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Hydrological Modeling of Musi River Basin and Impact Assessment of Land Use Change on Urban Runoff

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***Abstract* - The Hydrologic Modeling System is designed to simulate the precipitation-runoff processes of watershed systems. In this paper, a continuous simulation based hydrological model is developed through a distributed hydrological modeling approach for the Musi river basin, India using space inputs and impact assessment of land use/land cover change on runoff is done. The basin is geographically located between 17^0 58' N to 16^0 38' N latitude and 77^0 46'E to 79^0 48' E longitude.The hydrologic modeling approach includes rainfall-runoff modeling, flow routing, calibration and validation of the model with the field discharge data.To compute runoff volume,direct runoff and flow routing, methods like SCS Curve Number, Unit Hydrograph andMuskingum routing are chosen respectively. CARTO Digital Elevation Model (DEM) generated from Indian Remote Sensing Satellite Cartosat-1 of 30m resolution, land use/land cover derived from the Indian Remote Sensing Satellite (IRS-P6) AWiFS data, and soil textural data obtained from National Bureau of Soil Sciences and Land Use Planning (NBSS&LUP) of the study area are used in the modeling. The model is calibrated using HEC Geo HMS for the years 2010 and 2011 and validated for 2013 by observed data. From the calibration and validation results, it is found that for calibration period of stream flow are good on daily basis (NSE= 0.73,0.71 and for validation period NSE=0.72). Over all W100 sub catchment in HEC Geo HMS model of Musi river basin which is covering most of the urban area assessed that increase in built-up area influenced increase in runoff and the runoff Coefficient for the years 2010, 2011 and 2013 were found to be 0.55, 0.59, and 0.68.**

Key Words : Hydrological Modeling, Land use/Land cover, Musi River

1. INTRODUCTION

Long-term simulation of runoff response from a watershed helps the water resources assessment and planning for the development of the watershed.A semi-distributed model framework can be developed in the HEC-GeoHMS interface, an extension of ArcGIS developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) [23]. This allows for the easy creation of the basic basin parameters of a hydrologic model based on topographic data..AisyaAzizah Abas.et.al.(2014) were examined by comparing the impacts of urban expansion on estimated surface runoff in three years time period. Further, discussed in relation to differences in land use and drainage type and how progressive urban development has altered the catchments response to storm events. James D. Miller, et.al.(2014) uses a combination of hydro-meteorological observations and historical mapping of land use change as inputs to a hydrological model, thereby enabling an assessment of the impacts on storm runoff response of developing a rural to peri-urban area and how this compares with concurrent changes in a more mature urban area.B.Zhanget.al.(2015) investigated land cover changes in Beijing in the con-text of rapid urbanization and estimated the role of urban greenspaces in reducing stormwater runoff between ten years time period.Kadam, (2011) Hydrological modeling is a commonly used tool to estimate the basin's hydrological responsedue 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.

2. STUDY AREA

The Musi river basin extends over a geographical area of 11,270 sq. km approximately. Musi River is a tributary of the Krishna River in the Deccan Plateau flowing through Telangana state in India. Hyderabad stands on the banks of Musiriver. The river originates in Anantagiri Hills near Vikarabad, Ranga Reddy district, 90 kilometers to the west of Hyderabad and flows due east for almost its entire course. It joins the Krishna River at Vadapally in Nalgonda district after covering a distance of about 240 km. The basin is bounded by 17^0 58' N to 16^0 38' N latitude and 77^0 46'E to 79^0 48' Elongitude.Geographic setting of Musibasin is shown in Figure 1.

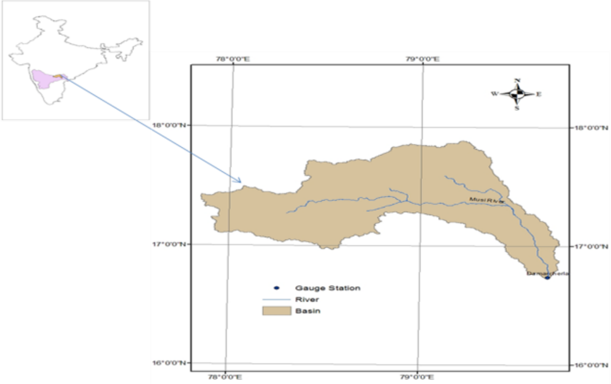
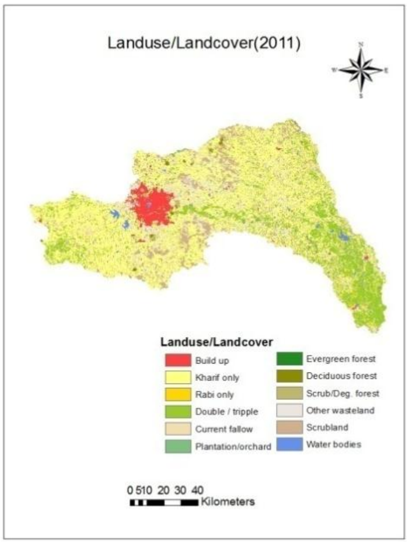
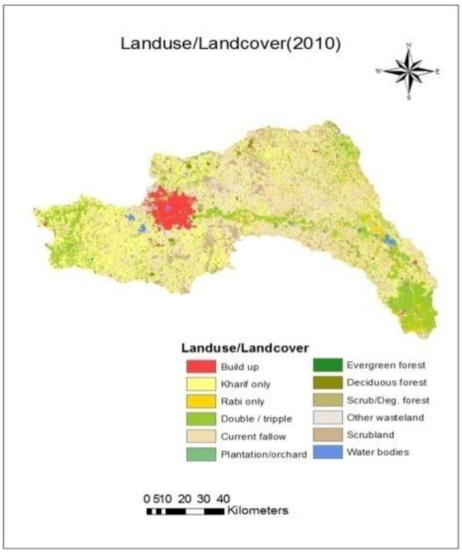


Fig.1: Geographic setting of Musi basin

3. SPATIAL AND NON SPATIAL DATA BASE

Land use/Land cover is a very important parameter in hydrological modeling. Land use/Landcover map was obtained from Resourcesat IRS-P6 Advanced Wide Field Sensor data of 56 mresolution. The Land use/Land cover of the basin is shown in Figure 2. The images corresponds tothe 2010, 2011, and 2013 year and consists ofKharif as major followed by current fallow, double/triple, scrubland, other wasteland, build up, rabi, water bodies, deciduous forest, scrub/Deg. Forest, plantation/orchard, and evergreen forest.





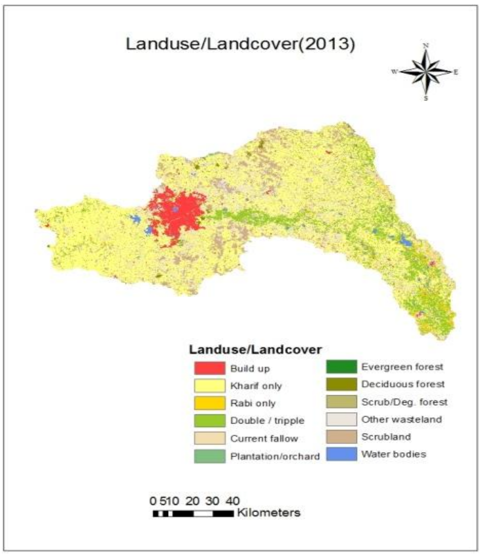


Fig. 2: The Land use/Land cover of the basin

A soil textural map of the study area at the 1:250,000 scale was obtained from the National Bureau of Soil Sciences and Land-Use Planning of India. The Figure 3 shows various categories of soils in the basin. The soils are classified based on the soil textural information as clayey, clayey skeletal, loamy, loamy skeletal.

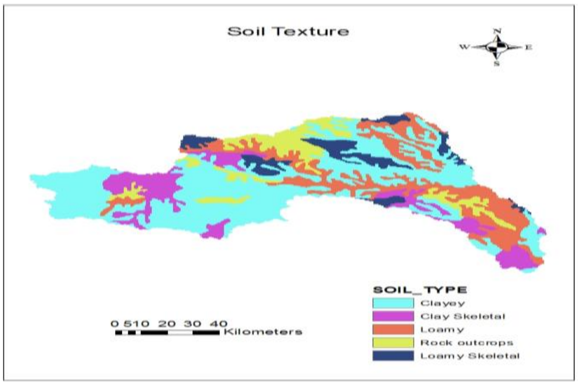


Fig. 3: Soil texture of the basin

The Figure 4 shows the Digital Elevation Model (DEM) of Musi river basin with 30 m resolution. The main input for topographic parameter extraction. The CARTO Digital Elevation Model (DEM) generated from Indian Remote Sensing Satellite Cartosat-1 of 30m resolution is used to extract various topographic and hydraulic parameters of the basin such as subbasin and channel slopes , Manning's coefficients, lag time,time of concentration, and so on. Subbasins and drainage network are also delineated using the DEM through an automated process. The figure no.4 represents the Slope map and Figure 6 shows Flow direction map.

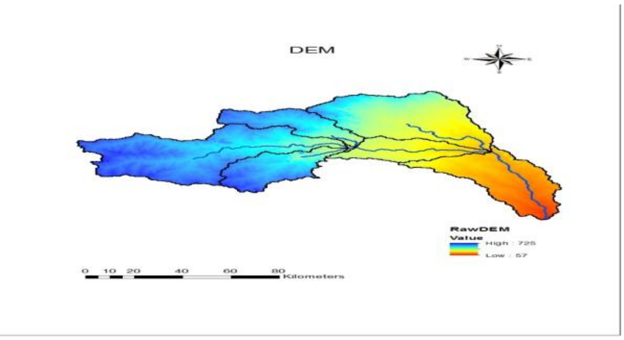
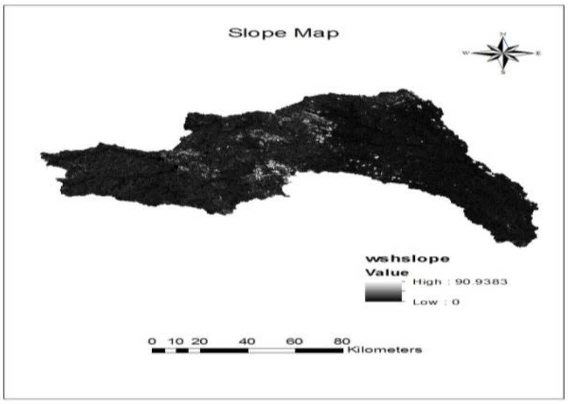


Fig. 4. Represents the DEM of Musi river basin



Fig, 5. Slope map of Musi river basin

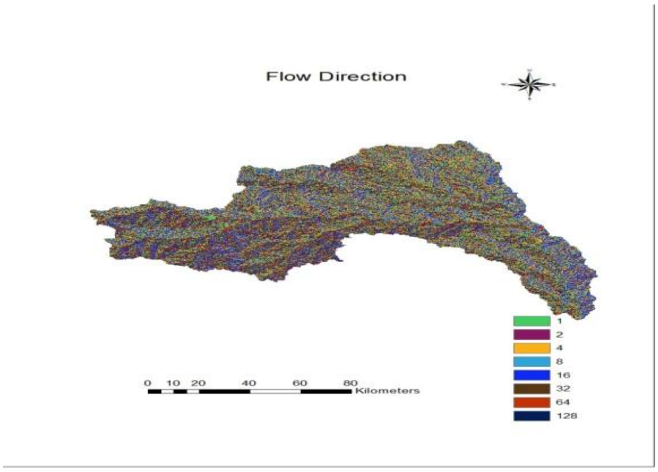


Fig. 6. Shows Flow direction map of Musi river Basin

Daily rainfall of all the subbasins was extracted from these grids and fed into model. Discharge data of Damarcherla station in the basin was collected from the Central Water Commission (CWC) and used for model calibration and validation. Discharge data of 2010 and 2011 were used for model calibration and 2013 data was used for validation of the model.

4. METHODOLOGY

Hydrological modeling is a mathematical representation of natural processes that influence primarily the energy and water balances of a watershed. The main purpose of using hydrological modeling is to provide information for managing water resources in a sustained manner. In a distributed modeling the spatial variations of topographic and meteorological parameters are considered and the runoff is computed in the spatial domain. HEC-HMS and HECGeoHMS are used as a modeling environment for developing the rainfall-runoff model for the Musi river basin. Methodology involves basin and sub-basin delineation, topographic and hydrologic parameter extraction, hydro-meteorological model setup, computing runoff volume, modeling direct runoff, flow routing, calibration, and validation. Terrain pre-processing is a series of steps to derive various topographic and hydraulic parameters. These steps consist of computing the flow direction, flow accumulation, stream definition, watershed delineation, watershed polygon processing, stream processing, and watershed aggregation.

4.1 Hydrologic Parameter Extraction

Topographic characteristics of streams and watersheds have been computed using a model pre-processor. The physical characteristics extracted from DEM, Slope map and flow direction map values are placed below in the Table.1and Table 2.

Table- 1: Musi river basin parameters

Name	Shape_ Length	Basin Slope	Basin CN	Basin Lag	Area_ HMS
W80	357252.118	1.98	78.75	28.641	2664.41
W90	273083.7404	2.53	77.49	23.787	1010.214
W100	510572.047	2.33	82.66	28.057	3404.14
W110	30589.8282	1.71	80.06	3.553	15.56
W120	276420.8144	2.99	82.34	14.886	1219.74
W130	238600.6612	1.69	78.32	23.281	964.63
W140	361701.5482	1.56	80.51	28.305	1991.80

Table- 2 The Musi river stream profile all along the sub basin wise details are as placed below

Slope	Name	ElevUP_HMS	ElevDS_HMS	RivLen_HMS
0.0043	R10	419	329	20934.95
0.0024	R20	339	329	4082.50
0.0018	R30	329	206	67003.35
0.0019	R40	329	206	62361.71
0.0033	R50	417	339	23275.42
0.0023	R60	542	339	85691.11
0.0017	R70	206	57	83076.40

The above physical characteristics are useful in estimating hydrological parameters of basins. The Physical characteristics of all streams and basins are stored in the attribute tables that can be exported to the model for further modeling processes. The physical characteristics that are extracted for the streams and sub basins are river length, river slope, basin centroid, longest flow path, centroidal flow path, and so forth. The When the stream and sub-basin physical characteristics are extracted, hydrological parameters can be easily derived. The Infiltration rate is estimated as grid based quantities that are based on land-use and soil-types other hydrological parameters such as time of concentration, lag time, and Muskingum routing parameters arecomputed from the terrain characteristics.

All the above mentioned hydrologic parameters are extracted for all the subbasins of the study area and fed into the model. Complete topographic model setup is shown in Figure 7

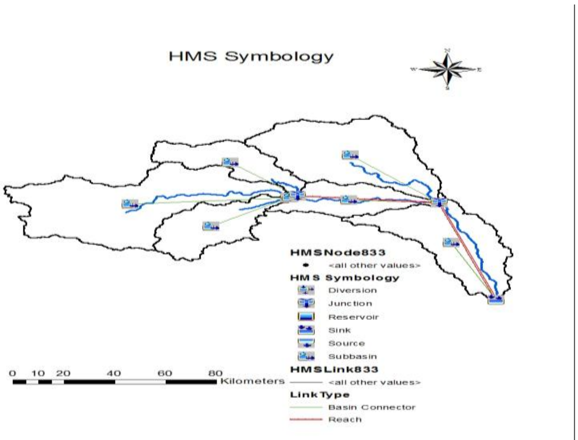


Fig. 7: Topographic model setup of the basin

4.2. Model Setup and Simulations for Hydrological Modeling

In this study, semi-distributed modeling approach is adopted in discharge hydrograph computation. The methodology involved in computing the discharge hydrograph of the basinat the outlet can be broadly divided into five stages, including computing runoff volume ,modeling direct runoff, flood routing, calibration of the model, and model validation. For runoff estimation, SCS Curve Number method is used. SCS Unit Hydrograph technique is used for direct runoff estimation and Muskingum routing technique is used for flow routing. A brief description of these methods is given below.

SCS Curve Number method:

The SCS Runoff Curve Number method is developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) and is a method of estimating rainfall excess from rainfall (Hjelmfelt, 1991). The method is described in detail in National Engineering Handbook (2004). The chapter was prepared originally by Mockus (1964), and was revised by Hjelmfelt (1998) with assistance from the NRCS Curve Number work group and H.F. Moody. Despite the wide use of the curve number procedure, documentation of its origin and derivation are incomplete (Hjelmfelt, 1991).

The conceptual basis of the curve number method has been the object of both support and criticism (Ponce and Hawkins, 1996). The major disadvantages of the method are sensitivity of the method to Curve Number (CN) values, fixing the initial abstraction ratio, and lack of clear guidance on how to vary Antecedent Moisture Conditions (AMC). However, the method is used widely and is accepted in numerous hydrologic studies. The SCS method originally was developed for agricultural watersheds in the mid-western United States; however it has been used throughout the world far beyond its original developers would have imagined.

The basis of the curve number method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall. Mockus found equation 1 appropriate to describe the curves of the field measured runoff and rainfall values (National Engineering Handbook, 2004). Equation 1 describes the conditions in which no initial abstraction occurs.

$$\frac{F}{S} = \frac{Q}{P} \qquad \text{Equation-1}$$

Here: *F*=*P*–*Q*=actual retention after runoff begins; *Q* = actual runoff
S = potential maximum retention after runoff begins (S ³ F)
P = potential maximum runoff (i.e., total rainfall if no initial abstraction).

For most applications, a certain amount of rainfall is abstracted. The three important abstractions for any single storm event are rainfall interception (Meteorological rainfall minus throughfall, stem flow and water drip), depression storage (topographic undulations), and infiltration into the soil. The curve number method lumps all three abstractions into one term, the Initial abstraction (*Ia*), and subtracts this calculated value from the rainfall total volume. The total rainfall must exceed this initial abstraction before any runoff is generated. This gives the potential maximum runoff (rainfall available for runoff) as *P – Ia*. Substituting this value in equation 1 yields following equation:

$$\frac{Q}{S} = \frac{P - Ia - Q}{P - Ia} \qquad \text{Equation-2}$$

It is important to note the potential maximum retention term, *"S"*, excludes *Ia*. Hence, for a given storm, maximum loss of rainfall is *S* plus *Ia*.Rearranging terms in Equation 2 for Q gives

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad \text{Equation-3}$$

Establishing the relation to estimate *Ia* was challenging. The SCS provided the following empirical Equation 4 based on the assumption *Ia* was a function of the potential maximum retention *S*.

$$Ia = 0.2S \quad \text{----} \qquad \text{Equation4}$$

The potential maximum retention *S* is related to the dimensionless parameter CN in the range of 0 <= CN <= 100 by Equation 5.

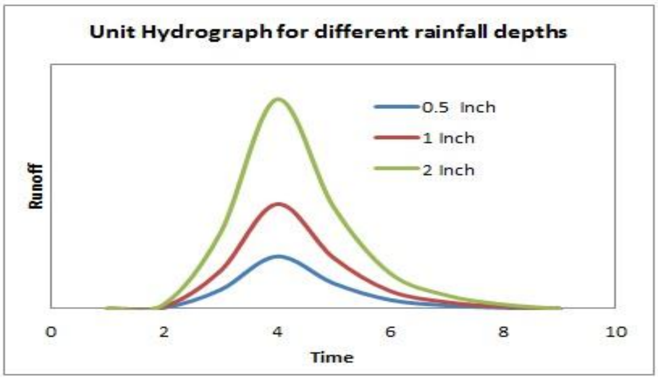
$$S = \frac{25400}{CN} - 254 \qquad \text{Equation5}$$

Substituting Equation 4 into Equation 3 yields,

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \qquad \text{--- Equation 6}$$

Equation 6 has only one parameter that needs to be evaluated (i.e., S) which can be determined by using Equation 5 and curve number tables published by the SCS.
SCS Unit Hydrograph method:

It is a typical hydrograph of direct runoff which gets generated from one centimeter of effective rainfall falling at a uniform rate over the entire drainage basin uniformly during a specific duration. Effective rainfall is that portion of rainfall which fully contributes towards direct runoff. Therefore, unit hydrograph can also be defined as the hydrograph of a drainage basin which gives one centimeter of direct runoff from a rain storm of specific duration. The Figure 8 indicates of a unit hydrograph of 0.5 inch to 3 inch peak flow graph.



Fig, 8 Unit Hydrograph

The Unit hydrograph can be used to predict the peak-flood hydrograph if the rainfall producing the flood, infiltration characteristics of the catchment. The unit hydrograph of the catchment is then operated upon by the design storm to generate the desired flood hydrograph.

Muskingum Routing method:
In the Muskingum method the storage Sin the routing reach is represented by the following discharge-storage equation:
S=K[X + (1 —X) Q] Equation-7

in which the rism storage in the reach is KQ,

where K is a proportionality coefficient, and the volume of the wedge storage is equal to KX (I–Q),

For a given channel reach by selecting a routing interval Δt and using the Muskingum equation, the change in Storage is

S2-S1=K(x(I2–I1)+(1-x)(Q2-Q1)) Equation -8

Where suffixes 1 and 2 refer to the conditions before and after the time interval Δt the continuity equation for the reach is

S2-S1=((I2+I1)/2)Δt-((Q2+Q1)/2)Δt Equation-9

From above equations 3.13& 3.14 Q2 is evaluated as

Q2 = Co+I2+C1I1+C2Q1

Co= -Kx+0.5 Δt / K-Kx+0.5 Δt

C1 = Kx+0.5 Δt / K-Kx+0.5 Δt

C2 = K-Kx-0.5 Δt / K- Kx+0.5 Δt

C0+C1+C2=1.0
In a general form for the nth time step as

$Qn=C_0In+C_1In-1+C_2Qn-1$ Equation-10

Muskinggum Routing equation provides a simple linear equation for channel routing. It has been found that for best results the routing interval should be chosen that K>Δt>2Kx, Δt<2x,the coefficient C0 will be negative. Touse Muskingmum equation to route a given inflow hydrograph through a reach,the values of K and x for the reach and the value of the outflow,Q1 from the reach at the start are needed.

5. CALIBRATION AND VALIDATION OF THE MODEL

Model calibration is the process of adjusting model parameter values until model results match historical data. The process can be completed using engineering judgment by repeatedly adjusting parameters and computing and inspecting the goodness-of-fit between the computed and observed hydrographs. During the simulation run, the model computes direct runoff of each watershed and the inflow and outflow hydrograph of each channel segment. The model computes the flood hydrograph at the outlet after routing flows from all subbasins to the basin outlet. The computed hydrograph at the outlet is compared with the observed hydrograph at Damarcherla station.

After computing the exact value of the unknown variable during the calibration process, the calibrated model parameters are tested for another set of field observations to estimate the model accuracy. In this process, if the calibrated parameters do not fit the data of validation, the required parameters have to be calibrated again. Thorough investigation is needed to identify the parameters to be calibrated again. In this study hydro meteorological data of 2013 was used for model validation.

6. RESULTS AND DISCUSSION

In the present study, hydrological model for the Musi basin through semi-distributed modeling approach has been developed. SCS Unit Hydrograph technique has been used for direct runoff estimation and Muskingum routing technique has been used for flow routing. Infiltration rate has been estimated as grid-based quantities that are based on land use and soil types. Topographic and hydraulic parameters of the basin such as subbasin and channel slopes, Manning's coefficients, lag time, time of concentration and so on have been derived using CARTO DEM of 30 m resolution and also subbasins and drainage network have been delineated through an automated process. Rainfall grids of the basin were prepared in ArcGIS. The model has been calibrated and validated by using observed discharge data.

Gauge discharge data of Damarcherla station was used in calibrating and validating the model. Simulated discharges were compared with the field observed discharges at Damarcherla. It is found that there are small differences between the simulated and observed values of all the parameters used for calibration. The calculated parameters were then optimized using the optimization tool available in HEC-HMS model. Curve number and basin lag are found to be more sensitive. For optimization, Univariate Gradient Method is used. The univariate gradient search algorithm makes successive corrections to the parameter estimate. That is, if xk represents the parameter estimate with objective function f (xk) at iteration k, the search defines a new estimate xk+1 at iteration k+1 as in equation-11

$$x^{k+1} = x^k + \Delta x^k \qquad \text{Equation-11}$$

in which Δx^k is the correction to the parameter. Table 3 shows the Optimized values in the model..

Table- 3 Optimized parameters in HEC-HMS

Sl.no	Sub Catchment No	Calculated		Optimized	
		CN value	Basin lag	CN value	Basin lag
1	W80	78.75	28.64	86.63	24.35
2	W90	77.79	23.79	85.24	20.22
3	W100	82.66	28.06	90.93	23.85
4	W110	80.07	3.55	88.08	3.02
5	W120	82.35	14.88	90.58	12.65
6	W130	78.33	23.88	86.16	19.79
7	W140	80.51	28.31	88.56	24.06

With the help of these optimized parameters, discharges were again simulated. Simulated and observed hydrographs at Damarcherla station for the year 2010 and 2011 are shown in figure 9 and figure 10 respectively. Figure. 11 represents Simulated and observed hydrograph during the validation process at Damarcherla stations respectively for the year 2013. These figures indicate that computed hydrographs match well with the observed hydrographs. Due to the hydrological modeling technique, accuracy in discharge computations is improved. Discharge in any sub basin of the study area can be predicted separately with the adoption of this hydrological modeling approach. The Overall peak discharge values of the years 2010,2011 and 2013 with respect to simulated and observed at Damaracharla station placed below Table 4.

Table- 4. shows the peak discharges of simulated and observed.

Event year	Discharge (in Cumec)	
	Observed at	Simulated
	Damarcharla station	By HEC HMS Model
2010	461.5	572
2011	282	288.6
2013	3656.3	3146.3

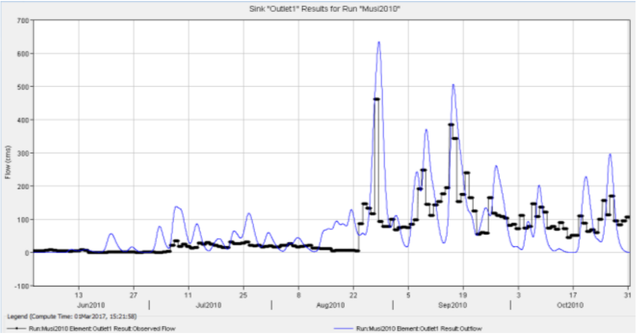


Fig. 9: Simulated and observed hydrographs at Damarcherla station for the year 2010

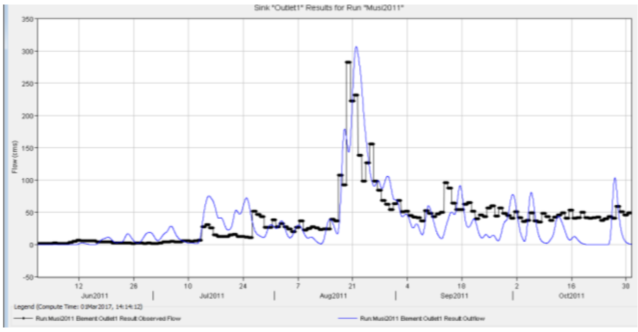


Fig. 10: Simulated and observed hydrographs at Damarcherla station for the year 2011

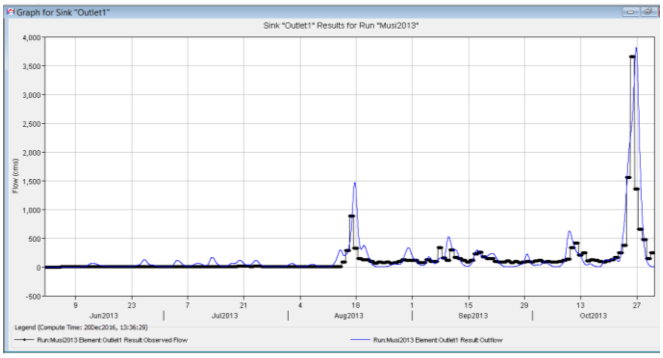


Fig. 11: Simulated and observed hydrographs at Damarcherla stationfor the year 2013

Runoff has been estimated for the years 2010, 2011, and 2013. Rainfall Vs Runoff of subbasin W100 for the years 2010, 2011, and 2013 is shown in Chart-1 . From the figure, it was observed that, the average annual rainfall of the study area for the years 2010, 2011, and 2013 were 167.72 mm, 114.25mm, and 343.15mm and the runoff was estimated at 92.26 mm, 67.41, and 236.77 respectively.Runoff Coefficient for the years 2010, 2011 and 2013 were found to be 0.55, 0.59, and 0.68. Most of the urban area lies in the subbasin W100. Further, from the Figure12, it was observed that runoff has been increased with the urban area. Graphical representation of run off in sub basin W100 indicates increase of built-up area proportionately increase in runoff.

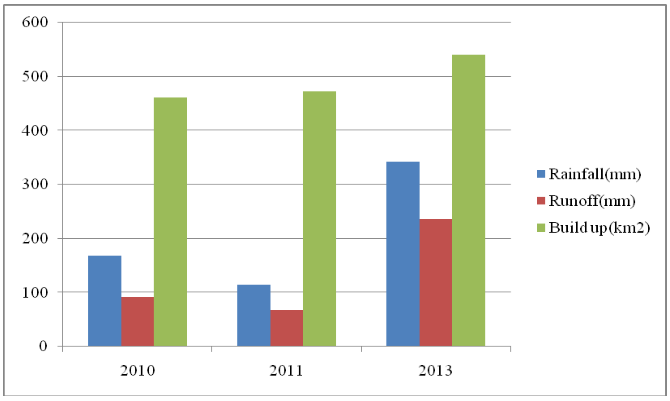


Chart-1: Rainfall Vs Runoff of subbasin W100 for the years 2010, 2011, and 2013

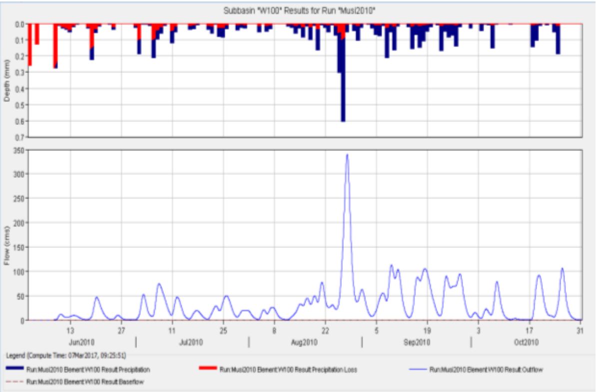


Fig.- 12 Rainfall-Runoff graph for the sub-basin W100 for the year 2010

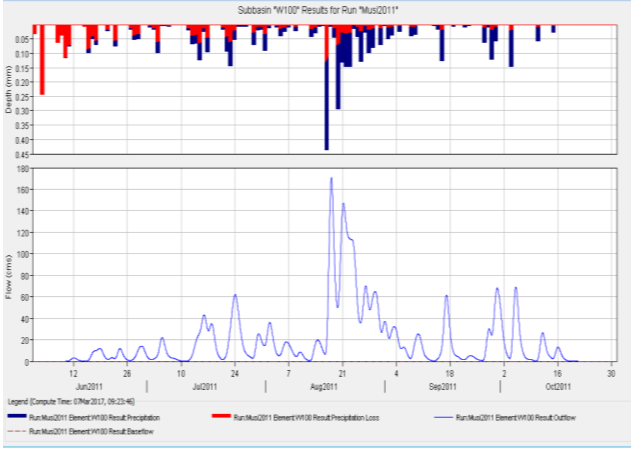


Fig.-13 Rainfall-Runoff graph for the sub-basin W100 for the year 2011

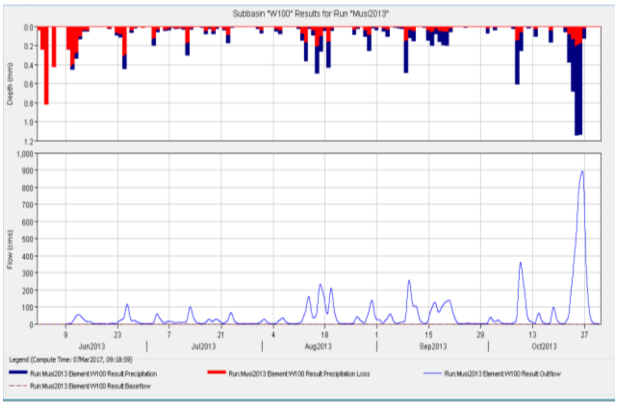


Fig.-14 Rainfall-Runoff graph for the sub-basin W100 for the year 2013

7.0 PERFORMANCE OF MODEL

To evaluate the performance of the developed HEC Geo HMS model quantitatively , statistical analysis the Nash–Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. It is defined as:

$$E = 1 - \frac{\sum_{t=1}^{T} (Q^t m - Q^t o)}{\sum_{t=1}^{T} (Q^t o - \overline{Q}o)} \qquad \text{Equation-12}$$

Where

$Q^t m$ is modeled discharge at t time,

$Q^t o$ is observed discharge at time t.

$\overline{Q}o$ is mean observed data at t time period

Table- 5. NSE values of the HEC Geo HMS model

Year	NSE (HEC- GeoHMS)
2010	0.73
2011	0.71
2013	0.72

8.0 SUMMERY AND CONCLUSION

With this hydrological modeling approach, discharge estimation at any river confluence can be issued, and influence of any tributary can be examined separately. Urban area has been increased from 461 to 541 sq. km. from 2010 to 2013; Most of the urban area lies in the subbasin W100, So Runoff of the subbasin W100 was also increased from 2010 to 2013 as urbanization increases. The simulation shows that the computed hydrographs match well with the observed hydrographs. Accuracy in computing peak discharge was 75 percent approximately when compared to the observed flows. Runoff Coefficient for the years 2010, 2011 and 2013 were found to be 0.55, 0.59, and 0.68.The performance of the model for runoff estimation on daily basis found to be good as per Nash–Sutcliffe model efficiency coefficient.

ACKNOWLEDGEMENT

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