

**DEVELOPMENT OF GEOMORPHOLOGICAL
INSTANTANEOUS UNIT HYDROGRAPH (GIUH) MODEL
FOR AN UNGAUGED WATERSHED**

THESIS

Submitted in partial fulfilment of the requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(SOIL AND WATER CONSERVATION ENGINEERING)

By

Miss. Shinde Sayali Vitthal

(ENDPM/2020/193)

DEPARTMENT OF SOIL AND WATER CONSERVATION

ENGINEERING

COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,

DAPOLI



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VIDYAPEETH, DAPOLI, RATNAGIRI (MS) 415 712**

DECEMBER, 2022

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Assistant Professor



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DECEMBER, 2022

DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the Thesis entitled "DEVELOPMENT OF GEOMORPHOLOGICAL INSTANTANEOUS UNIT HYDROGRAPH (GIUH) MODEL FOR AN UNGAUGED WATERSHED" or part thereof has neither been submitted for any other degree or diploma of any University nor the data have been derived from any thesis/publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged and that no part of the thesis has been submitted for any other degree or diploma.

Place: Dapoli

Date: 28 DEC 2022


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The assistance and help received during the course of investigation have been fully acknowledged.

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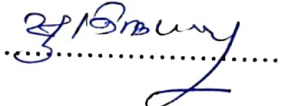
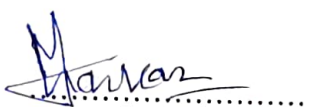
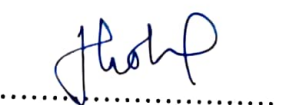
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List of Abbreviations

A	Cross-sectional area of the channel
AAE	Absolute average error
Ac	Area of circle
AEV	Average error in volume
ARS	Agricultural Research Service
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
Au	Basin area
C	Constant of channel maintenance
CAET	College of Agricultural Engineering and Technology
cm	Centimeter
D	Duration
DBSKKV	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
Dc	Diameter of circle
D _d	Drainage density
DEM	Digital Elevation Model
DRH	Direct Runoff Hydrograph
DSRO	Direct Surface Run-Off
E	East
EFF	Efficiency
Engg.	Engineering
ENS	Nash-Sutcliffe efficiency
Equ.	Equation
ERH	Effective Rainfall Hydrograph
<i>et.al</i>	And others
Fig.	Figure
GIS	Geographical Information System
GIUH	Geomorphological Instantaneous Unit Hydrograph
H	Maximum basin relief
Ha	Hectares
HEC	Hydrological Engineering Centers
h	Hour
I	Excess rainfall intensity

i.e	That is
ILWIS	Integrated Land and Water Information System
IRS	Indian Remote sensing
IUH	Instantaneous Unit Hydrograph
k	Scale parameter
km	kilo meter
km/km ²	kilo meter per kilo meter square
km ²	kilo meter square
L _b	Length of basin
L _{bm}	Maximum basin length
L _g	Length of overland flow
L _h	Horizontal distance
L _u	Mean stream length
LU/LC	Land Use –Land Cover
m/s	Meter/second
m ³	Meter cube
mm	Millimeter
mm/h	Millimeter per hour
n	Shape parameter
N	North
n _m	Manning's roughness coefficient
No.	Number
N _u	Number of stream
Ø-index	Phi index
P	Perimeter of basin
PEP	Percentage error in peak
PETP	Percentage error in time To peak
PMF	Probable Maximum Flood
Q	Discharge of channel
Q _e	Equilibrium discharge
q _p	Peak discharge
R	Hydraulic radius of channel
R _B	Bifurcation ratio
R _A	Stream area ratio
R _c	Circulatory ratio

rd	Depth of direct runoff
R _f	Form factor
RH	Runoff Hydrograph
Rhp	Relative relief
R _L	Stream length ratio
R _l	Elongation ratio
RMSE	Root Mean Square Error
Rn	Relative ratio
RS	Remote sensing
S	Slope steepness factor
SCS	Soil Conservation Services
SOI	Survey of India
Sq.	Square
SRTM	Shuttle Radar Topography Mission
SUH	Synthetic Unit Hydrograph
T	Drainage texture
t _p	Time to peak (h)
u	Stream order
UH	Unit Hydrograph
V	Dynamic velocity parameter (m s ⁻¹)
Vd	Volume of direct runoff

Glossary

➤ **Hydrograph**

A plot of the discharge in a stream against time is called a hydrograph.

➤ **Unit hydrograph**

Hydrograph of direct runoff resulting from 1 cm of effective rainfall generated uniformly over the basin area at a uniform rate during a specific period.

➤ **Watershed**

A Watershed is a hydrological unit from which runoff resulting from precipitation flowing from a single point into a large stream, river, lake, or pond.

➤ **Instantaneous Unit Hydrograph (IUH)**

A conceptual unit hydrograph known as an Instantaneous Unit Hydrograph (IUH) shows the direct runoff hydrograph produced by an instantaneous precipitation with one cm of effective rainfall that has an infinitesimally short duration in the watershed.

CHAPTER I: INTRODUCTION

Soil and water conservation measures play an important role in maintaining and enhancing productivity in the basin. In addition, it also maintains ecological balance. Water and erosion control facilities are an integral part of any soil and water conservation program and are key components of watershed management. In areas with rainfall, small increases in water availability can significantly increase crop yields and reduce the risk of crop failure. Flood estimation is an integral part of surface water hydrology for the water resources planning, management and development including the mitigation and prevention of flood hazards. Estimating the maximum flood discharge is necessary for predicting watershed hydrological behavior. Flood management in a basin will not be successful unless the watershed hydrological behaviors are predicted (Bhadra *et al.*, 2008). Many hydrologists have undertaken simulations of rainfall-runoff processes to estimate the volume of runoff and the peak discharge value of watersheds. Determining basin peak discharge value and the runoff volume of a watershed is important for natural disaster management and water structure design and construction. The production and behavior of runoff are functions of land use types and changes. The hydrological response of a river basin is based on the relationship between basin geomorphology and its hydrology.

1.1 Concept of unit hydrograph

A plot of the discharge in a stream against time is called a hydrograph. By studying the hydrographs principle, hydrological engineers can predict the magnitude as well as the timing of the flood peak. Sherman (1932) proposed the principle of a unit hydrograph as a hydrograph of direct runoff resulting from 1 inch of effective rainfall generated uniformly over the basin area at a uniform rate during a specific period. To obtain the runoff hydrograph resulting from a storm of varying intensities, it is preferable to have a unit hydrograph of very short duration. Theoretically, the shortest duration is zero. Sherman paved the manner for the development of watershed rainfall-runoff evaluation with his UH technique. Unit Hydrograph (UH) and Synthetic Unit Hydrograph (SUH) concept is a doubtlessly effective tools in watershed hydrology. The conventional unit hydrograph (UH) approach requires historical rainfall-runoff data. The geomorphological parameters are mostly time-invariant and therefore, the geomorphology-based approach could be the most suitable technique for modeling the rainfall-runoff technique for ungauged catchments.

The catchment in which observed available time-series discharge data is inadequate for calibration or catchments in which the river discharges have not been measured is referred to as an ungauged catchment. The method of development of the unit hydrograph depends upon the availability of observed rainfall and runoff data. Mathematical modeling of hydrologic systems requires a huge amount of data and system information; withinside the absence of pertinent data modeling of ungauged/poorly gauged watersheds becomes quite difficult and challenging

(Nongthomban *et al.* 2011). To overcome this problem, the use of physically based rainfall-runoff estimation methods such as the Geomorphological Instantaneous Unit Hydrograph (GIUH) technique has evolved.

1.2 Introduction to morphometric parameters

Geomorphology of a river basin describes the status of the topographic features of the surfaces and streams. The topographic and geometric properties of the watershed and its drainage channel network are reflected using geomorphology. It controls the hydrologic techniques from rainfall to runoff, and subsequent flow routing through the drainage network (Himanshu *et al.* 2015).

The relationship between the hydrologic characteristics of the catchment and the geomorphologic parameters can provide insight into the hydrologic behavior of the ungauged catchments. Snyder (1938) proposed the synthetic unit hydrograph technique (SUH) for the ungauged basin as a feature of the catchment area, basin shape, topography, channel slope, stream density and channel storage; and derived the basin coefficient by averaging out different parameters. Further advancement was made by different workers notably by Clark (1945) and Nash (1957) mainly highlighted the advantage of the parametric technique for the derivation of Unit Hydrograph (UH) to establish the relationship between the UH and the catchment characteristics of ungauged catchment or watershed (Narayan *et al.* 2012).

1.3 Concept of Geomorphological Instantaneous Unit hydrograph (GIUH)

Geomorphological Instantaneous Unit hydrograph (GIUH) technique is a workable approach and has direct applicability to an ungauged catchment for predicting runoff responses resulting from a rainfall response. The concept of Geomorphological Instantaneous Unit Hydrograph (GIUH) was introduced by Rodriguez-Iturbe and Valdes (1979). The pioneering work of Rodriguez-Iturbe and Valdes (1979) explicitly integrates the geomorphology information and the climatological characteristics of a basin, in a framework of travel distribution, which is a boon for streamflow synthesis in basins having scant or no facts on past data. Their quantitative understanding opened a new size within the hydrological analysis, especially for the ungauged river basin. In this technique, excess rainfall is assumed to follow different probabilistic flow paths in the channel and in overland regions to reach the catchment outlet (Khaleghi *et al.* 2014).

1.4 Advantages of GIUH

The GIUH technique is more advantageous than the traditional IUH methods such as the Clark IUH model (Clark, 1945) and the Nash IUH model (Nash, 1957) because it avoids the requirement of stream flow data. The GIUH technique is more advantageous than the regionalization technique because it no longer requires any information about the other catchments in the hydro-meteorologically homogeneous region. Another advantage of the GIUH technique is

its potential for deriving the UH using the geomorphological characteristics obtainable from topographic maps or remote sensing, possibly linked with Geographic Information System (GIS) and Digital Elevation Model (DEM).

1.5 Use of Remote sensing and GIS

Remote Sensing and GIS techniques are increasingly used for planning, development and management of natural resources at regional, countrywide and global levels. It is becoming a significant tool in hydrological modeling because of its capacity to handle a large amount of spatial and attribute data. The significant factors for the planning and management of floods in watersheds are their physiographical characteristics, drainage and geomorphology, soil, land use/land cover and available natural resources. The application of RS and GIS provides an efficient and accurate means for the preparation of various thematic maps which include land use land cover maps, slope maps and drainage maps of the basin.

Jagbudi river catchment (i.e., Chatav watershed) was selected as the study area for the present research. Jagbudi is the tributary of the Vashishti river and it meets Vashishti near Bahiravali. It originates from Khopi in the Ratnagiri district. The Jagbudi river basin has witnessed high rainfall and consequent floods of various intensities during recent years. Flood management in a catchment will be unsuccessful unless the catchment's hydrological behaviors are predicted. Water conservation and flood protection structures are required to manage natural disasters such as floods and droughts. The determination of the watershed's peak discharge value and total runoff volume is critical for the design and construction of flood protection structures.

Estimating runoff response from ungauged catchments is an important area of study in surface water hydrology. As a result, the current study was carried out to develop a spatially distributed unit hydrograph model suitable for ungauged basins.

Keeping these needs in view, the present study entitled, 'Development of geomorphological instantaneous unit hydrograph model for ungauged watershed' is undertaken with the following objectives.

1. Determination of geomorphological parameters of the watershed using remote sensing and geographic information system
2. Determination of Nash model parameters
3. Development of Geomorphological Instantaneous Unit Hydrograph (GIUH) for an ungauged watershed

CHAPTER II: REVIEW OF LITERATURE

This chapter deals with the review of study carried out by various investigators on the applications of GIS, geomorphological characteristics of watershed and development of Geomorphological Instantaneous Unit Hydrograph.

2.1 Determination of geomorphological parameters of watershed

Strahler (1957) performed a quantitative analysis of watershed geomorphology. It includes two classes, linear scale measurement, and a dimensionless number. Linear scale measurement includes the length of stream channel of a given order, drainage density, constant of channel maintenance, basin perimeter, and relief. Dimensionless properties that may be applied to the systematic description of drainage basins developed by normal processes of water erosion included stream order number, stream length and bifurcation ratios, mean slopes, relief ratios, and hypsometric curve properties.

Malik *et al.* (2011) studied drainage morphometric analysis of Lidder catchment in Kashmir Valley using a Geographic Information System covering an area of 1159.38 km². Various linear and areal aspects of the catchment were computed using GIS. The study showed that the total number, as well as the total length of the stream segments, is maximum in first-order streams and decreases as the stream order increases. The drainage density values of the different watersheds exhibit a high degree of positive correlation (0.97) with the stream frequency (F_s) suggesting that there is an increase in stream population concerning an increase in drainage density and vice versa.

Pingle *et al.* (2012) performed a morphometric analysis of the Maun watershed Tehri-Garhwal district of Uttarakhand using GIS. A survey was conducted at the Maun watershed in the Tehri-Garhwal district of Uttarakhand. The drainage network in the study area was dendritic to sub-dendritic. The results showed the relations among various morphometric attributes of the basin. The drainage density was found to be 3.54 km/km². The circulatory ratio (R_c) was estimated to be 0.52 whereas, form factor and elongation ratio were found to be 0.32 and 0.64, respectively.

Chavare and Shinde (2013) performed a morphometric analysis and determine the drainage pattern and characteristics of the Urmodi river in Satara district basin using topographical maps, SRTM data, and geospatial techniques. Morphometric parameters such as stream order (V), mean bifurcation ratio (6.76), stream frequency (3.66), relief ratio (13.88), elongation ratio (0.52), circulatory ratio (0.44), and form factor (0.21) are calculated using the various technique. The drainage density of the basin is 3.30 km/km².

Dahiphale *et al.* (2014) carried out morphometric analysis of sub-basins in Jaisamand catchment in the Udaipur district of Rajasthan using geographical information system. The total stream length of the catchment is 7351.83 km. The values of the stream length ratio vary from 2.31 to 6.29. The average relief of the catchment is 413 m and it varies from 83 m to 413 m in the sub-basins of the study area. The ruggedness number is 1.74, indicates that the area is extremely rugged with high relief and high stream density.

Rai *et al.* (2014) carried out an analysis of morphometric parameters of the Kanhar river basin at Gidha-Dhodha on the Khudia plateau in Jashpur district of Chhattisgarh with the help of a geographic information system (GIS). Morphometric parameters like stream order (VII), mean stream length (21.47 km.), mean bifurcation ratio (4.92), drainage density (1.72 km/km²), stream frequency (2.45), form factor (0.18), circulatory ratio (0.15) etc., are calculated. The increase in stream length ratio from lower to higher order shows that the study area has reached a mature geomorphological stage.

Sharma (2014) used GIS to perform a morphometric analysis of the Imphal river basin at Imphal city Manipur. In the study area, various linear and areal aspects of the river basin were determined. Drainage density (2.84 km/km²), texture ratio (10.29), circulatory ratio (0.35) and elongation ratio (0.53) showed that the area has a gentle slope, low rainfall, permeable bedrock, fine drainage texture, and narrow and elongated basin. The low value of relief ratios (0.0472) of the basin characterized fewer resistant rocks indicating erosional processes in the area.

Patil *et al.* (2015) carried out a morphometric analysis of the Karwadi-Nandapur watershed which falls under the micro watershed category in the Kayadhu river watershed in the Marathwada region of Maharashtra. Various thematic maps such as drainage, land use, land cover, soil, and contour maps were created using the PCI Geomatica 10.0 software with LISS-III data and Cartosat data along with Google Earth Pro. The results showed that the watershed is of a 3rd order drainage basin. This study proved to be useful for the efficient planning of water harvesting structures and groundwater projects on a watershed basis.

Sahu *et al.* (2016) studied the morphometry analysis of the Minjwada watershed in Nagpur, Maharashtra. They used GIS to perform aspects of linear, areal, and relief. Analysis shows that the drainage pattern is dendritic and the stream order in the watershed varies from 1 to 4. The bifurcation ratio reflects the geological and tectonic characteristics of the watershed and estimated as 3.08. The drainage density of the watershed is 3.63 km/sq. km and it indicates the closeness of spacing of channels. The systematic analysis of the various parameters of the GIS will help you better understand the soil resources distribution, watershed prioritization, planning, and management.

Radwan *et al.* (2017) performed the morphological analysis of the catchment of the watershed dam using an integrated GIS-based approach. The basin is having eighth stream order and a relatively high value of bifurcation ratio (4.012) thus the value of bifurcation ratio is consistent with the high drainage density value of 2.064 km/km², which confirms the impermeability of the subsurface material and mountainous relief on the basin.

Afreeda and Kannan (2018) studied the morphological parameters of the three sub-watersheds in the Nilgiris district of Tamilnadu. They used four different DEM sources: Toposheet, ASTER, SRTM, and Cartosat data to delineate the boundaries of the watershed. Three sub-watersheds i.e., Devarshola, Pykara, and Parsons Valley River were delineated for comparison of morphological parameters. The stream length ratio between streams of different orders indicates that there are different variations due to changes in slope and topography. The lower values of the bifurcation ratio indicate that watersheds have suffered fewer structural disturbances and the drainage pattern has not been distorted because of the structural disturbances.

Bansod and Ajabe (2018) used GIS technology to analyze the topographical features of the Karpi-Kalu watershed in Sangamner tehsil of Ahmednagar district of Maharashtra. The linear, areal, and relief aspects of the basin were estimated. Morphological characteristics show that the watershed had a 4th order stream and the value of elongation ratio (0.734) observed that it was less elongated. The bifurcation ratio is 3.166 indicating a complex structure and low permeability. The drainage density value for the basin area (2.024 km/km²), the basin was observed as poorly drained.

Bera *et al.* (2018) studied the morphometric characteristics of the Adula River Basin in Maharashtra using GIS and Remote Sensing techniques. Stream networks, and different linear, areal, and relief aspects of the basin were analyzed using ArcGIS 10.1 software. The elongation ratio (0.46) and circulatory ratio (0.19) shows the elongated shape of the basin. The relief aspects of the Adula basin reveal that the major part of the basin has low to moderate relief.

Chethan and Vishnu (2018) carried out morphometric analysis of the Thuthapuzha river basin in Tamil Nadu using GIS. This river has dendritic type of drainage network with an elongated basin. Drainage texture is found to be 10.5 which reveals that the intensity of the stream network is finer indicating that the surface runoff is more. The average bifurcation ratio and stream frequency is found to be 1.83 and 2.4 respectively which describe the stream characteristics. The basin is having a ruggedness number of 3.402 which exhibits higher stream velocity, hence Thuthapuzha river basin is prone to soil erosion.

James *et al.* (2018) carried out geomorphological parameters of the Bhagirathi River Basin by using the geospatial technique. A maximum 6th order of stream is encountered in the study area, and the pattern is mainly of dendritic and radial type. The low value of the mean bifurcation ratio

of 4.68 in the basin indicates that there is a less structural disturbance in the drainage pattern of the basin.

Mahala (2019) used remote sensing and GIS to perform hydrological and morphological characteristics of the Kosi river basin and Kangsabati river basin. All linear morphometry of the Kosi river basin shows high food potential, whereas, linear morphometry of the Kangsabati river basin shows less food potentiality. The mean bifurcation ratio (1.56) also indicates that the Kosi river has greater food potentiality than the Kangsabati river. All relief characteristics indicate that the Kosi river basin is in a rejuvenated or young stage of geomorphological development and the Kangsabati river basin is in the mature stage of geomorphological development.

Rai *et al.* (2019) worked on the Varuna river basin in India for morphometry analysis using ASTER-DEM data using the GIS platform. The value of the bifurcation ratio of the basin was observed as 3.92 which indicates that the basin is normal. The elongation ratio of the Varuna basin was calculated as 0.52 which represents the basin is elongated. The drainage density in the basin was observed as 1.72 km/km² which indicates that basin is moderate. A low relief ratio value (0.30) was observed due to the resistant basement rocks of the drainage basin and the low degree of the gradient.

Kale and Deshmukh (2020) performed a morphometry analysis of the WGKD sub-watershed in Sati watershed, Wainganga catchment of Godavari basin. The mean bifurcation ratio is 3.93 indicating that there is negligible structural disturbance and very less distortion in the drainage pattern. Drainage density (2.54) and length of overland flow (1.27) show a low permeability and high runoff. Drainage texture 8.55 with a textural ratio of 6.47 show a fine to very fine texture.

Nirmala *et al.* (2020) described the morphological analysis and the impact of the Suvarnavati river basin and its sub-watersheds in Karnataka on hydrology. The linear, areal, and relief aspects of the morphometric parameters of 13 watersheds were estimated using GIS software. The circularity ratio, elongation ratio and form factor represent the elongated shape of the study area. These studies are useful to mark the groundwater potential zone and artificial recharge area and help plan for watershed management.

Varma *et al.* (2020) carried out a morphometric analysis of the Barkheda Nathu watershed in Bhopal and Sehore district of Madhya Pradesh using GIS. The highest stream order observed in the watershed is 5th with a mean bifurcation ratio (3.345) indicating less lithological heterogeneity and structural command in the area. The value of the elongation ratio was found to be 3.56 which indicates relatively high infiltration capacity and low runoff. A drainage density was observed as 1.24 km/km² for the watershed under study.

Bogale (2021) carried out morphometric analysis of Gilgel Abay watershed in the Lake Tana Basin, upper Blue Nile, Ethiopia. The study addressed linear and areal morphometric aspect of the watershed. The morphometric analysis of the basin revealed that Gilgel Abay is forth-order drainage basin. The mean bifurcation ratio is 5.16, it indicates that basin is mountainous and susceptible to flooding. Low drainage density is observed which is 0.6 km^{-2} . It indicates that basin is highly permeable and thick vegetation cover. Areal aspect of the morphometric analysis revealed that the basin is slightly potential to flooding and soil erosion.

Gautam *et al.* (2021) determined the geomorphological characteristics of Jakham river basin in Udaipur Rajasthan. Remote sensing and GIS techniques was used for determination of geomorphometric parameters. The study involves morphometric linear, areal and relief aspects of Jakham river basin, which is a tributary of Mahi river in southern Rajasthan. The catchment area of river basin is 950 km^2 with dendritic drainage pattern. The mean bifurcation ratio ranges 3.28 to 4.02 indicate the effect of geological formations to the drainage pattern in the basin. Shape factor (circulatory and elongation ratio) indicates that sub-watersheds are less to moderate elongated in shape have less susceptibility to peak flood.

Kandekar *et al.* (2021) estimated the geomorphological characteristics of the Agadgaon watershed by using Remote Sensing and GIS. The main watershed consists of two sub-watersheds i.e., W1 (296 ha) and W2 (96 ha). The morphometric parameters include the linear, areal, and relief aspects. The mean bifurcation ratio of W1 was 4 and 2.45 for W2 which shows that the basin was largely controlled by structures. It shows high drainage density indicates that the catchment area is more prone to flooding and a low value of relative relief indicates a peak discharge rate.

Patil *et al.* (2021) performed the morphological analysis of the Asond watershed by using the GIS technique. Various areal, linear, and relief aspects were estimated in the study area. The total lengths of the streams and the total number of streams for each order decrease as the order increase. The bifurcation ratio is 1.61 and the Form factor is 0.44. The Elongation ratio (0.9) showed that the watershed is oval. Drainage density (1.98 km/km^2) that is basin is poorly drained.

Salunke and Wayal (2021) performed a quantitative analysis of the Panzara river to determine the linear, areal, and relief parameters of the Panzara river. The drainage density (2.56) and mean bifurcation ratio (5.065) indicate that the less effect of structural deformations on the basin. The stream frequency of the river basin is 3.20 with low relief and high permeability. This study shows that GIS technology applications are reliable, fast, and able to manage large databases for the management of river basins.

Singh *et al.* (2021) performed a morphometric analysis of Dudhnai watershed of Dudhnai river in Meghalaya using ArcGIS software. The results of bifurcation ratio, drainage density,

drainage intensity and constant of channel maintenance showed that Dudhnai watershed is a well-dissected watershed with less risk to flooding and soil erosion. However, significantly high values of infiltration number and ruggedness number obtained are indicative of very low infiltration which may result in high surface runoff and soil erosion. The study also revealed that channel erosion is stronger than sheet erosion in the basin.

Lakshminarayana *et al.* (2022) determined the morphological parameters of Tidi watershed in Udaipur district of Rajasthan, India using remote sensing and geographic information system approaches. GIS was used in evaluation of basic, linear, areal and relief aspects of morphometric parameters. The Tidi watershed occupies an area of 114.36 km² with a dendritic drainage pattern. The basin has drainage density value of 1.74 km/km² which exhibits gentle to moderate slope terrain and medium dense vegetation. The mean bifurcation value of the watershed is 3.88 and the value varies from 2 to 4.14 which shows that the drainage network formed on homogeneous rocks when the influences of geologic structures on the stream network were negligible. An elongation ratio of 0.79 implies that the watershed is less elongated in shape.

Shekar and Mathew (2022) carried out morphometric analysis of Murredu watershed in Telangana State. Evaluation of various morphometric characteristics such as linear aspects, relief aspects, and aerial aspects has been carried out for every sub-watershed to prefer ranking. The sub-watersheds were categorized into three groups as low, medium, and high, for soil and water conservation priority based on morphometric and LULC analysis. The coefficient of regression results reveals that stream length and stream order, and stream number and stream order, have a strong association.

2.2 Determination of Nash Model Parameters

Nash (1957) derived an equation for the instantaneous unit hydrograph by assuming the operation performed by the watershed on the effective rainfall is analog to the routing of flow through a series of the linear reservoir. He demonstrated the method by which the instantaneous unit hydrograph of this form can be derived from a complex flood.

Rosso (1984) related the Horton's order ratio, such as bifurcation ratio (R_B), stream length ratio (R_L), and stream area ratio (R_A), to the parameters of the Nash IUH model based on a geomorphological model of the catchment response. He found that the shape parameters, n , of the Nash model were dependent on Horton's ratios R_B , R_L , and R_A of a catchment. The scale parameter, K , of the Nash model is time-varying and depends on both, the catchment geomorphology, and the average streamflow velocity along with the stream network.

Kumar *et al.* (2007) derived a Geomorphological Instantaneous Unit Hydrograph (GIUH) from the geomorphological characteristics of the Ajay catchment in Eastern India. To determine the Geomorphological characteristics, they used the GIS package and Integrated Land and Water Information System (IL WIS). They compared the performance of GIUH based Clark and Nash model with the HEC-1 package. The DSRO hydrograph was computed with reasonable accuracy with Clark and Nash model.

Bahremand and Mostafazadeh (2009) calculated the mathematical computation of the Nash model for predicting the hydrograph of the Jafar Abad watershed located in Golestan Province in Iran. The model has two ways. The result of this study concluded that the Nash model presents an acceptable performance in the Jafar Abad River basin. Thus, the Nash model, as a simple model, can be easily applied to any ungauged watershed still expecting some reasonable results.

Choi *et al.* (2011) estimated the Nash model parameters based on the concept of the geomorphological dispersion stemming from spatial heterogeneity of flow paths within a catchment. Finally, the IUHs, estimated from regional analysis, and modeled in hydrodynamic approaches, are performed, the proposed formulas for the Nash model in this study can be a useful tool to simulate rainfall-runoff processes in ungauged basins.

Ghumman *et al.* (2012) developed an IUH for a large watershed with hill torrent flows in the semi-arid region of Pakistan. It was divided into a series of linear cascades and hydrologic parameters required for Nash's conceptual model and was estimated using the geomorphology of the basin. Model efficiency was found to be more than 90% and root mean square error to be about 5%. The values of bifurcation ratio R_B , length ratio R_L , and area ratio R_A for Kaha watershed were found to be 4.8847, 2.43, and 5.18, respectively. Various values of storage coefficient were used and it was observed that the value determined from geomorphology and the dynamic velocity produced the best results.

Pandit and Atre (2013) studied the hydrological response of different watersheds viz. Agadgaon watershed, Kolhewadi watershed, Maheshgad watershed, and Sasure watershed in Ahmednagar, Maharashtra using geomorphologically determined parameters of the conceptual model of IUH. The Nash IUH model was used for GIUH development.

Nourani *et al.* (2014) developed three rainfall-runoff simulation models based on geomorphology. Out of those two models were unit hydrograph (UH) model and one contained a non-linear routing approach. GIS tool was used for determining the watershed geomorphological parameters. The results of these models compared with Nash's black box model and the geomorphological SCS model for the Amaneh watershed, Iran.

Himanshu *et al.* (2015) derived Nash model parameters from GIUH for a Himalayan River using ASTER DEM. The geomorphological parameters of the basin were estimated from 30 m ASTER (Advanced Space Borne Thermal Emission and Reflection Radiometer Sensor) DEM (Digital Elevation Model) and LandSat imageries using ARC-GIS 9.3 and ERDAS IMAGINE 9.3 software. The parameters of the Nash Model 'n' and 'k' have been derived from the qp and tp of the GIUH. Utilizing these values of n and k and the two-parameter equation given by Nash the complete shape of the GIUH has been derived.

Patel (2016) derived a geomorphological unit hydrograph for the Devak basin of the Ujha river in the western Himalayas using remote sensing and GIS. Various geomorphological characteristics like bifurcation ratio, length ratio, and area ratio using GIS software and found as 4.263, 3.720, and 4.997 respectively. The results obtained from DEM were computed with the results obtained from the toposheet and variations in different aspects were studied.

Katarzyna (2017) estimated the Nash model parameters (n & k parameters) of a catchment discharge hydrograph at the Kostrze gauging station in Crocow, Poland. Effective rainfall was calculated for each rainfall episode using the SCS-CN method. A direct discharge hydrograph was calculated based on an effective rainfall hyetograph and using the Nash Model. It has been shown that the impact of the Nash Model parameter estimation method on discharge hydrographs is minimal.

Rao (2018) developed Geomorphological Instantaneous Unit Hydrograph (GIUH) for the Khanapur watershed which is an ungauged watershed lying in the mid-Godavari basin. Using GIS software various maps like drainage maps, contour maps, soil maps, etc. were prepared and by using this Horton's morphological parameters and other parameters required were estimated. For estimation of dynamic parameter velocity, he used the time of concentration method, and Nash parameters n and k were calculated which were found as 3.81 and 0.24 h respectively.

Patil and Bhagwat (2019) determined the suitable method of synthetic unit hydrograph for various ungauged or data paucity watershed characteristics. They used four different methods in which the Conceptual SUH method contains Clark's method and the Nash IUH method. In the Nash method, mathematical parameters like n and k are found. The geomorphological class of the SUH models can be thought of as the most useful and appealing approach for while predicting runoff in ungauged or data paucity catchments

Monajemi *et al.* (2021) derived a new conceptual model for producing instantaneous unit hydrograph (IUH) is introduced by a linear combination of the Nash model, which assumes that the discharge from a reservoir is a linear function. The results show that the model yields more

accurate results compared to other studied models and may be considered a new model for simulating IUHs.

2.3 Development of geomorphological instantaneous unit hydrograph

Rodrigues and Valdes (1979) in their pioneering study first introduced the concept of Geomorphological Instantaneous Unit Hydrograph (GIUH) which was subsequently generalized by Gupta et al. (1980).

Gupta *et al.* (1980) worked on the representation of an Instantaneous Unit Hydrograph based on geomorphology. A general but explicit representation of the IUH of a basin was obtained based on the geomorphology. Two examples were developed which led to the analytical formulae developed for an IUH. These examples were formally analogous to the solution that would result if the basin was represented in terms of linear reservoir and channels, respectively in series and parallel.

Jakeman *et al.* (1989) computed the instantaneous unit hydrograph for two small upland catchments in Wales. Their approach was based upon three factors. The results demonstrate that at sampling intervals of the order of one-hour, successful separation of quick and slow flow components can be achieved with short time series of rainfall and streamflow.

Sudharsanan *et al.* (2010) derived GIUH, which uses the geomorphological parameters, is used to stimulate basin runoff. The main aim of this study is to develop a 1-H Unit Hydrograph (UH) from the GIUH using Linear Geomorphological Model (LGM) with the help of GIS. The overland region for each path is delineated and measured with the help of GIS. GIUH is developed for 15 minutes time step using the probability density function. Lagging the GIUH, 1-H Unit Hydrograph (UH) is prepared.

Khalegi *et al.* (2011) compared the accuracy and reliability of a geomorphological model with Snyder, SCS, Triangular, Rosso, and Geomorphoclimatic unit hydrographs. The comparison of calculated and observed hydrographs showed that the geomorphologic model had the most direct agreement for the parameters of peak time and peak flow of direct runoff. The study's results confirm the high efficiency of the Geomorphoclimatic Unit Hydrograph and its ability to increase simulation accuracy for runoff and hydrographs.

Narayan *et al.* (2012) studied GIS-supported Instantaneous Unit Hydrograph (GIUH) of Varuna River basin using geomorphological characteristics. GIUH could use as a transfer function for modeling the transformation of excess rainfall into surface runoff, in which excess rainfall is an excitation to the hydrological system.

Himanshu *et al.* (2013) estimated the flood of the site situated at Joshimath, district Chamoli, Uttarakhand along with a few geomorphological parameters. They derived results using ArcGIS and ERDAS Imagine on data acquired 1-hour Synthetic Unit Hydrograph peak discharge at that site was found to be 878.5 Cumecs, based on which design flood was estimated considering PMP and peak flood discharge at the site was found to be 6188 Cumecs.

Khaleghi *et al.* (2014) carried out regional analysis using the Geomorphologic Instantaneous Unit Hydrograph (GIUH) method. He used the GIUH technique for simulation of rainfall-runoff processes and also for determination of the shape and dimensions of outlet runoff hydrograph in a 37.1 km² area for Ammameh catchment located in northern Iran. He concluded that Statistical analysis of the models demonstrated that the GIUH model had the smallest main relative and square error.

Nema and Lohani (2015) used the geomorphologic instantaneous unit hydrograph concept for runoff prediction in an ungauged catchment. Classical techniques for design flood or flow peaks estimation use historical rainfall-runoff data for unit hydrograph development and modelling. The geomorphological characteristics of a catchment were related with the shape and scale parameters of the Nash IUH to derive the complete shape of the GIUH based Nash model. The DSRO hydrographs are computed with reasonable accuracy by the GIUH based Nash model, which simulate the DSRO hydrographs of the catchment considering the study watershed to be ungauged.

Rigon *et al.* (2015) presented an overview of Geomorphological Instantaneous Unit Hydrograph theories. The history of the GIUH is subdivided into three major sections. The first is based on a treatment of water discharges with 'travel times' that could provide a rich interpretation of the theory of the IUH. The second section focuses on the Width-Function-based IUH (WFIUH) approach. The third approach is to estimate the water budget by 'travel times', which derives from a suitable use of the water budget equation, and some hypotheses have been introduced and disentangled. This study presented the excursus of the GIUH theories, and analyzed their successful path, without hiding their limitations

Roy and Thomas (2016) developed a unit hydrograph for the Bharathpuzha river basin. The unit hydrograph developed by two-parameter gamma distribution and three structures could not be obtained due to certain restrictions in acquiring the data from authorized agencies. The results obtained is the unit hydrograph developed by the gamma distribution is matching with the one developed by the CWC method.

Hussain (2017) developed a synthetic unit hydrograph at Kakkadavu dam in Kerala. With the development of synthetic unit hydrograph, a 1-day Probable Maximum Flood (PMF)

hydrograph, by convolution and two Bells system approach at Kakkadavu dam site have also been developed. The peak of the probable maximum flood hydrograph by using convolution method and two Bells approach was found to be 2570 m³/s and 3142 m³/s respectively.

Cho *et al.* (2018) developed the concept of Clark's unit hydrograph. In Distribution-Clark, the Soil Conservation Service (SCS) curve number method is utilized to estimate spatially distributed runoff depth, and a set of separated unit hydrographs is used for runoff routing to obtain a direct runoff flow hydrograph. Results demonstrate a relatively good fit to observed streamflow, with a Nash-Sutcliffe efficiency (ENS) of 0.84 and coefficient of determination (R^2) of 0.86, as well as a better fit in comparison with outputs of spatially averaged rainfall data simulations for two models including HEC-HMS.

Sulistiyowati *et al.* (2018) developed unit hydrograph modeling using Geomorphological Instantaneous Unit Hydrograph (GIUH) Method. Analysis of physical watershed parameters was conducted on ArcGIS. A sensitivity analysis was conducted on parameter of RL and Nash model k. Accuracy test of the simulated GIUH runoff hydrograph using Nash-Sutcliffe Efficiency (NSE) shows that Keduang watershed gives a satisfying result, while Wiroko watershed gives less satisfactory result. The inaccuracies occur due to limited flood events used to derive the observed UH and stream tributaries that were not properly modeled based on Strahler method.

Ashwini and Mamatha (2019) developed GIUH based Nash model for Hemavathi catchment using ASTER DEM (30m) with the help of ArcGIS 10.3 software. The values of n and k for various dynamic velocities were derived and by substituting the values of R_a (0.465), R_b (3.38), and R_l (1.98) final GIUH was obtained, and then obtained GIUH was compared with the CWC method of the unit hydrograph. The results show that the obtained GIUH with a dynamic velocity of 4 m/s for the catchment shows closer agreement with the CWC approach.

Bamufleh *et al.* (2020) derived the geomorphological instantaneous unit hydrograph of arid basins in Saudi Arabia. The equivalent Horton-Strahler ratios are used to derive GIUH based on the Nash and Frechet hydrograph model. The comparison between the measured and the equivalent hydrographs of Nash and Frechet models for each event shows that there are obvious discrepancies in terms of peak discharge (Q_P), time to peak (T_P), and time lag (T_{Lag}) and the runoff volume. The results of Nash models are relatively better to represent the measured hydrograph.

Arafat *et al.* (2020) studied the hydrograph of Palu river water. By using the hydrograph model of flood plan for Palu River Watershed with the approach of Synthetic Unit Hydrograph Nakayasu, hydrograph calculation of flood in Palu river watershed obtained alpha coefficient equal to 0,651 and T_r coefficient 0,3 with cash value model 71,491%.

Zhang and Niu (2021) estimated the parameters of the Nash Instantaneous Unit Hydrograph using the particle swarm optimization method. Compared with the reported results, the simulation accuracy in terms of peak magnitude and the peak time is all improved, and the convergence rate is significantly improved, which demonstrates the superiority of the particle swarm method in parameter optimization of the Nash IUH method.

Hassan *et al.* (2022) developed Geomorphological Instantaneous Unit Hydrograph (GIUH) Model for a Watershed of Damodar Valley Corporation, Hazaribagh (Jharkhand), India. The model was calibrated and validated for five storm events, by comparing their ordinates with the ordinates of IUH. The GIUH was tested with APE of the ordinate of peak discharge. On comparison, it was found that, most of the GIUH models overestimated the runoff at initial stage, while underestimated at the latter stage in comparison to the IUHs. The Absolute Prediction Errors (A.P.E.) were computed to be 5.97, 18.09, 23.32, 9.64 and 7.52% of the ordinates of peak discharge for the storm events of June 24 -25 (1992), October 12 -13 (1993), November 2 -3 (1993), June 28 (1994) and August 6 (1996), respectively.

CHAPTER III: MATERIALS AND METHODS

This chapter briefly describes the study area, data used, and methodology for the determination of geomorphological characteristics of the watershed using RS and GIS, to derive the Nash-based Geomorphological Instantaneous Unit Hydrograph (GIUH) is presented.

3.1 Study area:

In Jagbudi river catchment, Chatav watershed, Khed (Ratnagiri) was selected as the study area for the present research. Jagbudi is the tributary of the Vashishti river and it meets Vashishti near Bahiravali. It originates from Khopi in the Ratnagiri district. The watershed is located at Chatav in Khed tehsil and district Ratnagiri of Maharashtra state. It lies between latitude ranges from 17°71' N to 17°90' N and longitude ranges from 73°32' E to 73°63' E. The total area of the watershed is 17700 ha. The watershed is demarcated on Survey of India toposheet No. 47 G/9 and 47 G/10 (1:50,000). The Jagbudi river basin has witnessed high rainfall and consequent floods of various intensities during recent years.

The average annual rainfall in the study area is 3511 mm and the mean annual temperature is 23.8°C. It has an average elevation of 25 metre. Alphonso mangoes are grown in the area around the town. The study area lies between Kashedi Ghat and Bhoste ghat. The region surrounding the study area is mostly mountainous.

3.2 Data Collection and Pre-processing

Various types of data were gathered from a variety of sources to the needs of the study.

1. Hourly rainfall and hourly runoff data of seven years in the study area were used for the development of GIUH and observed unit hydrograph. It was collected from the Hydrological Data Users Group Nasik, Maharashtra.
2. SRTM DEM data were downloaded from the (<http://srtm.csi.cgiar.org>) website. The DEM was processed for further development of the slope map.
3. Toposheets of the study area were downloaded from the Survey of India website which was used for the validation of the boundary of the watershed.

3.2.1 Software and System

Data creation, data analysis, and output generation were carried out using Arcs-GIS10.4 Arc-GIS 10.4 is a sophisticated program for data manipulation, overlay analysis, hydrological analysis, geographic analysis, and other tasks. MS Office was utilized for purposes of documentation and analysis.

LOCATION MAP

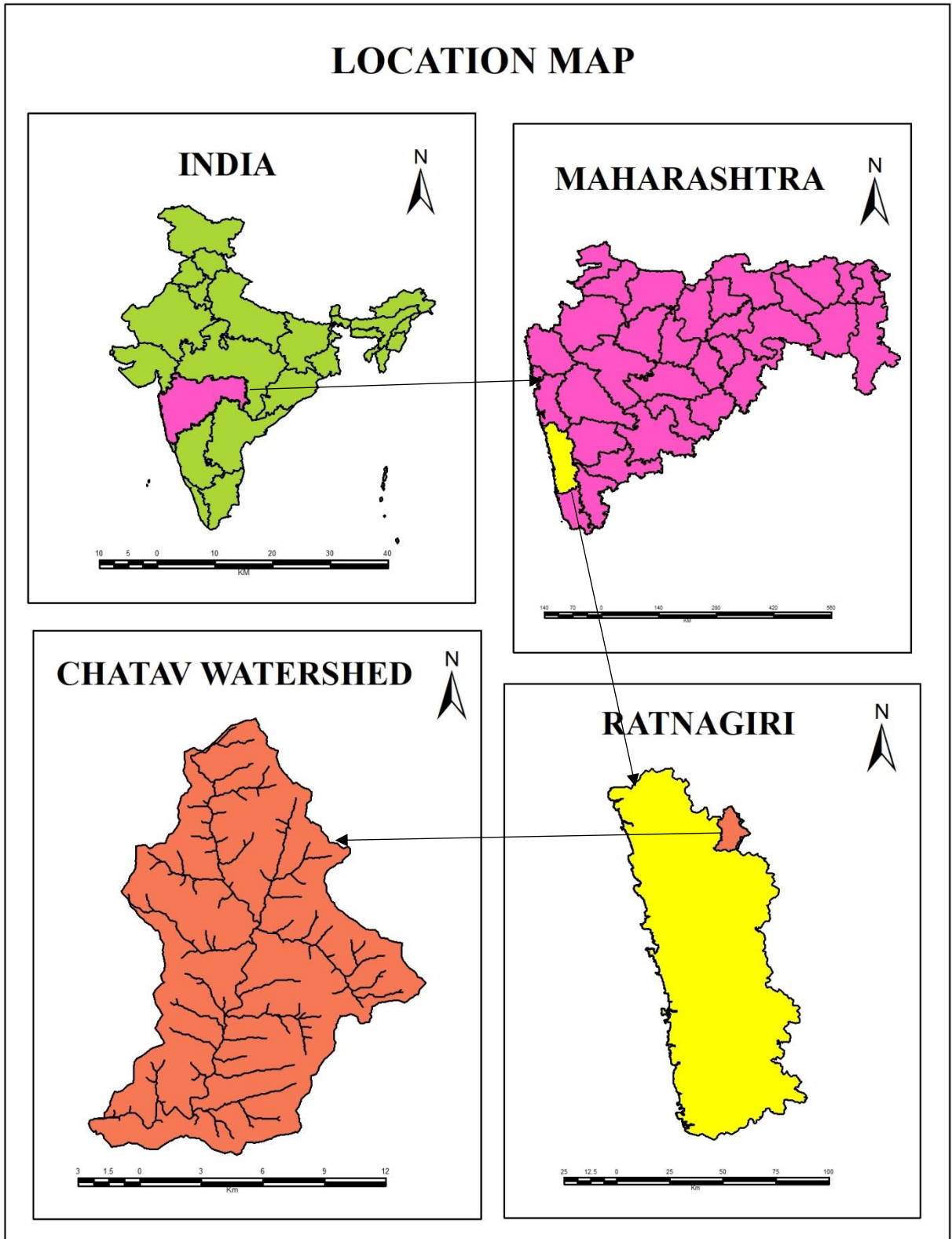


Fig 3.1 Location Map of the Study Area

3.3 Development of Thematic Maps:

Thematic map focuses in a specific idea and theme. For this project, a variety of approaches and interpretive techniques were used to create thematic maps. A thorough description of the methods used to achieve the objectives is covered in this part.

3.3.1 Watershed Delineation

A Watershed is a hydrological unit from which runoff resulting from precipitation flows past a single point into a large stream, river, lake, or pond. Watershed delineation plays an important role in watershed management. ArcGIS 10.4.1 was used to carry out the watershed delineation. The watershed delineation was then validated using toposheets with the numbers 47 G/9 and 47 G/10. Toposheets offer details about the location, drainage system, and contours. The following flow chart was used to determine the watershed's boundaries.

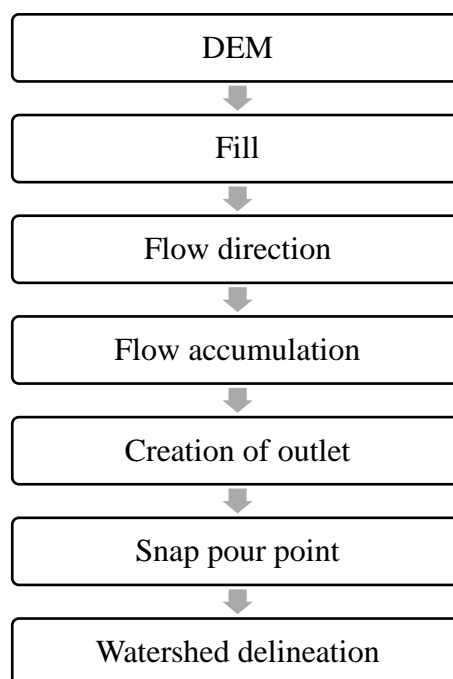


Fig. 3.2 Flowchart for the watershed delineation

3.3.2 Slope Map

The runoff, recharge, and movement of surface water are all influenced by the topographic features of the area. One of the crucial factors for developing activities is slope. Slope map gave the idea about the topography of land. The Digital Elevation Model (DEM) obtained from SRTM DEM imageries (<http://srtm.csi.cgiar.org>) of 30 m spatial resolution was used to create the slope map for the study area. The continuous representation of elevation values over a topographic surface by a regular array of altitudes, related to a common datum, is known as a Digital Elevation Model (DEM). ArcGIS software was used to create a slope map of the research area. One of the main needs for creating a Geographical Instantaneous Unit Hydrograph was the slope map.

3.3.3 Drainage Network Map

Drainage network maps of study area provide an idea of slope, elevation, and flow generation. Drainage networks help to delineate catchment areas. The drainage network for the study area was extracted from Shuttle Radar Topography Mission (SRTM) DEMs using spatial analyst tool in ArcGIS software using the raster calculator. The drainage network was extracted and validated by using Survey of India toposheet. This map helps to determine parameters such as total length of all streams, average stream length ratio, bifurcation ratio, form factor, elongation ratio, stream frequency, stream order and stream length.

3.4 Geomorphological Characteristics of Watershed

Morphometric analysis of watersheds is the best method to identify the relationship of various aspects in the area. The geometry of the drainage basin and its stream channel system required the following measurements.

1. The linear aspect of the drainage network
2. An areal aspect of the drainage basin
3. Relief aspect of channel network and contributing ground slopes

3.4.1 Linear Aspects of Drainage Networks

It is concerned with the streams and their network. Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed (Afreeda and Kannan, 2018). It includes a one-dimensional component. These are one-dimensional properties as mentioned below.

3.4.1.1 Watershed Area

It is defined as the area enclosed within the boundary of the watershed divide. It is the most important characteristic of the hydrologic design.

3.4.1.2 Basin Length

It is the greatest distance between the outlet and any point on the perimeter.

3.4.1.3 Stream order (U)

Stream order is the ranking of a stream channel segment in a drainage network (Salunke and Wayal, 2021).

3.4.1.4 Stream number

The number of stream channels in its order is known as stream number.

3.4.1.5 Stream length (L_u)

Stream length is the length of all the streams having order u . (Bansod and Ajabe, 2018).

3.4.1.6 Bifurcation ratio (R_b)

Bifurcation ratio, defined as the ratio of the number of streams in N^{th} order to $N+1^{\text{th}}$ order (Horton, 1945), is an important parameter describing stages of river development. Strahler (1957) observed that R_b characteristically ranges from 3 to 5 for the watershed in which geologic structures do not distort the drainage pattern.

$$R_b = \frac{N_u}{N_{u+1}} \quad \dots (3.1)$$

Where,

R_b = bifurcation ratio

N_u = number of streams of order u

N_{u+1} = number of streams of order $u+1$

3.4.1.7 Mean Stream Length (\bar{L}_u)

The mean stream length is defined as the summation of the total length of all streams to the number of streams (Suresh R. 2019)

$$\bar{L}_u = \frac{\sum_{i=1}^N L_u}{N_u} \quad \dots (3.2)$$

Where,

\bar{L}_u = mean length of the channel of order 'u',

N_u = total no. of stream segment of order 'u'.

3.4.1.8 Stream Length Ratio (R_L)

It is the ratio of the mean length of stream (L_u) of a particular order to the mean stream length of the next lower order (L_{u-1}) (Horton, 1945)

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \quad \dots (3.3)$$

Where,

\bar{L}_u = Average length of stream of order u

\bar{L}_{u-1} = Average length of stream of order $u-1$

3.4.1.9 Stream Area Ratio (R_A)

The channel area of order, A_i is the area of the watershed that contributes to the channel segment of order i and all lower order channels. It can be quantified as

$$R_A = \frac{\bar{A}_u}{\bar{A}_{u-1}} \quad \dots (3.4)$$

Where,

\bar{A}_u = Average basin area of stream of order u

\bar{A}_{u-1} = Average basin area of stream of order $u-1$

3.4.2 Areal Aspects of Drainage Network

The areal aspect represents the characteristics of the catchment area and describes how the catchment area controls and regulates the hydrological behavior.

3.4.2.1 Form Factor (R_F)

It determines the shape of the basin. Form factor is defined as the ratio of basin area to the square of the basin length (Horton, 1945)

$$R_F = \frac{A_u}{L_b^2} \quad \dots (3.5)$$

Where,

A_u = Area of basin

L_b = Length of the basin

3.4.2.2 Circularity ratio (R_c)

Circularity ratio is the ratio of basin area to the area of circle having equal perimeter as the perimeter of drainage basin. The R_c proportional is mostly concern with its length, land use land cover, stream frequency and slope (Smith, 1950).

$$R_C = \frac{A_u}{A_c} \quad \dots (3.6)$$

Where,

A_u = basin area

A_c = area of circle

3.4.2.3 Elongation Ratio (R_e)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). The elongation ratio typically varies from 0.6 to 1.0.

$$R_e = \frac{D_c}{L_{bm}} \quad \dots (3.7)$$

Where,

D_c = Diameter of circle with the same area as the basin

L_{bm} =Maximum basin length

3.4.2.4 Drainage Density (D_d)

It is the ratio of total length of channels of all orders in the basin to the drainage area of the basin (Horton, 1945). This term was first introduced by Horton (1932)

$$D_d = \frac{\sum_{i=1}^K \sum_{i=1}^N L_u}{A_u} \quad \dots (3.8)$$

Where,

D_d = Drainage density

K = Principal order = highest order stream

L_u =Length of stream segments

A_u =basin area, km²

N =total no. of streams

3.4.2.5 Constant of Channel Maintenance (C)

It is the ratio between the area of the drainage basin and total length of all the channels, expressed as square meter per meter. It is also equal to reciprocal of drainage density.

$$C = \frac{1}{D_d} \quad \dots (3.9)$$

Where,

D_d = Drainage density

3.4.2.6 Length of Overland Flow (L_g)

The length of overland flow is approximately equal to half of the reciprocal of drainage density (Horton, 1945). It is the length of water over the ground before it gets concentrated into definite stream channels.

$$L_g = \frac{1}{2D_d} \quad \dots (3.10)$$

Where,

D_d = Drainage density

3.4.3 Relief Aspects of Drainage Network

Linear and areal features have been considered as the two-dimensional aspect lie on a plan. The third dimension introduces the concept of relief or altitude (Kandekar *et al.* 2021).

3.4.3.1 Watershed slope

It is important morphometric parameter.

3.4.3.2 Relief

Relief is the maximum vertical difference between highest and lowest point in the watershed. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

3.4.3.3 Relief Ratio (R_r)

It is the ratio of relief (H) to the horizontal distance (L) on which relief was measured (Schumm, 1956). The R_r shows the basins average steepness and is measure of the rate of erosion. A high basin relief gives circular basin shape and small basin are increases the R_r value of any basin.

$$R_r = \frac{H}{L_h} \quad \dots (3.11)$$

3.4.3.4 Relative Relief (R_R)

It is the ratio of maximum watershed relief to the perimeter of watershed (Melton, 1957).

$$R_R = \frac{H}{P} * 100 \quad \dots (3.12)$$

3.4.3.5 Ruggedness Number (R_n)

Ruggedness number (R_n) is a cross product of relief (H) and drainage density (D) in the same unit (Strahler 1957).

$$R_n = H * D_d \quad \dots (3.13)$$

3.5 Development of average unit hydrograph for catchment

In order to forecast the discharge flow for each given rainfall event, it is required to construct an average unit hydrograph for the watershed. Therefore, it is essential to create an average unit hydrograph for the catchment that may be used to predict the discharge flow for every specific rainfall event. When compared to a unit hydrograph that was generated for each event, the average unit hydrograph of the watershed provides less accurate estimates of the time to peak and peak flow rates. However, in order to generate a unit hydrograph that may be applicable to the widest variety of rainfall events and antecedent soil moisture conditions, the averaging process required to be carried out (Kumar *et al.* 2002).

3.5.1 Storm Selection

In order to precisely determine the amount and distribution of rainfall over the watershed, it was preferable to collect as many rainfall records as possible from the Chatav watershed. In order to obtain a more precise UH, our study analyzed rainfall information spanning 7 years. The following method was used for storm selection and storm screening.

1. Individual storms that occur.
2. Storms that evenly distribute rain throughout the period of rainfall excess.
3. Storm with uniform spatial distribution over the entire watershed.

Due to these limitations, the unit hydrograph technique can only be applied to watershed areas smaller than 5000 km².

3.5.2 Storm Screening

Before they were finally chosen for analysis, the preliminary screening of acceptable storms for determining the unit hydrograph were screened using more stringent and restrictive criteria.

1. The rainfall event's duration should be between 10 and 30 per cent of the basin's lag time or time to peak.
2. The selected storm's direct runoff should have a range of 1 to 4.5 cm.
3. It is necessary to analyze a sufficient number of storms to determine the ordinates for a particular unit hydrograph on average.

The derivation of the unit hydrograph had been completed once the proper concurrent rainfall-runoff events had been chosen. The effective rainfall was calculated from the observed rainfall, and the resulting direct runoff was separated from the overall hydrograph as the first steps in the derivation of a unit hydrograph.

3.5.3 Base flow separation

Base flow separation is somewhat arbitrary and there is no reliable method to accurately separate base flow from surface runoff (Bedient and Huber, 1992). Straight line method was employed for this study among the three accessible methods. The starting point of the surface runoff was connected to a point on the hydrograph's recession limb where normal base flow resumes by means of an inclined line.

3.5.4 Determination of excess rainfall

The volume of surface runoff was determined by the area above the base flow separation line and within the hydrograph. The estimated direct volume was divided by the watershed's area to determine the equivalent depth of runoff (mm) for the catchment area. This was the effective rainfall from the storm.

The next stage was to identify the portion of the overall rainfall that made up the effective rainfall. The excess rainfall was calculated using the Φ -index, an easier method since stream flow data was available. The constant rate of abstraction (mm/h) that will result in an excess of rainfall is known as the Φ -index. The depth of direct runoff across the watershed equals the total depth of this excess rainfall (Chow, 1988).

3.5.5 Determination of Effective rainfall hydrograph (ERH) from Runoff Hydrograph (RH) and stream flow hydrograph

Effective rainfall is the sum of the total rainfall and the losses from interception, evaporation, transpiration, depression storage, and infiltration. The steps for determining ERH were as follows.

1. The stream flow data and rainfall data were derived as sample data and pulse data, respectively, for a single storm.
2. After separating the base flow from the stream flow, the DRH was determined by deducting the base flow from the stream flow.
3. Direct runoff volume (V_d) was calculated.
4. By dividing the volume of direct runoff by the watershed's area, the equivalent depth of direct runoff was calculated.
5. By dividing DRH by excess rainfall, the effective rainfall hydrograph was calculated (equivalent depth of direct runoff)

3.5.6 Unit Hydrograph Development

The unit hydrograph method was only applied to normal storm events where the storm hydrograph had a smooth shape. The reciprocal of the depth of rainfall excess for each occurrence was multiplied by each ordinate of the direct runoff hydrograph to create the 1-hour unit hydrograph. The direct runoff hydrograph was changed into a unit hydrograph by using the depth of rainfall excess as a proportionality constant.

3.6 Derivation of Nash model parameters from q_p and t_p of GIUH

3.6.1 Instantaneous Unit Hydrograph (IUH)

A conceptual unit hydrograph known as an Instantaneous Unit Hydrograph (IUH) shows the direct runoff hydrograph produced by an instantaneous precipitation with one cm of effective rainfall that has an infinitesimally short duration in the watershed. It has a single peak with a narrow base. The benefit of IUH over unit hydrograph is that IUH gets beyond the issue of rainfall duration and the limitation on distribution of rainfall. The Nash IUH approach is the most very well widely accepted of the several methods available for the derivation of IUH.

3.6.2 The Nash Model

The Nash (1957) had proposed the conceptual model based on the concept of routing of the instantaneous inflow through a cascade of linear reservoirs with equal storage coefficients. The equation for instantaneous unit hydrograph for the Nash model is given as

$$u(0, t) = \frac{1}{\Gamma(n)} \frac{1}{k} \left(\frac{t}{k}\right)^{n-1} e^{-t/k} \quad \dots (3.14)$$

Where,

$u(0,t)$ = ordinate of IUH, hour⁻¹

t = sampling time interval, hour

n = number of linear reservoirs

K = storage coefficient, hour

$\Gamma(n)$ = standard gamma function

3.6.3 Parameter estimation of the GIUH based Nash Model

The relationship used for peak discharge q_p and peak time t_p of the IUH as a function of geomorphologic characteristics of the catchment (Rodriguez-Iturbe and Valdes, 1979) were given as follows,

$$q_p = 1.31R_L^{0.43} \left(\frac{V}{L_w}\right) \quad \dots (3.15)$$

and

$$t_p = 0.44 \left(\frac{L_w}{V} \right) \left(\frac{R_B}{R_A} \right)^{0.55} R_L^{-0.38} \quad \dots (3.16)$$

Where,

q_p = Peak discharge, m³/s

R_L = Stream length ratio

V = maximum velocity for peak flow, m/s

t_p = Peak time, hour

w = stream order of the catchment

L_w = length of highest order stream channel in the basin, km

R_B = Bifurcation ratio

R_A = Stream area ratio

t_b = base flow time

The assumption for the shape of IUH with increasing q_p and decreasing t_p was verified with available data.

Multiplication of Equations 3.15 and 3.16 gave a non-dimensional term (Rosso, 1984) which was independent of dynamic velocity and storm characteristics. It was purely a function of the geomorphologic characteristics which were as follows

$$q_p \times t_p = 0.5764 \left(\frac{R_B}{R_A} \right)^{0.55} R_L^{0.05} \quad \dots (3.17)$$

On the other hand, the derivative of equation 3.14 gave the time to peak as follows

$$t_p = (n - 1) \times K \quad \dots (3.18)$$

Substituting this equation 3.17 in equation 3.14 the peak discharge q_p of the IUH was obtained as

$$q_p = \frac{(n-1)^{(n-1)}}{K \times \Gamma(n)} \times e^{-(n-1)} \quad \dots (3.19)$$

The product of equation 3.17 and equation 3.18 gave the equation for the Nash model in terms of n . Thus,

$$q_p \times t_p = \frac{(n-1)^n}{\Gamma(n)} \times e^{-(n-1)} \quad \dots (3.20)$$

Equating equation 3.16 and equation 3.19, the following relationship arrived

$$\frac{(n-1)^n}{\Gamma(n)} \times e^{-(n-1)} = 0.5764 \left(\frac{R_B}{R_A} \right)^{0.55} R_L^{0.05} \quad \dots (3.21)$$

The IUH parameter Nash model n was obtained as follows, (Karegoudar *et al.* 2005)

$$n = 3.29 \left(\frac{R_B}{R_A} \right)^{0.78} R_L^{0.07} \quad \dots (3.22)$$

The Nash model parameter k for the given velocity (V) was obtained using equation 3.15 and equation 3.17 and the value of the parameter k is as follows;

$$k = 0.44 \frac{L\Omega}{V} \left(\frac{R_B}{R_A} \right)^{0.55} R_L^{-0.38} \frac{1}{(n-1)} \quad \dots (3.23)$$

The entire shape of the Nash-based GIUH was determined using the derived values of n and k . In this methodology, the velocity (V) is the dynamic parameter to estimate the value of k .

A typical velocity value is needed to derive IUH using the GIUH model. Different methods are employed to calculate the dynamic parameter velocity, by using the relationship between the velocity relationship and the Kirpich formula. Dynamic parameter velocity can also be computed using the relationship between excess rainfall intensity along with geometric cross-sectional properties, Manning's roughness coefficient, etc. However, numerous researchers have successfully used this approach for medium and large-sized watersheds (Kumar *et al.* 2002; Kumar *et al.* 2007; Bhagwat *et al.* 2011; Khalegi *et al.* 2011; Mehboob *et al.* 2014). This method depends on the geometrical characteristics of the channel cross-section and the assessment of the excess rainfall intensity of Manning's roughness coefficient. Although the method is time-consuming and necessitates a variety of hydrologic and other data for a watershed, it took both the characteristics of the watershed and the rainfall characteristics into account when estimating peak discharge. Since both of them play a significant part in the generation of runoff. As a result, this method provided accurate peak discharge and time to peak estimation (Kumar *et al.* 2002). By keeping these things in mind for the present research this approach was selected.

3.6.4 Development of relationship between intensity of excess rainfall and the velocity:

In their research, Rodriguez and Valdes (1979) made the assumption that the dynamic velocity (v) at any given time during the storm could be regarded as constant throughout the basin. As the storm intensifies, the basin's characteristic of velocity changes everywhere around the basin. However, because the peak discharge for this ungauged catchment was unknown, this criterion for estimating velocity could not be used. So, the velocity was estimated using relationship of velocity with intensity of excess rainfall.

3.6.4.1 Relationship between intensity of excess-rainfall and the velocity of runoff:

This approach requires the information regarding geometric properties of the gauging section and the Manning's roughness coefficient. The geometric properties of gauging station were

known and Manning's roughness coefficient was possible to assume from available information (Kumar *et. al* 2002). The step involved in this approach were as below

- i. Cross sectional area (A), wetted perimeter (P) and Hydraulic radius (R) were computed based on records of cross-sectional details corresponding to different depths.
- ii. The frictional slope was assumed equal to bed slope of the channel.
- iii. An appropriate value of Manning's roughness coefficient (n) had been chosen from the values given in the literature for various surface condition of the channel.
- iv. The discharge (Q) was computed using the Manning's formula corresponding to each depth.
- v. Depth verses discharge and depth verses area curves were plotted.
- vi. The equilibrium discharge (Q_e , m^3/s) corresponding to an excess rainfall intensity (I, mm/hr) was computed using the equation:

$$Q_e = 0.2778 i A_c \quad \dots (3.24)$$

Where,

A_c is catchment area in km^2 .

- vii. The depth corresponding to equilibrium discharge (Q_e) was find out using depth verses discharge curve
- viii. The area was computed corresponding to the depth computed at step (vii) using the depth verses area curve.
- ix. Velocity (V) was determined by dividing the discharge (Q_e) by the area computed at step (viii).
- x. Repeat steps (vi) to (ix) to find equilibrium velocity with respect to different intensities of excess-rainfall.
- xi. Develop the relationship between equilibrium velocity and excess-rainfall obtained at step (x) in the form:

$$V_e = ai_e^b$$

By using the method of least squares. Here, a and b are the regression coefficients.

3.6 Error functions used for evaluation of the computed hydrographs:

The research suggests using a variety of error functions to evaluate GIUH-based hydrographs. The majority of the time, two to three error functions out of six were employed to compare the observed hydrograph and the GIUH-based hydrograph. Six error functions were used in this investigation. The error functions employed for evaluation of the hydrographs derived by GIUH based Nash model approach for comparison with observed hydrographs. These error functions are (i) Efficiency (ii) Absolute average error, (iii) Root mean square error, (iv) Average error in volume (v) Percentage error in peak (vi) Percentage error in time to peak.

3.6.1 Efficiency (EFF)

Efficiency is computed as follows (Nema and Lohani, 2015)

$$EFF = \frac{\sum_{i=1}^n (Q_{oi} - \bar{Q})^2 - \sum_{i=1}^n (Q_{oi} - Q_{ci})^2}{\sum_{i=1}^n (Q_{oi} - \bar{Q})^2} \times 100 \quad \dots (3.25)$$

Where,

Q_{oi} = i^{th} ordinate of the observed discharge

\bar{Q} = average of the ordinates of observed discharge

Q_{ci} = Computed discharge

3.6.2 Absolute average error (AAE)

Absolute average error (AAE) is computed as follows (Nema and Lohani, 2015)

$$AAE = \frac{\sum_{i=1}^n |Q_{oi} - Q_{ci}|}{n} \quad \dots (3.26)$$

Where,

n = No. of ordinates

3.6.3 Root mean square error (RMSE)

Root mean square error (RMSE) is computed as follows (Nema and Lohani, 2015)

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (Q_{oi} - Q_{ci})^2}{n}} \quad \dots (3.27)$$

3.6.4 Average error in volume (AEV)

Average error in volume (AEV) is computed as follows (Nema and Lohani, 2015)

$$AEV = \frac{(Vol_o - Vol_c)}{n} \quad \dots (3.28)$$

Where,

Vol_o = Observed runoff volume

Vol_c = Computed runoff volume

3.6.5 Percentage error in peak (PEP)

Percentage error in peak (PEP) is computed as follows (Nema and Lohani, 2015)

$$PEP = \frac{(Q_{op} - Q_{cp})}{Q_{op}} \times 100 \quad \dots (3.29)$$

Where,

Q_{op} = Observed peak discharge

Q_{cp} = Computed peak discharge

3.6.6 Percentage error in time to peak (PETP)

Percentage error in time to peak (PETP) is computed as follows (Al-Wagdany and Rao 1998).

$$PETP = \frac{OT_p - CT_p}{OT_p} \times 100 \quad \dots (3.30)$$

Where,

OT_p = Time to peak of observed discharge

CT_p = Time to peak of computed discharge

The disparities between GIUH-based hydrographs and observed hydrographs were compared using these error functions. Error function values were used to check for errors and the acceptability of GIUH-based hydrographs for ungauged watersheds.

CHAPTER IV: RESULTS AND DISCUSSION

The purpose of this chapter is to discuss the creation of a Geomorphological Instantaneous Unit Hydrograph (GIUH) of the Jagbudi river catchment using Remote Sensing and a Geographical Information System. This chapter presents the findings and analysis of various thematic maps created from remote sensing data as well as a comparison between the observed unit hydrograph and the unit hydrograph created using the geomorphological instantaneous unit hydrograph. The accuracy of the hydrologic response of the basin's estimation was examined in the results analysis. Findings are discussed below for conclusions.

4.1 Thematic Map Layers

4.1.1 Slope Map Layer:

The slope map of the study area showed the variations in the slopes in different parts of the watershed. The slope map was obtained from delineated watershed. Higher slopes were concentrated in outer part of the watershed, whereas lower slopes were observed in middle most part of the watershed. The slope map of the study area was divided into six classes as shown in Table 4.1. The slope map is shown in Figure 4.1.

Table 4.1 Spatial distribution of slope classes in Jagbudi River catchment

Sr. No	Slope	Class	Area (ha)	Area (%)
1.	0-3	Nearly level	3339	18.79
2.	3-5	Gentle	4052	22.80
3.	5-10	Moderately gentle	4188	23.56
4.	10-15	Steep	3507	19.73
5.	15-20	Moderately steep	2031	11.43
6.	>20	Very steep	652	3.67

4.1.2 Drainage Network Map Layer

Drainage network map of the study area i.e., Chatav watershed was created by utilizing SRTM-DEM. The drainage network showed that the Chatav watershed has fifth order drainage network. The drainage channels in study area are mainly fed by primary rivers with the maximum length of drainage channels being 80.24 km, covering approximately 69.54% of the total length of the drainage channels. The next order, was his second order with a length of 43.49 km. This was 16.72% of the total length of drainage, followed by 3rd order stream (21.94 km, 6.41%) and 4th order stream (19.98 km, 1.47%).

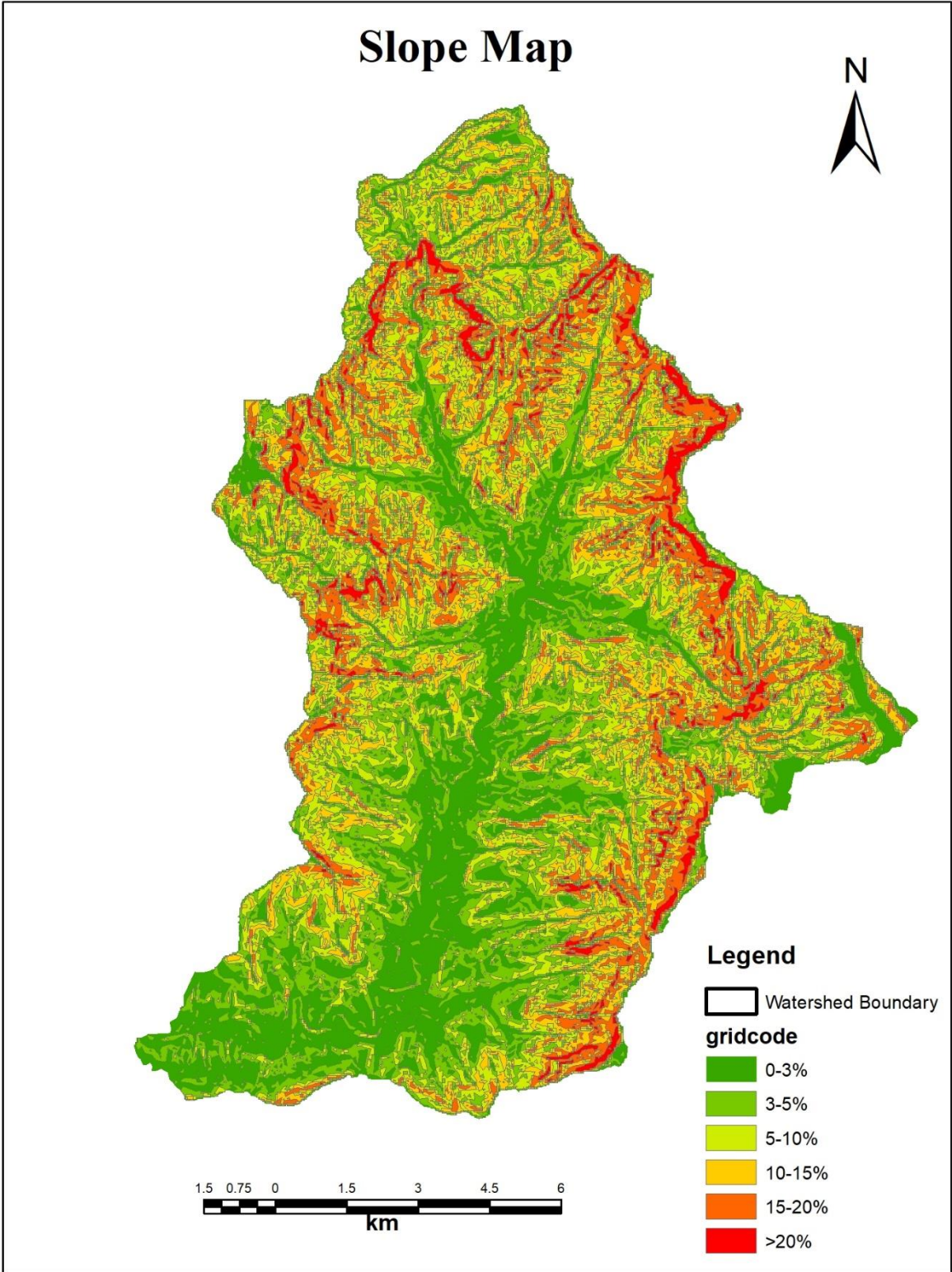


Fig 4.1 Slope Map of Chatav Watershed

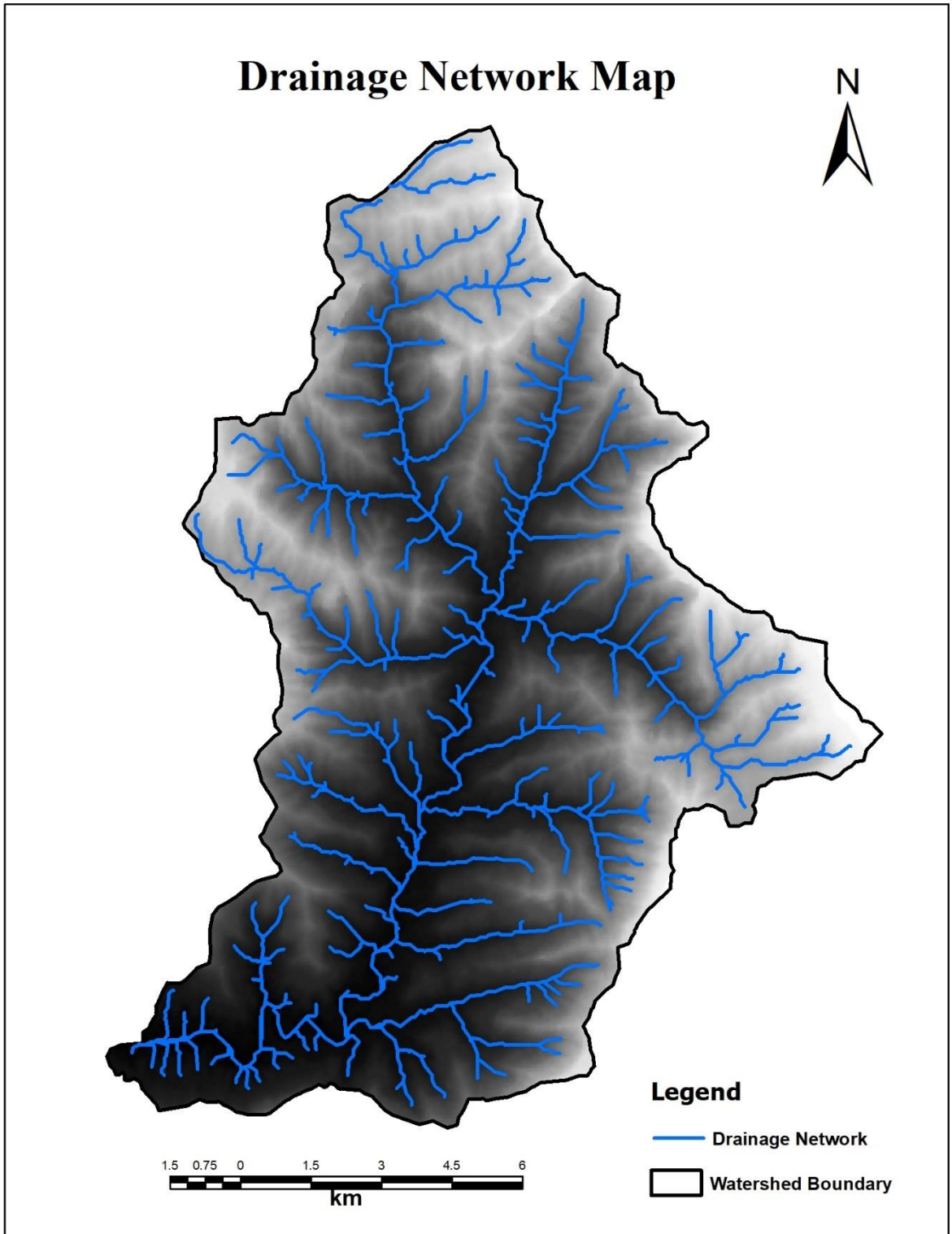


Fig 4.2 Drainage Network Map of Chatav Watershed

4.2 Morphological characteristics

The Chatav watershed of Jagbudi river basin has 4th order drainage network. It is having the total area of 17773.58 ha. Linear, Areal and Relief aspects of drainage network are given in Table 4.2, 4.3, 4.4 respectively.

4.2.1 Linear Aspects of Drainage Networks

Table 4.2 Linear aspects of the drainage network

Stream Order (u)	No. of Streams (N _u)	Stream Length km	Mean Stream Length km	Mean Stream Area km ²	Bifurcation Ratio (R _b)	Stream Length Ratio (R _L)	Stream Area Ratio (R _a)
1	93	80.245	0.862	0.965			
2	39	43.490	1.115	3.269	2.384	1.292	3.384
3	30	21.948	0.731	5.215	1.3	0.656	1.595
4	22	19.989	0.908	8.078	1.363	1.241	1.548
Average					1.68	1.06	2.17

4.2.1.1 Stream order

The study area has a 4th order drainage basin covering an area of 177 sq. km. There was a total of 184 streams, out of which 93 are of 1st order, 39 are of 2nd order, 30 are of 3rd order and 22 are of 4th order streams. The higher stream order of the watershed indicated the greater discharge and higher velocity of the stream flow. The channel segment of the drainage basin has been ranked according to the Strahler stream ordering method.

4.2.1.2 Stream number

It was revealed from Table 4.2, that number of streams of particular order decreases with an increase in stream order. It means that the number of streams of any given order was less than that of the immediate lower order but more than the next higher order. It is observed in the Strahler approach. The higher number of streams in lower order led to lesser permeability and infiltration. It was observed that maximum frequency was in the case of first-order streams. It indicates that there is the possibility of flash floods after heavy rainfall on the downstream side. As the stream order increased, a decrease in stream frequency was observed.

4.2.1.3 Stream length

One of the basin's most important hydrological parameters is stream length since it provides information about surface runoff. A sub watershed's streams of various orders were counted and their lengths from mouth to drainage divide were measured. Areas with greater slopes and finer textures tend to have streams that are somewhat shorter in length. The maximum total length of stream segments was observed in the first order i.e., 80 km and decreases with an increase in the

stream order. That means, results show that as the stream order increases with decrease in stream numbers.

4.2.1.4 Bifurcation ratio (R_b)

Bifurcation ratio (R_b) of watershed varied from 1.3 to 2.38. The bifurcation ratio depends upon the geological and lithological development of the drainage basin (Strahler, 1964). The R_b values of the study area (Table 4.1) indicated that there was a decrease in R_b values from the first order streams to the third order streams and again increase in the R_b values was noticeable from the third order stream to the fourth order stream. These differences are depending upon the geological and lithological development of the drainage basin (Strahler, 1964). The mean bifurcation ratio was 1.68 which indicates that the drainage pattern has strong structural control.

4.2.1.5 Mean stream length

Mean stream lengths of the first order, second order, third order, and fourth-order streams were 0.862 km, 1.115 km, 0.731 km and 0.908 km respectively. This may be due to the geomorphologic, lithological, and structural control and contrast. The length of the highest order channel causes a maximum effect on the peak of the GIUH. If the length of the highest order stream is more, it is expected to produce higher runoff (Khalegi *et al.*, 2011).

4.2.1.6 Stream length ratio (R_L)

Stream length ratio (R_L) of the II/I order was 1.292, III/II order was 0.656, and IV/III order was 1.241. These differences in the ratio in the research area were brought on by variances in topography and slope. Out of all the Horton's ratios, the stream length ratio has the greatest impact on the peak of the GIUH peak. Higher R_L values would create favorable conditions for flooding in the downstream area. The R_L values do not depend upon the size of the river basin but it is characterized by basin shape.

4.2.1.7 Stream area ratio (R_a)

Stream area ratio (R_a) of II/I order was 3.38, III/II order was 1.59, IV/III order was 1.54. Average of stream area ratio for Chatav watershed is 2.17, which is considered as low. At low values of the stream area ratio ($R_a < 6$) the peak discharge of the hydrograph decreases but at higher values of the area ratio ($R_a > 6$) the peak discharge of the hydrograph increases with increase in area ratio.

4.2.2 Areal Aspects of Drainage Networks

The areal aspect represents the characteristics of the catchment area and describes how catchment area controls and regulates the hydrological behavior.

Table 4.3 Areal aspects of the drainage network

Sr. No.	Morphometric Parameters	Symbol	Value
1	Area (sq. km)	A	177.73
2	Perimeter (km)	P	72.54
3	Basin Length (km)	L_b	21.4
4	Form factor	R_F	0.388
5	Circulatory ratio	R_C	0.42
6	Elongation ratio	R_L	0.70
7	Drainage density (km/km ²)	D_d	0.932
8	Constant of channel maintenance (km ² /km)	C	1.072
9	Length of overland flow (km)	L_g	0.53

4.2.2.1 Form factor

The results of the study show that form factor was observed as 0.38. The lower value of form factor indicates that watershed is elongated in shape. An elongated basin with low form factor indicated that the basin had flatter peak for longer duration. Flood flows in such elongated basins are easier to manage than of the circular basin because the whole volume of discharge doesn't get accumulated at same time at outlet like circular basin.

4.2.2.2 Circularity ratio

The circulatory ratio of Chatav watershed was 0.424. When the basin is shaped like a complete circle, the ratio is equal to one, falling to 0.785 when it is square, and continuing to fall until the basin is elongated (Miller, 1953). The higher circular basin will affect peak discharge in high rainfall season. The current value of the circularity ratio indicated that the basin is elongated in shape, with high to moderate relief and a structurally controlled drainage system. Additionally, it showed that the basin has a low runoff discharge.

4.2.2.3 Elongation ratio

It is an important index for the analysis of basin shape. This parameter is used to determine whether the basin's shape is similar to a circular. Roundness and a low level of integration within a basin are indicated by elongation ratio values between 0.1 and 0.6. Watershed shapes can be classified using the index of elongation ratio, which includes circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (less than 0.5). The elongation ratio of watershed is calculated as 0.7. It is observed that the watershed is elongated in shape. It suggests that the watershed is seeing flatter peak flows over a longer period of time.

4.2.2.4 Drainage density

The drainage density indicates the closeness of spacing of channels, for the whole basin. Based on drainage density, watersheds are classified as low (less than 2.0 km/km²), moderate (2.0-2.5 km/km²), high (2.5-3.0 km/km²), or very high (greater than 3.0 km/km²). The drainage density of the Chatav watershed is calculated as 0.93 km/km². It comes under the low drainage density which indicates that the watershed has dense vegetation cover and low relief.

4.2.2.5 Constant of channel maintenance

The constant of channel maintenance shows how many square kilometers of basin surface are needed to create and maintain a channel that is one kilometer long. It is the inverse of the drainage density (Schumm, 1956). As a result, as drainage density increases, constant of channel maintenance decreases and vice versa. The constant of channel maintenance was found as 1.07 indicates that the study area is under the influence of less structural disturbances.

4.2.2.6 Length of overland flow

The length of the overland flow is referred as the distance that precipitated water must travel over the surface of the ground in order to reach a stream. It is a significant independent variable that has a significant impact on the amount of water needed to exceed a specified erosion threshold. A high value for the length of the overland flow indicates a high level of surface runoff, whereas a low value for the length of the overland flow indicates a low level of surface runoff. The length of overland flow of the study area was 0.53 km²/km which indicates the low surface runoff.

4.2.3 Relief aspects of drainage network

The various factors of relief assessed in this study are explained as follows and given in table 4.4.

Table 4.4 Relief Aspects of the Drainage network

Sr. No.	Parameters	Value
1	Relief (km)	1.181
2	Relief ratio	0.055
3	Relative relief	1.628
4	Ruggedness number	1.098

4.2.3.1 Relief (H)

Relief is the vertical distance between highest and lowest of watershed. It is also known as the maximum watershed relief (H). The total relief for Jagbudi river catchment was 1.18 km. Minimum relief shows the maximum time of concentration and low peak discharge.

4.2.3.2 Relief ratio (R_r)

It indicates the overall steepness of the drainage basin and related degradation processes. The present study shows that the relief ratio for Jagbudi river catchment is 0.055. The presence of a hilly region in the catchment was indicated by this relief ratio value.

4.2.3.3 Relative relief (R_R)

It is an indication of the regular elevation of the watershed from peak to the outlet point. Relative relief for watershed was found to be 1.628 which is considered to be low. These low relative relief values indicate that peak discharge rates and catchment erosion are likely to be less.

4.2.3.4 Ruggedness number (R_n)

The value of ruggedness number was observed 1.09. Low ruggedness number value found in study area due to gentle slope and low peak discharge. This provides an idea of the overall roughness of the water.

4.3 Geomorphological Instantaneous Unit Hydrograph:

The geomorphological structure of the drainage basin has decisive role in quantifying the hydrograph. It is also difficult to determine which characteristics have a significant influence. Stream network properties were used to evaluate hydrograph parameters in the GIUH model.

Horton's ratios were used to estimate the shape parameter (n) of the river catchment. The shape parameter is unaffected by the velocity of the stream. It revealed that the morphological characteristics of the watershed have a distinct influence on runoff production. It is unaffected by the characteristics of the rainfall. The scale parameter (k) is affected by catchment geomorphology and stream dynamics such as stream velocity; however, stream flow velocity (V) was the main explanatory factor of the GIUH, reflecting variation in effective rainfall. The technique used for the watershed's velocity prediction has a significant impact on the accuracy of the unit hydrograph predicted using the GIUH technique.

The shape parameter (n) for the catchment was found to be 2.7. The parameter K was inversely proportional to the dynamic velocity and was extremely sensitive to changes in the dynamic velocity. The computed velocities of the various storms were higher, which could be attributed to higher slopes of the main channels and low values of k (less than 0.6 h) (Alemngus *et al.* 2014).

The Nash parameters n and k were used to develop GIUH. Validation of the GIUH-based Nash model for runoff was done using observed unit hydrographs. GIUH was analyzed using seven-year rainfall-runoff data from the catchment. Each year, five storms were chosen. For the Basin, a total of 35 storms were studied. Year-wise analysis of each storm is described below.

4.3.1 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2003:

The runoff producing intense storms were recorded on the 28th June, 29th June, 30th June, 9th July, and 28th August in the year 2003 were chosen. The rainfall excess for selected storms was calculated. The calculated value of rainfall excess was used to predict velocity. Peak discharge and time to peak were calculated using the estimated velocity value. Nash parameters, velocity, time to peak and peak discharge for selected storms of year 2003 are mentioned in Table 4.5

Table 4.5 Unit hydrograph parameters for different storm events in year 2003

Shape Parameter	Date	V (m/s)	K (h)	t _p (h)	Q _p (m ³ /s)
n=2.7	28-Jun-2003	1.613	2.591	4.403	40.969
	29-Jun-2003	2.403	1.738	2.955	59.185
	30-Jun-2003	2.531	1.650	2.806	62.201
	09-Jul-2003	1.663	2.512	4.271	42.176
	28-Aug-2003	1.014	4.117	6.998	25.862

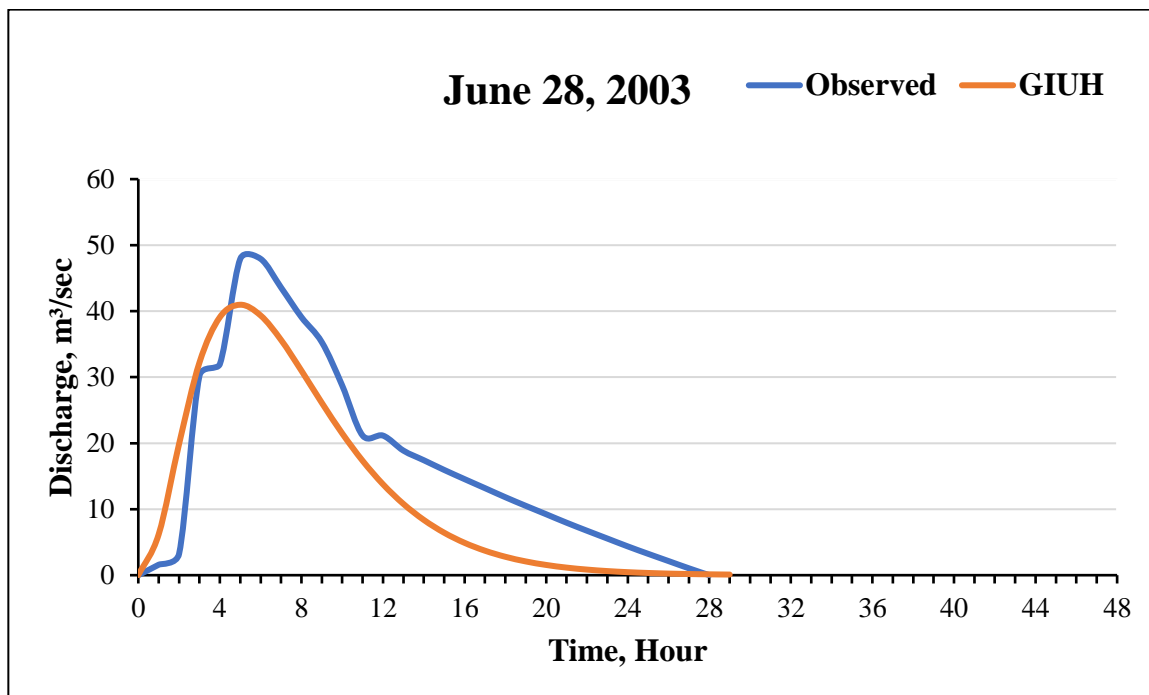


Fig 4.3 One h-Unit hydrograph on June 28, 2003

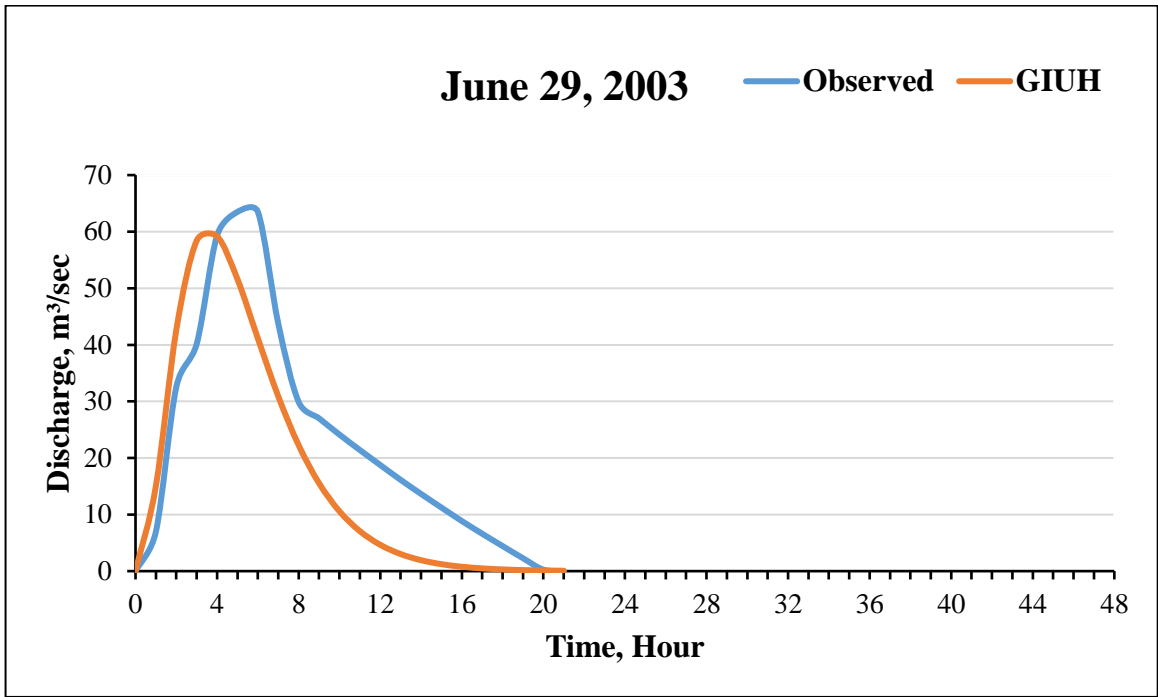


Fig 4.4 One h-Unit hydrograph on June 29, 2003

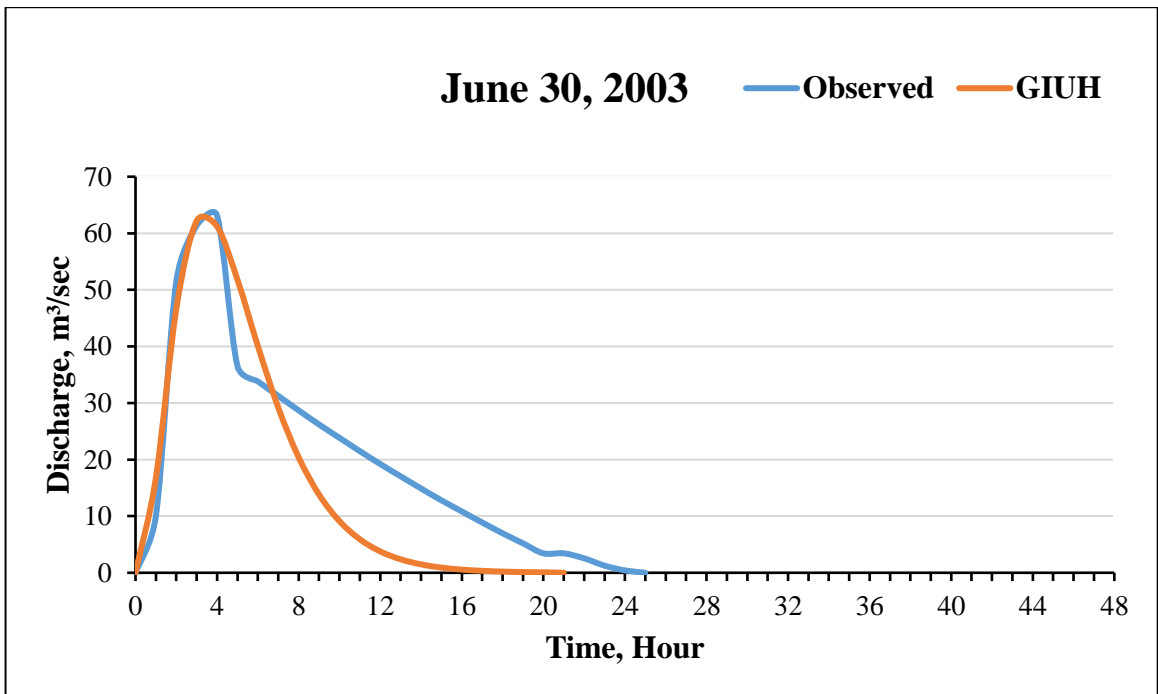


Fig 4.5 One h-Unit hydrograph on June 30, 2003

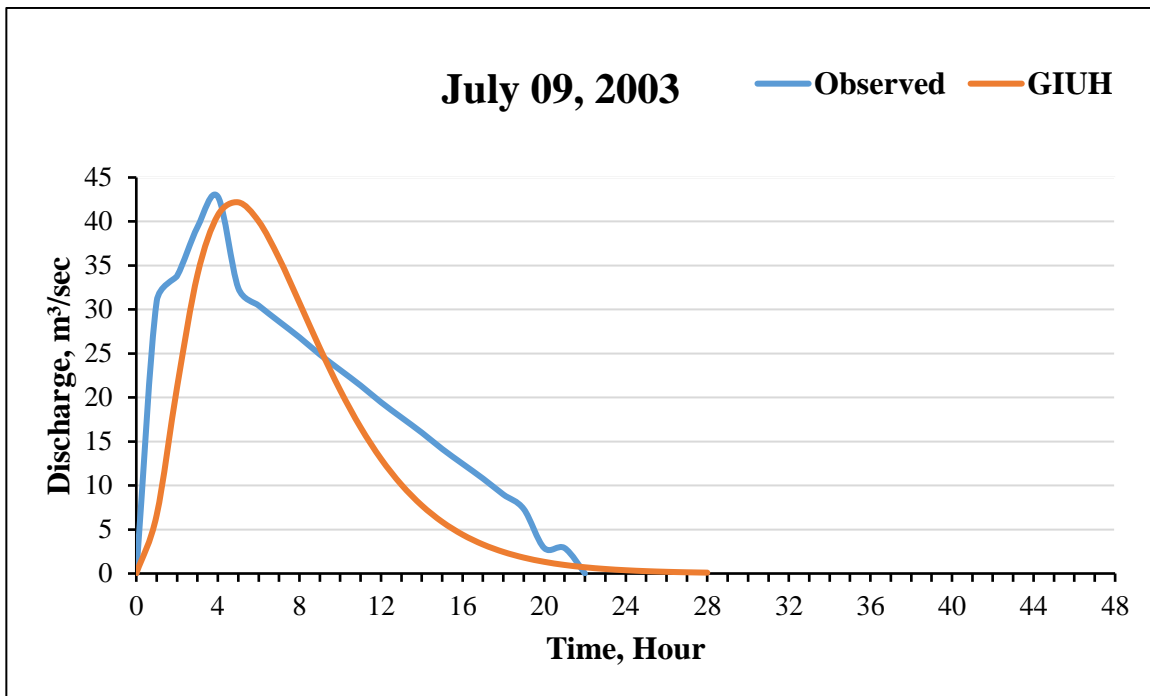


Fig 4.6 One h-Unit hydrograph on July 09, 2003

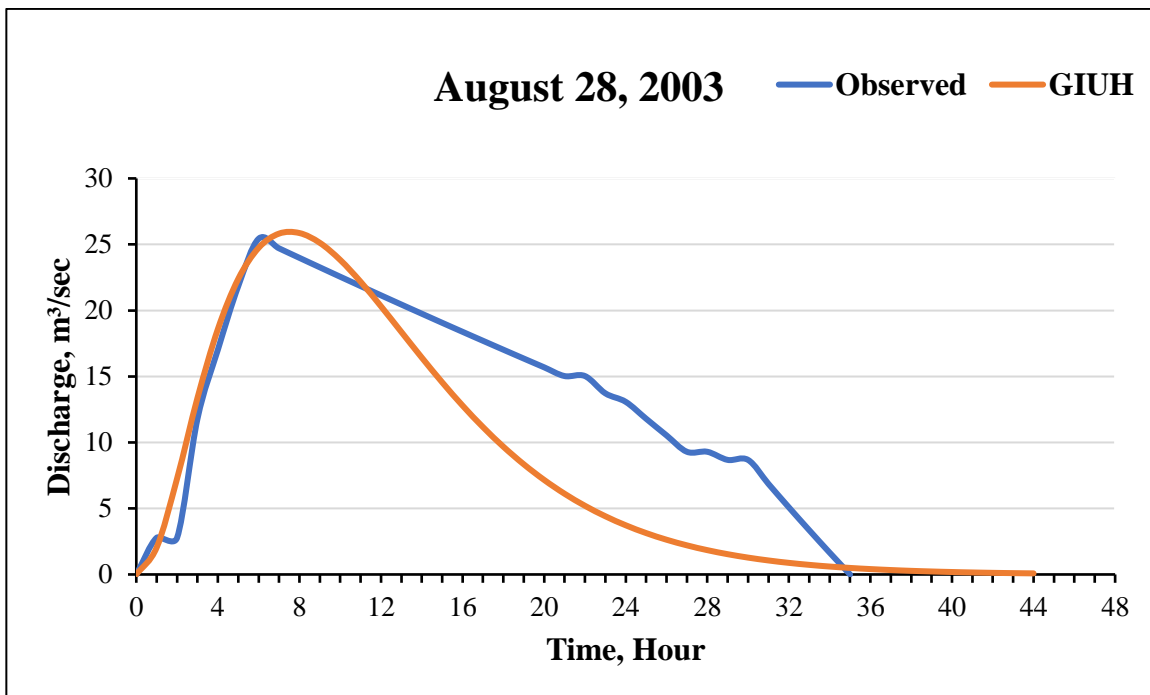


Fig 4.7 One h-Unit hydrograph on August 28, 2003

It is observed from the results presented in Table 4.1 shows that the velocity is inversely proportional to time to peak. From the selected storms of year 2003, the maximum velocity of 2.531 m/s was observed on June 30th, 2003 with a scale parameter 1.650. An influence of average channel velocity on GIUH is presented in figures from 4.3 to 4.7. It is also observed that with increase in velocity scale parameter decreases and it tends to increase peak discharge and going to decrease time to peak.

The Nash model-derived unit hydrographs were compared to the observed ones using various performance evaluation indices, including efficiency (EFF), absolute average error (AAE), root mean square error (RMSE), average error in volume (AEV), percentage error in peak (PEP), and percentage error in time to peak (PETP). Table 4.6 shows the performance evaluation of a selected storm in the year 2003.

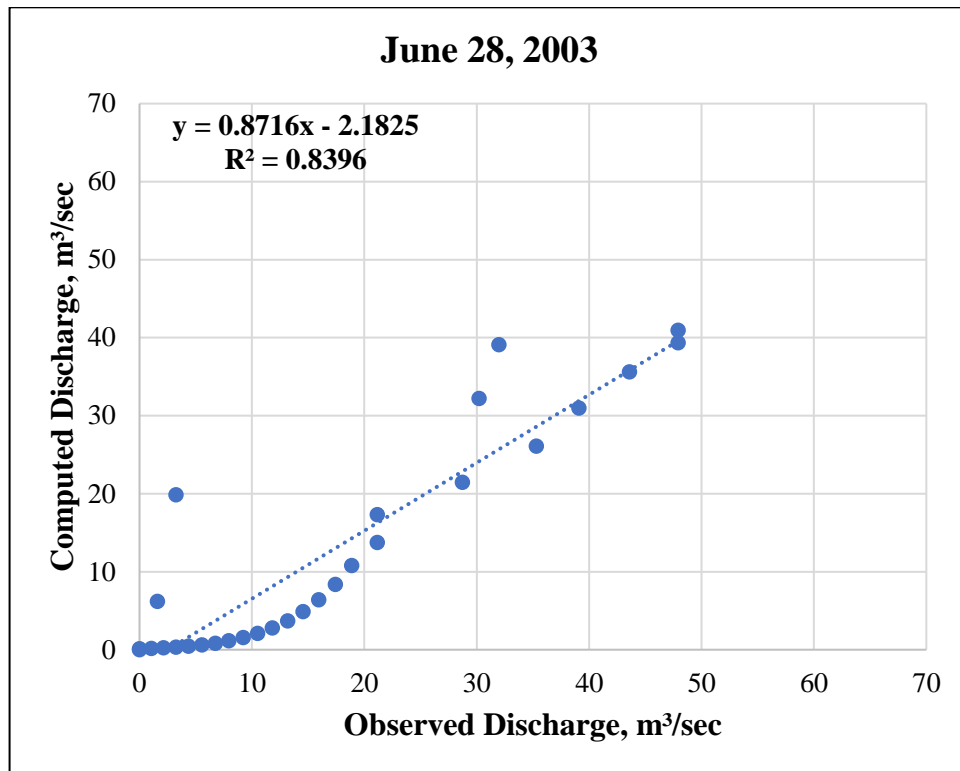


Fig 4.8 Variation of computed discharge with observed discharge on June 28, 2003

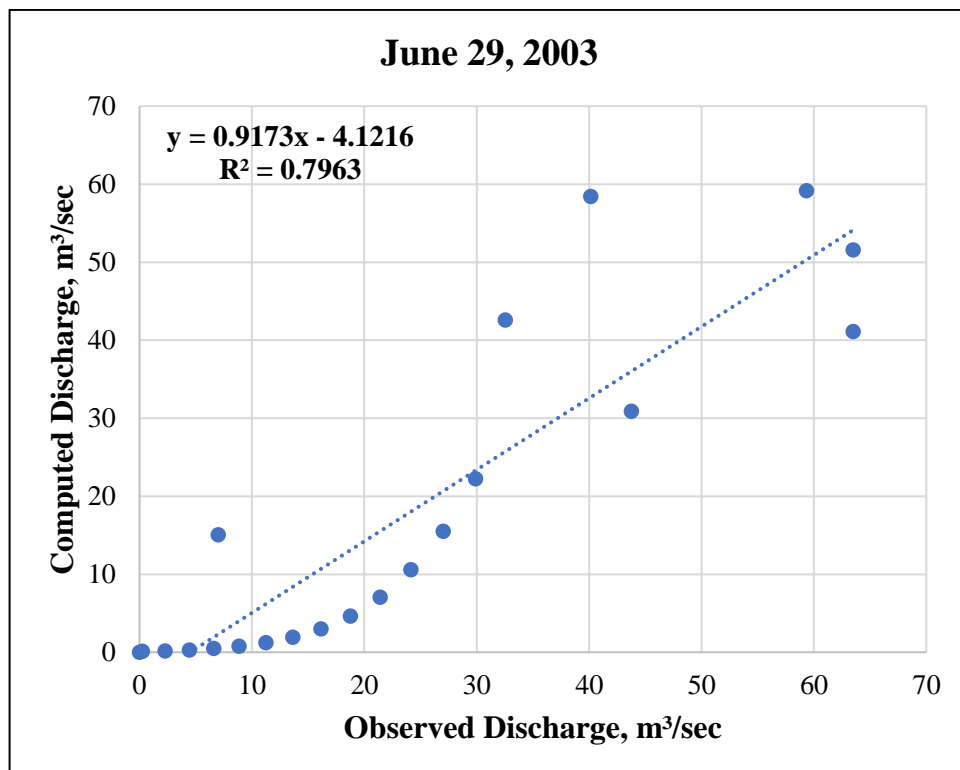


Fig 4.9 Variation of computed discharge with observed discharge on June 29, 2003

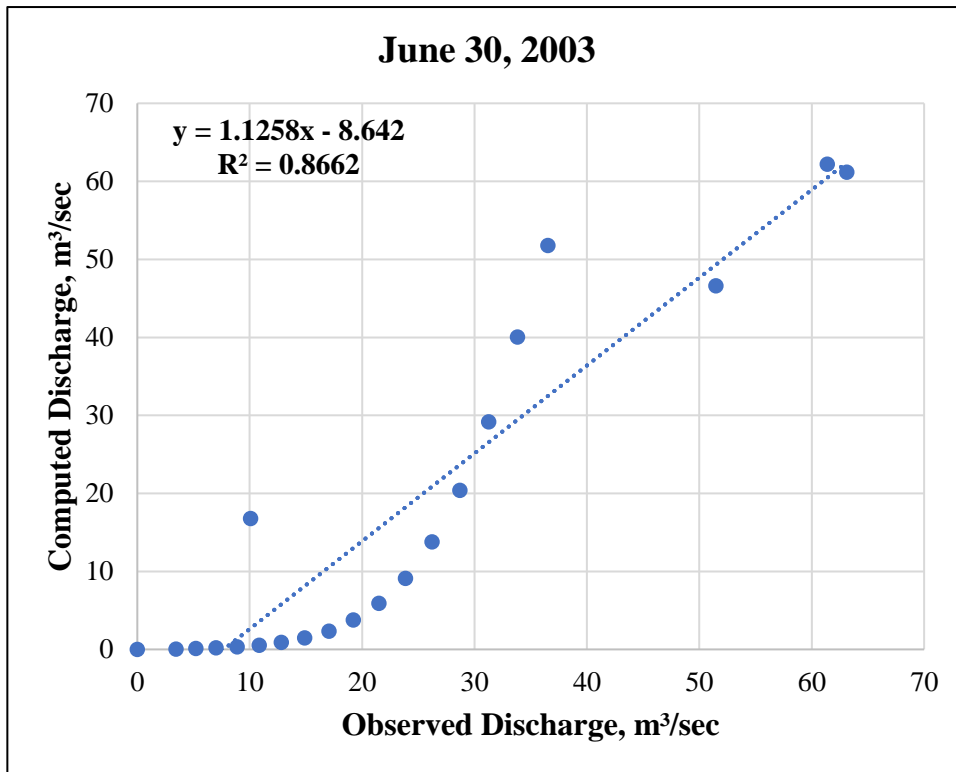


Fig 4.10 Variation of computed discharge with observed discharge on June 30, 2003

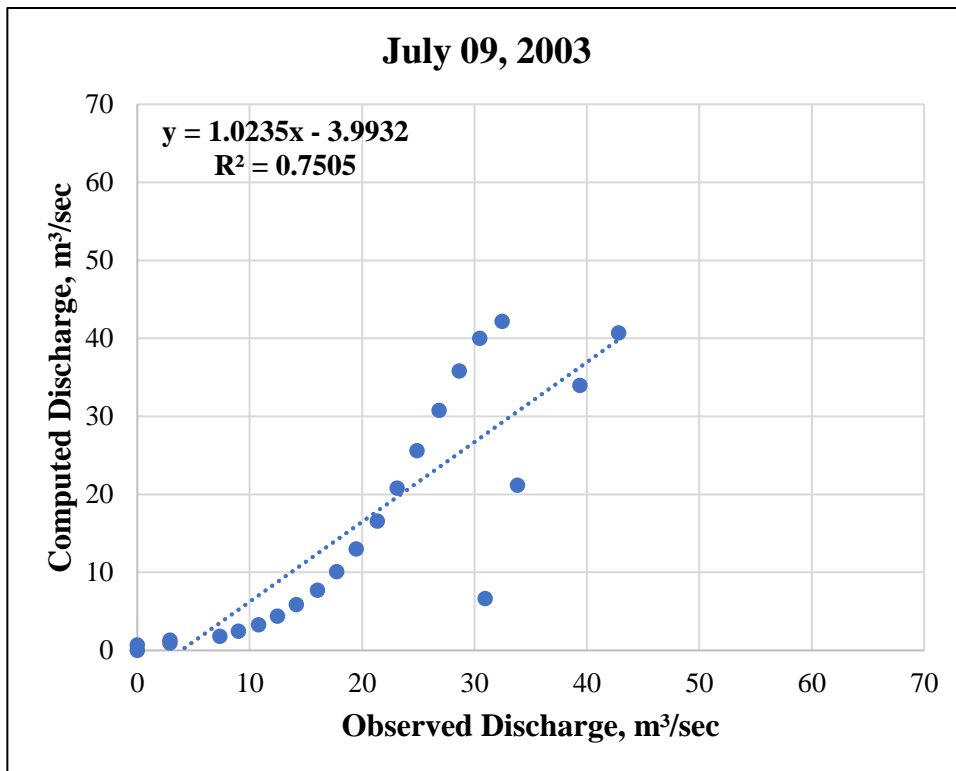


Fig 4.11 Variation of computed discharge with observed discharge on July 09, 2003

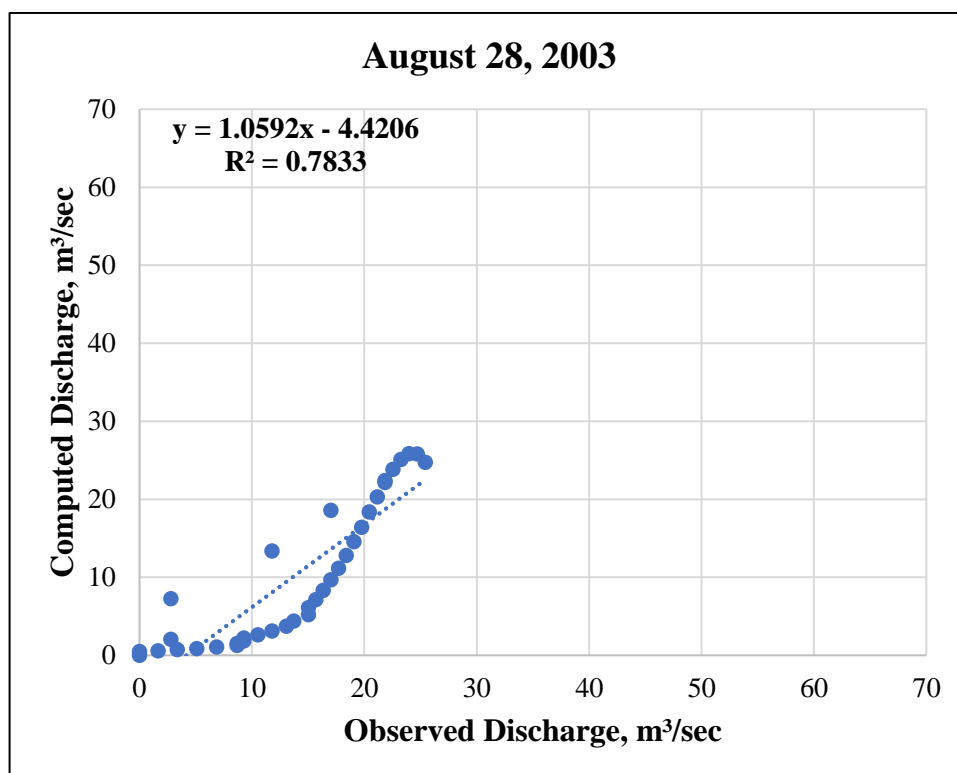


Fig 4.12 Variation of computed discharge with observed discharge on August 28, 2003

It is observed from above Fig 4.8 to 4.12 that the R-square value ranges between 75.05% to 86.62%. The maximum R-square of 86.62% was observed on June 30th, 2003 which shows the minimum variations between observed and predicted discharge. From the above results it was concluded that as there are minimum variations between observed and predicted discharge, it showed maximum accuracy of the model.

Table 4.6 Performance evaluation indices of GIUH based Nash model for year 2003

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	28-Jun-2003	76.153	4.223	7.245	4.223	0.145	0
2	29-Jun-2003	70.451	5.789	10.913	5.789	6.795	20
3	30-Jun-2003	75.224	4.917	8.962	4.917	1.437	25
4	09-Jul-2003	67.970	2.765	7.984	2.765	0.014	-25
5	28-Aug-2003	70.399	2.842	4.937	2.842	-1.697	-33.333

Efficiencies of GIUH for year 2003 had varied from 67.97 to 76.15 percent. Absolute average error (AAE) ranged between 2.765 to 5.789 and RMSE also ranged from 4.937 to 10.913, AEV varied between 2.765 to 5.789. PEP also varied from -1.697 to 6.795 and PETP ranged from 0 to 25. Performance evaluation of storms in 2003 showed that estimated and recorded value match reasonably. The difference between the estimated and recorded time to peak was less than 10 percent. It reflected good match for time to peak. All other performance evaluation indices for year 2003 were in acceptable range for application of GIUH base UH in ungauged catchment of Jagbudi River.

4.3.2 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2004:

Runoff producing intense storms recorded on 4th August, 5th August, 8th August, 17th August, 19th August in year 2004 were selected. Nash parameters, velocity, time to peak and peak discharge for selected storms of year 2004 are mentioned in Table 4.7.

Table 4.7 Unit hydrograph parameters for different storm events in year 2004

Shape Parameter	Date	V (m/s)	K (h)	t _p (h)	Q _p (m ³ /s)
n=2.7	04-Aug-2004	2.104	1.984	3.375	13.273
	05-Aug-2004	1.676	2.493	4.238	42.466
	08-Aug-2004	1.612	2.592	4.406	40.954
	17-Aug-2004	4.23	0.987	1.679	24.425
	19-Aug-2004	2.809	1.487	2.528	15.121

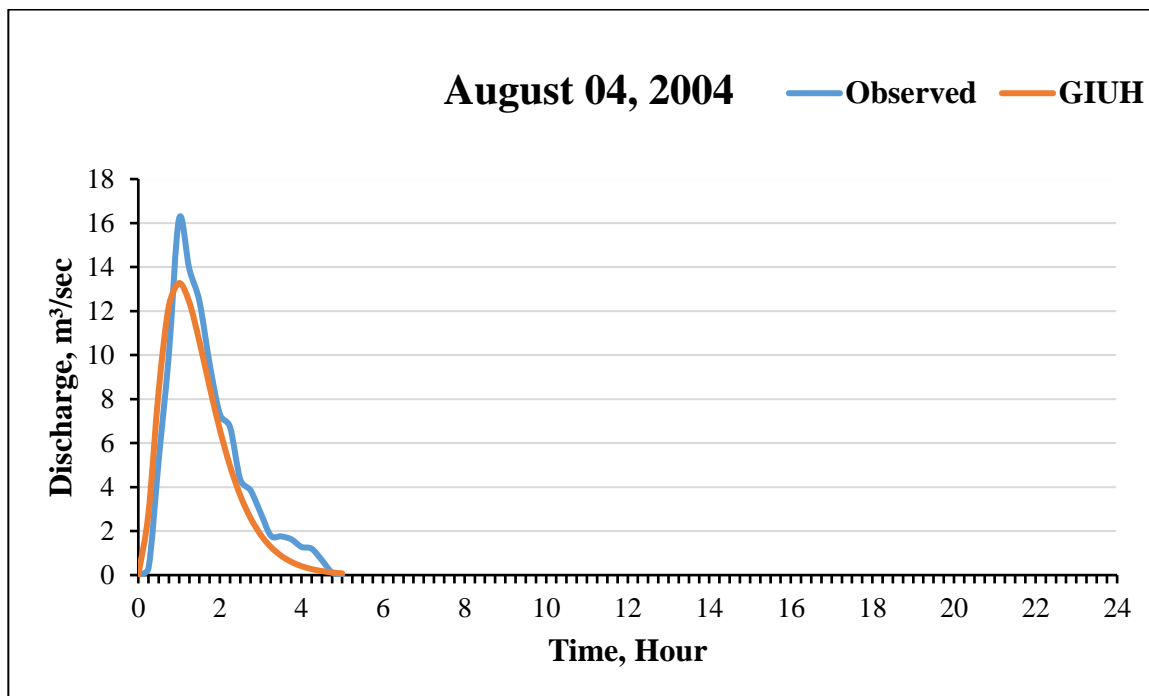


Fig 4.13 0.25 h-Unit hydrograph converted to One h-Unit hydrograph on August 04, 2004

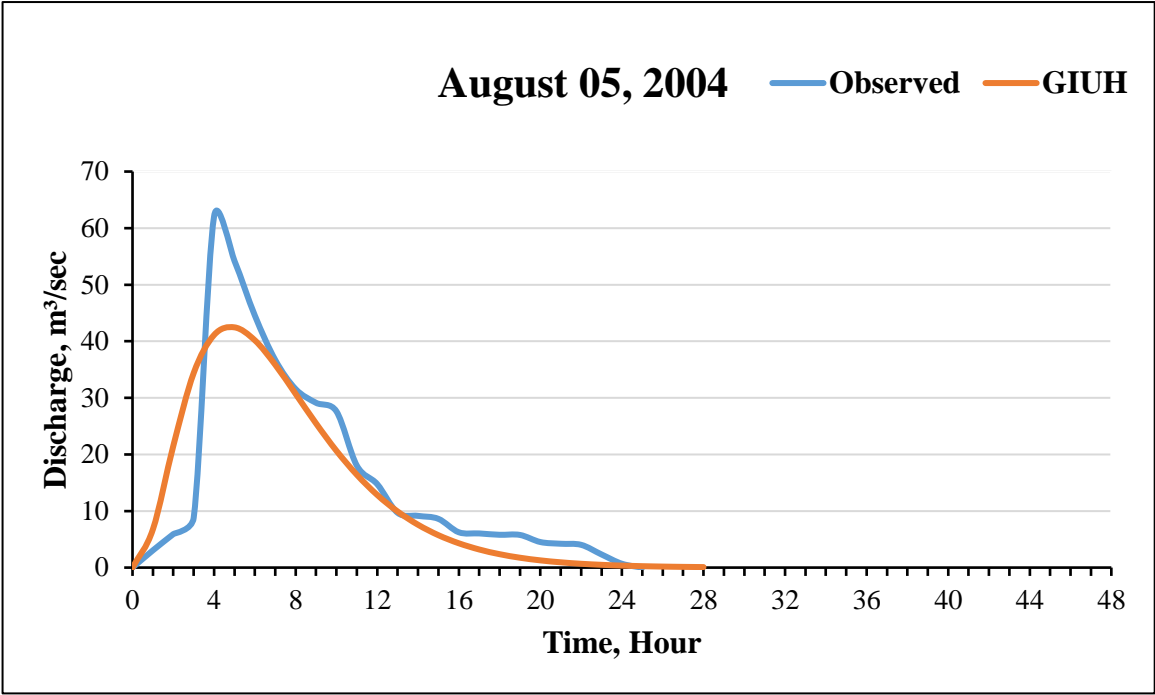


Fig 4.14 One h-Unit hydrograph on August 05, 2004

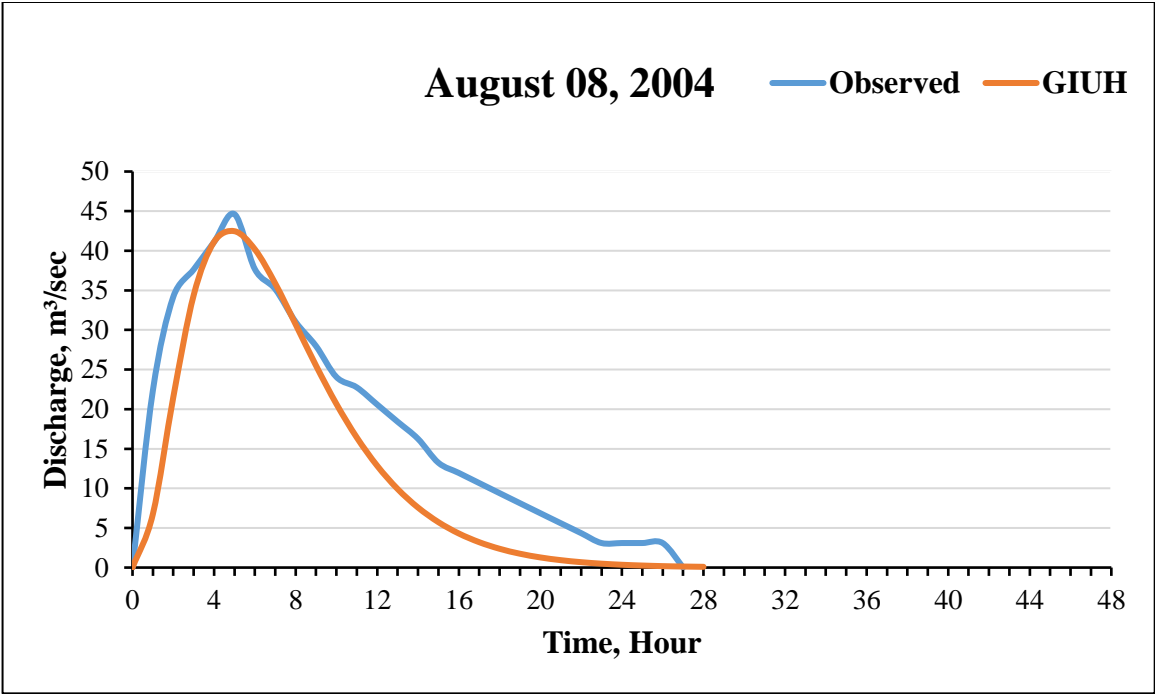


Fig 4.15 One h-Unit hydrograph on August 08, 2004

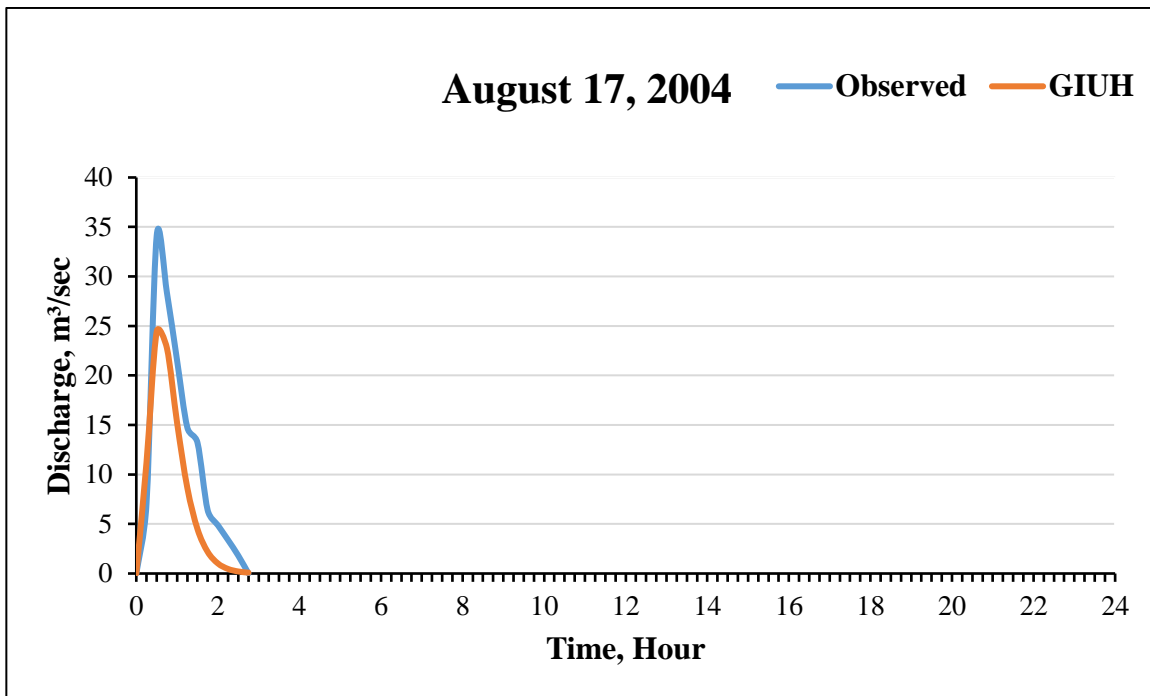


Fig 4.16 0.25 h-Unit hydrograph converted to One h-Unit hydrograph on August 17, 2004

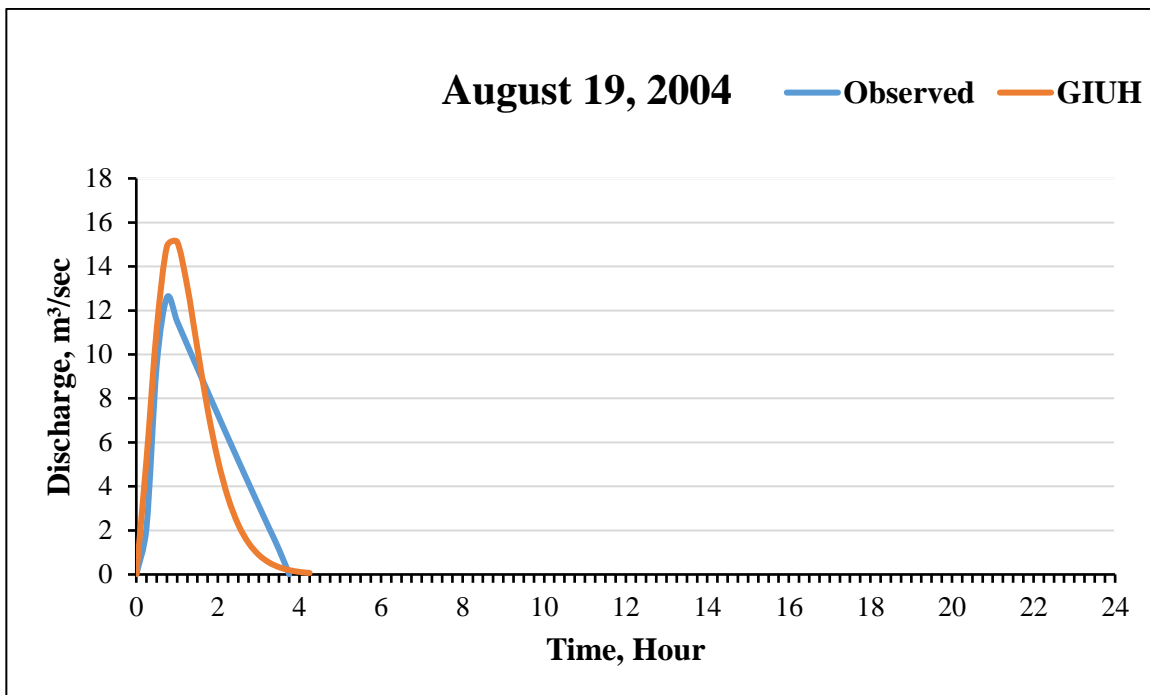


Fig 4.17 0.25 h-Unit hydrograph converted to One h-Unit hydrograph on August 19, 2004

In 2003, the computed runoff was high as compared to 2004 because the rainfall excess generated in selected storm was high. Among the selected storm for 2004 maximum velocity 4.23 m/s was observed on 17th August with scale parameter 0.987. An influence of average channel velocity on GIUH is presented in Figures from 4.13 to 4.17. It was observed that stream velocity was directly proportional to peak discharge and inversely proportional to time to peak. The computed peak discharge was 42.466 m³/s and time to peak was 4.238 h. These values are similar

to previous reference of estimated peak discharge 46.4 m³/s and time to peak 5 h (Kumar *et. al.*, 2002). Performance evaluation indices of selected storm in year 2004 are given in Table 4.8.

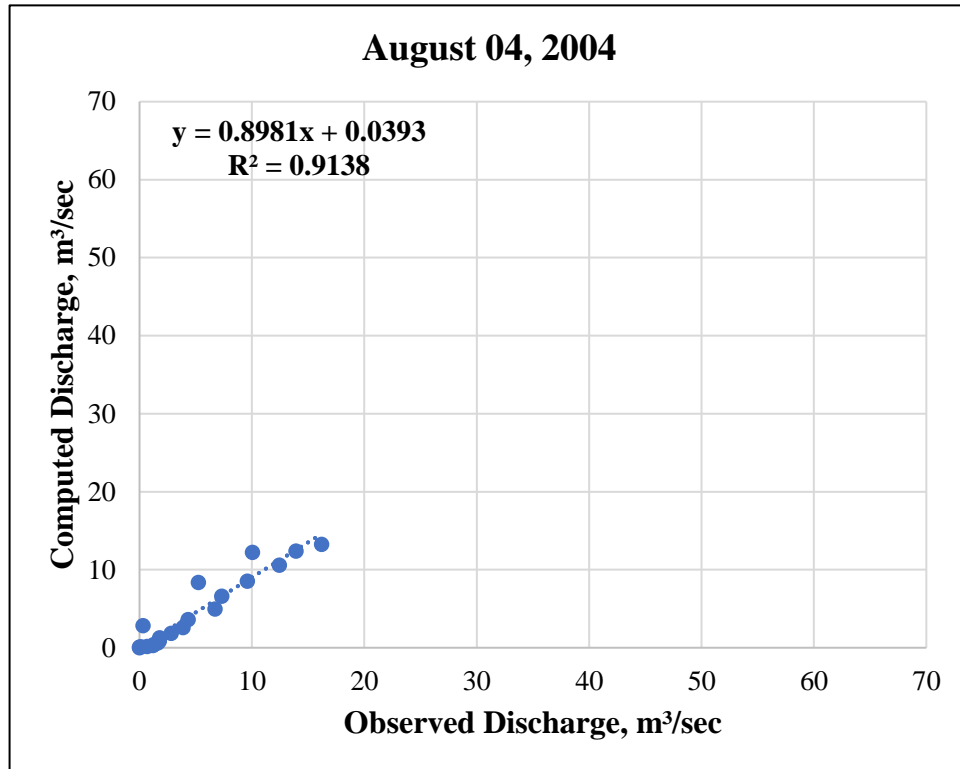


Fig 4.18 Variation of computed discharge with observed discharge on August 04, 2004

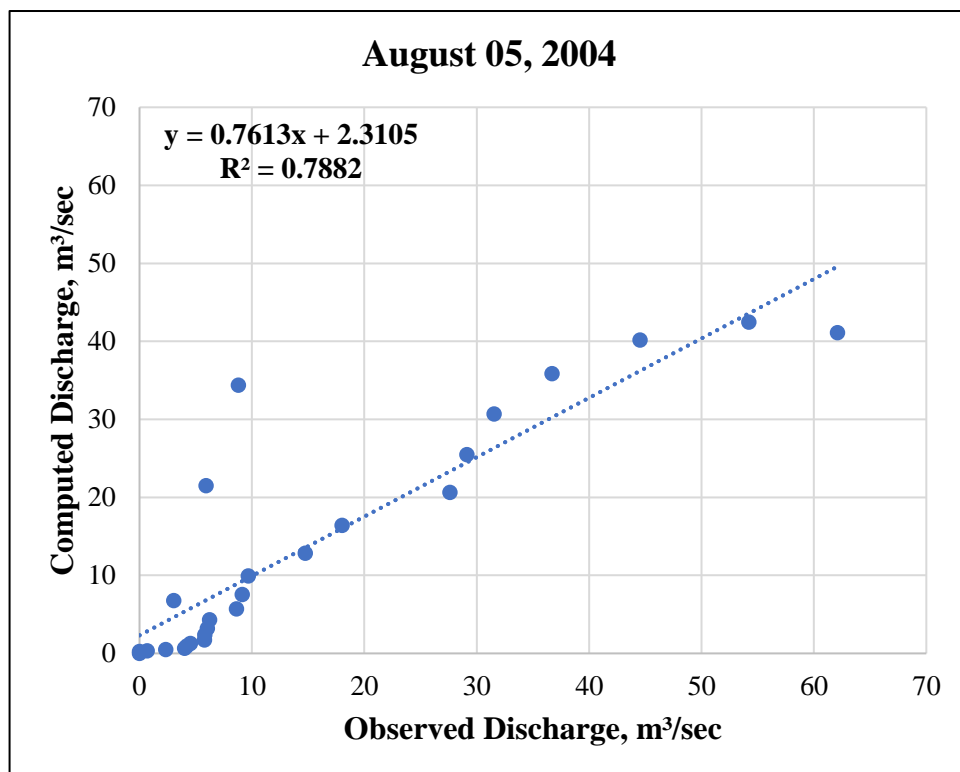


Fig 4.19 Variation of computed discharge with observed discharge on August 05, 2004

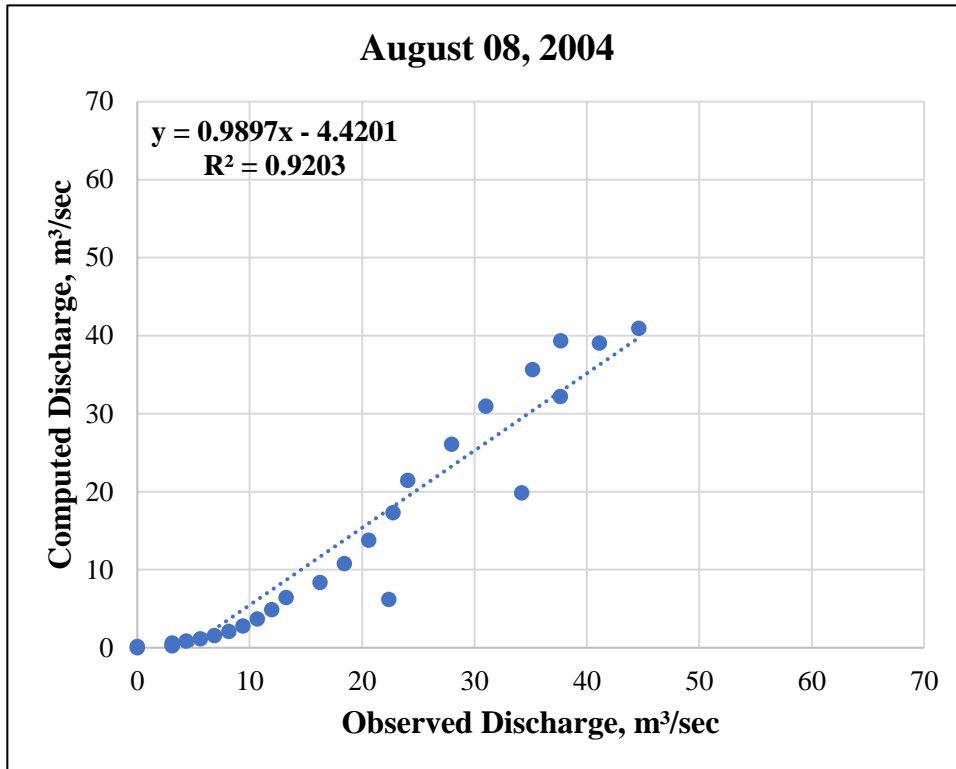


Fig 4.20 Variation of computed discharge with observed discharge on August 08, 2004

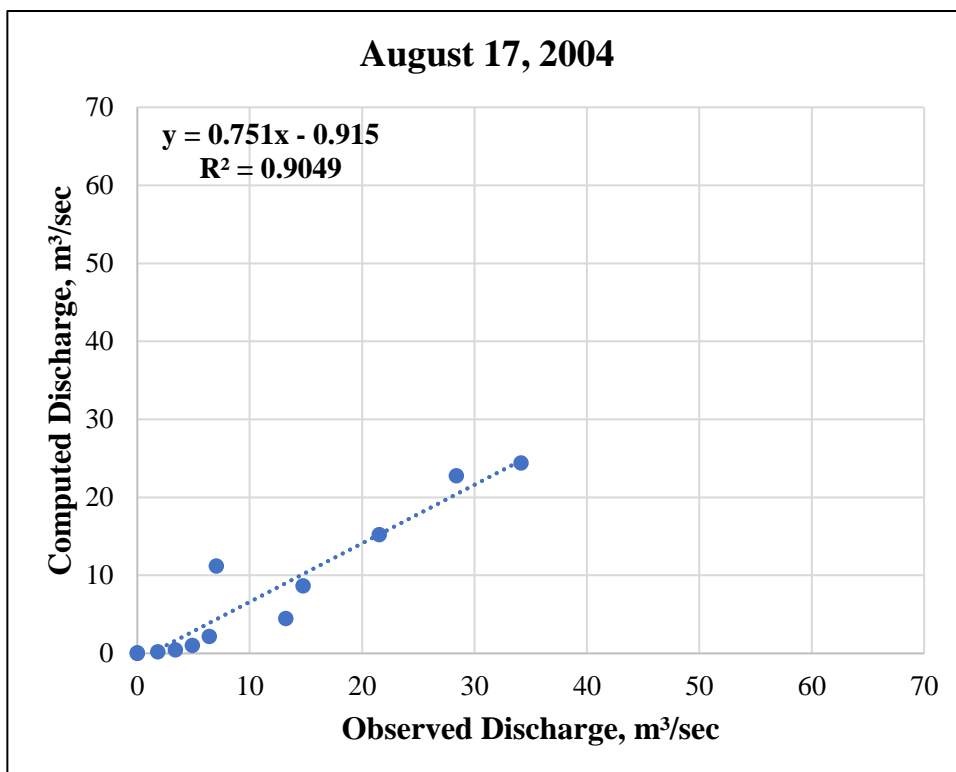


Fig 4.21 Variation of computed discharge with observed discharge on August 17, 2004

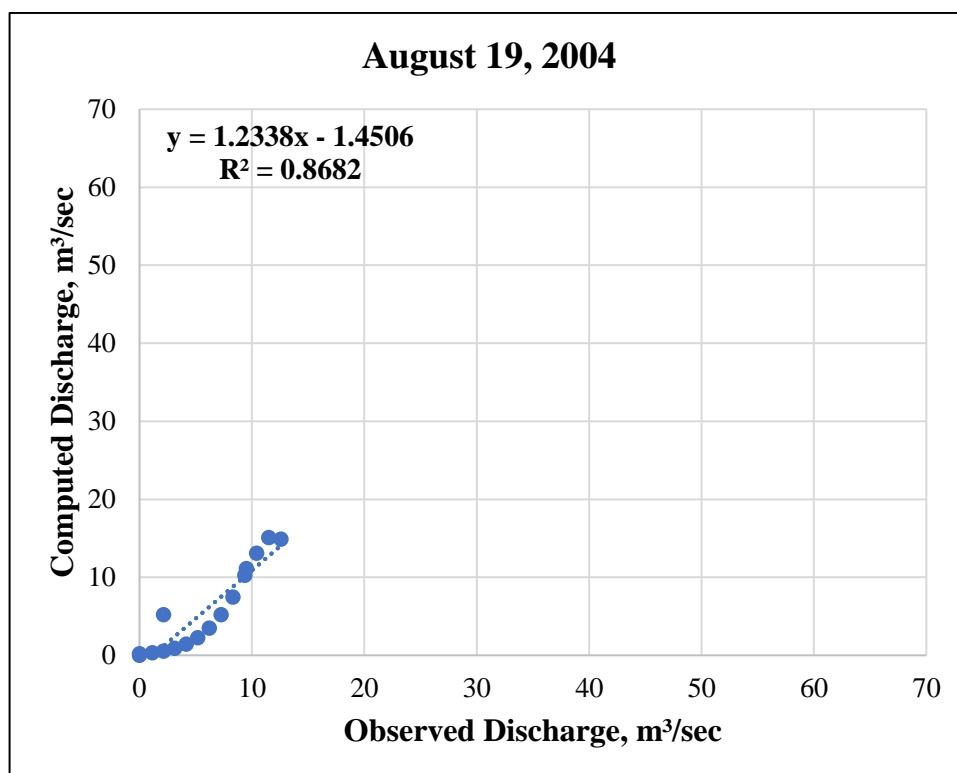


Fig 4.22 Variation of computed discharge with observed discharge on August 19, 2004

It is observed from above Fig 4.18 to 4.22 that the R-square value ranges between 78.82% to 92.03%. The maximum R-square of 92.03% was observed on August 8th, 2004 which shows the minimum variations between observed and predicted discharge. From the above results it was concluded that as there are minimum variations between observed and predicted discharge, it showed maximum accuracy of the model.

Table 4.8 Performance evaluation indices of GIUH based Nash model for year 2004

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	04-Aug-2004	90.488	0.452	1.498	0.452	0.180	0
2	05-Aug-2004	79.966	1.236	7.577	1.236	0.316	-25
3	08-Aug-2004	82.260	4.287	5.875	4.287	0.082	0
4	17-Aug-2004	76.177	3.726	5.318	3.726	0.284	0
5	19-Aug-2004	77.252	0.070	2.038	0.070	-0.201	-33.333

Efficiencies of GIUH for year 2004 had varied from 76.177 to 90.488 per cent. Absolute average error (AAE) ranged between 0.070 to 4.287 and RMSE also ranged from 1.498 to 7.577, AEV varied between 0.070 to 4.287. PEP also varied from -0.201 to 0.316 and PETP ranged from -33.333 to 0. Based on performance evaluation indices it is inferred that prediction of runoff from ungauged Jagbudi river catchment is easy using GIUH based Nash model.

4.3.3 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2007:

Runoff producing intense storms recorded on 23th June, 12th August, 19th September, 20th September and 24th September in year the 2007 were selected Nash parameters, velocity, time to peak and peak discharge for selected storms of year 2007 are mentioned in Table 4.9.

Table 4.9 Unit hydrograph parameters for different storm events in year 2007

Shape Parameter	Date	V (m/s)	K (h)	t _p (h)	Q _p (m ³ /s)
n=2.7	23-Jun-2007	1.831	2.281	3.878	45.850
	12-Aug-2007	2.662	1.569	2.668	32.930
	19-Sep-2007	7.11	0.587	0.999	36.369
	20-Sep-2007	3.49	1.197	2.035	20.885
	24-Sep-2007	2.511	1.664	2.828	61.585

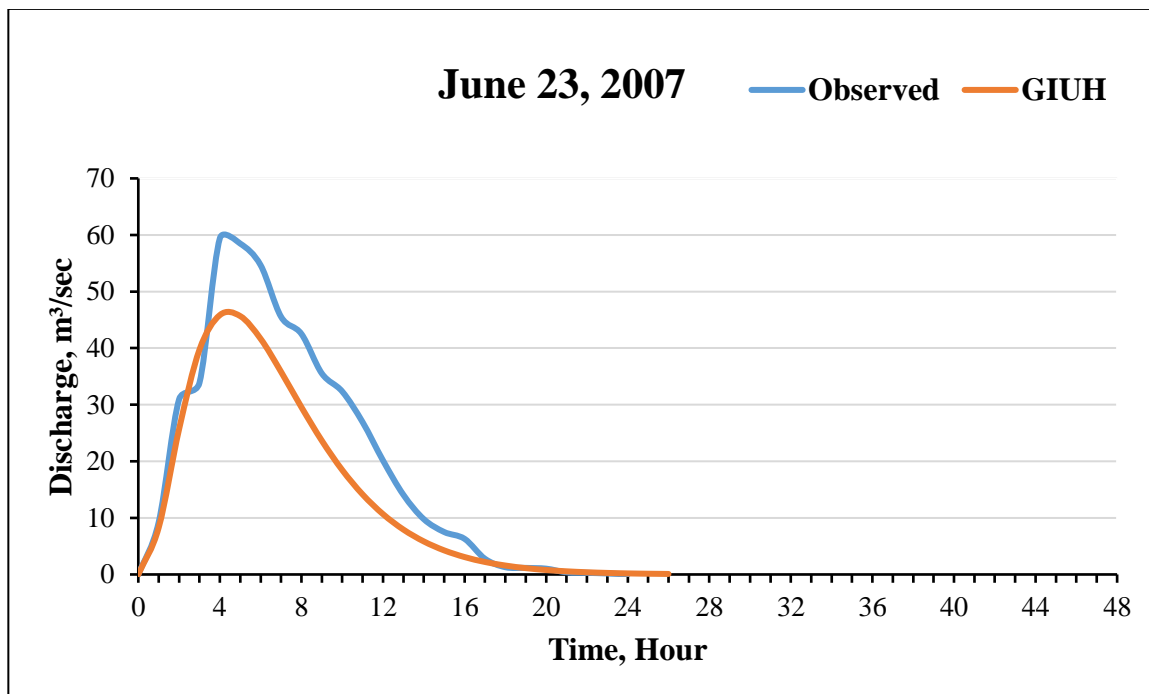


Fig 4.23 One h-Unit hydrograph on June 23, 2007

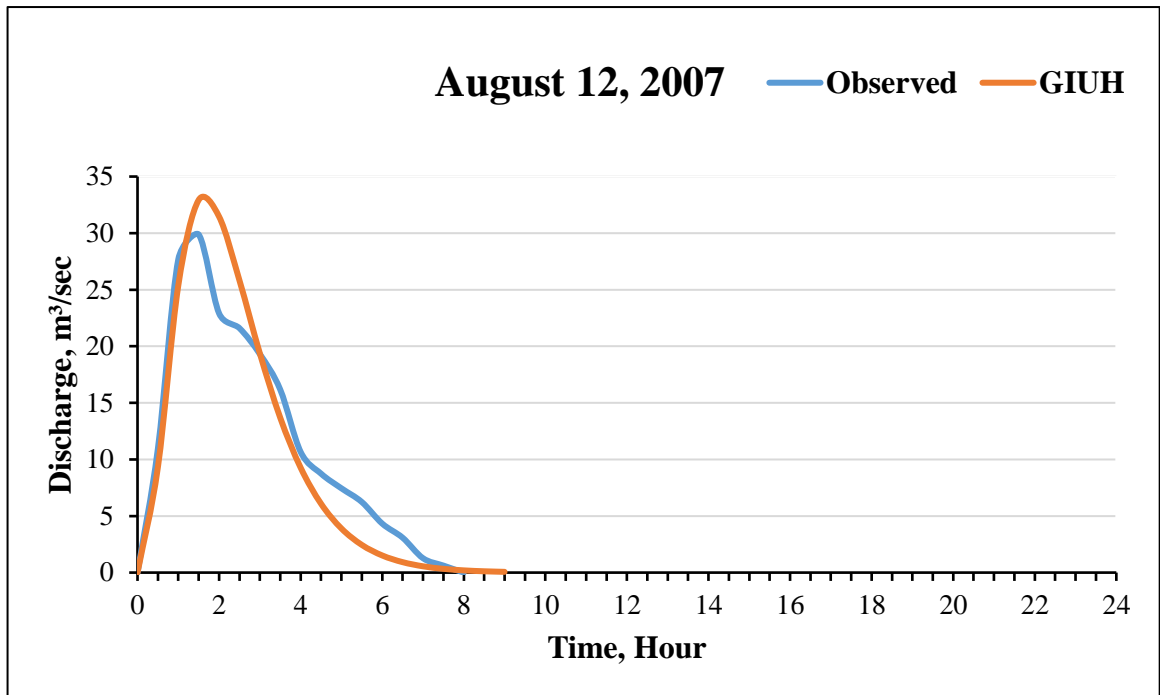


Fig 4.24 0.5 h-Unit hydrograph converted to One h-Unit hydrograph on August 12, 2007

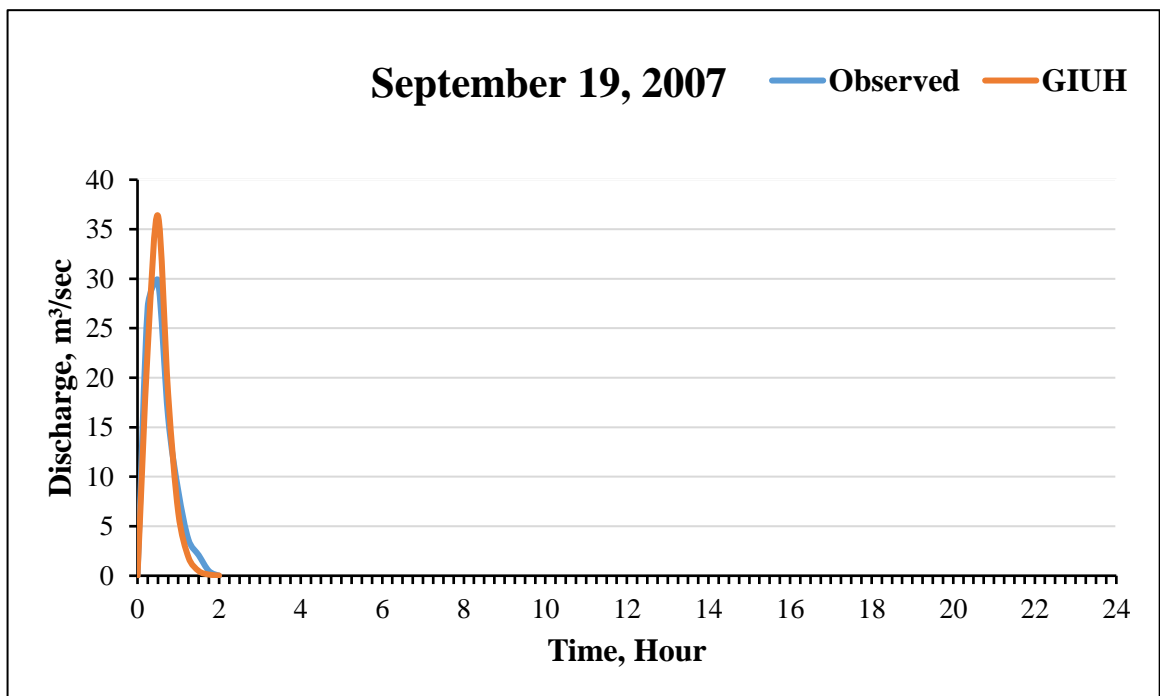


Fig 4.25 0.25 h-Unit hydrograph converted to One h-Unit hydrograph on September 19, 2007

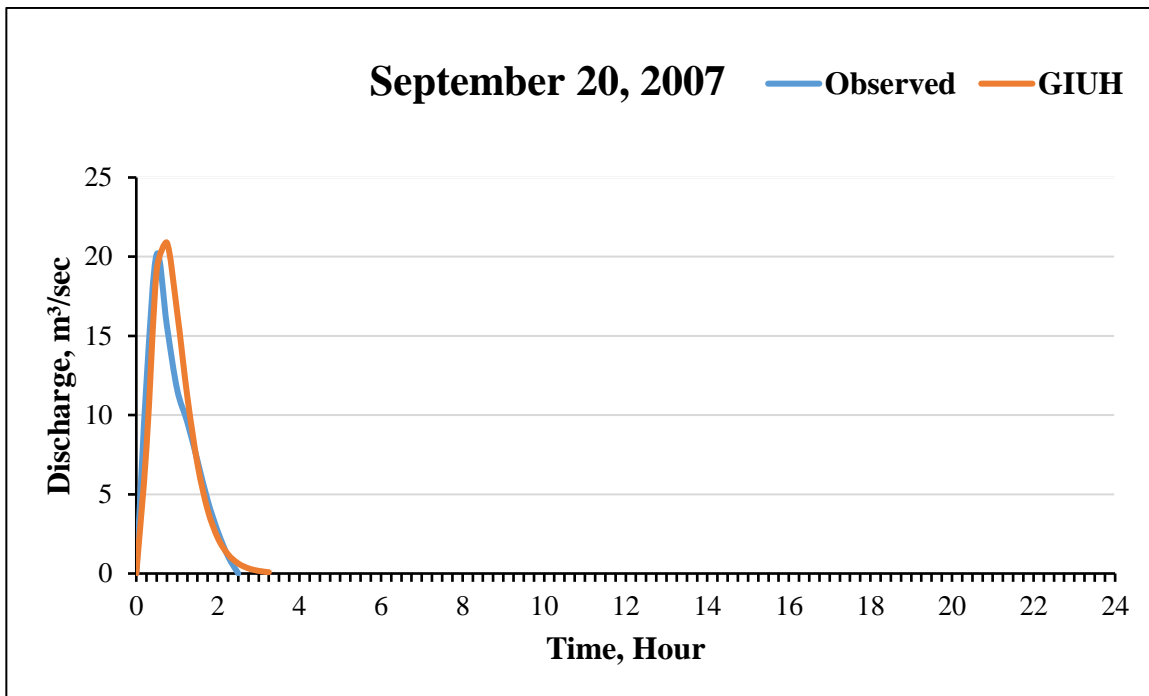


Fig 4.26 0.25 h-Unit hydrograph converted to One h-Unit hydrograph on September 20, 2007

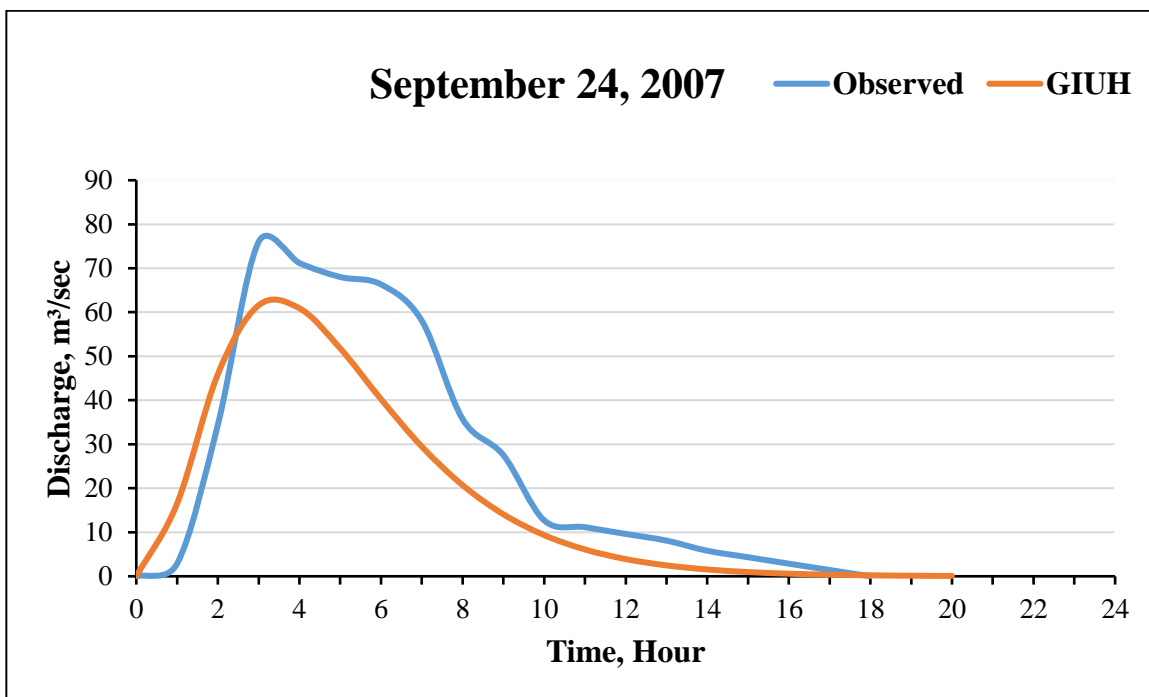


Fig 4.27 One h-Unit hydrograph on September 24, 2007

The maximum velocity of 7.11 m/s among the selected storm for 2007 was observed on 19th September 2007 with scale parameter 0.587. An influence of average channel velocity on GIUH is presented in Figures from 4.23 to 4.27. It was observed that increase in stream flow velocity tends to increase peak discharge and going to decrease time to peak. The computed peak discharge was 61.585 m³/s and time to peak was 2.828 h. Performance evaluation of selected storm in year 2007 are given in Table 4.10.

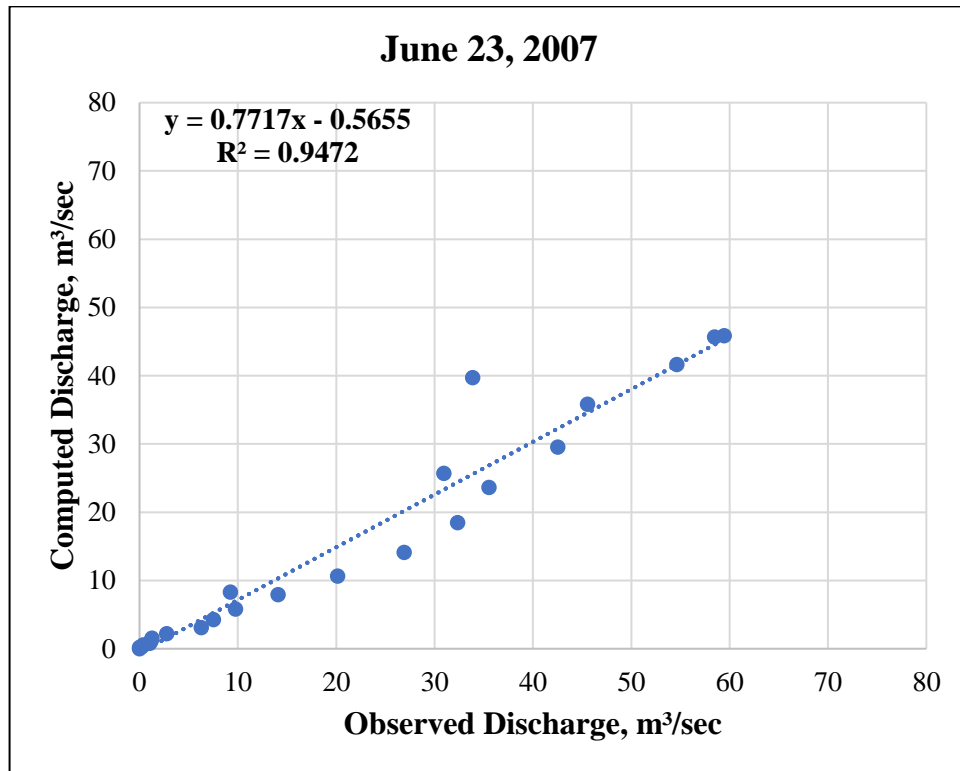


Fig 4.28 Variation of computed discharge with observed discharge on June 23, 2007

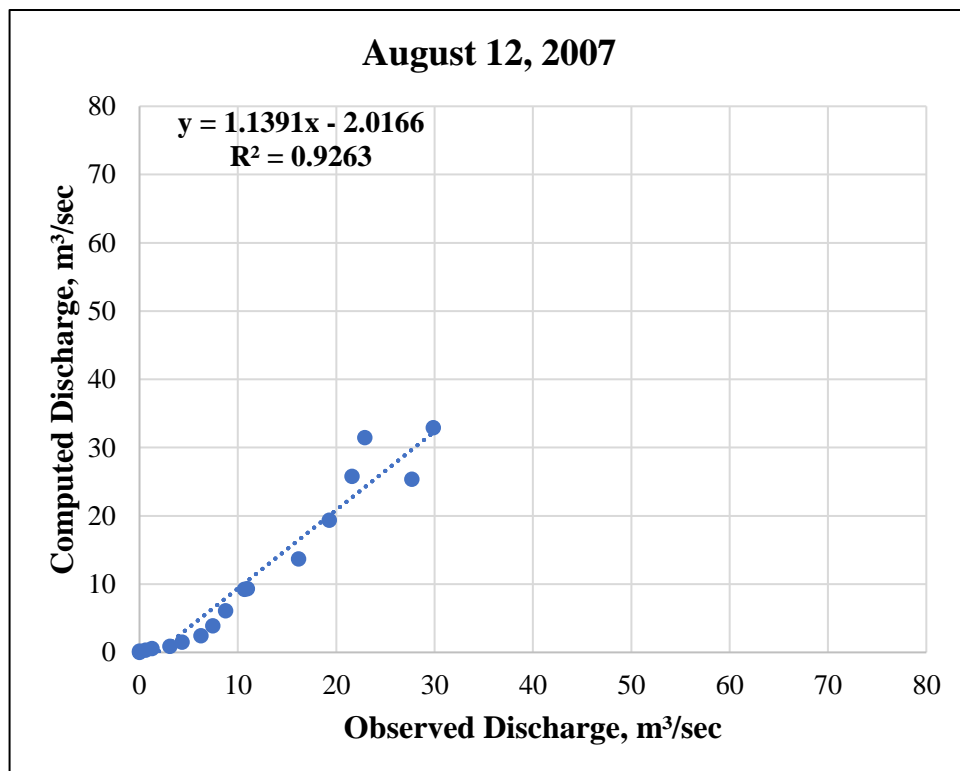


Fig 4.29 Variation of computed discharge with observed discharge on August 12, 2007

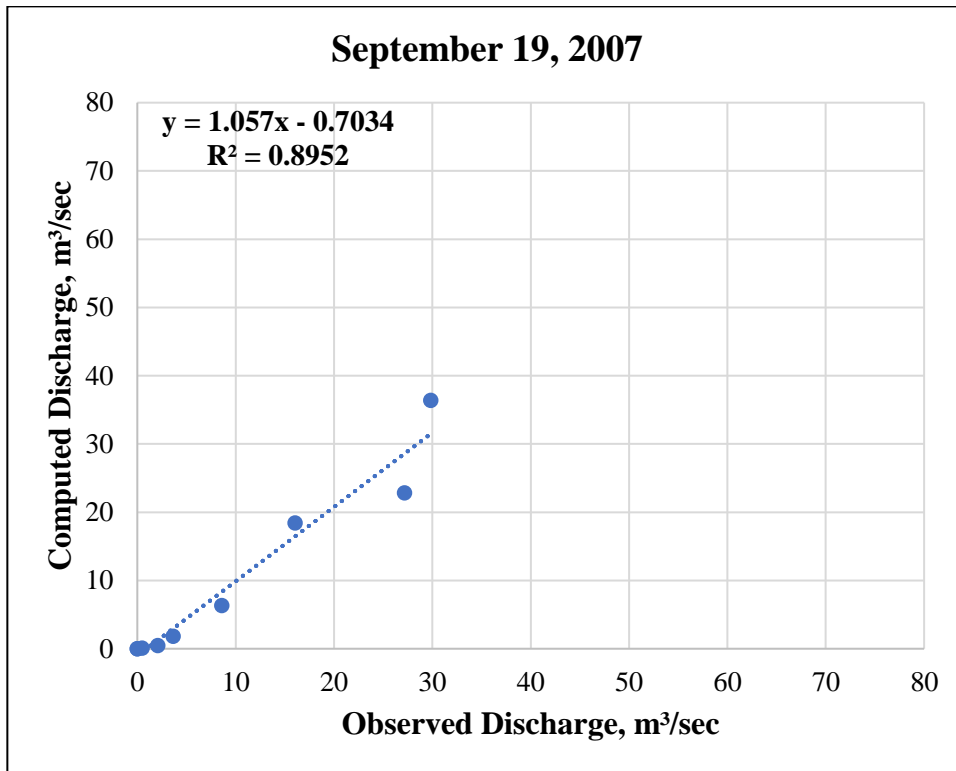


Fig 4.30 Variation of computed discharge with observed discharge on September 19, 2007

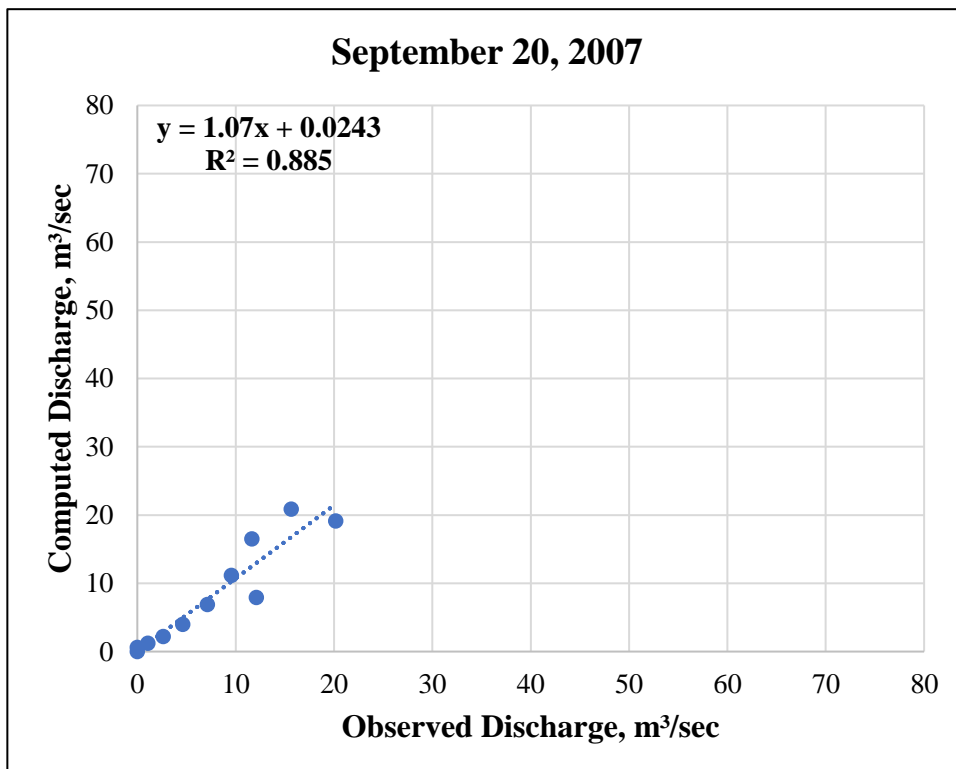


Fig 4.31 Variation of computed discharge with observed discharge on September 20, 2007

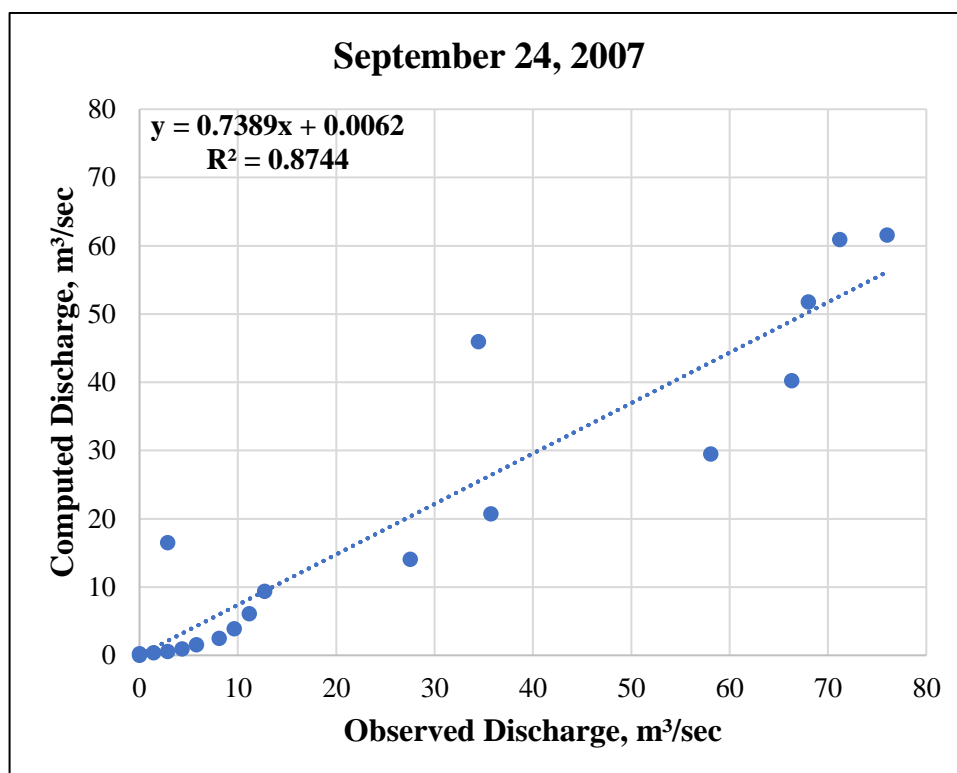


Fig 4.32 Variation of computed discharge with observed discharge on September 24, 2007

It is observed from above Fig 4.28 to 4.32 that the R-square value ranges between 87.44% to 94.72%. The maximum R-square of 94.72% was observed on June 23rd, 2007 which shows the minimum variations between observed and predicted discharge. From the above results it was concluded that as there are minimum variations between observed and predicted discharge, it showed maximum accuracy of the model.

Table 4.10 Performance evaluation indices of GIUH based Nash model for year 2007

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	23-Jun-2007	86.140	4.695	7.466	4.695	0.228	0
2	12-Aug-2007	91.052	0.397	2.934	0.397	-0.189	0
3	19-Sep-2007	93.063	0.147	2.937	0.147	-0.339	0
4	20-Sep-2007	88.370	-0.482	2.289	-0.482	-0.036	-33.333
5	24-Sep-2007	80.908	6.154	11.826	6.154	0.189	0

Efficiencies of GIUH for year 2007 had varied from 86.140 to 93.063 percent. Absolute Average Error (AAE) ranged between -0.482 to 6.154. RMSE ranged from 2.289 to 11.826. AEV varied from -0.482 to 6.154. PEP also varied from -0.036 to 0.228 and PETP varied between -33.33 to 0. It was observed that all the performance evaluation indices were in very good acceptable range. It has made GIUH based UH as good model for prediction of runoff for ungauged watershed.

4.3.4 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2010:

Runoff producing intense storms recorded on 17th June, 02th July, 20th July, 27th July, 19th October in year 2010 were selected. Nash parameters, velocity, time to peak and peak discharge for storms selected from year 2010 are mentioned in Table 4.11.

Table 4.11 Unit hydrograph parameters for different storm events in year 2010

Shape Parameter	Date	V (m/s)	K (h)	t _p (h)	Q _p (m ³ /s)
n=2.7	17-Jun-2010	2.704	1.545	2.626	16.743
	02-Jul-2010	1.905	2.193	3.728	47.935
	20-Jul-2010	2.433	1.717	2.919	29.840
	27-Jul-2010	4.232	0.987	1.678	97.701
	19-Oct-2010	2.238	1.867	3.173	56.027

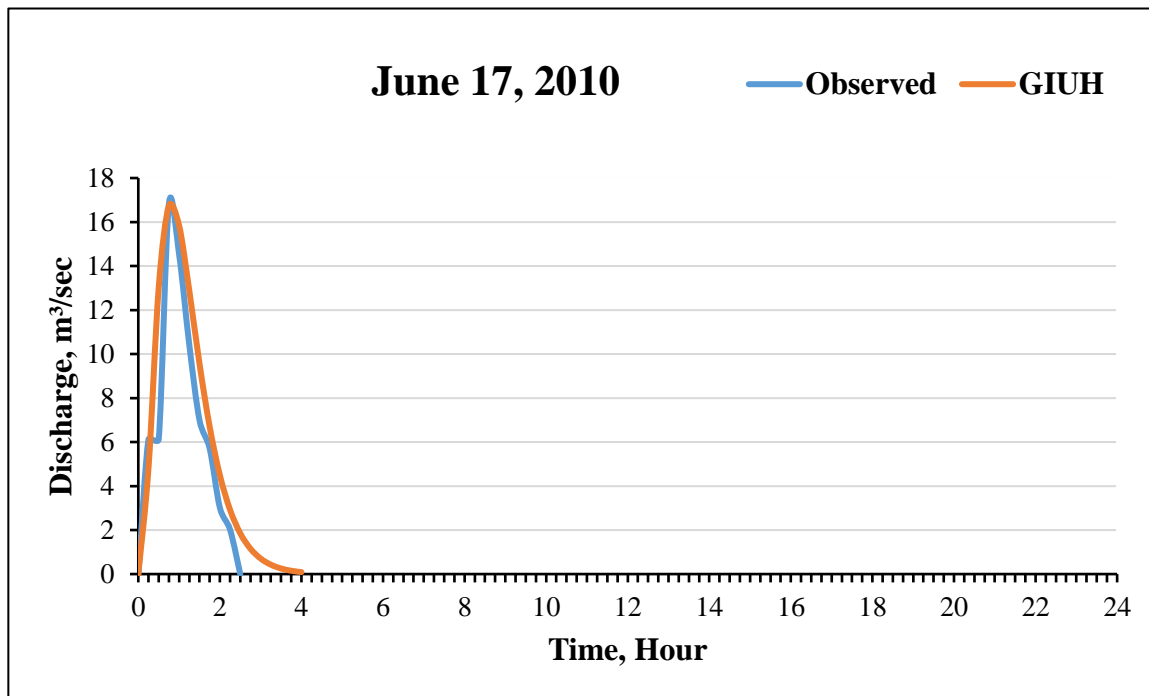


Fig 4.33 0.25 h-Unit hydrograph converted to One h-Unit hydrograph on June 17, 2010

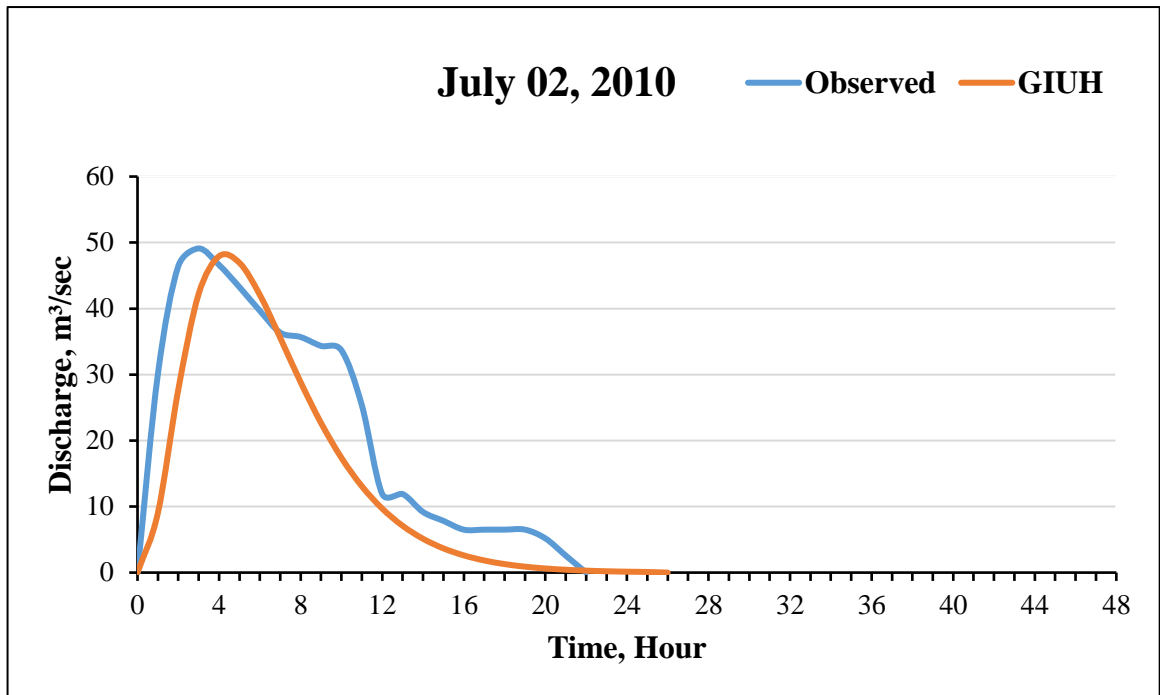


Fig 4.34 One h-Unit hydrograph on July 02, 2010

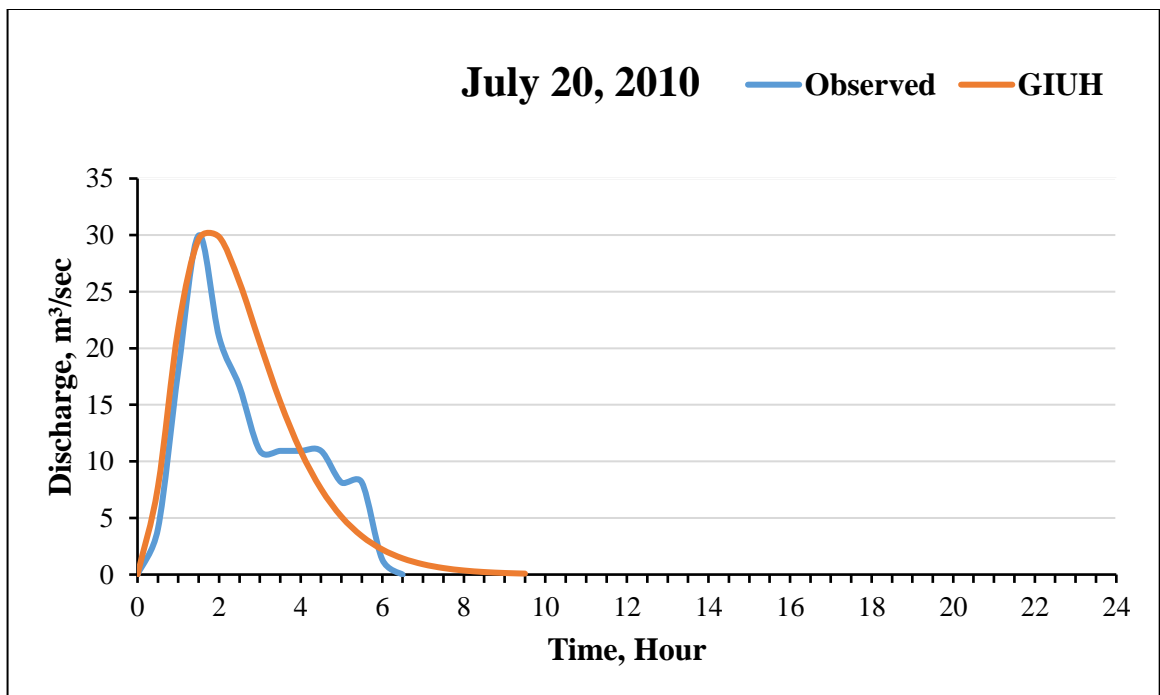


Fig 4.35 0.5 h-Unit hydrograph converted to One h-Unit hydrograph on July 20, 2010

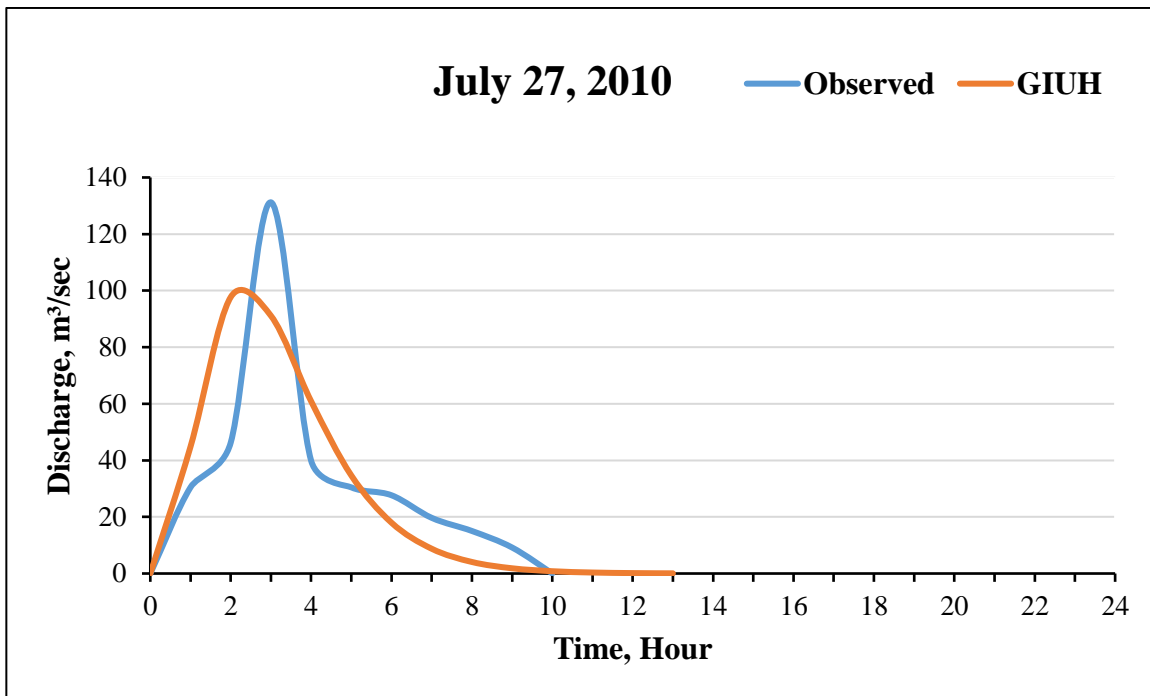


Fig 4.36 One h-Unit hydrograph on July 27, 2010

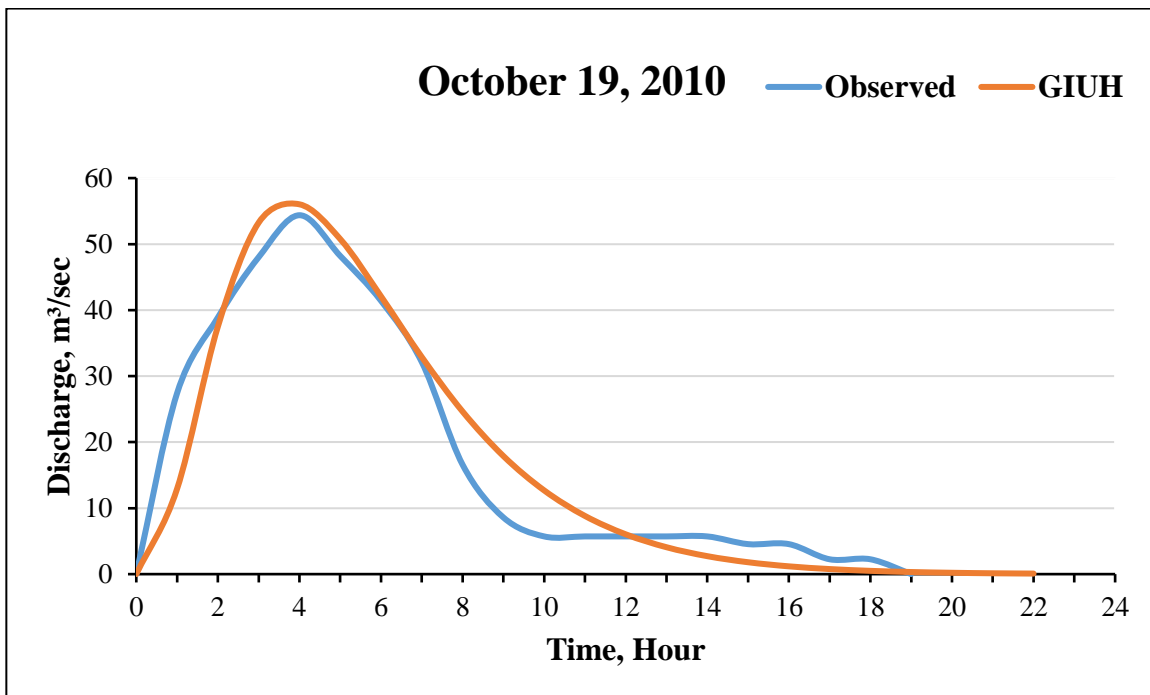


Fig 4.37 One h-Unit hydrograph on October 19, 2010

The maximum velocity was observed 4.232 m/s with scale parameter 0.987 on 27th July 2010. The computed peak discharge is 97.701 m³/s and time to peak is 1.678 hr. Performance evaluation indices of selected storm in year 2010 are given in table 4.12. An influence on average channel velocity on GIUH is presented in Figures from 4.33 to 4.37. It can be inferred that as velocity increases value of scale parameter decreases and it tends to increase peak discharge and going to decrease time to peak.

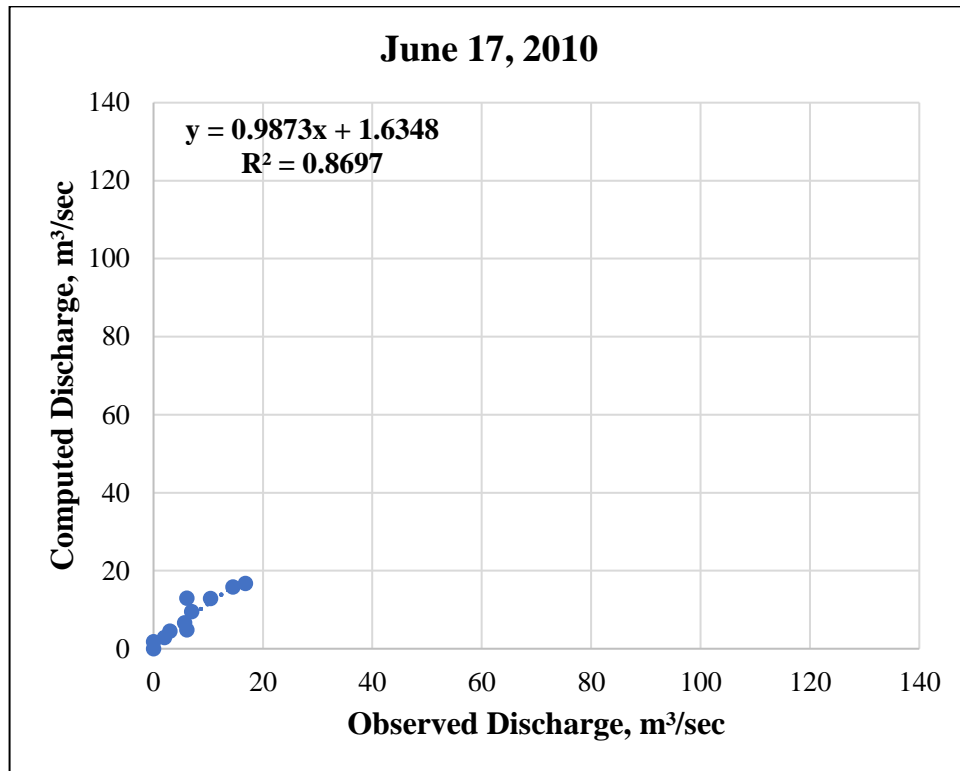


Fig 4.38 Variation of computed discharge with observed discharge on June 17, 2010

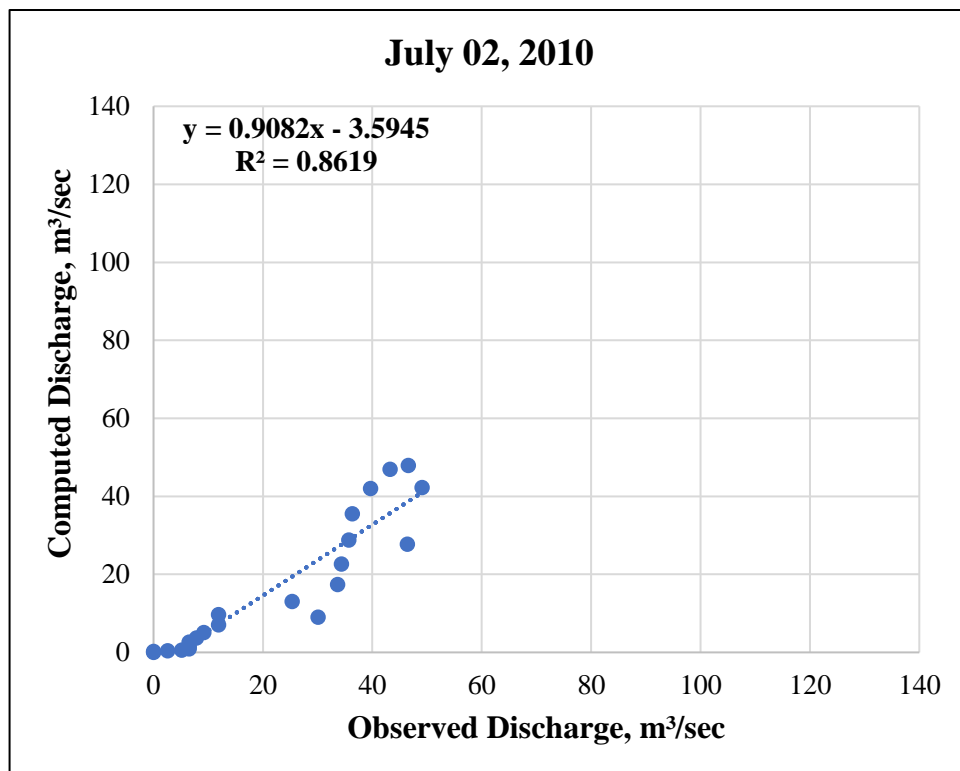


Fig 4.39 Variation of computed discharge with observed discharge on July 02, 2010

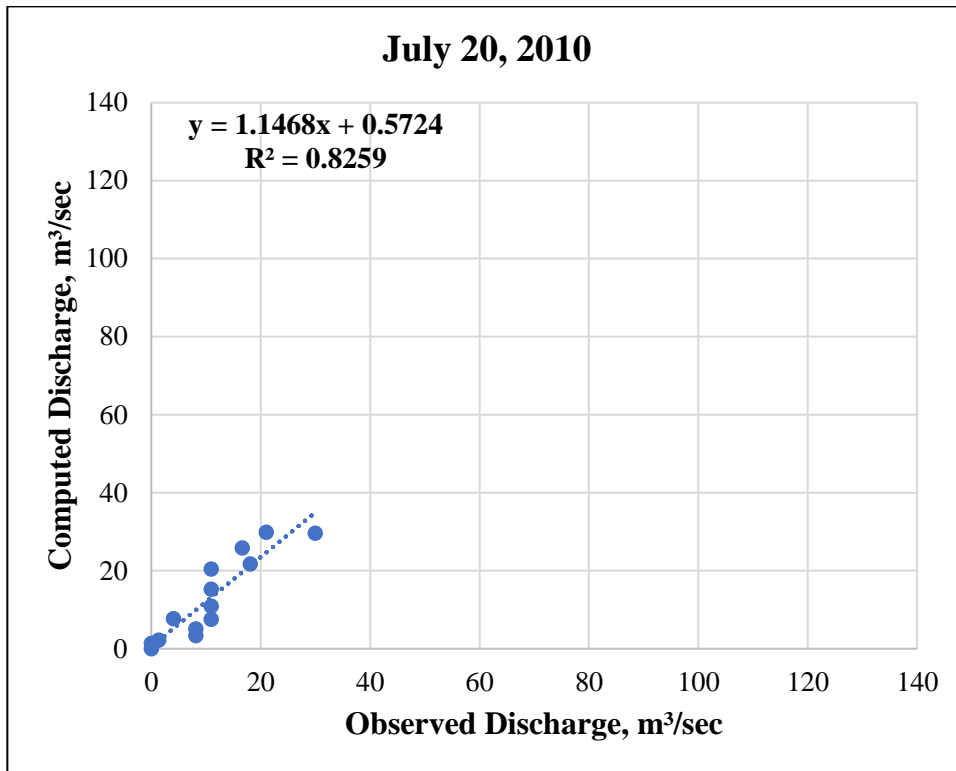


Fig 4.40 Variation of computed discharge with observed discharge on July 20, 2010

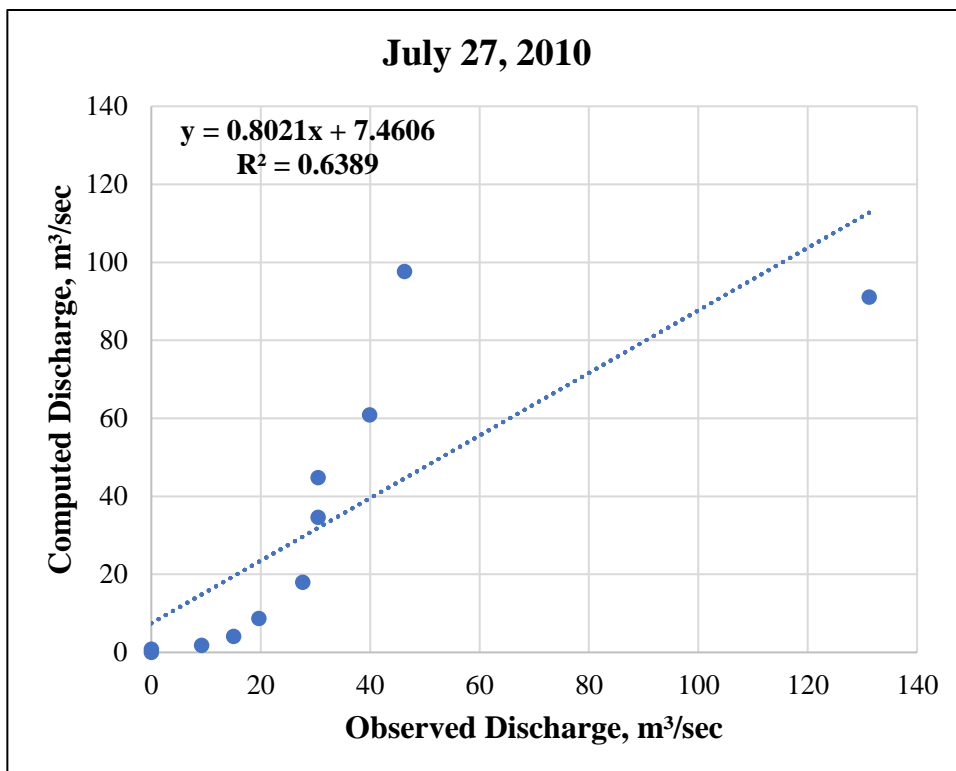


Fig 4.41 Variation of computed discharge with observed discharge on July 27, 2010

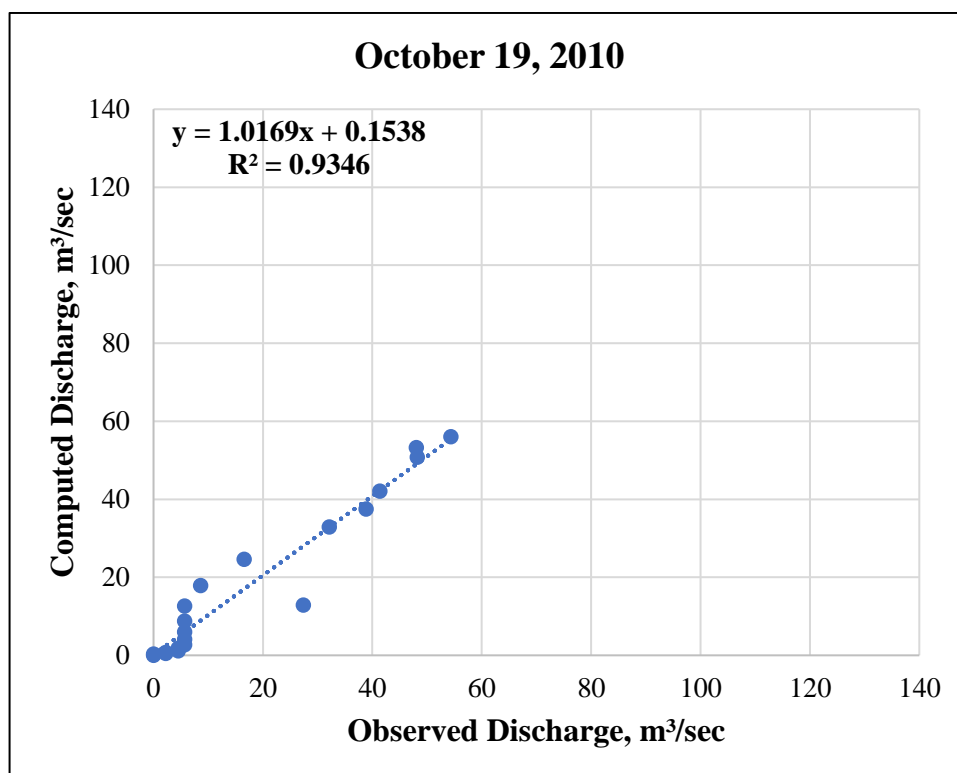


Fig 4.42 Variation of computed discharge with observed discharge on October 19, 2010

It is observed from above Fig 4.38 to 4.42 that the R-square value ranges between 63.89% to 93.46%. The maximum R-square of 93.46% was observed on October 19th, 2010 which shows the minimum variations between observed and predicted discharge. From the above results it was concluded that as there are minimum variations between observed and predicted discharge, it showed maximum accuracy of the model.

Table 4.12 Performance evaluation indices of GIUH based Nash model for year 2010

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	17-Jun-2010	86.931	-1.167	2.073	-1.167	0.004	0
2	02-Jul-2010	79.469	4.910	7.949	4.910	0.023	-33.333
3	20-Jul-2010	78.787	-1.623	4.168	-1.623	0.004	-33.333
4	27-Jul-2010	67.188	-0.956	19.469	-0.956	0.255	33.333
5	19-Oct-2010	93.586	-0.414	0.935	-0.414	-0.030	0

Efficiencies of GIUH for the catchment had varied from 67.188 to 93.586 percent. Absolute average error (AAE) ranged between -0.414 to 4.910. RMSE ranged from 0.935 to 19.469. AEV varied from -0.414 to 4.910. PEP also varied from -0.030 to 0.255 and PETP ranged between -33.333 to 33.333. All the performance evaluation indices for year 2010 were in acceptable range for application of GIUH based UH in ungauged river catchment.

4.3.5 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2011:

Runoff producing intense storms recorded on 17th June, 22th June, 27th June, 12th July, 15th July in year 2011 were selected. Velocity, scale parameter, time to peak and peak discharge for storms selected from year 2011 are mentioned in Table 4.13.

Table 4.13 Unit hydrograph parameters for different storm events in year 2011

Shape Parameter	Date	V (m/s)	K (h)	t _p (h)	Q _p (m ³ /s)
n=2.7	17-Jun-2011	3.58	1.167	1.984	84.863
	22-Jun-2011	2.287	1.827	3.105	57.021
	27-Jun-2011	4.329	0.965	1.640	50.103
	12-Jul-2011	2.419	1.727	2.936	59.445
	15-Jul-2011	3.020	1.383	2.352	74.719

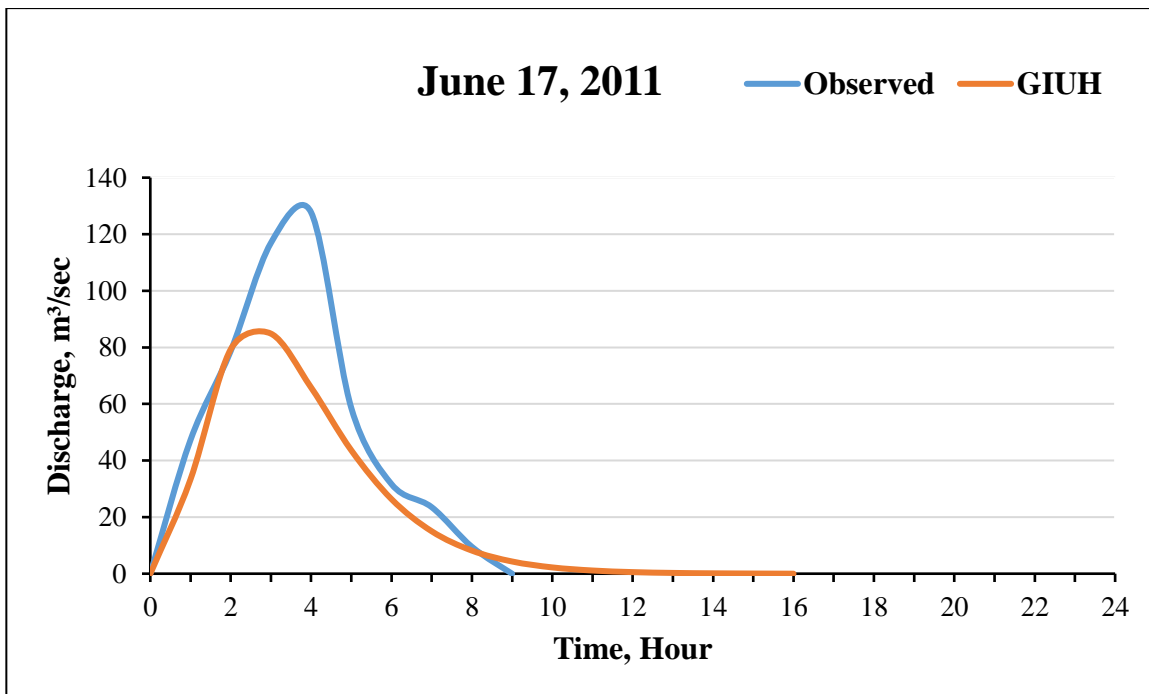


Fig 4.43 One h-Unit hydrograph on June 17, 2011

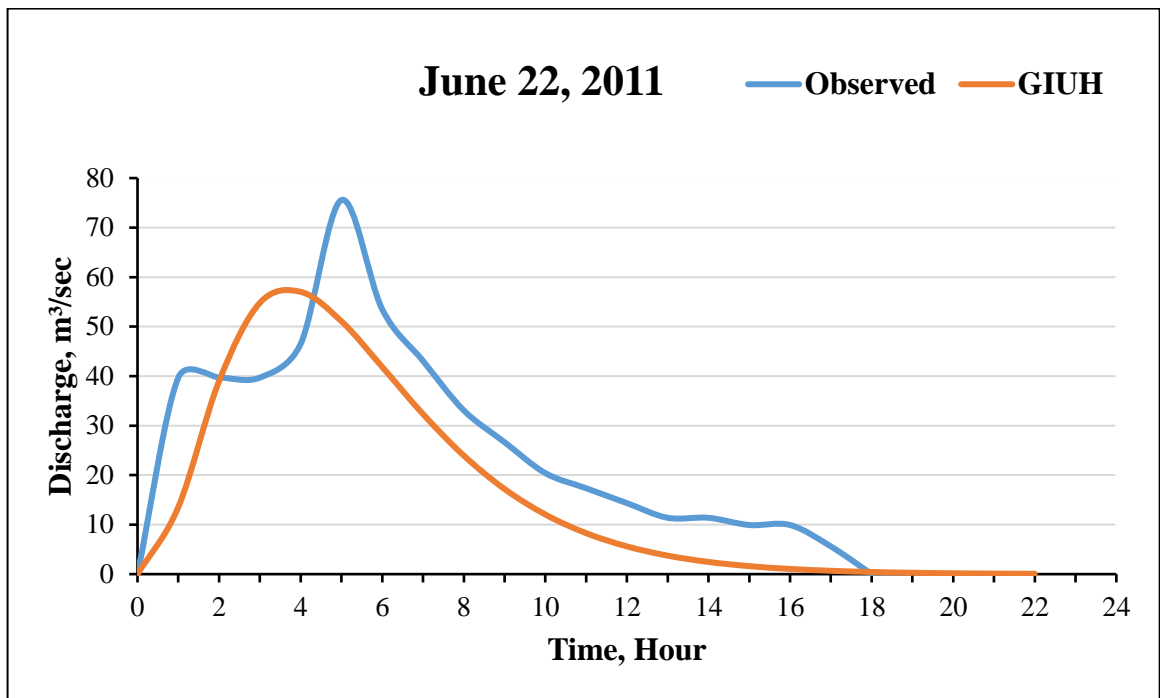


Fig 4.44 One h-Unit hydrograph on June 22, 2011

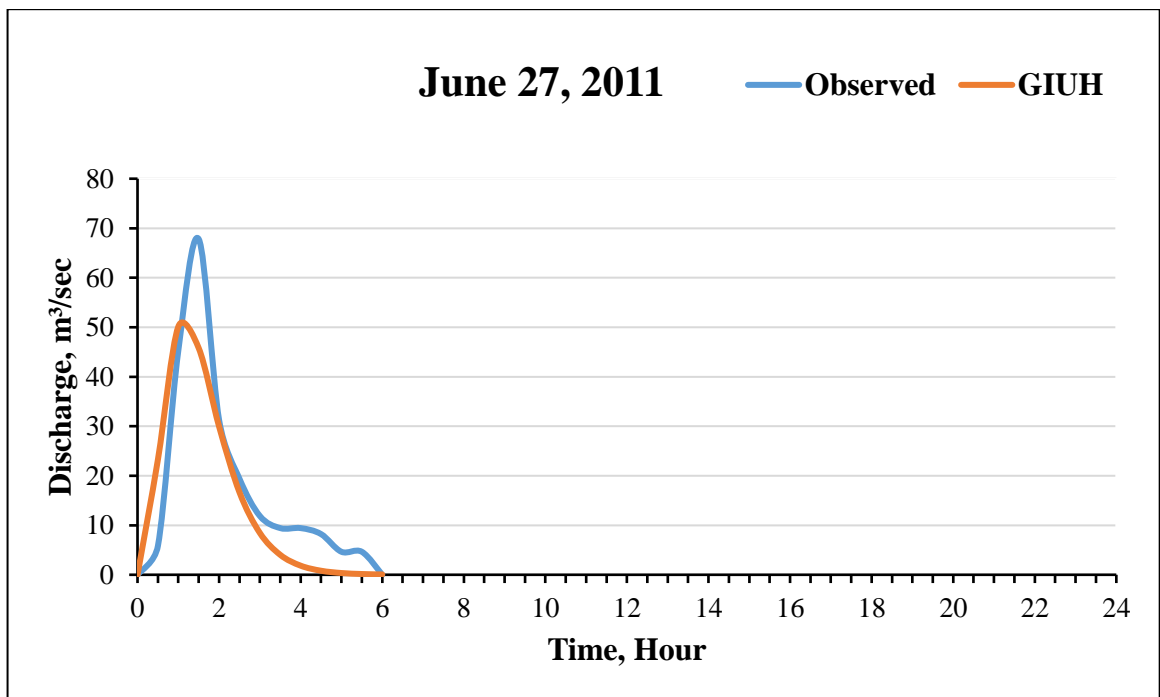


Fig 4.45 0.5 h-Unit hydrograph converted to One h-Unit hydrograph on June 27, 2011

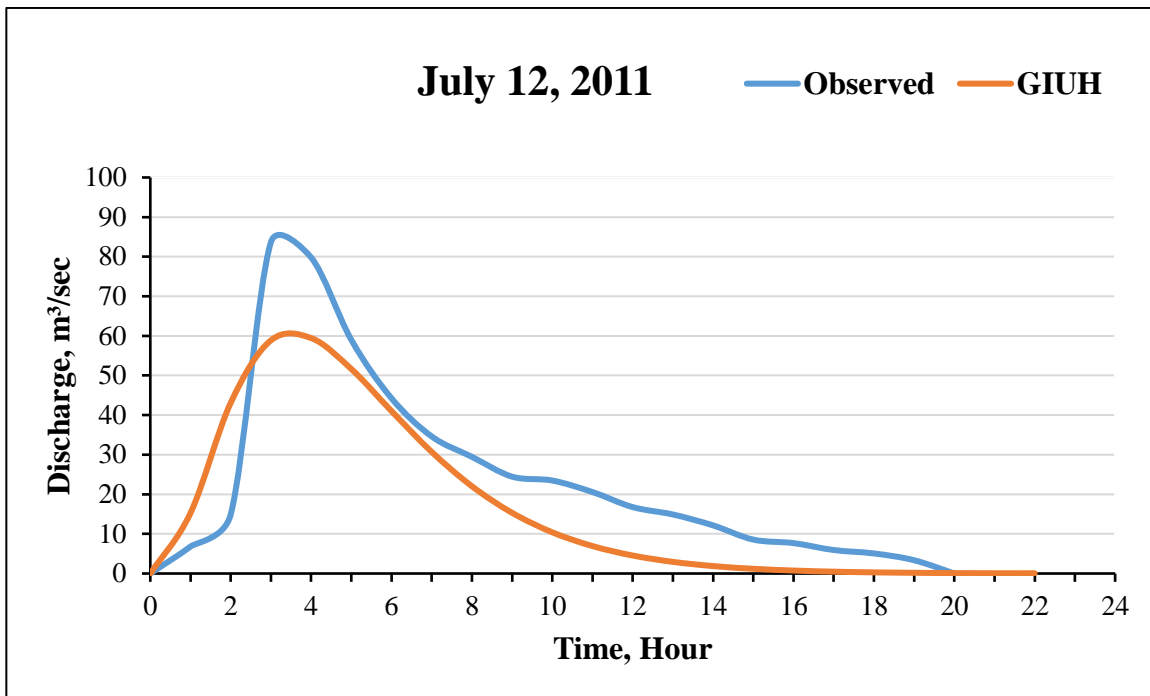


Fig 4.46 One h-Unit hydrograph on July 12, 2011

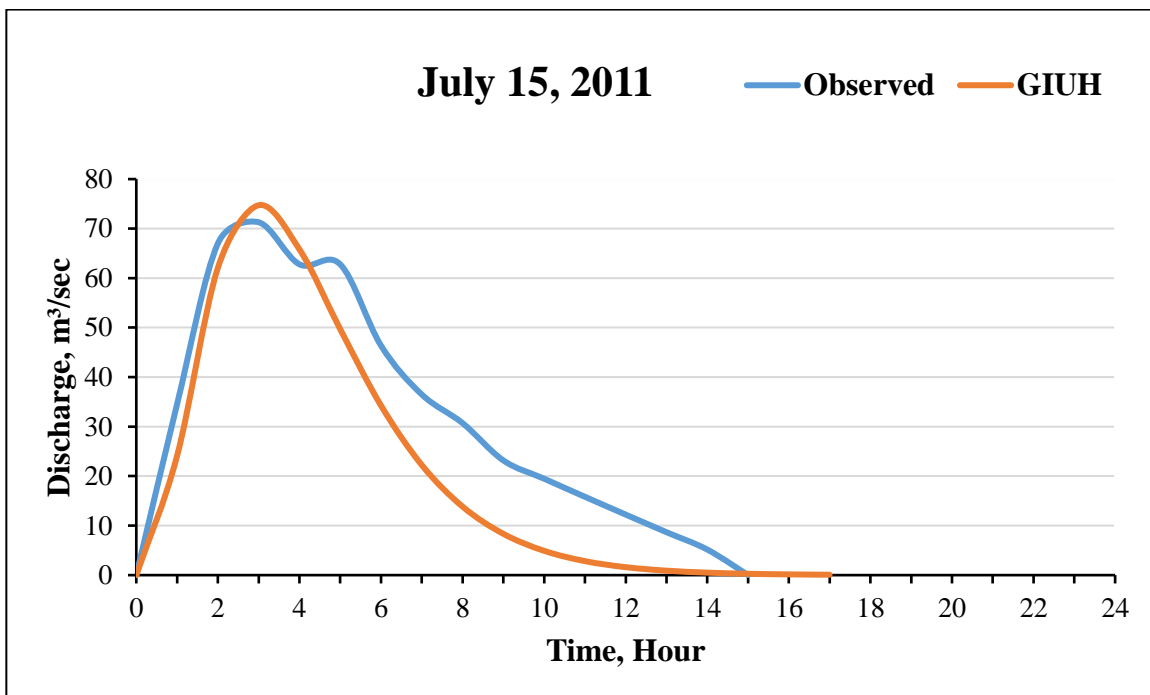


Fig 4.47 One h-Unit hydrograph on July 15, 2011

The maximum velocity of 4.329 m/s was observed on 27th June 2011 with scale parameter 0.965. An influence of average channel velocity on GIUH is presented in figures from 4.43 to 4.47. It was observed that the stream velocity is directly proportional to the peak discharge and inversely proportional to the time to peak. Hence, increase in velocity tends to increase peak discharge and going to decrease the time to peak.

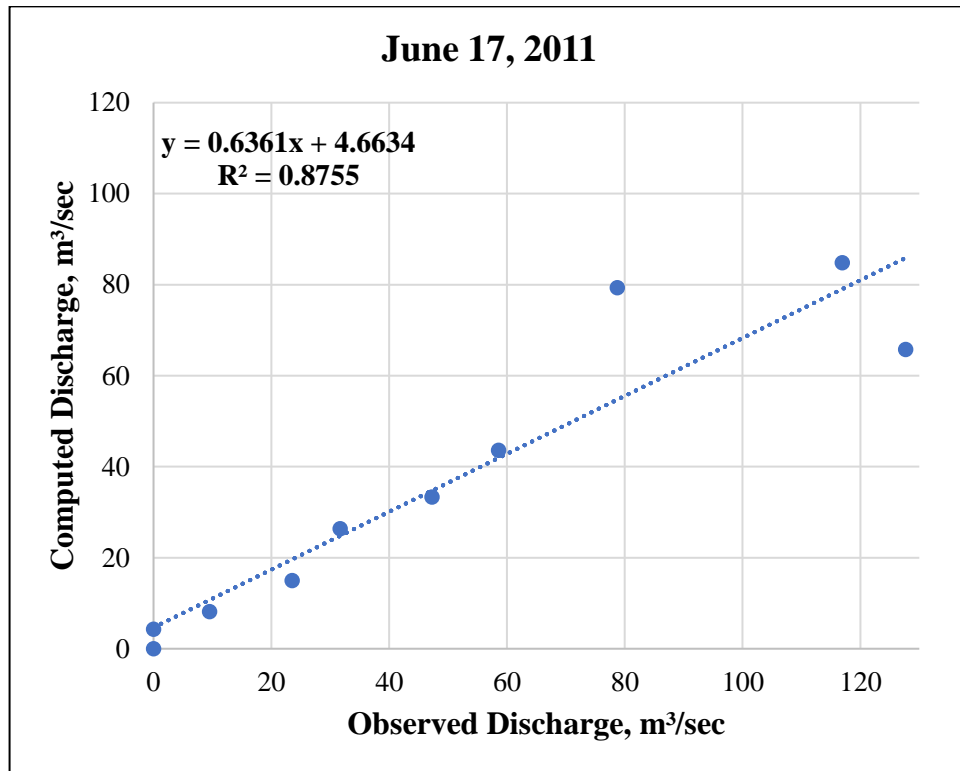


Fig 4.48 Variation of computed discharge with observed discharge on June 17, 2011

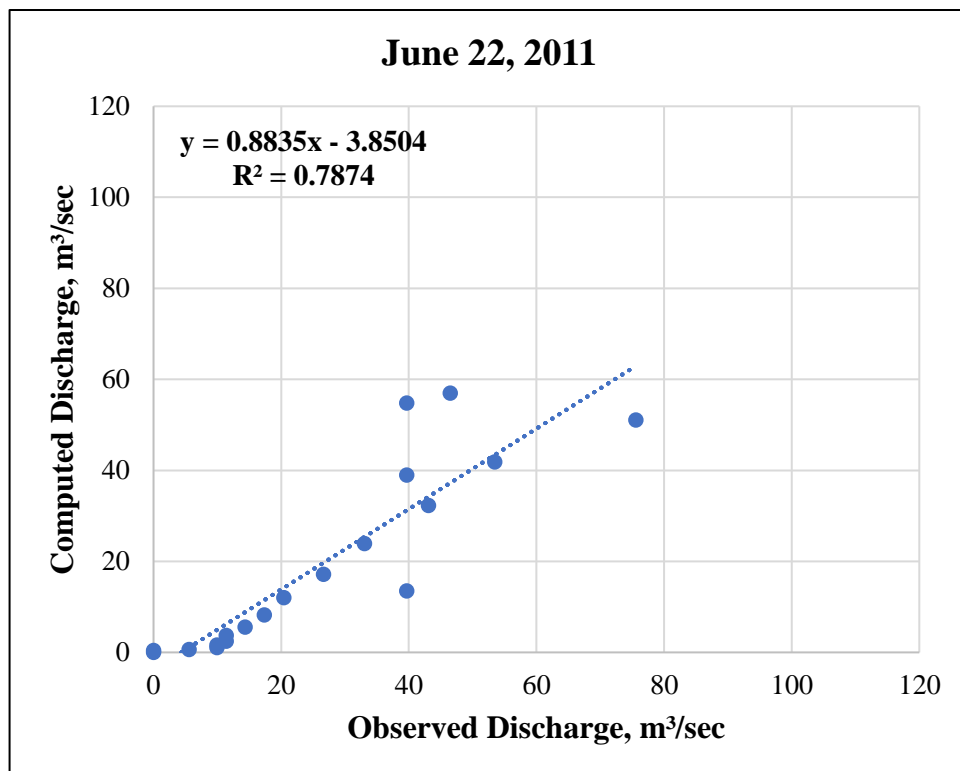


Fig 4.49 Variation of computed discharge with observed discharge on June 22, 2011

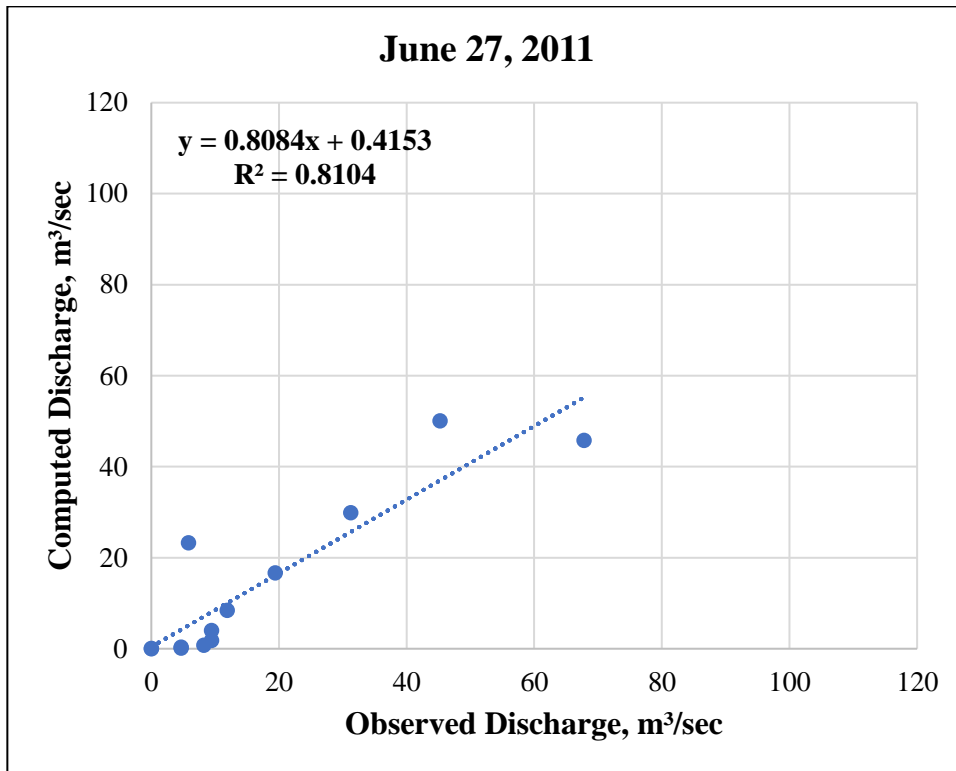


Fig 4.50 Variation of computed discharge with observed discharge on June 27, 2011

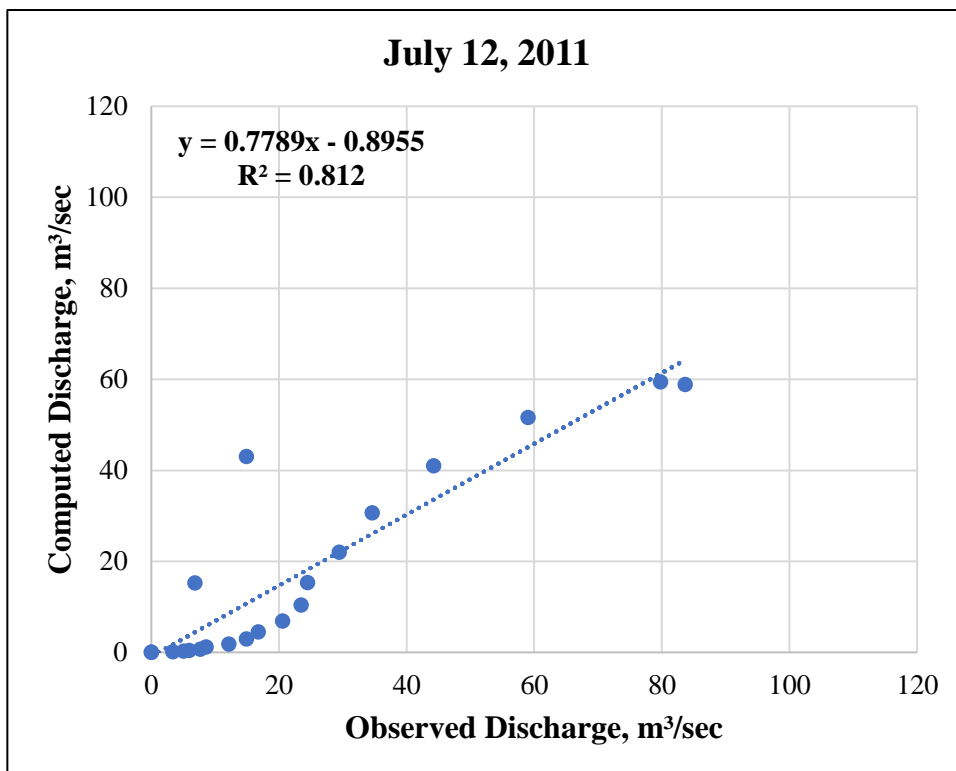


Fig 4.51 Variation of computed discharge with observed discharge on July 12, 2011

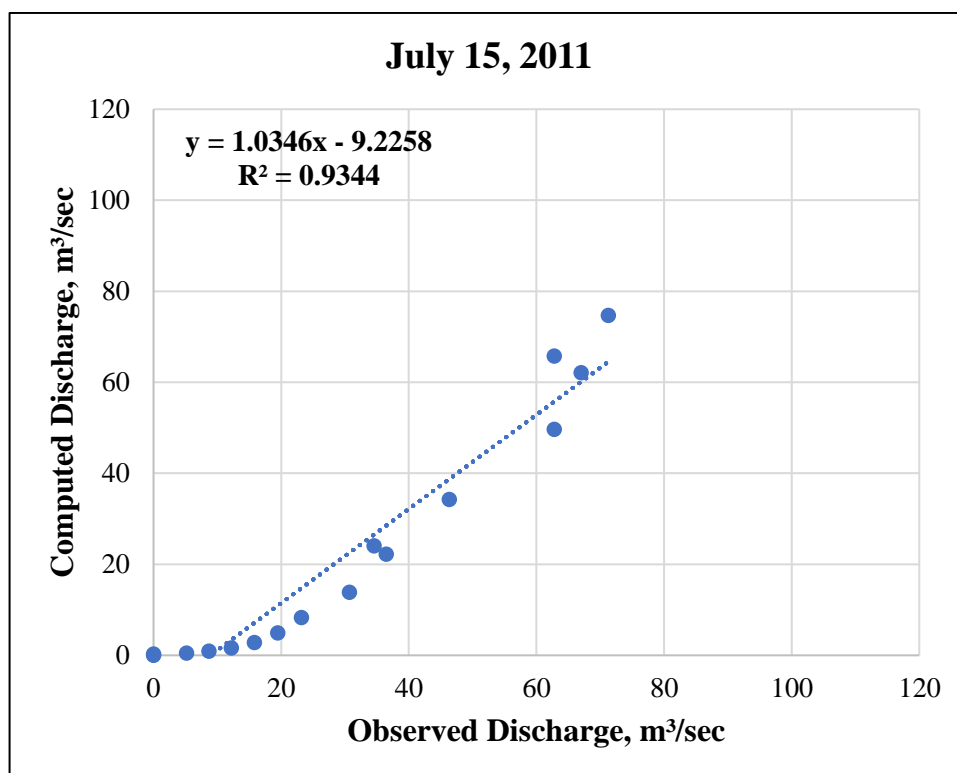


Fig 4.52 Variation of computed discharge with observed discharge on July 15, 2011

It is observed from above Fig 4.48 to 4.52 that the R-square value ranges between 75% to 86%. The maximum R-square of 93% was observed on July 15th, 2011 which shows the minimum variations between observed and predicted discharge. From the above results it was concluded that as there are minimum variations between observed and predicted discharge, it showed maximum accuracy of the model.

Table 4.14 Performance evaluation indices of GIUH based Nash model for year 2011

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	17-Jun-2011	83.974	8.043	18.379	8.043	0.335	25
2	22-Jun-2011	74.736	5.674	10.603	5.674	0.245	25
3	27-Jun-2011	78.929	2.793	8.833	2.793	0.261	33.333
4	12-Jul-2011	76.652	5.573	11.484	5.573	0.289	-33.333
5	15-Oct-2011	84.044	7.232	9.877	7.232	-0.048	0

Efficiencies of GIUH for Chatav watershed varied from 74.736 to 84.044 percent. Absolute average error (AAE) ranged between 2.793 to 8.043, RMSE also ranged between 8.833 to 18.379. AEV varied from 2.793 to 8.043. PEP varied between -0.048 to 0.335 and PETP varied between -33.333 to 25. Based on the performance evaluation indices it was concluded that GIUH based UH are effective for prediction of runoff from Jagbudi river catchment.

4.3.6 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2012:

Runoff producing intense storms recorded on 6th August, 14th August, 31th August, 5 September and 12th September in year 2012. Estimated velocity, scale parameter, time to peak and peak discharge for storms selected from year 2012 are mentioned in Table 4.15.

Table 4.15 Unit hydrograph parameters for different storm events in year 2012

Shape Parameter	Date	V (m/s)	K (h)	t _p (h)	Q _p (m ³ /s)
n=2.7	06-Aug-2012	6.810	0.613	1.043	35.746
	14-Aug-2012	5.137	0.813	1.382	118.773
	31-Aug-2012	2.956	1.413	2.402	73.264
	05-Sep-2012	5.412	0.772	1.312	124.004
	12-Sep-2012	2.118	1.972	3.353	53.393

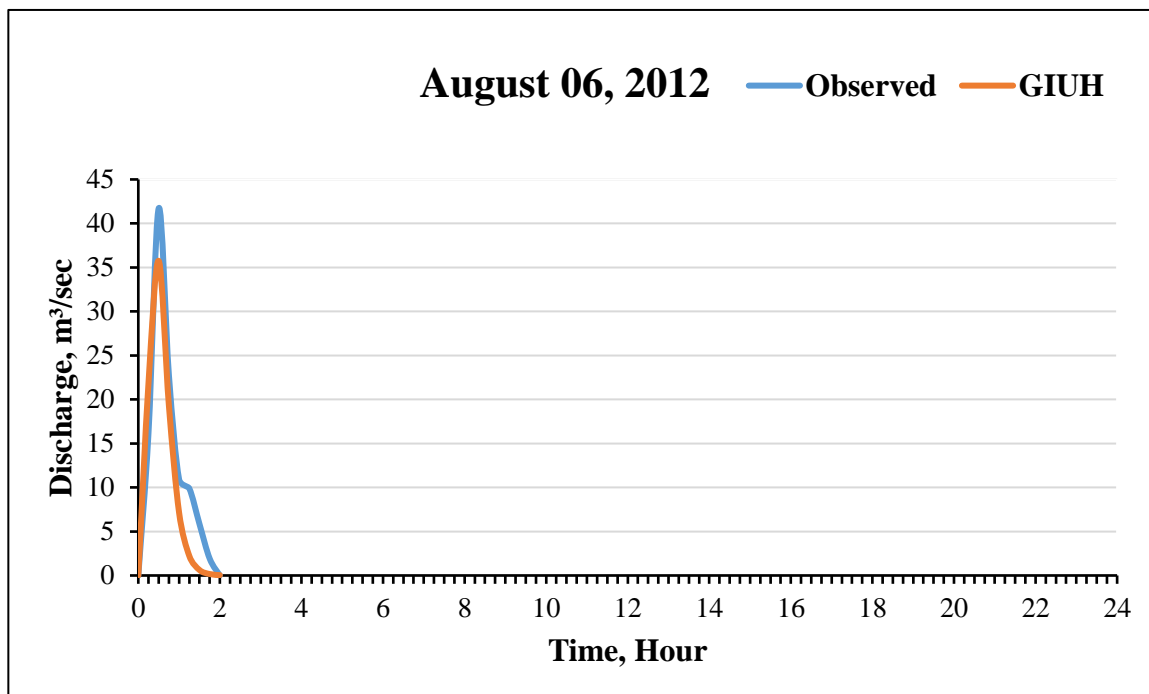


Fig 4.53 0.25 h-Unit hydrograph is converted to One h-Unit hydrograph on August 06, 2012

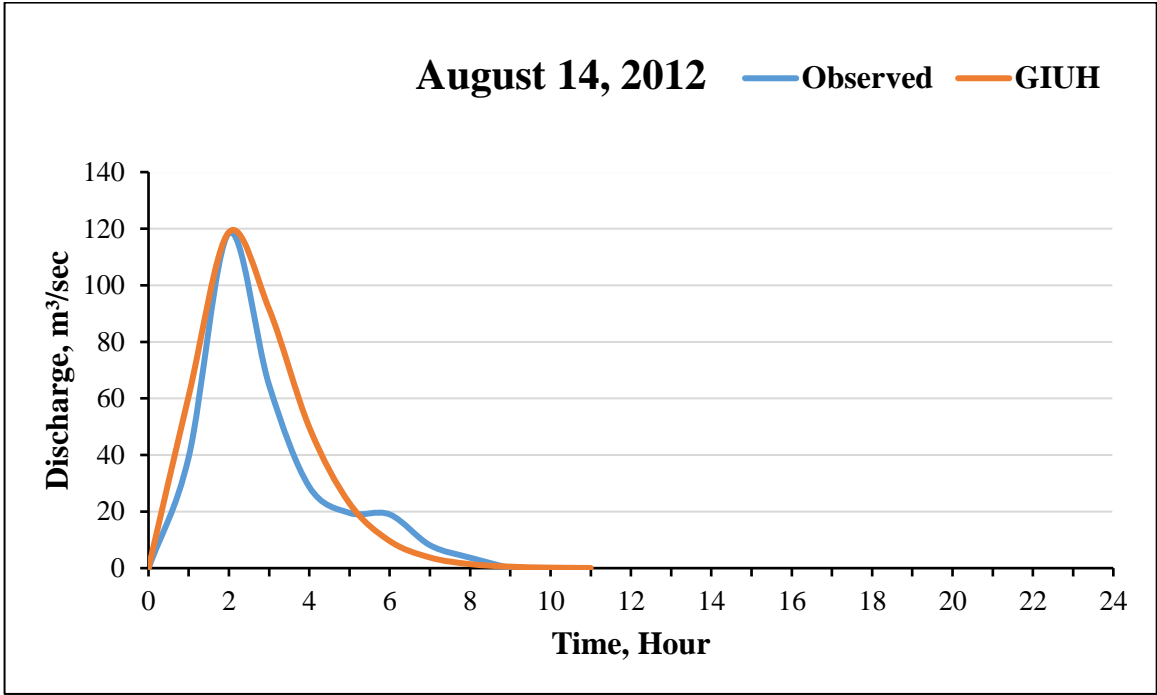


Fig 4.54 One h-Unit hydrograph on August 14, 2012

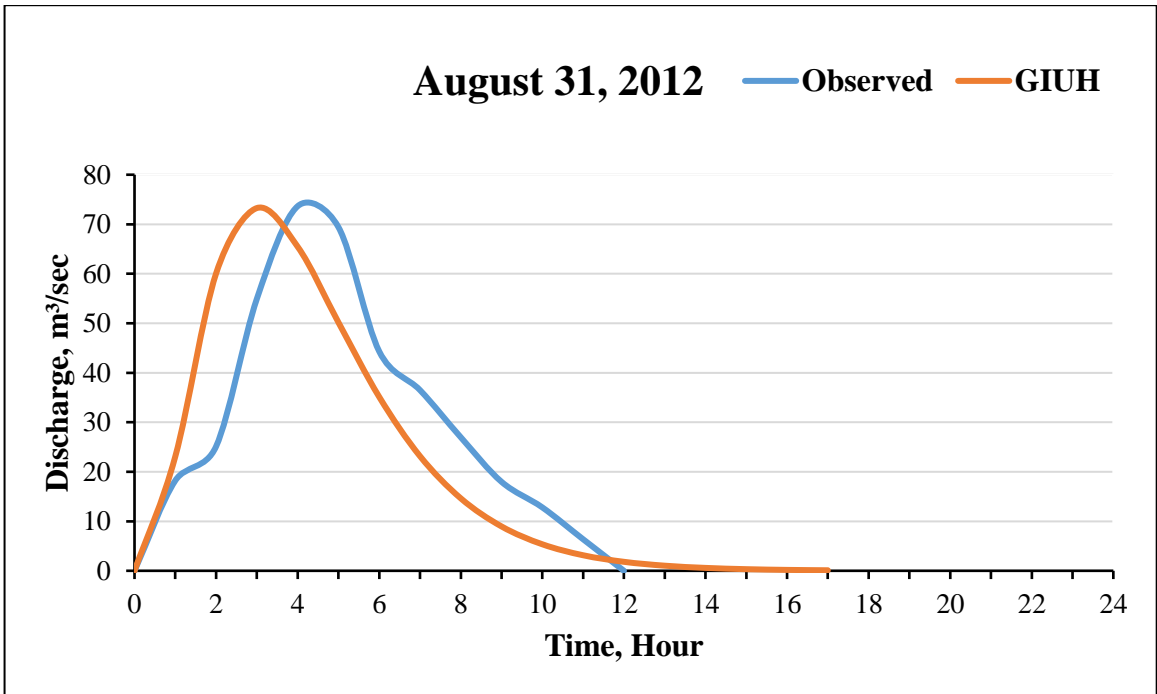


Fig 4.55 One h-Unit hydrograph on August 31, 2012

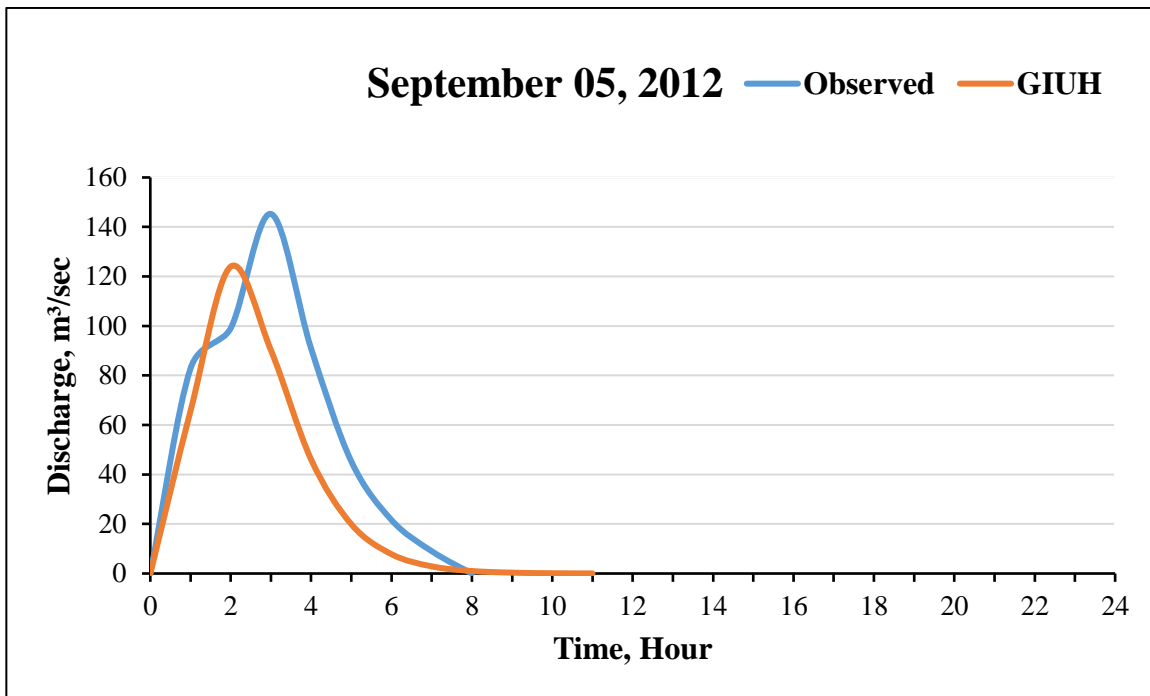


Fig 4.56 One h-Unit hydrograph on September 05, 2012

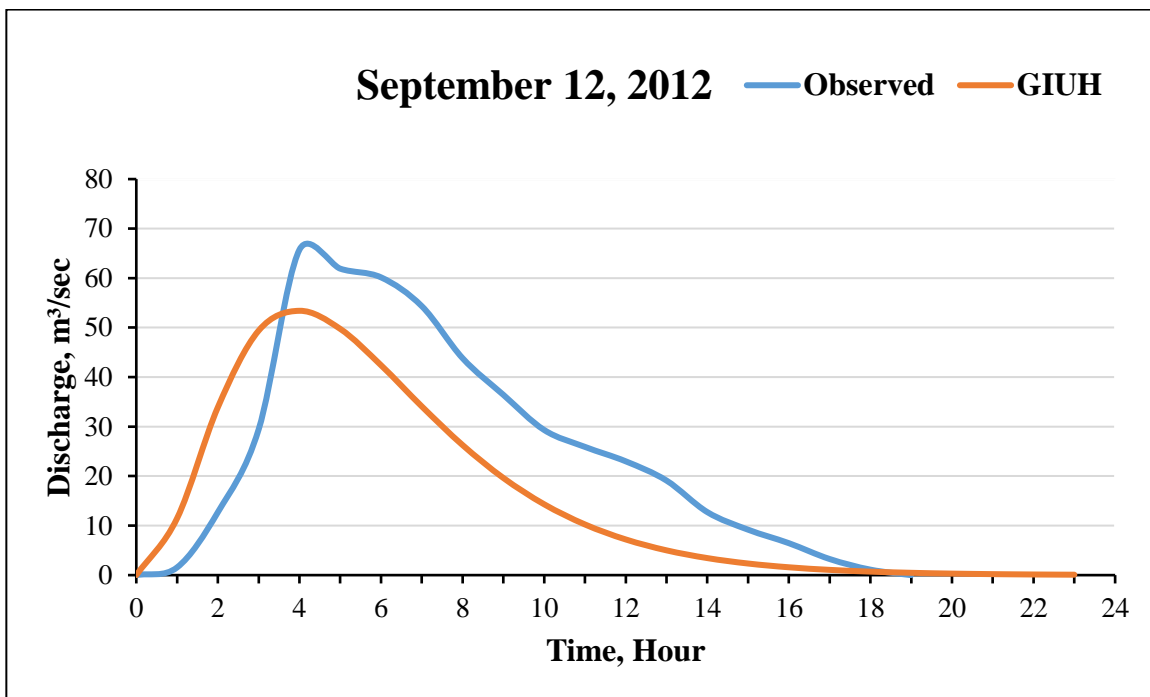


Fig 4.57 One h-Unit hydrograph on September 12, 2012

The maximum velocity of 6.810 m/s was observed on 6th August, which is with scale parameter 0.613. An influence of average channel velocity on GIUH is presented in figures from 4.53 to 4.57. It is evident from result that stream velocity is strongly and inversely proportional to time to peak. The computed peak discharge was 124.004 m³/s and time to peak was 1.312 hr.

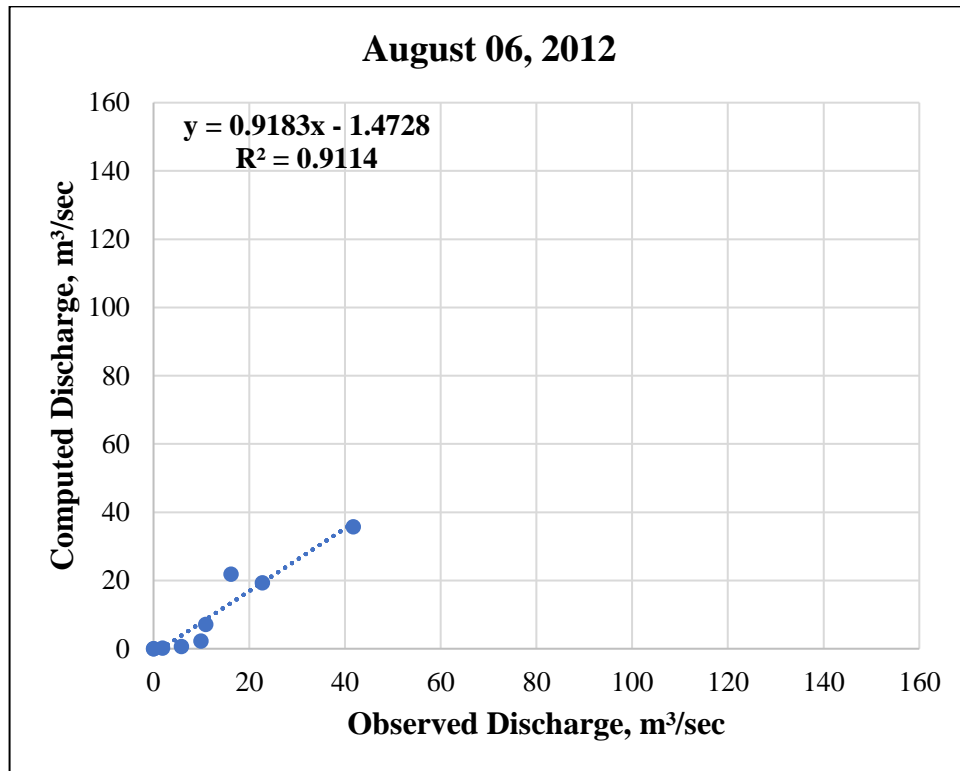


Fig 4.58 Variation of computed discharge with observed discharge on August 06, 2012

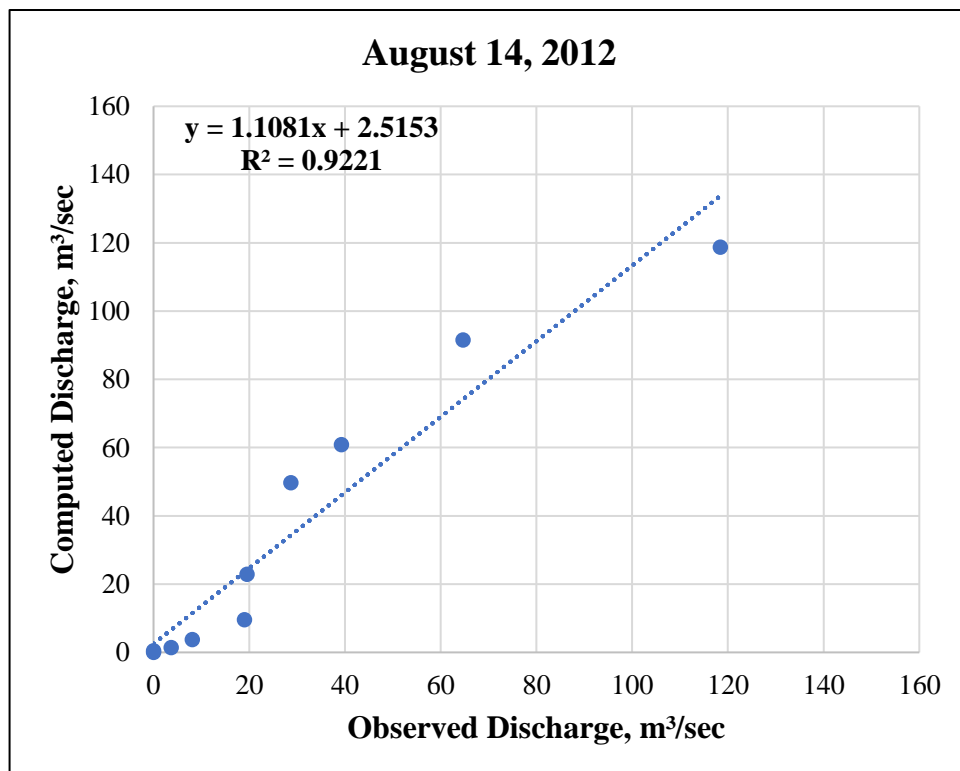


Fig 4.59 Variation of computed discharge with observed discharge on August 14, 2012

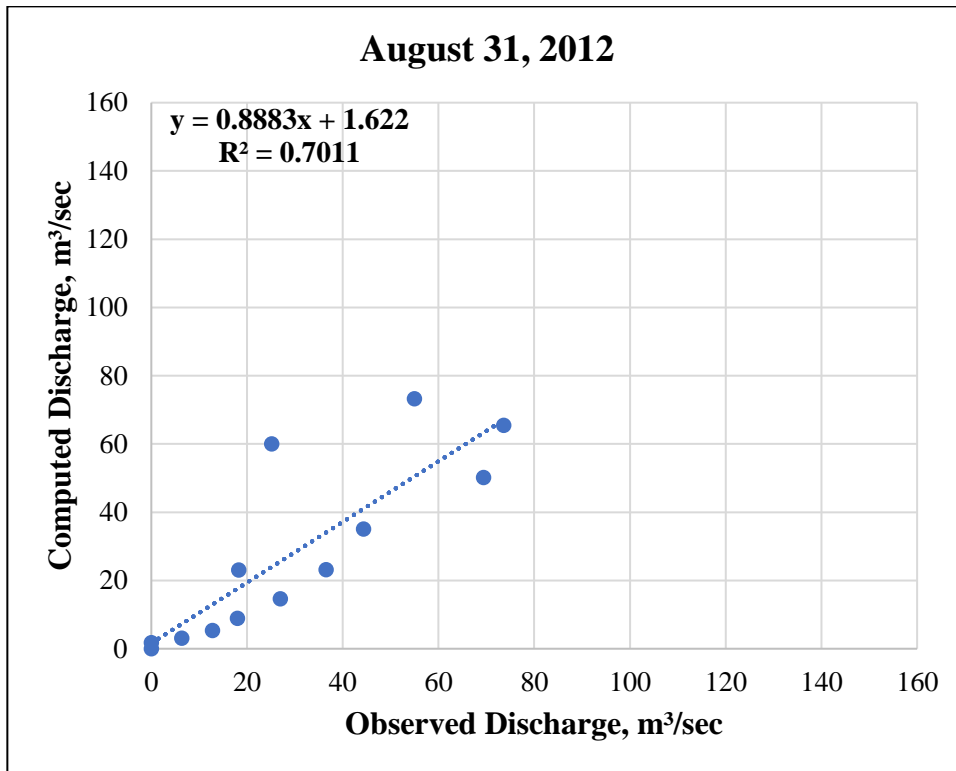


Fig 4.60 Variation of computed discharge with observed discharge on August 31, 2012

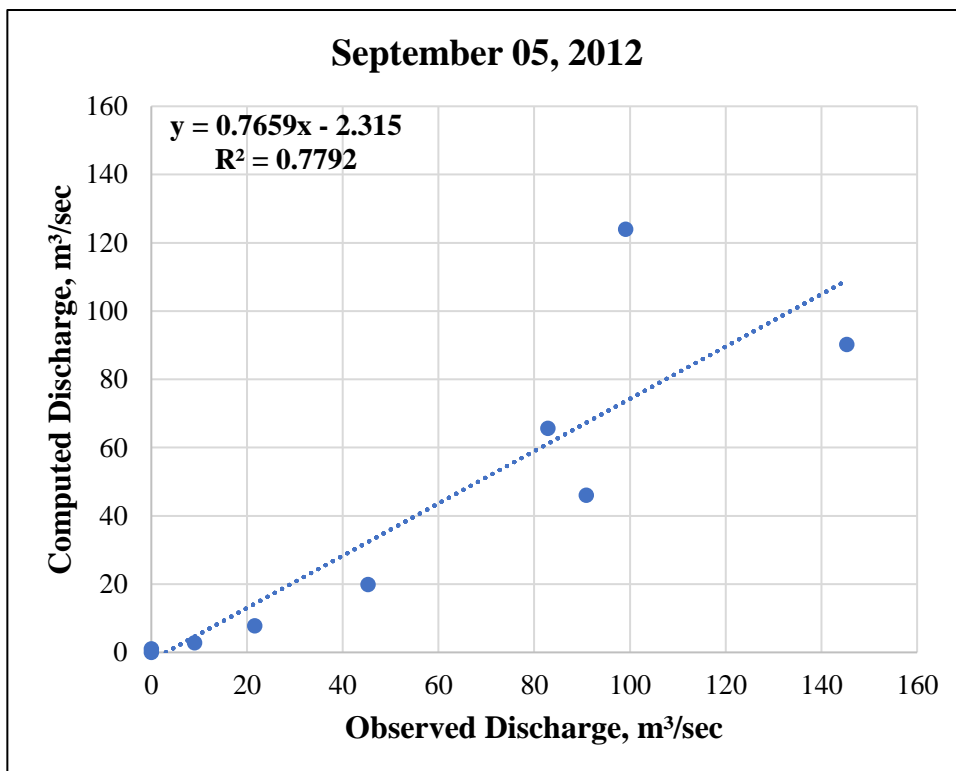


Fig 4.61 Variation of computed discharge with observed discharge on September 05, 2012

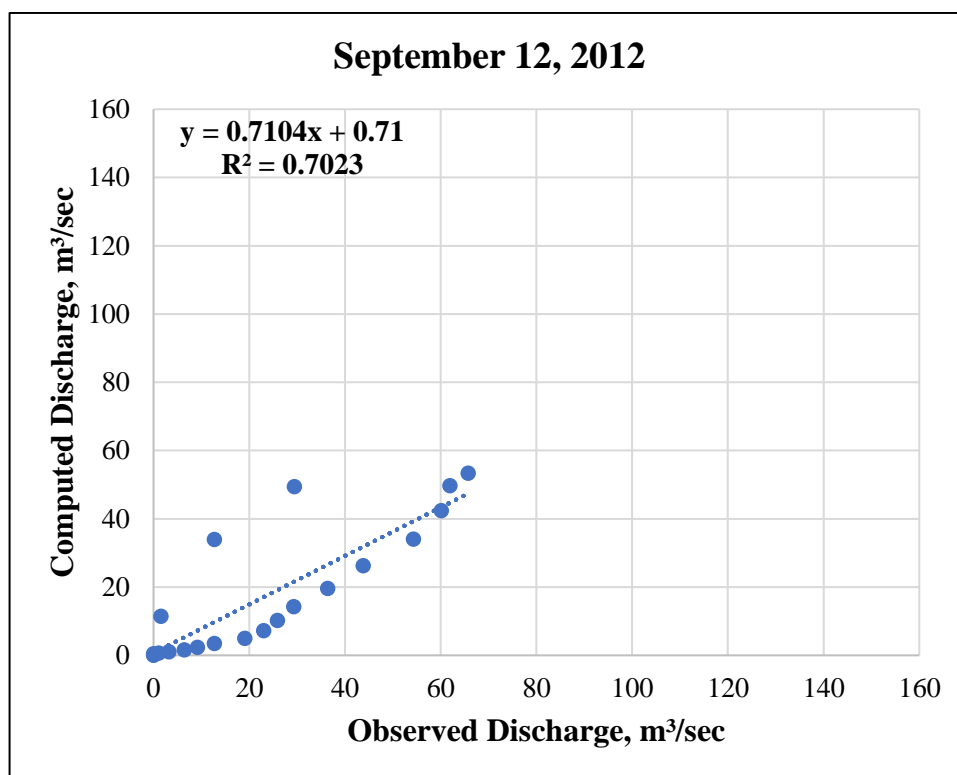


Fig 4.62 Variation of computed discharge with observed discharge on September 12, 2012

Table 4.16 Performance evaluation indices of GIUH based Nash model for year 2012

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	06-Aug-2012	87.361	2.465	4.512	2.465	0.143	0
2	14-Aug-2012	87.582	-4.832	12.094	-4.832	-0.002	0
3	31-Aug-2012	77.921	1.102	11.983	1.102	0.005	25
4	05-Sep-2012	77.659	11.329	23.853	11.329	0.146	33.333
5	12-Sep-2012	69.335	5.363	12.318	5.363	0.187	0

Efficiencies of GIUH for Jagbudi river catchment was varied from 69.335 to 87.582 percent. Absolute aAerage Error (AAE) ranged between -4.832 to 11.329. RMSE also ranged from 4.512 to 23.853. AEV varied from -4.832 to 11.329. PEP ranged between -0.002 to 0.187 and PETP varied between 0 to 33.333. It was observed that all the performance evaluation indices were in acceptable range

4.3.7 Geomorphological Instantaneous Unit Hydrograph for selected storms for the year 2015:

Runoff producing intense storms recorded on 22th June, 30th June, 20th July, 8th August, 15th September in year 2015 were selected. Estimated velocity, scale parameter, time to peak and peak discharge for storms selected from year 2015 are mentioned in Table 4.17.

Table 4.17 Unit hydrograph parameters for different storm events in year 2015

Shape Parameter	Date	V (m/s)	K (h)	t_p (h)	Q_p (m ³ /s)
n=2.7	22-Jun-2015	5.022	0.832	1.414	116.362
	30-Jun-2015	1.449	2.882	4.900	36.632
	20-Jul-2015	1.307	3.196	5.434	33.339
	08-Aug-2015	4.152	1.006	1.710	95.580
	15-Sep-2015	3.523	1.186	2.016	42.016

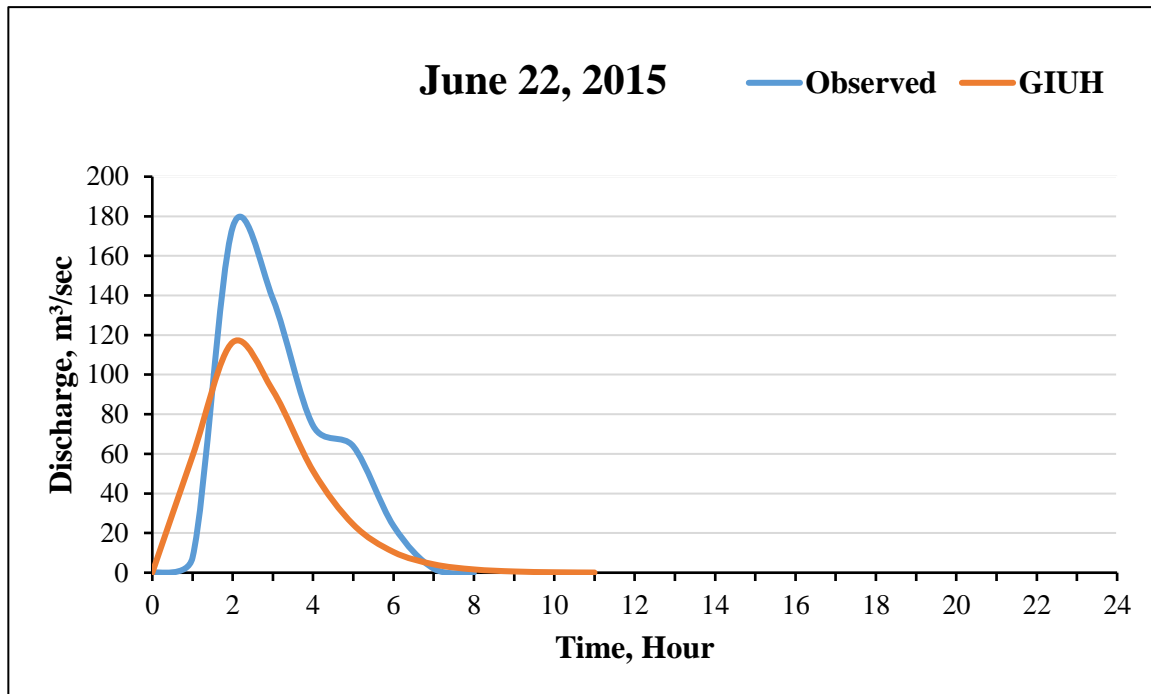


Fig 4.63 One h-Unit hydrograph on June 22, 2015

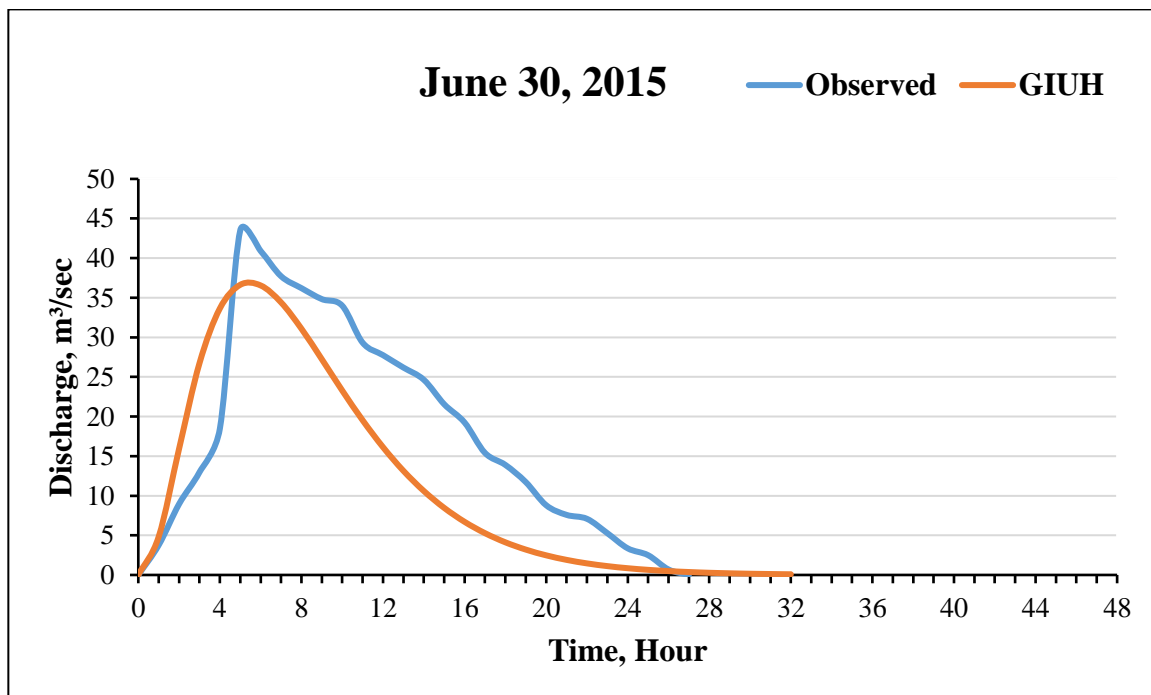


Fig 4.64 One h-Unit hydrograph on June 30, 2015

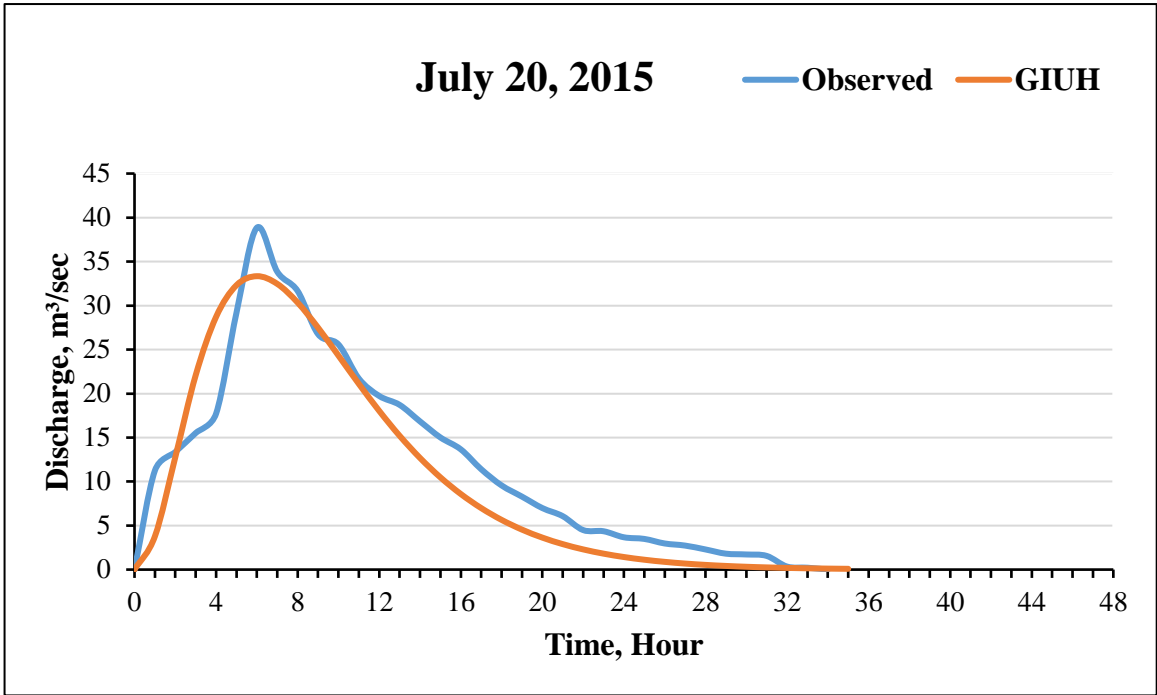


Fig 4.65 One h-Unit hydrograph on July 20, 2015

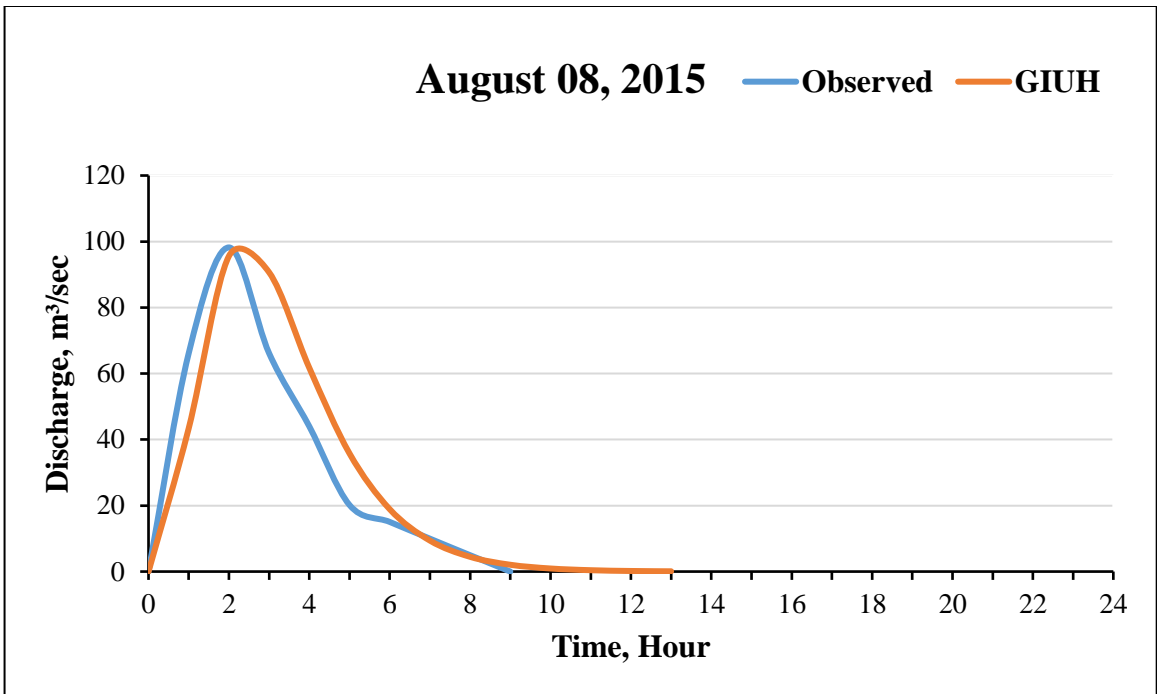


Fig 4.66 One h-Unit hydrograph on August 08, 2015

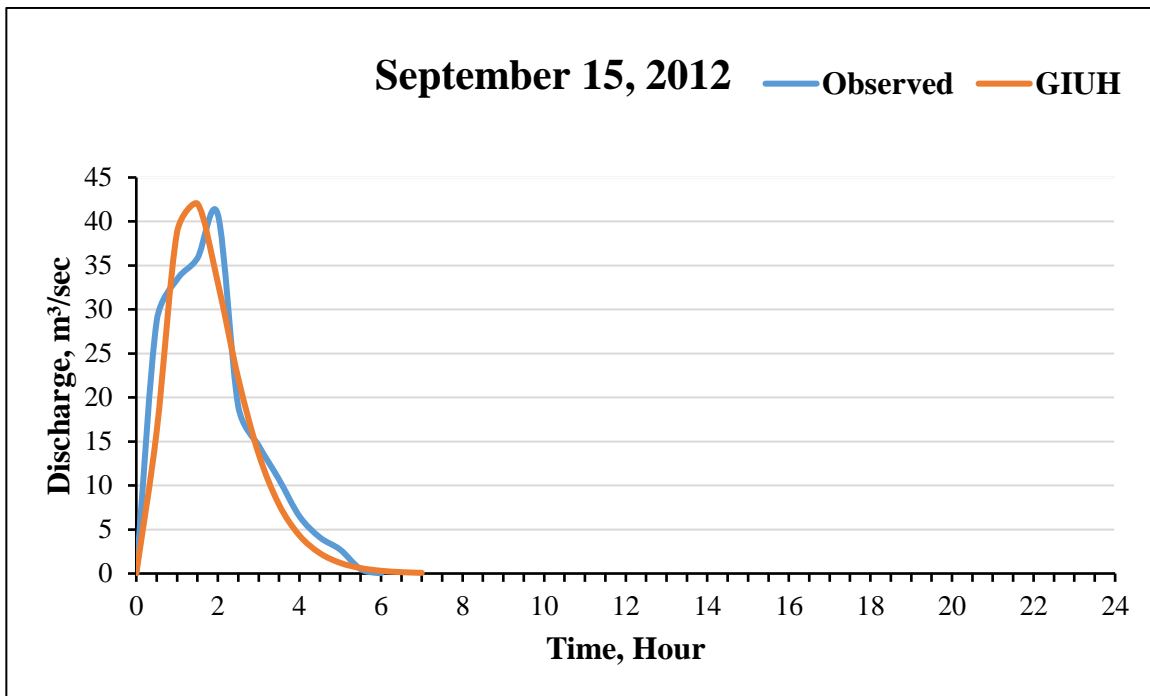


Fig 4.67 0.5 h-Unit hydrograph is converted to One h-Unit hydrograph on September 15, 2012

Among the selected storms maximum velocity 5.022 m/s was observed on 22th June 2015 with scale parameter 0.832. The computed peak discharge was 116.362 m³/s and time to peak was 5.434 h. It can be inferred from table 4.17 as the velocity increases value of scale parameter decreases and it tends to increase peak discharge and going to decrease time to peak.

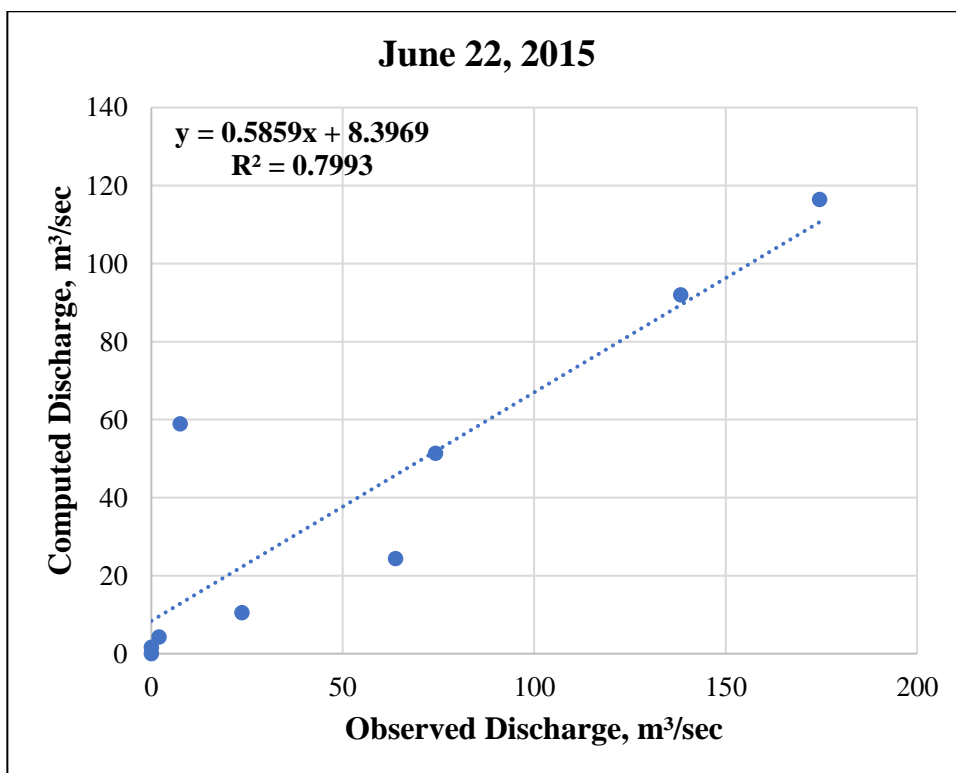


Fig 4.68 Variation of computed discharge with observed discharge on June 22, 2015

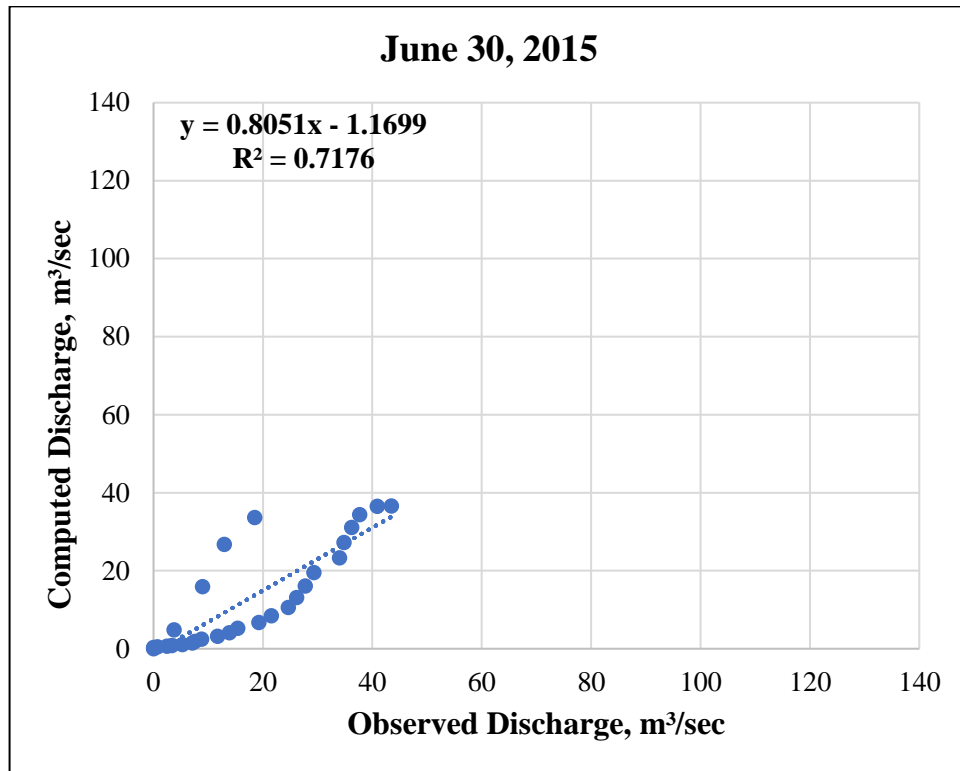


Fig 4.69 Variation of computed discharge with observed discharge on June 30, 2015

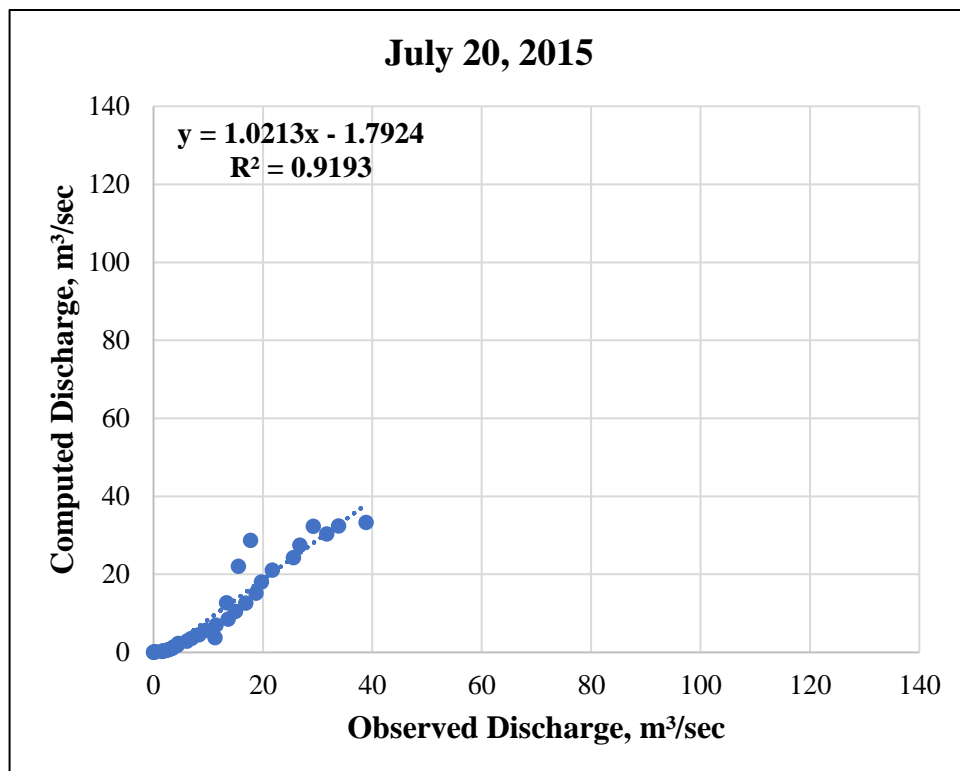


Fig 4.70 Variation of computed discharge with observed discharge on July 20, 2015

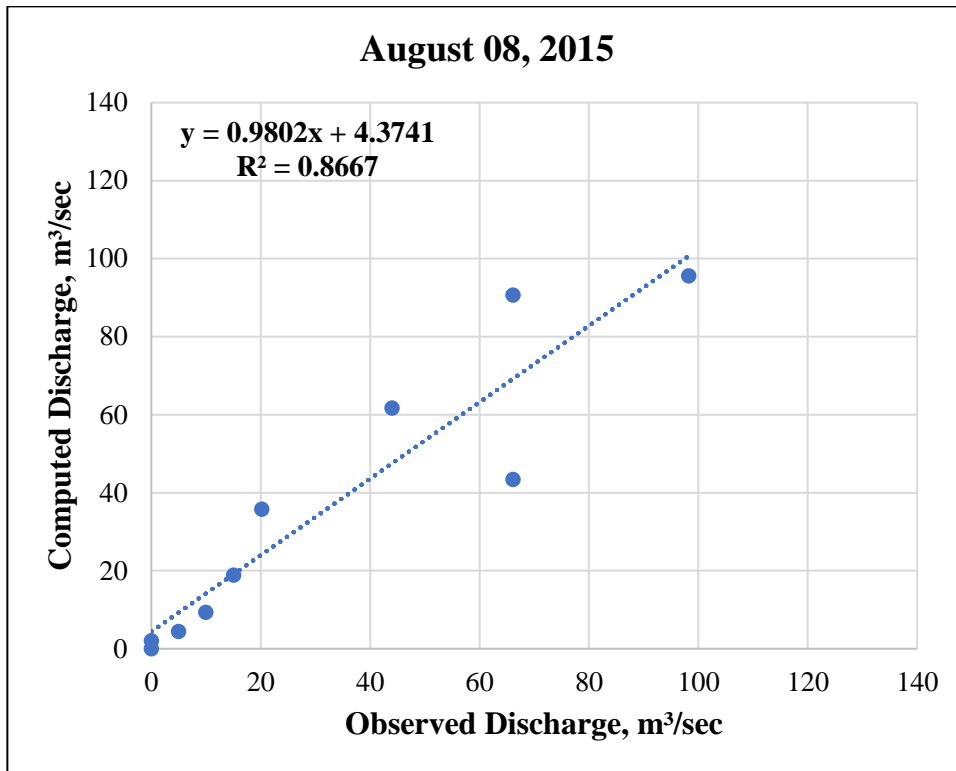


Fig 4.71 Variation of computed discharge with observed discharge on August 08, 2015

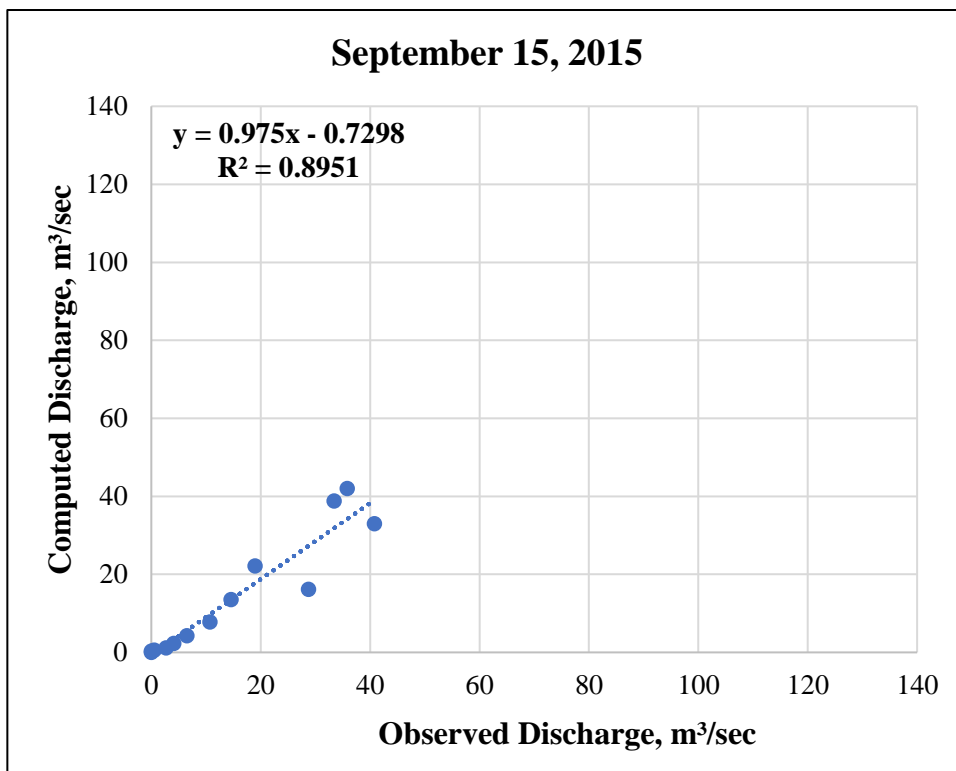


Fig 4.72 Variation of computed discharge with observed discharge on September 15, 2012

Table 4.18 Performance evaluation indices of GIUH based Nash model for year 2015

Sr. No.	Date	EFF (%)	AAE	RMSE	AEV	PEP (%)	PETP (%)
1	22-Jun-2015	73.619	10.328	29.472	10.328	0.333	0
2	30-Jun-2015	68.580	3.899	7.927	3.899	0.158	0
3	20-Jul-2015	89.143	1.490	3.554	1.490	0.141	0
4	08-Aug-2015	88.456	-2.779	11.032	-2.779	0.026	0
5	15-Sep-2015	89.929	0.945	4.576	0.945	-0.463	25

Efficiencies of GIUH for Jagbudi river catchment had varied from 68.580 to 89.929 percent. Average efficiency was 81.945 per cent. Absolute average error (AAE) ranged between -2.779 to 10.328. RMSE varied from 3.554 to 29.472, AEV ranged from -2.779 to 10.328, PEP varied from -0.463 to 0.333 and PETP varied between 0 to 25. It was observed that all the performance evaluation indices were in acceptable range. Performance evaluation indices of 2015 were better than 2012.

The results discussed above showed that the GIUH approach provides data on the effect of specific Geomorphoclimatic parameters on flood discharge. DEM and satellite pictures were used to calculate the variability of the watershed and land cover.

Two parameters, n and k , were the sole ones used to determine an instantaneous unit hydrograph obtained from the Nash model. In Figures 4.36 to 4.55, the impact of these parameters on the size and shape of the hydrograph is shown. It was found that the parameter k impacted the time of the peak discharge, whereas the parameter n affected the shape of the hydrograph. The greater the value of parameter k , the longer the peak discharge time. Peak discharge (Q) increased in the same proportion as the value of parameter n grew simultaneously.

The time base for the peak discharge is the main factor of instantaneous unit hydrograph and is determined by the excess rainfall. It was discovered that excessive rainfall intensity had a significant effect on both the peak flow rate and time to peak. Flow velocity increases with increase in excess rainfall intensity. This is because peak flow and flow velocity are the functions of excess rainfall. This means that the proposed IUH took into account the impact of varying rainfall intensity.

Flow velocity also has a great effect on peak flow rate and time to peak. As the flow velocity increased, the hydrograph shifted to the left and peak discharge occurred earlier. Changes in flow velocity appeared to have a greater impact on the time to peak than on the peak flow rate.

The velocity in the basin ranged from 1.014 to 7.11 m/s, with a scale parameter ranging from 0.587 to 4.117. On September 19, 2007, a storm with a maximum velocity of 7.11 m/s was spotted. It may be concluded that when velocity increases, the value of the scale parameter reduces,

causing to increase peak discharge and correspondingly decrease peak time. Peak discharge ranged from 13.273 to 124.004 m³/s, with the time to peak decreasing from 5.434 to 0.999 hr.

The shape of the hydrograph is mostly affected by the morphometric parameters like bifurcation ratio, stream length ratio and stream area ratio. Peak discharge and time to peak are significantly affected by the stream length area. Higher value of stream length ratio indicates the higher peak discharge. However, increasing stream area ratio and bifurcation ratio have increased in time to peak.

The model was able to capture the effects of changing land cover due to the use of remote sensing imagery to calculate roughness coefficient. This suggests that the GIUH approach can be modified to handle a watershed with inadequate hydrologic records. The approach can be considered as a good reference for designing and planning water resources for ungauged areas. The GIUH model can be used for similar types of ungauged watersheds to forecast stream flow up to 15 hours before the actual flood, it is concluded.

CHAPTER V: SUMMARY AND CONCLUSIONS

Remote Sensing (RS) and GIS techniques have proved to be more accurate and efficient tool used in surface water hydrology for water resource planning, management and development. The majority of watersheds in the world, particularly in developing nations, are ungauged. For predicting runoff response as a result of rainfall response, the Geomorphological Instantaneous Unit Hydrograph (GIUH) is an effective approach with direct applicability to an ungauged catchment. Rodriguez-Iturbe and Valdes first presented the idea of the Geomorphological Instantaneous Unit Hydrograph (GIUH) (1979). Their quantitative knowledge added a new perspective to the hydrological analysis, particularly for river basins without gauges. Taking into account all of these facts, the current study was conducted to develop a GIUH-based Nash model using RS and GIS and to compare the observed and estimated DRHs.

Jagbudi river catchment (i.e., Chatav watershed) was selected as the study area for the present research. The watershed is located at Chatav in Khed tehsil, district Ratnagiri of Maharashtra state. It is located 47 km away from Dapoli which lies between $17^{\circ}45'28.8''\text{N}$ Latitude and $73^{\circ}32'06.0''\text{E}$ Longitude. The total area of the watershed is 17700 ha. GIS software was used for the preparation of thematic maps and estimation of geomorphological characteristics. Firstly, watershed was delineated. Then, a drainage map and slope map were prepared by using Digital Elevation Model (DEM). The slope map was divided into six classes namely nearly level, gentle, moderately gentle, steep, moderately steep, and very steep. The morphometric parameters which include linear, areal, and relief aspects were determined. The bifurcation ratio for the basin varied from 1.03 to 2.38 which indicates that the drainage pattern has strong structural control. The value for the form factor is 0.38 which shows the elongated shape of the basin. The elongation ratio of the Jagbudi river basin is 0.7 which indicates the flatter peak flows over a longer period of time.

The Hortons ratios like bifurcation ratio, stream length ratio and stream area ratio were 1.68, 1.06 and 2.17 respectively were determined. The shape parameter (n) of the basin was determined as 2.7 and scale parameter varies according to each storm depending on rainfall excess. By using the values for n and k , the ordinates of the GIUH based Nash model were estimated. The performance of the model was evaluated using the error functions viz efficiency, absolute average error, root mean square error, average error in volume, percentage error in peak, percentage error in time to peak.

The findings of the models' calibration and validation revealed that the Nash model based on the GIUH has successfully replicated the shape of the unit hydrographs. It was discovered that the model performed better at simulating the unit hydrographs' shape and time to peak.

From the present study following conclusions has been drawn:

1. The mean stream length ratio is 1.06 of watershed fluctuates according to the change in topography and slope.
2. The shape parameters of the basin indicates that basin is elongated in shape.
3. The computed and observed design floods for the catchment varied from 13.27 to 124.00 m³/s and 16.19 to 145.27 m³/s, respectively.
4. Efficiency of GIUH based Nash model varies from 67.18 to 93.58 per cent which indicates the performance of the model in high to very high acceptable range.
5. The GIUH-based Nash model technique is particularly helpful in forecasting the temporal variation of surface runoff at the outlet of an ungauged basin, which is important in hydrologic/environmental engineering applications.
6. The given method can be used to determine the flood hydrograph for any basin or catchment, gauged or ungauged, at a reasonable cost and with reasonable accuracy because it just needs a catchment DEM, which is available for free from sources like SRTM or ASTER.
7. This GIUH model is useful in development of runoff in an event where the rainfall data is known.
8. The GIUH and GIS approach has potential application for the forecasting of the design flood particularly for the ungauged catchments.

CHAPTER VI: BIBLIOGRAPHY

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APPENDICES

APPENDIX A

Calculation for performance evaluation indices:

1. Efficiency:

$$\begin{aligned} \text{EFF} &= \frac{\sum_{i=1}^n (Q_{oi} - \bar{Q})^2 - \sum_{i=1}^n (Q_{oi} - Q_{ci})^2}{\sum_{i=1}^n (Q_{oi} - \bar{Q})^2} \times 100 \\ &= \frac{(8429.555 - 2088.433)}{8429.555} \times 100 \\ &= 75.22\% \end{aligned}$$

2. Absolute average error (AAE):

$$\begin{aligned} \text{AAE} &= \frac{(Q_{oi} - \bar{Q})}{n} \\ &= \frac{127.861}{26} \\ &= 4.917 \end{aligned}$$

3. Root mean square error (RMSE):

$$\begin{aligned} \text{RMSE} &= \sqrt{\frac{\sum_{i=1}^n (Q_{oi} - Q_{ci})^2}{n}} \\ &= \sqrt{\frac{2088.433}{26}} \\ &= 8.962 \end{aligned}$$

4. Average error in volume (AEV):

$$\begin{aligned} \text{AEV} &= \frac{(\text{Vol}_o - \text{Vol}_c)}{n} \\ &= \frac{(494.863 - 367.001)}{26} \\ &= 4.917 \end{aligned}$$

5. Percent error in peak (PEP):

$$\begin{aligned} \text{PEP} &= \frac{(Q_{op} - Q_{cp})}{Q_{op}} \times 100 \\ &= \frac{(63.108 - 62.201)}{63.108} \\ &= 1.437 \end{aligned}$$

6. Percent error in time to peak (PETP):

$$\begin{aligned} \text{PETP} &= \frac{O_{T_P} - C_{T_P}}{O_{T_P}} \times 100 \\ &= \frac{(4-3)}{4} \times 100 \\ &= 25 \end{aligned}$$

A.1 Observed and Computed discharge for event 30th June 2003

Time	Observed (Q_{oi})	GIUH (Q_{ci})	$Q_{oi} - Q_{ci}$	$(Q_{oi} - Q_{ci})^2$	$(Q_{oi} - Q)$	$(Q_{oi} - Q)^2$
0	0.000	0.000	0.000	0.000	-19.03	362.140
1	10.077	16.818	-6.740	45.433	-8.952	80.143
2	51.481	46.625	4.855	23.578	32.451	1053.073
3	61.388	62.201	-0.812	0.660	42.358	1794.255
4	63.108	61.211	1.897	3.599	44.078	1942.942
5	36.515	51.789	-15.273	233.278	17.485	305.744
6	33.817	40.055	-6.238	38.913	14.787	218.674
7	31.257	29.195	2.061	4.250	12.227	149.503
8	28.698	20.401	8.296	68.834	9.668	93.476
9	26.209	13.815	12.394	153.613	7.179	51.541
10	23.85	9.129	14.720	216.684	4.82	23.232
11	21.497	5.917	15.579	242.728	2.467	6.086
12	19.211	3.774	15.436	238.285	0.181	0.032
13	17.049	2.376	14.672	215.285	-1.980	3.923
14	14.895	1.479	13.416	179.993	-4.134	17.091
15	12.808	0.912	11.896	141.523	-6.221	38.703
16	10.838	0.558	10.280	105.681	-8.191	67.105
17	8.880	0.338	8.541	72.955	-10.149	103.017
18	6.986	0.204	6.781	45.990	-12.043	145.054
19	5.202	0.122	5.079	25.800	-13.827	191.210
20	3.433	0.073	3.360	11.292	-15.596	243.247
21	3.433	0.000	3.433	11.789	-15.596	243.247
22	2.550	0.000	2.550	6.506	-16.479	271.562
23	1.257	0.000	1.257	1.580	-17.772	315.874
24	0.414	0.000	0.414	0.171	-18.615	346.529
25	0.000	0.000	0.000	0.000	-19.03	362.140
Total	494.863	367.001	127.861	2088.433	0.083	8429.555

APPENDIX B

B.1 Observed and Computed discharge for event 05th August 2004

Time	Observed (Q_{oi})	GIUH (Q_{ci})	$Q_{oi}-Q_{ci}$	$(Q_{oi}-Q_{ci})^2$	$(Q_{oi}-Q)$	$(Q_{oi}-Q)^2$
0	0.000	0.000	0.000	0.000	-15.51	240.560
1	3.053	6.773	-3.720	13.839	-12.456	155.159
2	5.920	21.510	-15.589	243.042	-9.589	91.964
3	8.802	34.393	-25.590	654.896	-6.707	44.985
4	62.100	41.122	20.978	440.099	46.590	2170.712
5	54.215	42.466	11.748	138.021	38.705	1498.085
6	44.544	40.174	4.370	19.100	29.034	843.008
7	36.690	35.854	0.835	0.697	21.180	448.605
8	31.551	30.699	0.851	0.725	16.041	257.323
9	29.127	25.482	3.644	13.284	13.617	185.439
10	27.620	20.648	6.971	48.597	12.110	146.654
11	18.027	16.413	1.614	2.607	2.517	6.339
12	14.751	12.843	1.908	3.643	-0.758	0.574
13	9.691	9.918	-0.227	0.051	-5.818	33.858
14	9.145	7.576	1.569	2.463	-6.364	40.503
15	8.615	5.732	2.883	8.313	-6.894	47.531
16	6.246	4.301	1.944	3.783	-9.263	85.805
17	6.039	3.205	2.834	8.034	-9.470	89.682
18	5.799	2.373	3.426	11.740	-9.710	94.291
19	5.772	1.747	4.025	16.203	-9.737	94.816
20	4.518	1.279	3.238	10.490	-10.991	120.804
21	4.216	0.933	3.283	10.778	-11.293	127.543
22	4.022	0.677	3.344	11.183	-11.487	131.971
23	2.327	0.490	1.836	3.373	-13.182	173.780
24	0.680	0.353	0.326	0.106	-14.829	219.917
25	0.000	0.254	-0.254	0.064	-15.51	240.560
26	0.000	0.182	-0.182	0.033	-15.51	240.560
27	0.000	0.130	-0.130	0.016	-15.51	240.560
28	0.000	0.092	-0.092	0.008	-15.51	240.560
Total	403.483	367.634	35.848	1665.203	-46.306	8312.157

B.2 Observed and Computed discharge for event 24th September 2007

Time	Observed (Q_{oi})	GIUH (Q_{ci})	$Q_{oi}-Q_{ci}$	$(Q_{oi}-Q_{ci})^2$	$(Q_{oi}-Q)$	$(Q_{oi}-Q)^2$
0	0.000	0.000	0.000	0.000	-19.03	362.140
1	10.077	16.818	-6.740	45.433	-8.952	80.143
2	51.481	46.625	4.855	23.578	32.451	1053.073
3	61.388	62.201	-0.812	0.660	42.358	1794.255
4	63.108	61.211	1.897	3.599	44.078	1942.942
5	36.515	51.789	-15.273	233.278	17.485	305.744
6	33.817	40.055	-6.238	38.913	14.787	218.674
7	31.257	29.195	2.061	4.250	12.227	149.503
8	28.698	20.401	8.296	68.834	9.668	93.476
9	26.209	13.815	12.394	153.613	7.179	51.541
10	23.85	9.129	14.720	216.684	4.82	23.232
11	21.497	5.917	15.579	242.728	2.467	6.086
12	19.211	3.774	15.436	238.285	0.181	0.032
13	17.049	2.376	14.672	215.285	-1.980	3.923
14	14.895	1.479	13.416	179.993	-4.134	17.091
15	12.808	0.912	11.896	141.523	-6.221	38.703
16	10.838	0.558	10.280	105.681	-8.191	67.105
17	8.880	0.338	8.541	72.955	-10.149	103.017
18	6.986	0.204	6.781	45.990	-12.043	145.054
19	5.202	0.122	5.079	25.800	-13.827	191.210
20	3.433	0.073	3.360	11.292	-15.596	243.247
21	3.433	0.000	3.433	11.789	-15.596	243.247
22	2.550	0.000	2.550	6.506	-16.479	271.562
23	1.257	0.000	1.257	1.580	-17.772	315.874
24	0.414	0.000	0.414	0.171	-18.615	346.529
25	0.000	0.000	0.000	0.000	-19.03	362.140
Total	494.863	367.001	127.861	2088.433	0.083	8429.555

B.3 Observed and Computed discharge for event 27th July 2010

Time	Observed (Q_{oi})	GIUH (Q_{ci})	$Q_{oi}-Q_{ci}$	$(Q_{oi}-Q_{ci})^2$	$(Q_{oi}-Q)$	$(Q_{oi}-Q)^2$
0	0	0.000	0.000	0.000	-31.80	1011.24
1	30.453	44.825	-14.372	206.561	-1.347	1.814
2	46.260	97.701	-51.441	2646.178	14.460	209.100
3	131.218	91.123	40.095	1607.612	99.418	9883.998
4	39.891	60.892	-21.001	441.043	8.091	65.474
5	30.453	34.660	-4.207	17.700	-1.347	1.814
6	27.659	17.961	9.697	94.046	-4.140	17.143
7	19.673	8.753	10.920	119.260	-12.126	147.043
8	15.033	4.084	10.949	119.887	-16.766	281.104
9	9.195	1.845	7.350	54.024	-22.604	510.958
10	0	0.813	-0.813	0.661	-31.800	1011.240
11	0.000	0.351	-0.351	0.123	-31.800	1011.240
12	0.000	0.149	-0.149	0.022	-31.800	1011.240
13	0.000	0.062	-0.062	0.003	-31.800	1011.240
Total	349.839	363.224	-13.385	5307.125	-95.360	16174.65

B.4 Observed and Computed discharge for event 17th June 2011

Time	Observed (Q_{oi})	GIUH (Q_{ci})	Q_{oi}-Q_{ci}	(Q_{oi}-Q_{ci})²	(Q_{oi}-Q)	(Q_{oi}-Q)²
0	0.000	0.000	0.000	0.000	-49.38	2438.384
1	47.256	33.339	13.91	193.699	-2.123	4.507
2	78.718	79.318	-0.599	0.359	29.338	860.768
3	116.92	84.863	32.056	1027.641	67.539	4561.649
4	127.705	65.800	61.904	3832.21	78.325	6134.867
5	58.554	43.612	14.941	223.242	9.174	84.166
6	31.660	26.358	5.302	28.113	-17.719	313.967
7	23.511	14.992	8.519	72.579	-25.868	669.155
8	9.501	8.169	1.332	1.775	-39.878	1590.262
9	0.000	4.311	-4.311	18.588	-49.38	2438.384
10	0.000	2.219	-2.219	4.927	-49.38	2438.384
11	0.000	1.120	-1.120	1.255	-49.38	2438.384
12	0.000	0.556	-0.556	0.309	-49.38	2438.384
13	0.000	0.272	-0.272	0.074	-49.38	2438.384
14	0.000	0.132	-0.132	0.017	-49.38	2438.384
15	0.000	0.063	-0.063	0.004	-49.38	2438.384
Total	493.830	365.132	128.697	5404.799	-296.25	33726.42

B.5 Observed and Computed discharge for event 05th September 2012

Time	Observed (Q_{oi})	GIUH (Q_{ci})	$Q_{oi}-Q_{ci}$	$(Q_{oi}-Q_{ci})^2$	$(Q_{oi}-Q)$	$(Q_{oi}-Q)^2$
0	0.000	0.000	0.000	0.000	-54.88	3011.814
1	82.831	65.625	17.206	296.074	27.951	781.306
2	99.093	124.004	-24.911	620.559	44.213	1954.863
3	145.271	90.226	55.045	3029.959	90.391	8170.586
4	90.872	46.066	44.806	2007.587	35.992	1295.458
5	45.299	19.909	25.389	644.635	-9.580	91.789
6	21.615	7.813	13.801	190.480	-33.264	1106.556
7	9.013	2.879	6.134	37.626	-45.866	2103.711
8	0.000	1.015	-1.015	1.031	-54.88	3011.814
9	0.000	0.346	-0.346	0.120	-54.88	3011.814
10	0.000	0.115	-0.115	0.013	-54.88	3011.814
11	0.000	0.0376	-0.037	0.001	-54.88	3011.814
Total	493.997	358.040	135.957	6828.088	-164.562	30563.34

B.6 Observed and Computed discharge for event 22th June 2015



Time	Observed (Q_{oi})	GIUH (Q_{ci})	$Q_{oi}-Q_{ci}$	$(Q_{oi}-Q_{ci})^2$	$(Q_{oi}-Q)$	$(Q_{oi}-Q)^2$
0	0	0.000	0.000	0.000	-53.77	2891.213
1	7.537	58.867	-51.329	2634.69	-46.232	2137.415
2	174.479	116.362	58.116	3377.509	120.709	14570.66
3	138.251	91.930	46.320	2145.578	84.481	7137.055
4	74.202	51.316	22.886	523.771	20.432	417.488
5	63.804	24.297	39.507	1560.839	10.034	100.697
6	23.628	10.455	13.172	173.526	-30.141	908.523
7	2.040	4.226	-2.186	4.779	-51.729	2675.918
8	0	1.635	-1.635	2.674	-53.77	2891.213
9	0	0.612	-0.612	0.375	-53.77	2891.213
10	0.000	0.223	-0.223	0.050	-53.77	2891.213
11	0.000	0.080	-0.080	0.006	-53.77	2891.213
Total	483.944	360.007	123.936	10423.79	-161.296	39512.61

THESIS ABSTRACT

Geomorphological characteristics can be treated as features of hydrological response. Geomorphological Instantaneous Unit Hydrograph (GIUH) is an effective modeling approach in hydrology for ungauged watersheds. In this study geomorphological characteristics of the catchment were related to the basic characteristics of the IUH through the concept of Geomorphological Instantaneous Unit Hydrograph (GIUH). The Jagbudi River catchment was selected as the study area for the present study. It lies between 17°73'12.0"N Latitude and 73°48'01.6"E Longitude. The Geomorphological characteristics including Horton's ratios of the catchments were extracted from Digital Elevation Model (DEM) using RS data and GIS software called ArcGIS 10.4.1. The morphometric parameters considered for analysis include the basin's linear, areal, and relief aspects. The watershed is having an area of 177.73 sq. km and was 4th order drainage. The mean bifurcation ratio was 1.68 indicating that the drainage pattern has strong structural control. The basin has a low drainage density of 0.93 km/km² and is elongated in shape. The basin's length of overland flow value of the basin was 0.54, indicating less structural disturbance and high overland flow. The Bifurcation ratio, Stream length ratio, and stream area ratio of the Chatav watershed were 1.68, 1.06, and 2.17 respectively. These values are further used for the estimation of the shape and scale parameters of the Chatav watershed.

Thirty-five rainfall-runoff events were selected from available rainfall-runoff data. The hydrograph for outlet runoff was derived for each event. The Nash parameters were determined. The value of shape parameter (n) was 2.70. Scale parameter (K) changed accordingly rainfall-runoff event. Scale parameters ranged from 0.587 to 4.117. These values depend on the velocity of the stream, which ranged between 1.014 to 7.11 m/s. The peak discharge varied from 13.27 to 124 m³/s. The performance of the GIUH model was evaluated using the error functions, namely efficiency, absolute average error, root mean square error, the average error in volume, the percentage error in peak, and percentage error in time to peak. The performance indicators were in a very high to the high level of the acceptable range.

GIUH-based Nash model has adequately simulated the shape of the unit hydrographs. It was found that the model was better at simulating the shape of the unit hydrographs. So, it is concluded that GIUH based model can be used for similar kinds of ungauged watersheds for predicting stream flow.

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Morphometric analysis of Chatav watershed using GIS techniques

Sayali V Shinde, HN Bhange, BL Ayare, ST Patil, MH Tharkar and PR Kolhe

Abstract

A Watershed is an ideal unit for the management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. SRTM DEM data at 30m spatial resolution have been used for the analysis. In the present study, RS and GIS technique is used to estimate the geomorphological parameters and delineation of the watershed. The research is carried out in the Chatav watershed in Khed tehsil of Ratnagiri district, Maharashtra. The study area is located between 17°45'28.8"N Latitude and 73°32'06.0"E Longitude. The total geographical area under study is 17700 ha. The average annual rainfall in the study area is 3511 mm and the mean temperature is 23.8 °C. Linear, areal, and relief aspects of the watershed were estimated. The results revealed that the basin has 4th order drainage network. The mean bifurcation ratio is 1.68 which indicates, the drainage pattern has strong structural control. The value of drainage density indicates the dense vegetation cover and low relief. The low relative relief indicates that peak discharge rates and catchment erosion are likely to be low. The study will be useful for the planning of watershed harvesting and groundwater recharge projects on a watershed basis.

Keywords: Watershed, morphometric analysis, GIS, DEM, linear, areal, relief aspects

Introduction

A Watershed is an ideal unit for the management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. The development of morphometric techniques is a major advance in the quantitative description of the geometry of the drainage basins and their network. The morphometric parameters are useful in characterizing river basins and comparing their characteristics. For the first time, it was proposed by Horton in 1945^[4]. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, and dimension of its landforms (Rai *et al.* 2014)^[11].

Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of the watershed because it enables us to understand the relationship among different aspects of the drainage pattern of the basin and also to make a comparative evaluation of different drainage basins, developed in various geologic and climatic regimes (Pingale *et al.* 2012)^[9].

The measurement of these parameters is very laborious by the conventional methods, but by using the latest techniques like GIS, the morphometric analysis of natural drain can be better achieved. RS and GIS technique is used to estimate the geomorphological characteristics of the watershed. Various morphometric parameters need to measure in a drainage basin including stream order, stream length ratio, stream number, and basin area. Other morphometric parameters are basin shape factor (e.g. circularity ratio, elongation ratio, form factor, and compaction ratio), basin perimeter, bifurcation ratios, drainage density, stream frequency, and drainage intensity (Kandekar *et al.* 2021)^[5].

Arc GIS is a powerful software to analyse, visualize, update geographical information and create quality presentations that brings the power of interactive mapping and analysis. Geomorphological analysis helps in a better understanding of the hydrological system of the watershed which is useful for carrying out management strategies (Bansod and Ajabe, 2018)^[2]. The study will be helpful for the planning of water harvesting and groundwater recharge projects in the watershed.

Materials and Methods

Study area

In the Jagbudi river catchment, the Chatav watershed was selected as the study area for the present research. Jagbudi is the tributary of the Vashishti River and it meets Vashishti near Bahiravali. It originates from Khopi in the Ratnagiri district. The watershed is located at Chatav in Khed tehsil and district Ratnagiri of Maharashtra state. It lies between 17°45'28.8"N Latitude and 73°32'06.0"E Longitude. The total area of the watershed is 17700 ha. The average annual rainfall in the study area is 3511 mm and the mean annual temperature is 23.8 °C. The Jagbudi river basin has witnessed high rainfall and consequent floods of various intensities during recent years.

Data used and Methods

The boundary of the watershed is demarcated on Survey of India toposheet No. 47 G / 9 and 47 G / 10 (1:50,000). Digital Elevation Model (DEM) represents the relief of a surface between points of known elevation at a specific spatial resolution. The morphometric parameters were estimated using the SRTM DEM to an accuracy of 30 m. DEM data have been processed by the hydrological tool as in ArcGIS 10.4 software. Watershed delineation is carried out under the following steps fill, flow direction, flow accumulation, creation of outlet, snap pour point, and then watershed delineation.

A. Linear Aspects of Drainage Networks

It is concerned with the streams and their network. Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed (Afreeda and Kannan, 2018) [1]. It includes a one-dimensional component. These are one-dimensional properties as mentioned below.

Stream order

Stream order is the ranking of a stream channel segment in a drainage network (Salunke and Wayal, 2021) [12].

Stream number

The number of stream channels in their order is known as the stream number.

Bifurcation ratio (R_b)

Bifurcation ratio, defined as the ratio of the number of streams in Nth order to N + 1th order (Horton, 1945) [4], is an important parameter describing stages of river development. Strahler (1957) [14] observed that R_b characteristically ranges from 3 to 5 for the watershed in which geologic structures do not distort the drainage pattern.

$$R_b = \frac{N_u}{N_{u+1}} \quad (2.1)$$

Where,

R_b= bifurcation ratio

N_u = number of streams of order u

N_{u+1}= number of streams of order u+1

Mean Stream Length (\bar{L}_u)

The mean stream length is defined as the summation of the total length of all streams to the number of streams (R. Suresh, 2019) [10]

$$\bar{L}_u = \frac{\sum_{i=1}^N L_u}{N_u} \quad (2.2)$$

Where,

\bar{L}_u = mean length of the channel of order 'u',

N_u= total no. of stream segment of order 'u'.

Stream Length Ratio (R_L)

It is the ratio of the mean length of the stream (L_u) of a particular order to the mean stream length of the next lower order (L_{u-1}) (Horton, 1945) [4]

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \quad (2.3)$$

Where,

\bar{L}_u = Average length of stream of order u

\bar{L}_{u-1} = Average length of stream of order u-1

Stream Area Ratio (R_A)

The channel area of order, A_i is the area of the watershed that contributes to the channel segment of order i and all lower-order channels. It can be quantified as

$$R_A = \frac{\bar{A}_u}{\bar{A}_{u-1}} \quad (2.4)$$

Where,

\bar{A}_u = Average basin area of stream of order u

\bar{A}_{u-1} = Average basin area of stream of order u-1

B. Areal Aspects of Drainage Network

The areal aspect represents the characteristics of the catchment area and describes how the catchment area controls and regulates the hydrological behavior.

Form Factor (R_F)

It determines the shape of the basin. The form factor is defined as the ratio of the basin area to the square of the basin length (Horton, 1945) [4]

$$R_F = \frac{A_u}{L_b^2} \quad (2.5)$$

Where,

A_u = Area of the basin

L_b = Length of the basin

Circularity ratio (R_c)

The circulatory ratio is the ratio of the basin area to the area of the circle having an equal perimeter as the perimeter of a drainage basin.

$$R_C = \frac{A_u}{A_c} \quad (2.6)$$

Where,

A_u = basin area

A_c = area of a circle

Elongation Ratio (R_e)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956) [13]

$$R_e = \frac{D_c}{L_{bm}} \quad (2.7)$$

Where,

D_c = Diameter of a circle with the same area as the basin

L_{bm} = Maximum basin length

Drainage Density (D_d)

It is the ratio of the total length of channels of all orders in the basin to the drainage area of the basin (Horton, 1945) [4]. This term was first introduced by Horton (1932) [3]

$$D_d = \frac{\sum_{i=1}^K \sum_{j=1}^N L_{uj}}{A_u} \quad (2.8)$$

Where,

D_d = Drainage density

K = Principal order = highest order stream

L_u = Length of stream segments

A_u = basin area, km²

N = total no. of streams

Constant of Channel Maintenance (C)

It is the ratio between the area of the drainage basin and the total length of all the channels, expressed as a square meter per meter. It is also equal to the reciprocal of drainage density.

$$C = \frac{1}{D_d} \quad (2.9)$$

Where,

D_d = Drainage density

Length of Overland Flow (L_g)

The length of overland flow is approximately equal to half of the reciprocal of drainage density (Horton, 1945) [4]. It is the length of water over the ground before it gets concentrated into definite stream channels.

$$L_g = \frac{1}{2D_d} \quad (2.10)$$

A. Linear Aspects of Drainage Networks

Table 1: Linear aspects of the drainage network

Stream Order (u)	No. of Streams (N_u)	Stream Length km	Mean Stream Length km	Mean Stream Area Km ²	Bifurcation Ratio (R_b)	Stream Length Ratio (R_L)	Stream Area Ratio (R_a)
1	93	80.245	0.862	0.965			
2	39	43.490	1.115	3.269	2.384	1.292	3.384
3	30	21.948	0.731	5.215	1.3	0.656	1.595
4	22	19.989	0.908	8.078	1.363	1.241	1.548
Average					1.68	1.06	2.17

Stream order

The study area has a 4th-order drainage basin covering an area of 177 sq. km. There was a total of 184 streams, out of which 93 are of 1st order, 39 are of 2nd order, 30 are of 3rd order and 22 are of 4th order streams. The higher stream order of the watershed indicated the greater discharge and higher velocity of the stream flow. The channel segment of the drainage basin has been ranked according to the Strahler stream ordering method.

Stream number

It was revealed from Table 1, that number of streams of particular order decreases with an increase in stream order. It means that the number of streams of any given order was less

Where,

D_d = Drainage density

C. Relief Aspects of Drainage Network

Linear and areal features have been considered as the two-dimensional aspect lying on a plan. The third dimension introduces the concept of relief or altitude (Kandekar, 2021) [5].

Relief

It is the maximum vertical difference between the highest and lowest point in the watershed. Relief is indicative of the potential energy of a given watershed above a specified datum available to move water and sediment downslope.

Relief Ratio (R_r)

It is the ratio of relief (H) to the horizontal distance (L) on which relief was measured (Schumm, 1956) [13].

$$R_r = \frac{H}{L_h} \quad (2.11)$$

Relative Relief (R_R)

It is the ratio of maximum watershed relief to the perimeter of the watershed (Melton, 1957) [7].

$$R_R = \frac{H}{P} * 100 \quad (2.12)$$

Ruggedness Number (R_n)

Ruggedness number (RN) is a product of relief (H) and drainage density (D) in the same unit (Strahler 1957) [14].

$$R_n = H * D_d \quad (2.13)$$

Result and discussion

The Chatav watershed of the Jagbudi river basin has 4th order drainage network. Linear, Areal, and Relief aspects of the drainage network are given in Tables 1, 2, and 3, respectively.

than that of the immediate lower order but more than the next higher order. It is observed in the Strahler approach. The higher number of streams in lower order led to lesser permeability and infiltration. It was observed that maximum frequency was in the case of first-order streams. It indicates that there is the possibility of flash floods after heavy rainfall on the downstream side. As the stream order increased, a decrease in stream frequency was observed.

Stream length

One of the basin's most important hydrological parameters is stream length since it provides information about surface runoff. Sub-watersheds streams of various orders were counted and their lengths from mouth to drainage divide were

measured. Areas with greater slopes and finer textures tend to have streams that are somewhat shorter in length. The maximum total length of stream segments was observed in the first order i.e., 80 km, and decreases with an increase in the stream order. That means results show that the stream order increases with a decrease in stream numbers.

Bifurcation ratio (R_b)

The bifurcation ratio (R_b) of the watershed varied from 1.3 to 2.38. The bifurcation ratio depends upon the geological and lithological development of the drainage basin (Strahler, 1964) [15]. The R_b values of the study area (Table 1) indicated that there was a decrease in R_b values from the first-order streams to the third-order streams and again increase in the R_b values was noticeable from the third-order stream to the fourth-order stream. These differences are depending upon the geological and lithological development of the drainage basin (Strahler, 1964) [15]. The mean bifurcation ratio was 1.68 which indicates that the drainage pattern has strong structural control.

Mean stream length

Mean stream lengths of the first-order, second-order, third-order, and fourth-order streams were 0.8628 km, 1.1151 km, 0.7316 km, and 0.9086 km, respectively. This may be due to the geomorphologic, lithological, and structural control and contrast. The length of the highest-order channel causes a maximum effect on the peak of the GIUH. If the length of the

highest-order stream is more, it is expected to produce higher runoff (Khalegi *et al.*, 2011) [6].

Stream length ratio (R_L)

The stream length ratio (RL) of the II / I order was 1.2923, III / II order was 0.6560, and the IV / III order was 1.2419. These differences in the ratio in the research area were brought on by variances in topography and slope. Out of all Horton's ratios, the stream length ratio has the greatest impact on the peak of the GIUH peak. Higher RL values would create favourable conditions for flooding in the downstream area. The RL values do not depend upon the size of the river basin but it is characterized by basin shape.

Stream area ratio (R_a)

Stream area ratio (R_a) of II / I order was 3.38, III / II order was 1.59, IV / III order was 1.54. The average stream area ratio for the Chatav watershed is 2.17, which is considered as low. At low values of the stream area ratio ($R_a < 6$) the peak discharge of the hydrograph decreases but at higher values of the area ratio ($R_a > 6$) the peak discharge of the hydrograph increases with an increase in area ratio.

Areal Aspects of Drainage Networks

The areal aspect represents the characteristics of the catchment area and describes how the catchment area controls and regulates the hydrological behaviour.

Table 2: Areal aspects of the drainage network

Sr. No.	Morphometric Parameters	Symbol	Value
1	Area (sq. km)	A	177.73
2	Perimeter (km)	P	72.54
3	Basin Length (km)	L_b	21.4
4	Form factor	R_F	0.388
5	Circulatory ratio	R_C	0.42
6	Elongation ratio	R_L	0.70
7	Drainage density (km / km ²)	D_d	0.932
8	Constant of channel maintenance (km ² / km)	C	1.072
9	Length of overland flow (km)	L_g	0.53

Form factor

The results of the study show that the form factor was observed as 0.38. The lower value of the form factor indicates that the watershed is elongated in shape. An elongated basin with a low form factor indicated that the basin had a flatter peak for a longer duration. Flood flows in such elongated basins are easier to manage than in the circular basin because the whole volume of discharge does not get accumulated at the same time at an outlet like a circular basin.

Circularity ratio

The circulatory ratio of the Chatav watershed was 0.424. When the basin is shaped like a complete circle, the ratio is equal to one, falling to 0.785 when it is square, and continuing to fall until the basin is elongated (Miller, 1953) [8]. The current value of the circularity ratio indicated that the basin is elongated in shape, with high to moderate relief and a structurally controlled drainage system. Additionally, it showed that the basin has a low runoff discharge.

Elongation ratio

It is an important index for the analysis of basin shape. This parameter is used to determine whether the basin's shape is like a circular one. Roundness and a low level of integration

within a basin are indicated by elongation ratio values between 0.1 and 0.6. Watershed shapes can be classified using the index of elongation ratio, which includes circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (less than 0.5). The elongation ratio of the watershed is calculated as 0.7. It is observed that the watershed is elongated in shape. It suggests that the watershed is seeing flatter peak flows over a longer period.

Drainage density

The drainage density indicates the closeness of the spacing of channels, for the whole basin. Based on drainage density, watersheds are classified as low (less than 2.0 km / km²), moderate (2.0-2.5 km / km²), high (2.5-3.0 km / km²), or very high (greater than 3.0 km / km²). The drainage density of the Chatav watershed is calculated as 0.93 km / km². It comes under the low drainage density which indicates that the watershed has dense vegetation cover and low relief.

Constant of channel maintenance

The constant of channel maintenance shows how many square kilometres of basin surface is needed to create and maintain a channel that is one kilometre long. It is the inverse of drainage density (Schumm, 1956) [13]. As a result, as drainage density

increases, the constant of channel maintenance decreases and vice versa. The constant of channel maintenance was found as 1.07 indicating that the study area is under the influence of fewer structural disturbances.

Length of overland flow

The length of the overland flow is referred to as the distance that precipitated water must travel over the surface of the ground to reach a stream. It is a significant independent variable that has a significant impact on the amount of water needed to exceed a specified erosion threshold. A high value for the length of the overland flow indicates a high level of surface runoff, whereas a low value for the length of the overland flow indicates a low level of surface runoff. The length of the overland flow of the study area was 0.53 km² / km which indicates the high surface runoff.

Relief aspects of drainage network

The various factors of relief assessed in this study are explained as follows:

Table 3: Relief Aspects of the Drainage network

Sr. No.	Parameter	Value
1	Relief (km)	1.181
2	Relief ratio	0.055
3	Relative relief	1.628
4	Ruggedness number	1.098

Relief (H)

Relief is the vertical distance between the highest and lowest watershed. It is also known as the maximum watershed relief (H). The total relief for the Jagbudi river catchment was 1.18 km. The high value of relief led the low infiltration and high runoff from the catchment.

Relief ratio

The present study shows that the relief ratio for the Jagbudi river catchment is 0.0551. The presence of a hilly region in the catchment was indicated by this relief ratio value.

Relative relief

Relative relief for the watershed was found to be 1.628 which is considered to be low. These low relative relief values indicate that peak discharge rates and catchment erosion are likely to be low.

Ruggedness number (R_n)

The value of the ruggedness number was observed 1.09. R_n shows the structural complexity of the terrain in association with relief and drainage density. This provides an idea of the overall roughness of the water.

Conclusions

The morphometric characterization was achieved through the measurement of linear, areal, and relief aspects of the Chatav watershed using GIS techniques. For the analysis, the toposheet was used for the demarcation of the watershed boundary. The toposheet was downloaded from the Survey of India website (1:50,000 scale). SRTM DEM was used for watershed delineation and determination of morphological parameters. The Chatav watershed has 4th order drainage network and covers a total geographical area of 17700 ha. The total number of streams in the basin is 184. The number of lower-order streams is more than higher-order streams. The value for drainage density is 0.43 km / km² which indicates the dense vegetation and low relief. The bifurcation ratio, stream length ratio, and stream area ratio of the watershed is

1.68, 1.06, and 2.17, respectively. The value for the circulatory ratio and elongation ratio is 0.424 and 0.7 respectively which indicates the elongated shape of the basin. The relative relief of the watershed is 1.628. The Ruggedness number for the basin is 1.09 km.

The study will be helpful for the planning of water harvesting and groundwater recharge project on a watershed basis.

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9. Research papers published / Paper submitted

Shinde S. V., Bhange H. N., Ayare B. L., Patil S. T., Tharkar M. H. and P. R. Kolhe. 2022. Morphometric Analysis of Chatav Watershed Using GIS Techniques. The Pharma Innovation Journal. 11(11): 1135-1139.

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