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Spatio-Temporal Variation of Unit Hydrograph of Brahmani River Basin

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Abstract

The unit hydrograph is a direct runoff hydrograph produced when a significant amount of excess rainfall is generated uniformly over the watershed for a sufficient time. A well-known hydrologic engineering method for determining the runoff hydrograph given an excess rainfall hydrograph is the unit hydrograph method. The unit hydrograph can be developed using a variety of methods. However, most of these conventional techniques call for manually fitting the unit hydrograph across a few places, which does not ensure that the area under the unit hydrograph is uniform. Additionally, most stations are ungauged, making it challenging to develop the unit hydrograph. An analysis of the variation in the outcome is done using a spatial-temporal model, which involves showing a discharge-duration relationship for the river basin at a specified time interval. The Brahmani River basin and its four subbasins are examples of where the model has been successfully used (Jaraikela, Panposh, Boloni, Gomlai). Additionally, depending on topography, land use, and other factors, satellite data has been used to acquire yearly discharge statistics of the catchment and the area of the basins. The benefit has been maximized with the use of the model, which has also helped understand the factors that affect how much money can be saved on production while still maximizing the advantages. Additionally, the outcome of the Unit Hydrograph development of various gauging stations is examined, and the maximum discharge and time of concentration of each gauging station are displayed, showing the fluctuation in discharge throughout the period under consideration.

Keywords: Unit Hydrograph, Runoff, Brahmani River Basin, Discharge-Duration relationship.

1. Introduction

A hydrograph is a graph of the streamflow over time at a specific place in a stream. A hydrograph produced by too much rain is a runoff hydrograph. Due to the representation of the peak discharge, volume, and time distribution of runoff, it is a crucial part of hydrologic engineering design. A well-known hydrologic engineering method for determining the runoff hydrograph given an excess rainfall hydrograph is the unit hydrograph method. Unit hydrographs are helpful for the hydrologic design of hydraulic infrastructure that is both affordable and risk-minimized. Most hydrologic engineers employ the unit hydrograph method. It is used to calculate a direct runoff hydrograph from observed or planned storms by estimating an arbitrary watershed.

The unit hydrograph's main underlying assumptions are that the discharge at any given moment is proportional to the runoff volume and that the time-dependent variables influencing hydrograph shape are constant. Furthermore, if the timing and spatial distribution of the rainfall are equal, the ordinates of each hydrograph are proportional to the amount of runoff. A unit hydrograph is a hydrograph that represents a period of uniformly distributed excess rainfall (runoff) with a runoff volume that is equal to one inch of water across the entire watershed. The duration of a unit of rainfall is the length of time it takes for the rain to produce runoff (rainfall excess). A six-hour unit hydrograph is a hydrograph that results from a six-hour period of surplus rainfall. The assumption is that the time distribution and occurrence of the precipitation are uniform across the whole watershed. The hydrograph's shape is influenced by a variety of variables, including climatic ones like the kind of precipitation, rainfall intensity, duration, distribution, and storm movement direction. Physiographic elements include drainage density, stream slope, and basin characteristics like size and form.

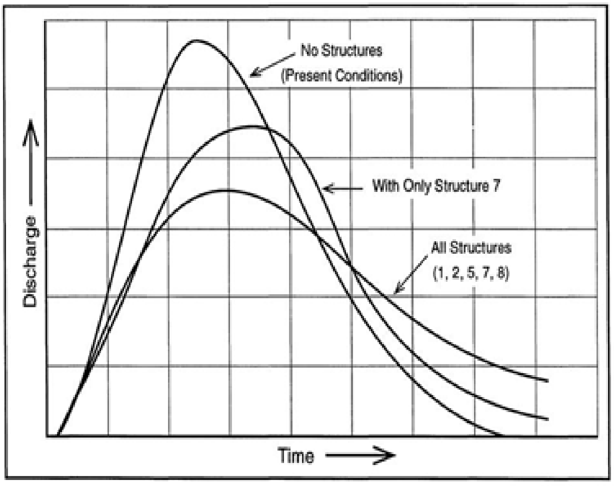


Figure 2. Hydrographs at Watershed A Outlet.

Figure 1 A typical representation of hydrograph

The creation of unit hydrographs is essential for modeling and forecasting floods. The terms "flood prediction" and "flood modeling describe how rainfall is converted into a flood hydrograph and how that hydrograph is then transmitted throughout a watershed or any other hydrologic system. These descriptions of the physical processes at play are either based on empirical, physically-based, or integrated conceptual-physical-based descriptions. Baseflow from the basin before the storm and runoff from the specific storm precipitation make up the total streamflow during a precipitation event. Combined streamflow Typically, direct runoff, baseflow, surface runoff, interflow, and groundwater runoff are considered to make up hydrographs.

The unit hydrograph approach assumes that the watershed characteristics influencing general unit hydrograph shape are invariant. These suppositions also lead to similarities in the morphologies of direct runoff hydrographs from storms with comparable rainfall characteristics. The watershed can be appropriately modeled as a linear system with respect to rainfall input and runoff output, among other assumptions intrinsic to the unit hydrograph approach. The time base of runoff of the unit hydrograph resulting from an excess rainfall pulse of a given effective time length is invariant, and the ordinates of all direct runoff hydrographs of a common time base are directly proportional to the total amount of direct runoff represented by each hydrograph. Excessive rainfall has a constant intensity within the effective duration and is uniformly distributed throughout the entire drainage area.

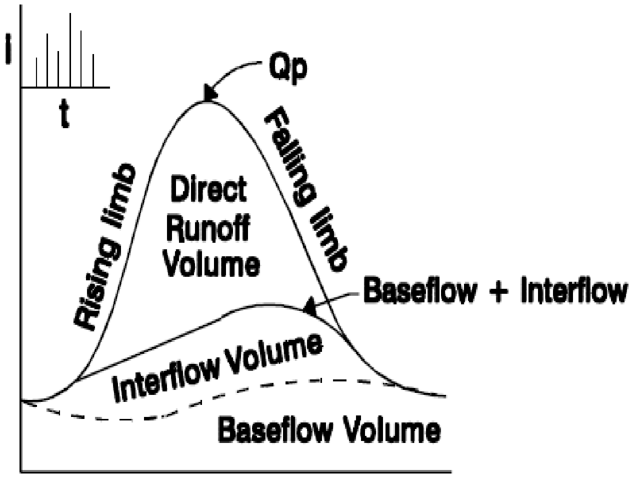


Figure 2 Components of the hydrograph

The procedures of converting rainfall into a flood hydrograph and transmitting that hydrograph throughout a watershed or any other hydrologic system are referred to as flood prediction and modeling. A rough description of the transformation processes resulting from rainfall and runoff is typically used in flood prediction and simulation. These descriptions of the physical processes at play are either based on empirical, physically-based, or integrated conceptual-physical-based descriptions. The resulting models are extremely useful in practice because they are straightforward and produce adequate estimates of flood hydrographs, despite the conceptualizations' overall tendency to ignore or oversimplify elements of the underlying hydrologic transport processes.

The impacts of evapotranspiration, interception, depression storage, and the interaction between the aquifer and the streams are not taken into account when simulating single floods. Because it is insignificant in comparison to other fluxes, such as infiltration, during the time when the flood builds, evapotranspiration can be disregarded. Physical models and mathematical models can be used to categorize hydrologic flood prediction models. Mathematical equations that express the connections between the system state, input, and output are used in mathematical models to describe how systems behave. Lumped models employ averages to represent regionally distributed functions and attributes but do not explicitly account for the spatial variability of hydrologic processes.

The goals of this study include creating the Brahmani River's unit hydrograph using the physical parameters of the watershed and creating a spatial-temporal variation of the unit hydrograph. Data on the study area's daily rainfall and discharge have been analyzed statistically, cross-correlatively, and throughout time. Finding the peak discharge and time to peak for the same by analyzing the hydrograph acquired for various intervals at the stations Jaraikela, Panposh, Bolani, and Gomlai.

2. Materials and Methods

2.1 Study Area and Data Source

2.1.1 Study Area

Nearly 1.6% of the nation's total geographic area, or 37,545 square kilometers, is covered by the catchment area of the Brahmani basin. On the Indian subcontinent, the basin extends from latitudes 20°28' to 23°38' north and longitudes 83°55' to 86°51' east (Map 1). The Chhotanagpur Plateau, the ridge separating it from the Mahanadi basin, and the Bay of Bengal form the basin's northern, western, and eastern boundaries. After the Mahanadi, the Brahmani is the second-longest river in Odisha, at around 480 kilometers. The states of Odisha, Jharkhand, and Chhattisgarh are included in the catchment region of the Brahmani River basin. Its catchment area is primarily in the states of Odisha and Jharkhand, with only a minor amount in Chhattisgarh. The South Koel and Sankh rivers merge to form the Brahmani in the important industrial town of Rourkela at 22 15' N and 84 47' E. The Sankh originated not far from the Netarhat Plateau, close to the Jharkhand-Chhattisgarh boundary. On the opposite side of a watershed from the Damodar River, the South Koel also emerges in Jharkhand, close to Lohardaga. These two sources are both located on the Chota Nagpur Plateau. According to folklore, the region where the Brahmani first appeared was where Sage Parashara fell in love with Satyavati, a fisherman's daughter who subsequently gave birth to Ved Vyasa, the author of the Mahabharata. Thus, the location is known as Ved Vyasa. The index map of the basin with CWC stage-discharge gauging stations is shown in Figure 3.

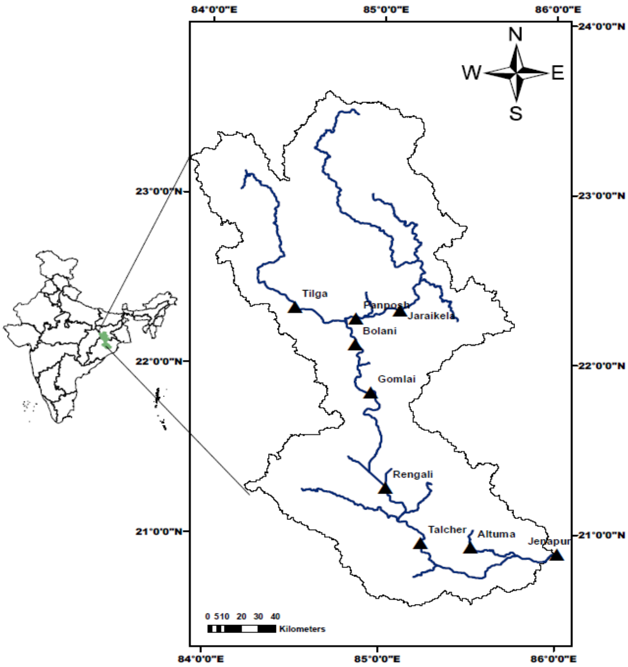
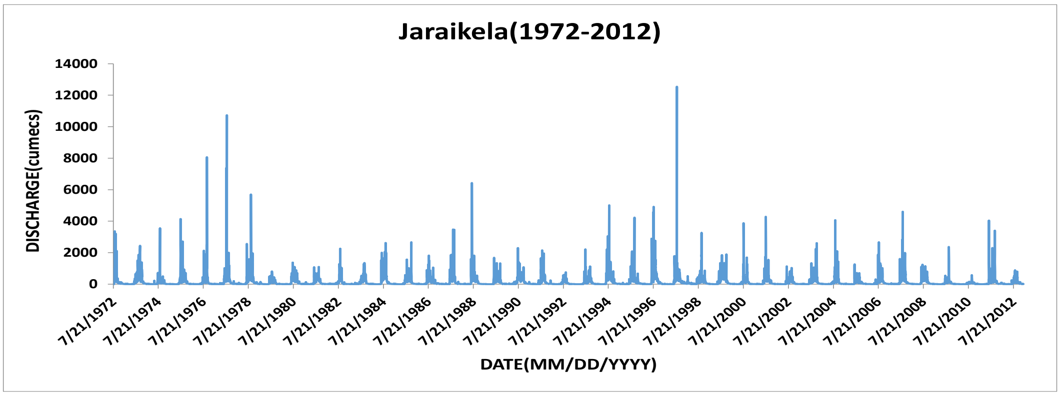


Figure 3 Index map of Brahmani River Basin with CWC stage-discharge gauging stations

2.1.2 Data collection

The Indian Water Portal and the IMD were used to gather rainfall data between 1972 and 2012. The CWC website is where the discharge information is gathered. For the period 1970–2012, time series graphs for Jaraikela, Panposh, Gomlai, Boloni, and Jenapur have been compiled from various sources. The Koel River contains the Jaraikela sub-basin, which is entirely contained within the state of Jharkhand. The Koel and Sankh rivers meet at the Panposh sub-basin, and the majority of the basin is located in Odisha. All of the Bolani basin's components are located in Odisha and are located in the Brahmani River downstream of Panposh. All of the basin's components are in Odisha, with the Gomlai sub-basin located in the Brahmani River downstream of Panposh. The discharge data of all these basins are represented graphically as shown below:



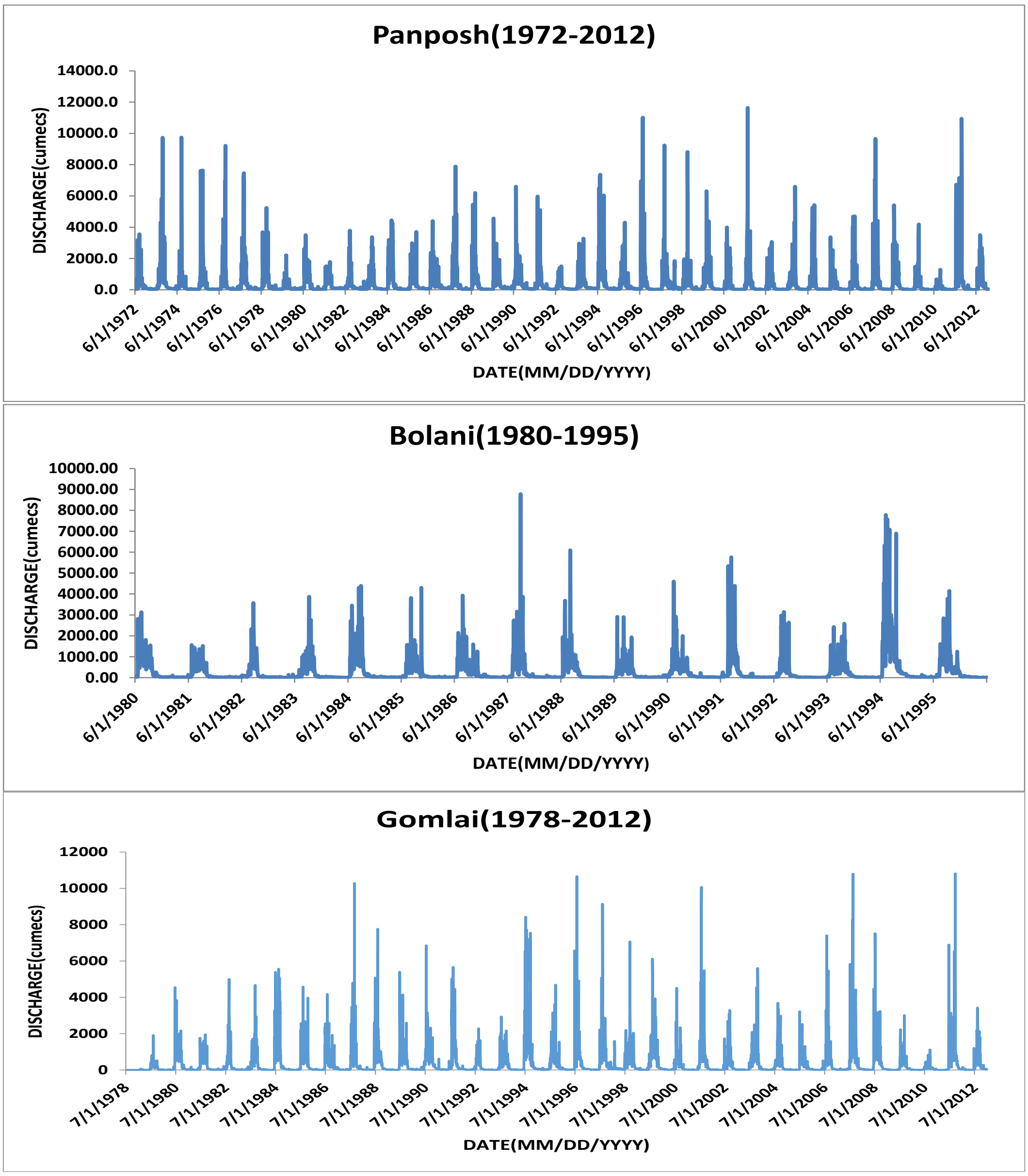


Figure 4 Graphical representation of discharge data of all sub-basins

2.2 Methodology

2.2.1 Derivation of Unit Hydrograph (UH)

The standard unit hydrograph method consists of four phases. First, it is important to gather historical data in order to determine the duration of the rainfall and the total discharge of that catchment. To create DRH, the base flow was subtracted from the runoff hydrograph. To calculate the total direct runoff, the area under the direct runoff hydrograph is integrated using the trapezoid rule. The entire direct runoff is split by each ordinate in the direct runoff hydrograph. A unit hydrograph is created by a hydrograph with a single depth.

2.2.2 Methods of Base flow separation

The techniques utilized for base flow separation are the subjective method and the area method. The subjective method involves picking the baseflow value at random and assuming that it stays constant for the length of the storm. This baseflow discharge marks the start of the ascending limb. A second approach entails picking at random the starting point of the groundwater recession on the hydrograph's falling limb (which is typically thought to occur at a theoretical inflection point) and connecting it directly to the starting point of the rising limb. The area method of baseflow separation consists in determining the beginning of the baseflow on the falling limb with the following empirical equation,

$$N = bA^{0.2}$$

When A is in square miles, b equals 1. When A is in square kilometers, b equals 0.8.

2.2.3 Steps to construct a Unit Hydrograph

The normal flow must be distinguished from the total flow before the unit hydrograph can be built. This can be done by drawing a line across the graph's base to indicate the uniform flow that existed prior to the storm in circumstances when this is the case. In cases where the flow was impacted by an earlier storm, the storm and groundwater flow can be distinguished by reproducing across the hydrograph base the hydrograph's descending leg from a point equal to the flow just before the storm whose unit hydrograph is to be obtained. All flow above this line would then be regarded as flood flow. The figures for a unit graph for this drainage area must then be determined. The ordinates will be in proportion to the ordinates of the storm hydrograph, as 1cm is the depth of runoff from the area.

$$\text{DRH= Discharge ordinate - Base flow}$$

Here, the straight-line approach can be used to determine the Base flow. The simplest one involves choosing the baseflow value at random and assuming that it stays constant over the course of the storm. This baseflow discharge marks the start of the ascending limb.

$$\text{Volume of DRH= Sum of DRH ordinate} * 24 * 3600 \text{ m}^3$$

$$\text{Effective Rainfall}= \frac{\text{Volume of DRH}}{\text{Area of catchment}}$$

Unit hydrograph ordinates can be obtained by dividing the DRH ordinate values with the effective rainfall obtained for the given catchment.

$$\text{Unit hydrograph ordinate}= \frac{\text{DRH Ordinate}}{\text{Effective rainfall}}$$

The values obtained as the ordinates can be plotted between discharge and duration of the rainfall, and the same is considered as the unit hydrograph for the required catchment area.

3. Results and Discussions

In the present work, the spatio-temporal analysis has been done for the sub-basins. Jaraikela, Panposh, Boloni & Gomlai. The spatio-temporal variation of the different catchments is obtained using the rainfall-runoff analysis and the equations of the unit hydrograph. The results obtained for all the sub-basins and the Brahmani basin as a whole are discussed below in chronological order.

3.1. Jaraikela Sub-basin

The Hydrograph, DRH, and Unit hydrograph for the rainfall events during the periods of 9th September 1972-21st September 1972, 27th Aug 1982–5th Sept 1982, 29th June 1992-10th July 1992, 20th Jul 2002- 30th Jul 2002 and 15th Jul 2012- 26th Jul 2012 are calculated and obtained as follows:

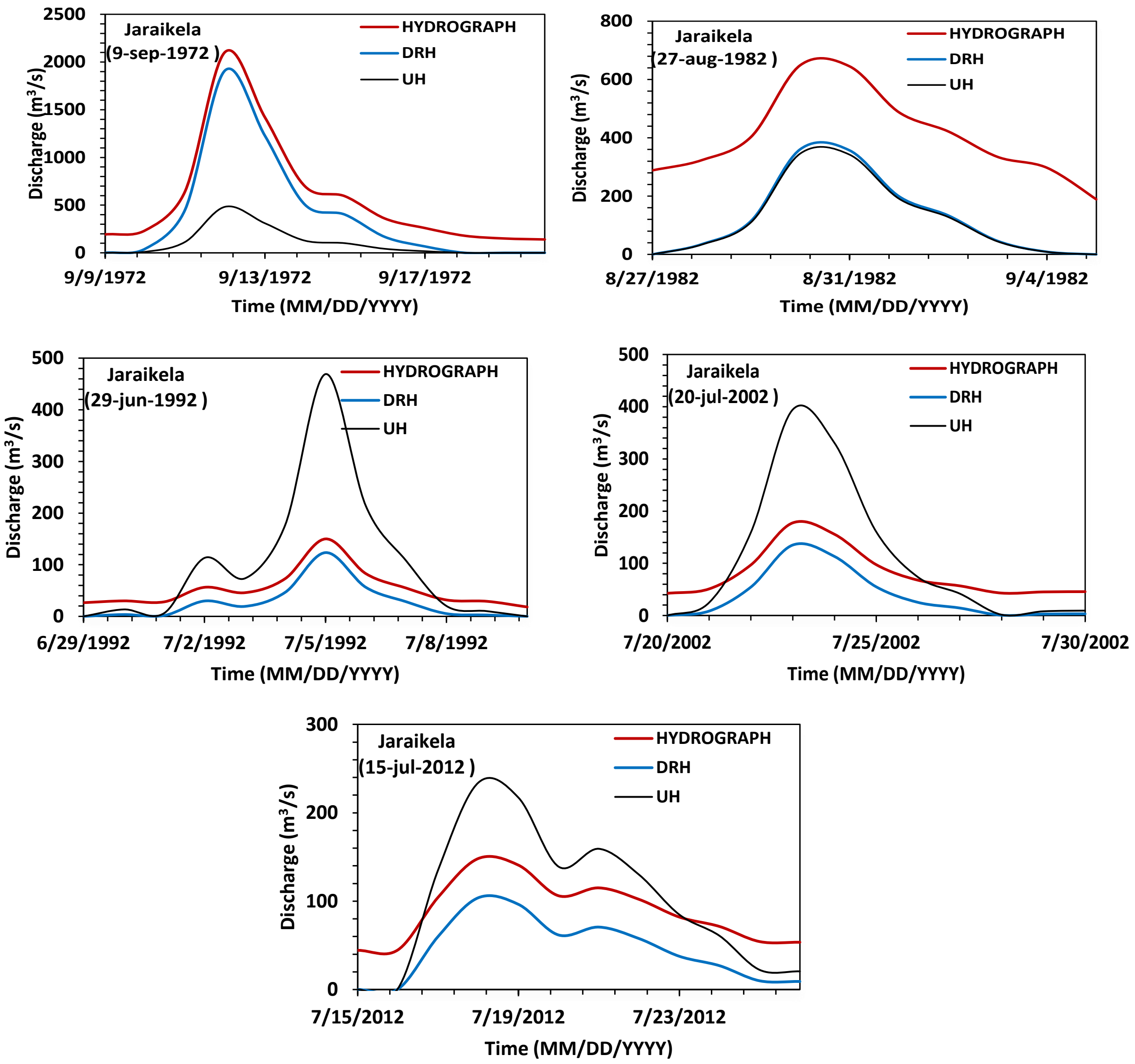


Figure 5 Representation of Hydrograph, DRH, and UH of Jaraikela Sub-basin

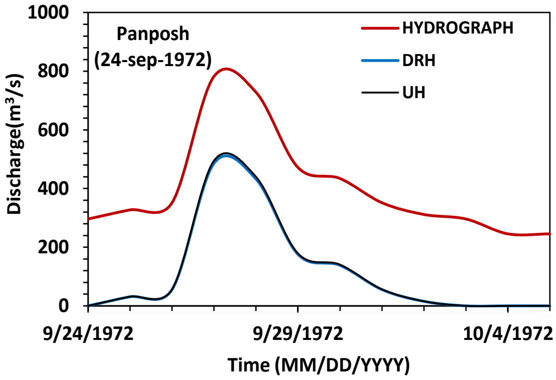
The catchment area of the jaraikela sub-basin is obtained as 10402041463 m^2. However, there is a variation in baseflow, effective rainfall, and volume of the basin across the five decades from 1972 to 2012. The variation is shown in **Table 1.**

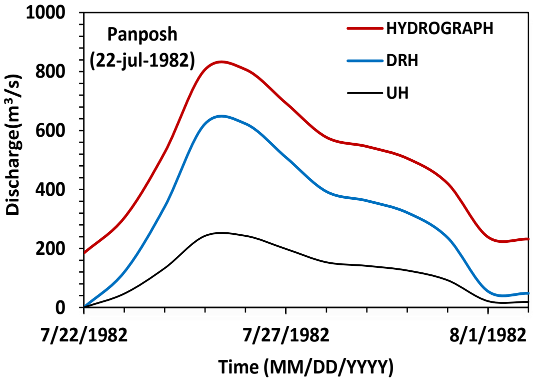
Year	Base Flow	Volume(M^3)	Effective Runoff(Cm)
1972	192.9	412119360	3.96
1982	288.34	108462240	1.04
1992	26.503	27379382	0.263
2002	48.489	35606304	0.342
2012	44.38	46160150	0.443

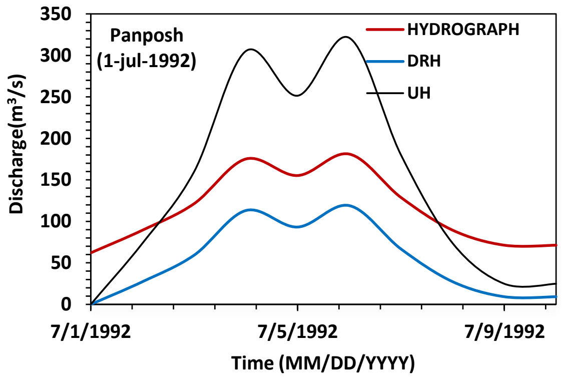
Table 1 Base Flow, Volume, and Effective runoff for Jaraikela sub-basin

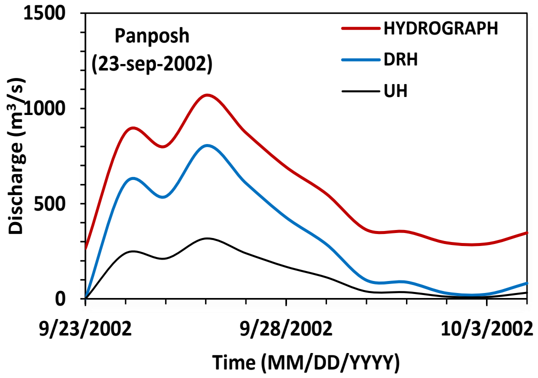
3.2. Panposh Sub-basin

The Hydrograph, DRH, and Unit hydrograph for the rainfall events during the periods of 24th September 1972-21st September 1972, 2nd Jul 1982–2nd Aug 1982, 1st July 1992-10th July 1992, 23rd Sept 2002- 7th Oct 2002 and 2nd Nov 2012- 16th Nov 2012 for panposh sub-basin are calculated and obtained as follows:









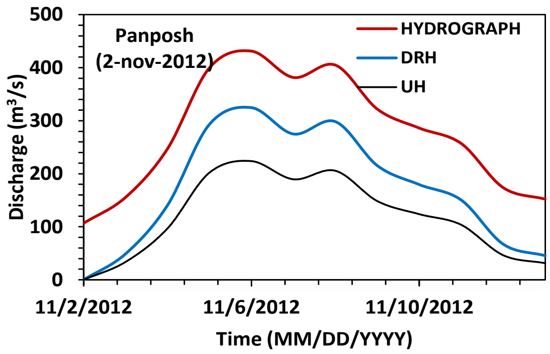


Figure 6 Representation of Hydrograph, DRH, and UH of Panposh Sub-basin

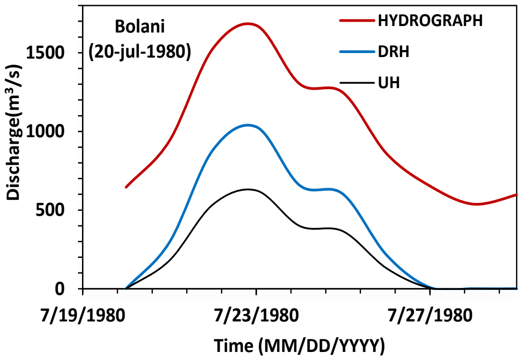
The catchment area of panposh sub-basin is obtained as 12224334645 m^2. However, there is a variation in baseflow, effective rainfall, and volume of the basin across the five decades from 1972 to 2012. The variation is shown in **Table 2.**

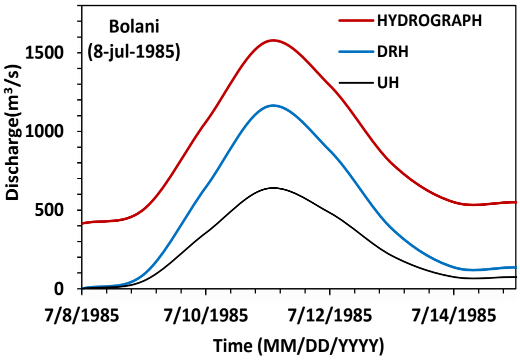
Year	Base Flow	Volume (m^3)	Effective runoff (cm)
1972	296.2	120045443	0.982
1982	184.1	313819030.1	2.567
1992	62.1	45294508.8	0.370
2002	264.769	310363834	2.538
2012	106.595	177333840	1.450

Table 2 Base Flow, Volume, and Effective runoff for panposh sub-basin

3.3. Bolani Sub-basin

The Hydrograph, DRH, and Unit hydrograph for the rainfall events during the periods of 20th Jul 1980 –29th Jul 1980, 8th Jul 1985 –17th Jul 1985, 20th Jul 1990 –28th Jul 1990, and 9th Nov 1995 – 19th Nov 1995 for bolani sub-basin is calculated and obtained as follows:





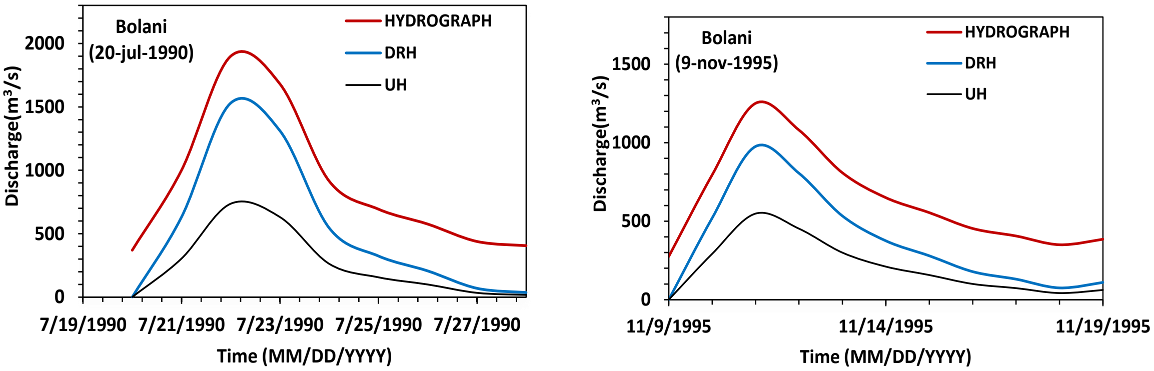


Figure 7 Representation of Hydrograph, DRH, and UH of Bolani Sub-basin

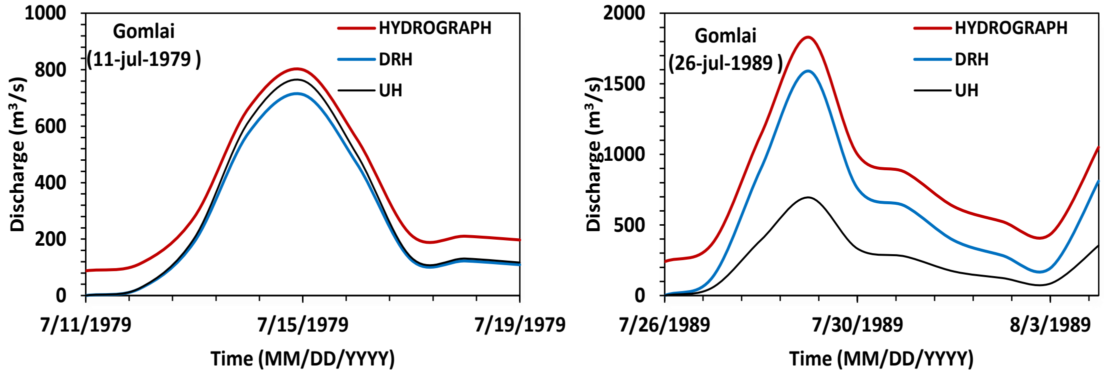
The catchment area of the Bolani sub-basin is obtained as 1933072797 m^2. However, there is a variation in baseflow, effective rainfall, and volume of the basin across the periods from 1980 to 1995. The variation is shown in **Table 3.**

Year	Base Flow	Volume (m^3)	Effective runoff (cm)
1980	645	318487680	1.647
1985	414.20	351570240	1.818
1990	369.48	401817888	2.08
1995	274.9	344122560	1.78

Table 3 Base Flow, Volume, and Effective runoff for Bolani sub-basin

3.4. Gomlai Sub-basin

The Hydrograph, DRH, and Unit hydrograph for the rainfall events during the periods of 11th Jul 1979 –19th Jul 1979, 26th Jul 1989 –4th Aug 1989, 17th Aug 1999 –26th Jul 1999, and 18th Jul 2009 – 28th Jul 2009 for bolani sub-basin is calculated and obtained as follows



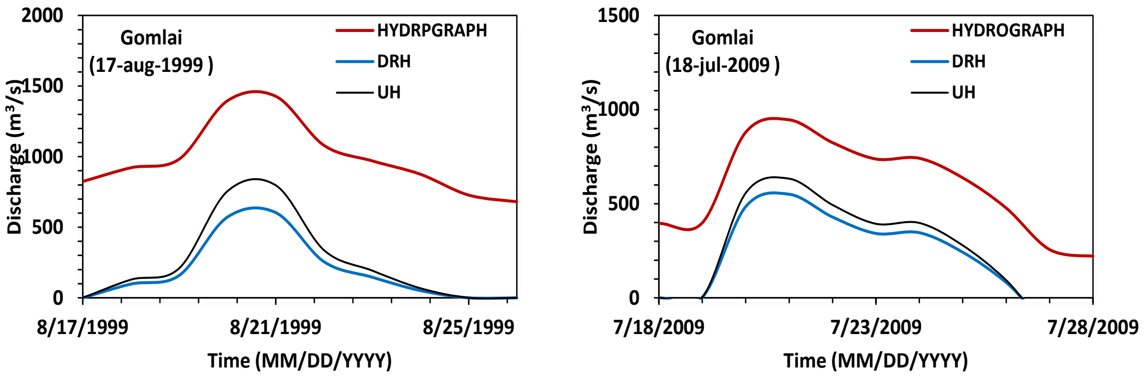


Figure 8 Representation of Hydrograph, DRH, and UH of Gomlai Sub-basin

The catchment area of panposh sub-basin is obtained as 21507727463 m^2. However, there is a variation in baseflow, effective rainfall, and volume of the basin across the four decades from 1972 to 2012. The variation is shown in **Table 4.**

Year	Base Flow	Volume (m^3)	Effective runoff (cm)
1979	87.652	201114403.2	0.935
1989	240.0	492022080	2.287
1999	824.1	162881280	0.757
2009	824.1	187000099.2	0.869

Table 4 Base Flow, Volume, and Effective runoff for Gomlai sub-basin

Analysis of Unit Hydrograph

The Unit hydrograph so obtained for considered basins of Brahmani river are analyzed, and the maximum discharge and the time of concentration for different stations are listed below in the table

Gauging Station	Year	Peak Flow (M^3/S)	Time To Peak (Days)
Jaraikela	1972	482.57	3
	1982	346.129	3
	1992	469.129	6
	2002	394.486	3
	2012	234.067	3
Panposh	1972	495.219	3
	1982	242.734	3
	1992	321.226	5
	2002	316.831	3
	2012	223.771	4
Bolani	1980	535.151	2
	1985	637.262	3
	1990	736.305	3
	1995	548.314	2

Gomlai	1979	616.041	4
	1989	694.948	3
	1999	797.422	4
	2009	632.916	3

Table 5 Peak discharge and time to peak of all sub-basins

From the above table, it is observed that for the Jaraikela station, the peak discharge was maximum in the year 1972 and the minimum in the year 2012. For Panposh station, the peak discharge was maximum in 1972 and minimum in 2012. For Bolani station, peak discharge is maximum in the year 1990 and minimum in the year 1980; for Gomlai, peak discharge in the year 1999 and minimum in the year 1979.

4. Conclusions

In this study, a method for applying the semi-distributed unit hydrograph approach to rainfall-runoff modeling is proposed. It takes advantage of a more conceptually sound synthesis of the rainfall-runoff-based catchment response. The network width function, which displays the number of network links at escalating distances from the catchment outflow, summarises the observed channel network topology. Additionally, the components of the hydrograph, as well as the channel's flow velocity and attenuation, have been described using hydrologic parameters. They are expected to be physically significant parameters that may one day be generated from topographic information. The resulting catchment response function fits a variety of events effectively and is considered to be a solid foundation for utilizing catchment-specific information in flood estimation. The river Brahmani basin has served as an example of the methodology, giving researchers a chance to investigate if, given the model's presumptions, geographic variability in rainfall has any bearing on how this particular big catchment responds hydrologically. The method for including the spatial component has been the network width function. The study also demonstrates how the Brahmani River's geographical fluctuation in rainfall during events can have a notable impact on the network response. In contrast, a linear model may actually be very useful in big catchments where there is a significant prevalence of channel routing and spatial and temporal averaging. Therefore, it would be advantageous to both investigate this theory and look into how to include spatial variability in a unit hydrograph rainfall-runoff model. In this paper, a methodology for producing a semi-distributed unit hydrograph is presented. My methodology is applied to the river Brahmani to demonstrate its use. With the proper adjustments to the input parameters, these models can also be used for very small, small, medium, large, and very large basins.

References

Bhatia, R., Malik, R. P. S., & Bhatia, M. (2007). Direct and indirect economic impacts of the Bhakra multipurpose dam, India. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *56*(2-3), 195-206.

Booker, J. F., & Young, R. A. (1994). Modeling intrastate and interstate markets for Colorado River water resources. *Journal of Environmental Economics and Management*, *26*(1), 66-87.

Boughton, W. (2009). New approach to calibration of the AWBM for use on ungauged catchments. *Journal of Hydrologic Engineering*, *14*(6), 562-568.

Essaw, D. W. (2008). Assumptions underlying integrated water resources Management concept–A review. *CRC for Irrigation Futures*.

Gopalakrishnan, M. (2006). Challenges of Water for Food, People and Environment–ICID's Initiative on "Country Policy Support Programme".

Hessari, B., & Khanmohammadi, M. (2017). Estimating the Environmental Flow Requirement in Downstream of Hydroelectric Power Plant of Zivkeh-Piranshahr. *Environment and Water Engineering*, *3*(2), 119-132.

Islam, A., Sikka, A. K., Saha, B., & Singh, A. (2012). Streamflow response to climate change in the Brahmani River Basin, India. *Water resources management*, *26*(6), 1409-1424.

Kishore, A. (2002). Social impact of canal irrigation: a review of 30 years of research. IWMI-TATA Water Policy Research Program Annual Partners' Meet, 2002. *IWMI Working Papers*, (H029648).

Lotz-Sisitka, H., & Burt, J. C. (2006). *A critical review of participatory practice in integrated water resource management*. Pretoria: Water Research Commission.

McKinney, D. C. (1999). Modeling water resources management at the basin level: Review and future directions.

Molden, D. (2013). *Water for food water for life: A comprehensive assessment of water management in agriculture*. Routledge.

NIH (National Institute of hydrology) (1996-1997). ―Daily rainfall runoff modeling of Brahmani River at Rengali reservoir.‖Deltaic region Centre, National Institute of Hydrology, Kakinada.

NIH (National Institute of hydrology) (1999-2000).‖Rainfall-runoff modeling using artificial neuron network technique, National Institute of Hydrology, Jal Vigyan Bhawan Roorkee,Uttarnchal.

NRSC and CWC (2011). ―Assessment of water resources at Basin scale using space Inputs.‖A pilot study for Godavari and Brahmani-Baitarni Basins,Water resources division,National Remote sensing centre,ISRO,Balangar,Hyderabad.

Shankar, P. V., Kulkarni, H., & Krishnan, S. (2011). India's groundwater challenge and the way forward. *Economic and political Weekly*, 37-45.

Verma, S., & Phansalkar, S. J. (2007). India's Water Future 2050: Potential Deviations from 'Business-as-Usual'. *International Journal of Rural Management*, *3*(1), 149-179.

Wurbs, R. A. (2005). Texas water availability modeling system. *Journal of Water Resources Planning and Management*, *131*(4), 270-279.