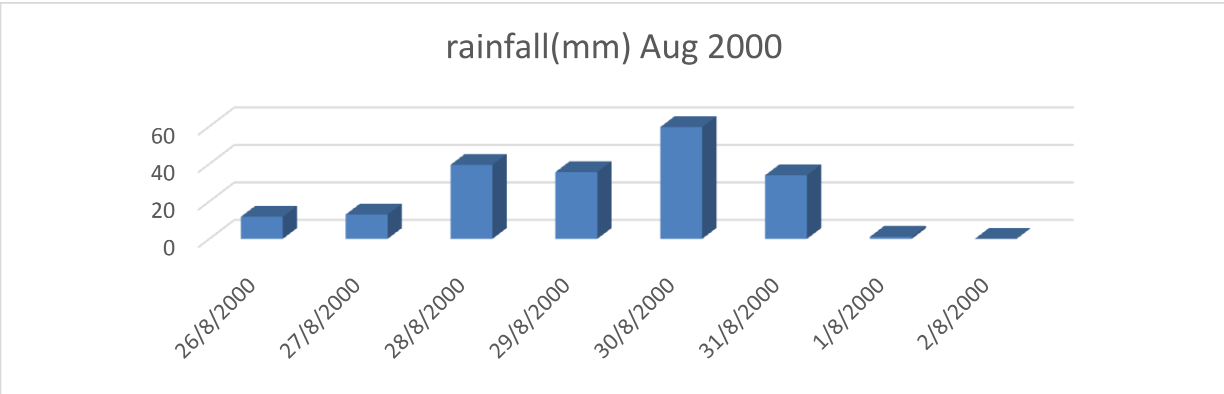


Figure 11: Rainfall hyetograph in Aug 2000

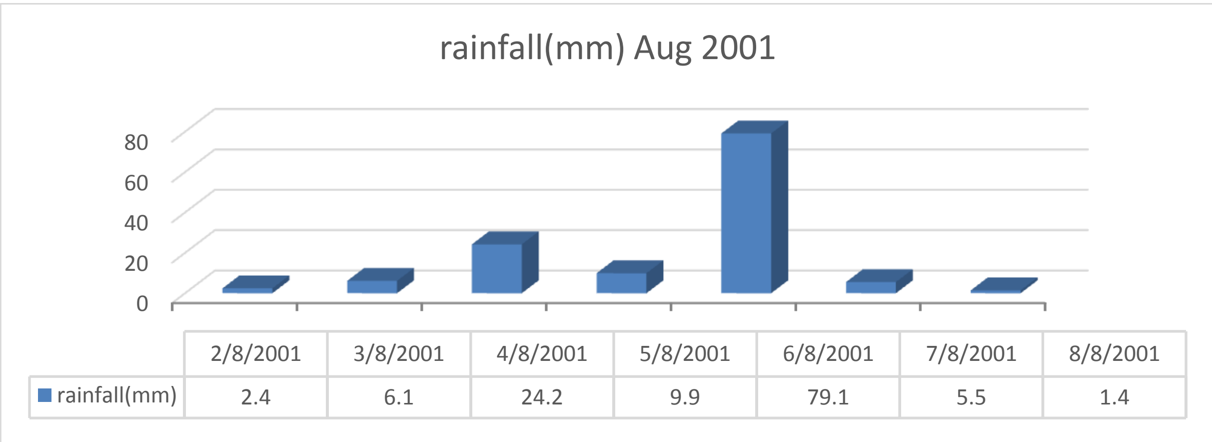


Figure 12: Rainfall hyetograph in Aug 2001

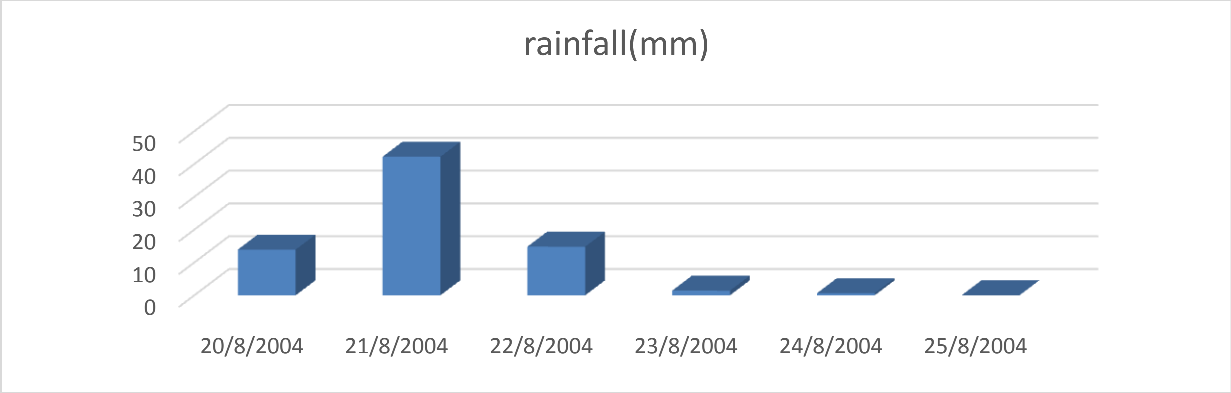


Figure 13: Rainfall hyetograph in Aug 2004

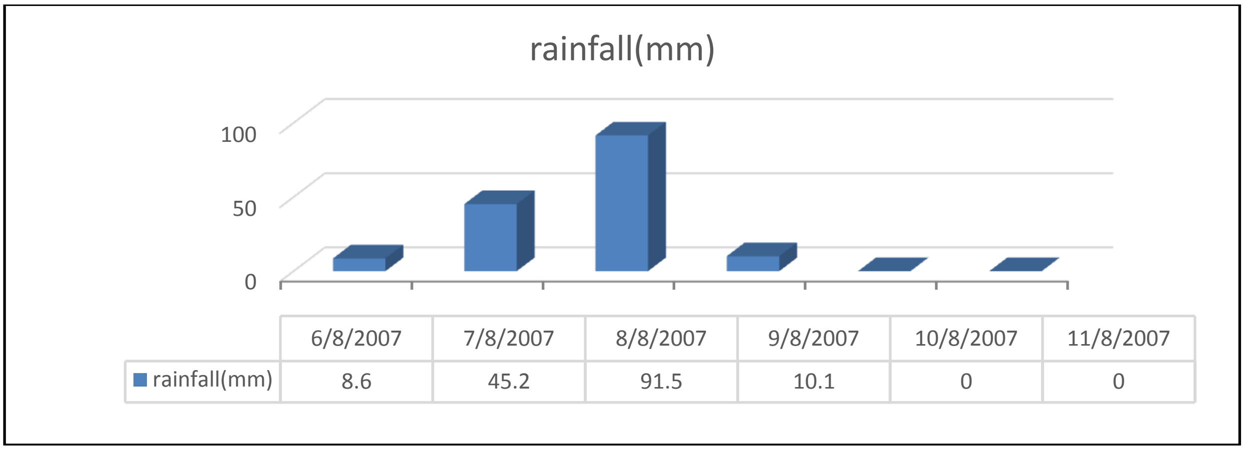


Figure 14: Rainfall hyetograph in Aug 2007

After various trials of simulation by calibrating Green and Ampt parameters, simulated runoff hydrographs were generated, figure 15, 16, 17 shows the simulated hydrographs. These are compared with observed hydrographs.

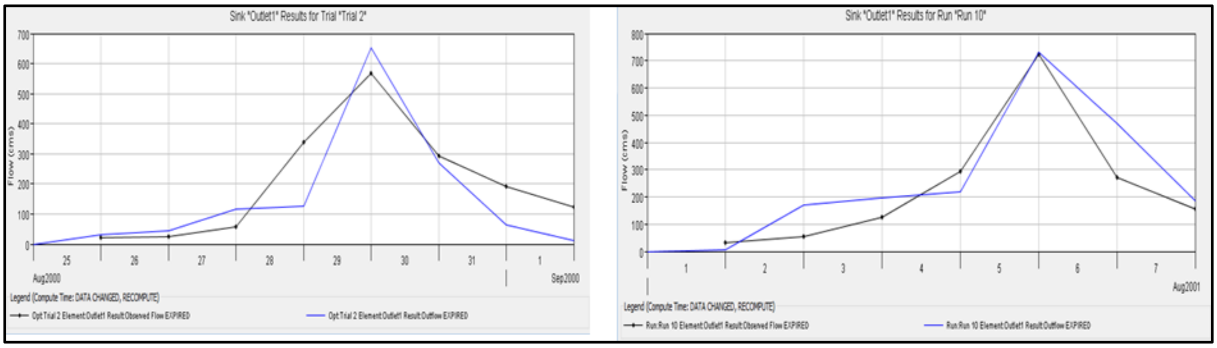
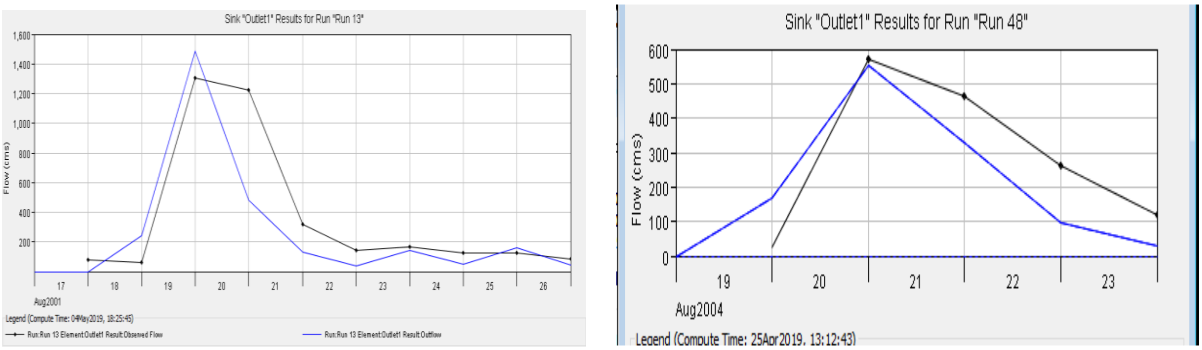


Figure 15: simulated (blue) and observed (black) events in Aug 2000 and Aug 2001(calibrated graphs)

Figure 16:simulated (blue) and observed (black) events in Aug 2001 and Aug 2004(calibrated graphs)



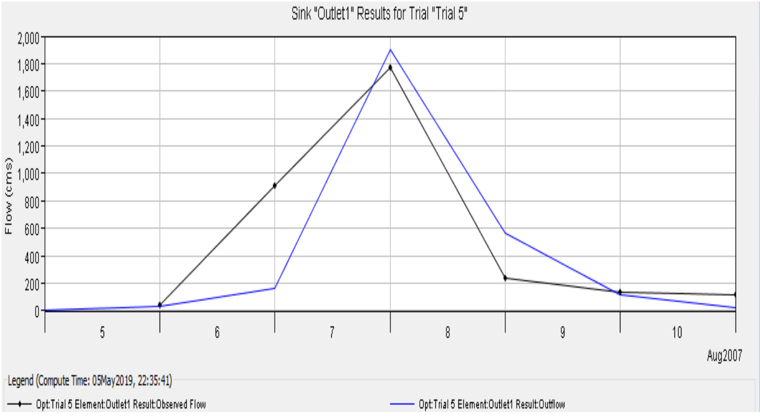


Figure 17: simulated (blue) and observed (black) events in Aug 2007(calibrated graphs)

From the simulation trails along with the simulated hydrograph, some results are also drawn. Table 6 gives a comparison of the computed and observed results. Table 7 gives the compatibility results of the simulated and observed hydrograph.

Table 6: Comparison of the simulated and observed result

CALIBRATED EVENTS	COMPUTED RESULT			OBSERVED DATA		
	Peak discharge(m3/s)	**Date of peak discharge**	**Volum e (MM)**	**Peak discharge(m3/s)**	**Date of peak discharge**	**Volume (MM)**
Aug 2000	651.5	30Aug2000	14.21	567.9	30Aug2000	16.92
Aug 2001	730.2	06Aug2001	20.47	722.4	06Aug2001	17.14
Aug2001	1484.6	20Aug2001	29.95	1302.657	20Aug2001	39.10
Aug 2004	552	21Aug2004	12.58	572.6	21Aug2004	15.05
Aug2007	1898.9	08Aug2007	30.22	1769.9	08Aug2007	34.23

Table 7: Compatibility results

Calibrated event	NSE	Mean Absolute Error(m3/s)	RMS error(m3/s)	Volume Residual(MM)
Aug 2000	0.666	80.8	97.6	-2.70
Aug 2001	0.815	73.5	88.7	3.33
Aug 2001	0.673	164.9	249	-9.15
Aug 2004	0.663	111.0	111.4	-2.47
Aug 2007	0.710	220	313.8	-4.01

4.3 Optimization of parameters

HEC-HMS optimization is done by using the classical Newton-Raphson method. Here, the objective function is Nash-Sutcliffe Efficiency, which must be maximized. Green and Ampt parameters were calibrated and maximized the Nash-Sutcliffe efficiency. Objective function sensitivity was also calculated. Figure 18 shows the increase in NSE by optimizing Green and Ampt parameters.

Table 8: Optimized Green and Ampt parameters

parameters	Initial value	Optimized value	Objective function sensitivity
Conductivity(mm/hr)	1.5	1.5294	-0.16
Initial content	0.231	0.21742	0.07
Saturated content	0.398	0.40384	-.0.12
Suction(mm)	218.49	221.75	-0.06

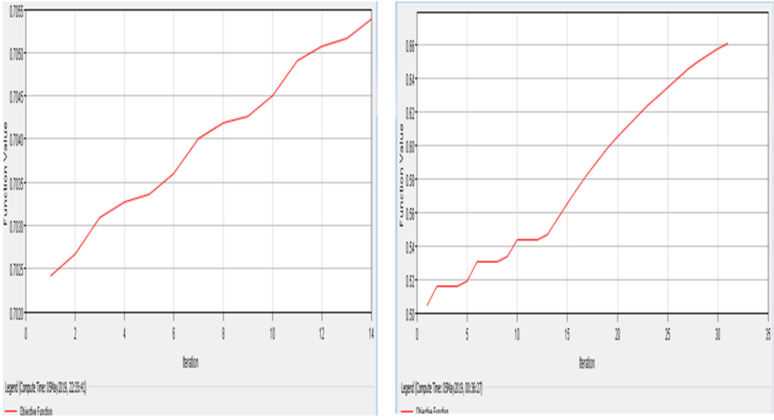


Figure 18: Increase of NSE after optimization of Green and Ampt parameters

4.4 Validation of events

After calibration and optimization of Green and Ampt parameters by maximizing NSE, three events are validated. Figure 19, 20 shows hyetographs of validated events, and based on these time-series data runoff hydrographs are produced.

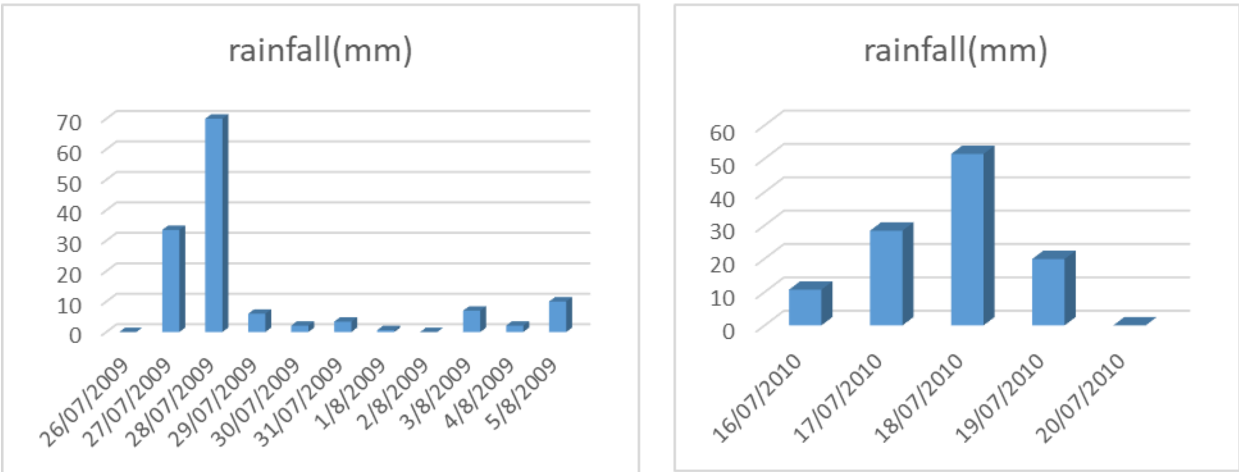


Figure 19: Rainfall hyetographs in July 2009 and 2010

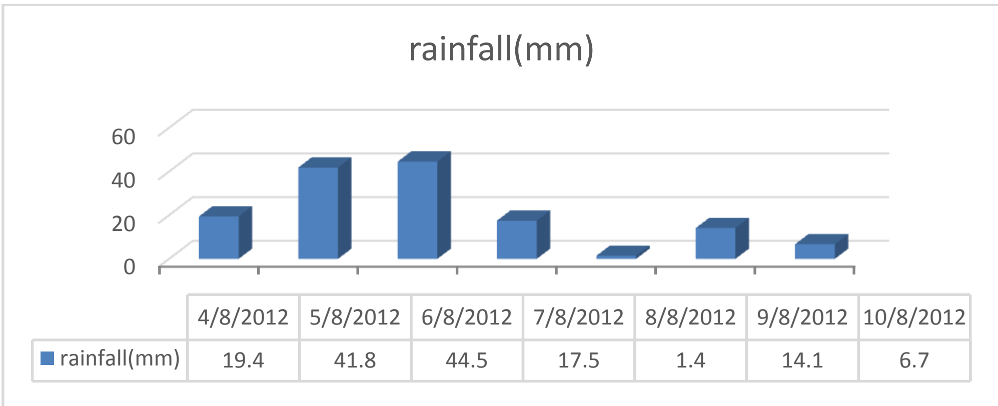


Figure 20: rainfall hyetograph in Aug 2012

Photographs from figures 19, 20 are taken for model validation. From the selected time series data discharge is simulated and compared with observed discharge data. Figures 21, 22 are the validated events that compare observed and simulated discharge.

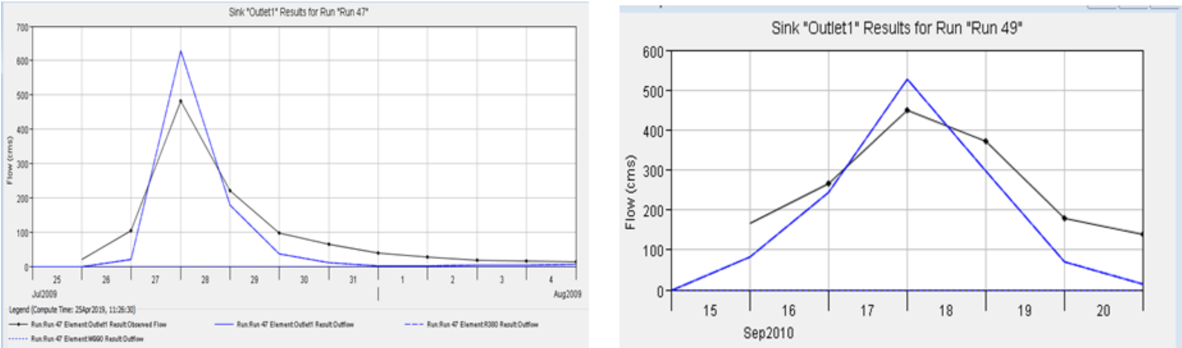


Figure 21: Simulated (blue) and observed(black) discharge for validated events in July 2009 and September 2010

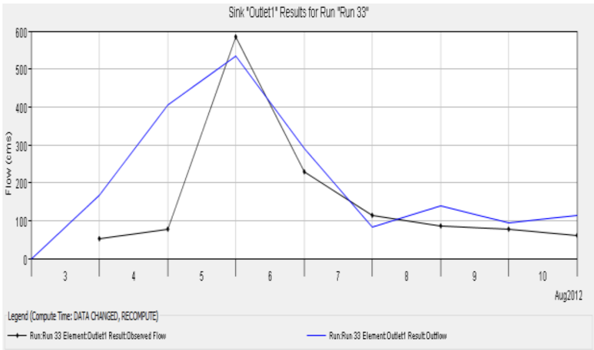


Figure 22: simulated (blue) and observed (black) discharge for validated events in August 2012

From the validation results, some conclusions were drawn. Table 9 describes the computed result and observed data of the validated events. Table 10 gives the compatibility results of the validated events. From table 10, NSE value is around 0.5-0.7, which is of the acceptable range.

Table 9: Comparison of Computed result and Observed data of validated events

	Computed result			**Observed data**		
	Peak discharge(m3/s)	Date of peak	Volume (MM)	Peak discharge(m3/s)	Date of peak	Volume (MM)
July 2009	629.8	28/09/2009	9.65	482.3	28/09/2009	11.88
Sept2010	516.4	18/09/2010	13.90	450.2	18/09/2010	17.27
Aug2012	535	06/8/2012	19.23	585.1	06/8/2012	13.63

Table 10: compatibility results of validated events

Validated events	**NSE**	**Mean absolute Error(m3/s)**	**RMS error(m3/s)**	**Volume residual(MM)**
July 2009	0.8	45.7	57.7	-2.23
Sept 2010	0.564	74.7	78.1	-3.37
Aug2012	0.420	88.1	121.9	5.61

4.5 DISCUSSION

From the analysis, we calibrated five events and optimized Green and Ampt parameters by maximizing the objective function Nash-Sutcliffe efficiency. Figure 23 shows the peak discharge comparison of calibrated events in the year Aug 2000, Aug 2001, Aug 2004, Aug2007. It shows that computed discharge is more than the observed discharge. Figure 24 shows that there is a difference of 7.7% between overall simulated and observed peak discharge of five calibrated events.

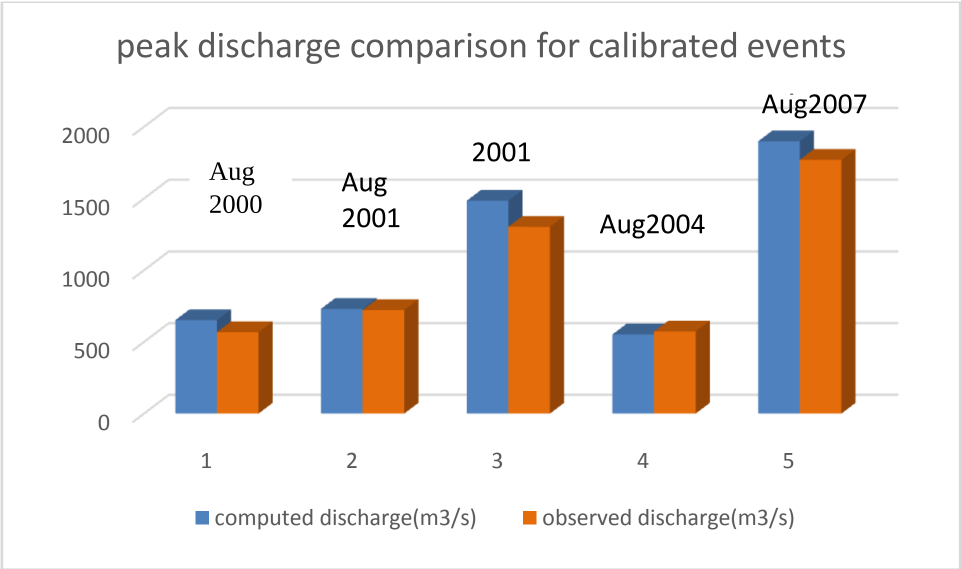


Figure 23: comparison of computed and observed peak discharge of validated events

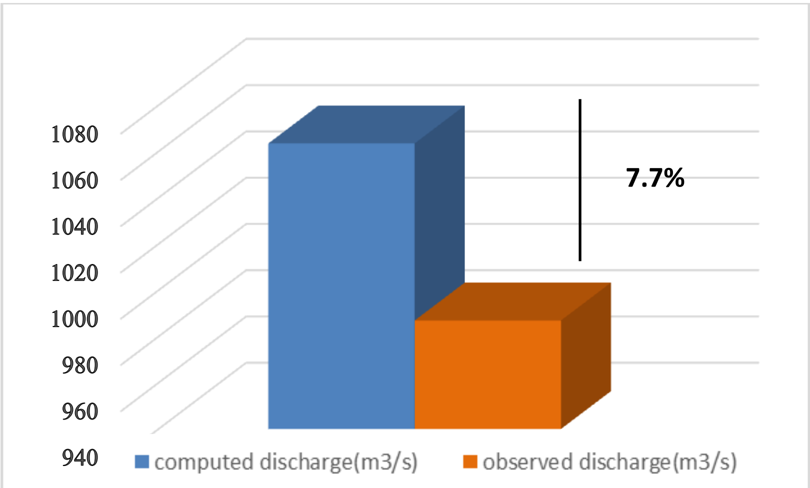


Figure 24: difference in the percentage of computed and observed peak discharge of calibrated events

After comparing the peak discharges of the calibrated events volume in MM, also compared. Figure 25 shows that the overall volume of the computed events is less than the observed events by 12%, which shows that the area under computed hydrograph is less than observed hydrograph for the calibrated events.

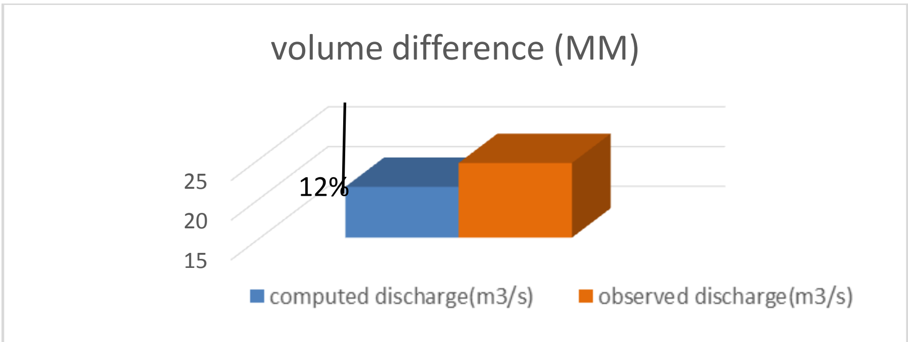


Figure 25: difference in the percentage of the observed and computed volume of calibrated events

For validated Event, peak discharge is more for two events out of three. Figure 26 shows computed and observed peak discharges of validated events.

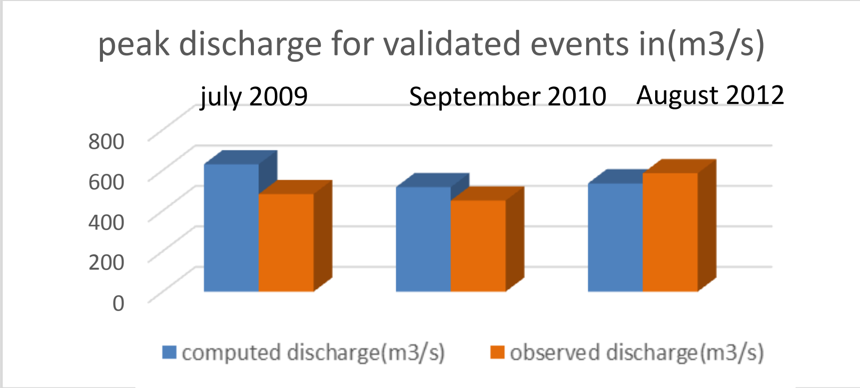


Figure 26: computed and observed peak discharge for validated events

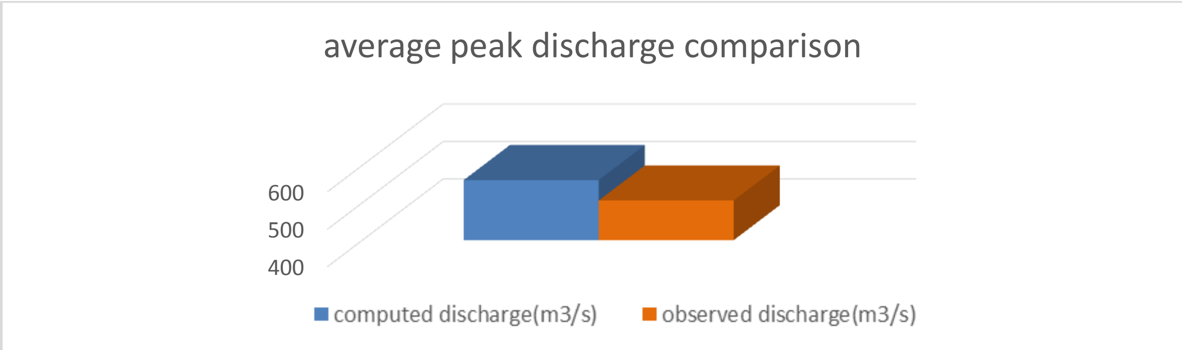


Figure 27: average computed and observed peak discharge for validated events.

The volume of the validated events are shown in figure 28 for two events computed volume is less than observed volume

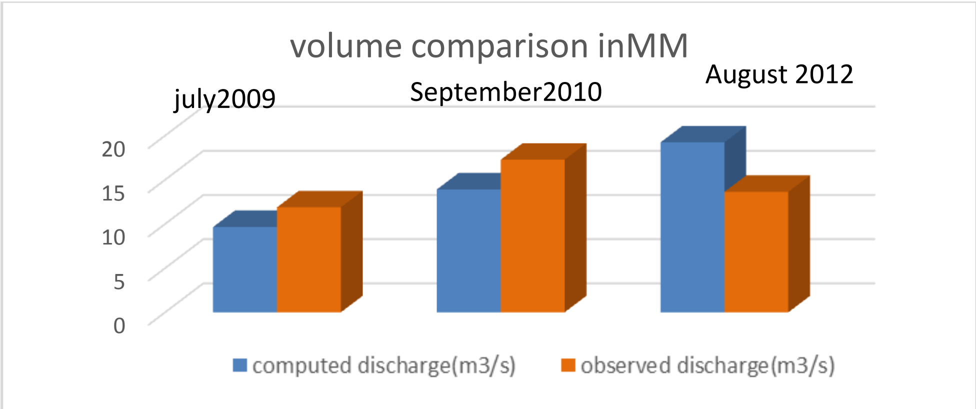


Figure 28: computed (blue) and observed volume (orange) for validated events

V. Conclusion

All the main points of the research work are written in this section. Ensure that the abstract and conclusion should not be same. Graph and tables should not use in conclusion.

5.1 Summary

Modeling is nothing but the prototype of the real world with assumptions taken using parameters. Here we used the hydrological modeling in the modeling of discharge. Modeling of extreme events helps in analyzing the flood of that particular area.

We calculated loss parameters using Green and Ampt parameters, transform parameters using SCS unit hydrograph. Nash-Sutcliffe efficiency is taken as an objective function. Here, we have to maximize the Nash-Sutcliffe Efficiency by optimizing Green and Ampt parameters. Four events were calibrated, and three events were validated.

5.2 Conclusions

The subsequent are the deductions drawn from the study carried out

1. 2000,2001,2004,2007 years extreme rainfall events were calibrated, and 2009, 2010, 2012 events were validated.
2. For calibration of the model, there is no much difference in observed peak discharge and modeled peak discharge.
3. In model validation for two events, modeled peak, discharge is higher than observed discharge.
4. Volume residual is negative for two validated events, which mean computed volume is less than observed volume.
5. The peak discharge is high for simulated events in both calibrated and validated events.
6. Volume is less for simulated events in calibrated and validated models, which means the area is less for simulated events compared to observed events.
7. From the model validated results, the model is reliable as Nash-Sutcliffe Efficiency is around 0.65-0.7.

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