DEVELOPMENT OF GIUH FOR SMALL CATCHMENTS IN SAGAR DISTRICT

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN, ROORKEE
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PREFACE

Simulation of transformation of rainfall into runoff has been identified as one of the thrust areas of research in the field of hydrology. The simplest among all the methodologies is the estimation of an empirical constant called runoff coefficient, which is used to estimate runoff from rainfall. The geomorphological parameters play important role in the simulation of rainfall-runoff process. In the past, several researchers have tried to correlate rainfall and runoff using geomorphological parameters. The geomorphological parameters, which are commonly used, may be broadly classified in the linear, areal and slope aspects of the catchment. The geomorphological characteristics can be evaluated either from topo-sheets or from other indirect means. Application of GIS provides an efficient and accurate means for evaluation of these characteristics.

The Clark model is a widely used model for rainfall-runoff simulation. This model is a single linear reservoir based model in which outflow hydrograph for any storm is characterized by the translation and storage effect of separable sub-areas of the basin. The National Institute of Hydrology, Roorkee (India) has developed a mathematical model in which the parameters of Clark model are computed using geomorphological characteristics of the basin.

The watershed development and management is the central focus of rural development in Madhya Pradesh. The need for scientific design of small water conservation structures with limited data is felt strongly. This study has been undertaken with the aim of application of geomorphology for rainfall-runoff modeling. In this study, the geomorphological parameters of twenty small watersheds of Dhasan and Bebas basins have been computed using ILWIS software. The GIUH based Clark model has been applied to five selected watersheds. This study will be useful for developing the rainfall-runoff relationships in the ungauged catchments in the region.

This study has been carried out by Sri R.K. Jaiswal, Sri T.Thomas and Sri R.V. Galkate of Ganga Plains South Regional Centre, Sagar, under the guidance of Dr. A.K. Bhar, Co-ordinator & Head, RC, Sagar.

(K. D. Sharma)
DIRECTOR

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ABSTRACT

The geomorphological characteristics are mainly useful in rationalization of the hydrological models of rainfall runoff process, which aim at development of scientific basis for predicting the model parameters of the ungauged watersheds from hydrologic and physiographic characteristics of that watershed. For estimating the parameters of hydrologic models, either optimization technique using rainfall and runoff data or topographical and climatic information of the basin may be used.

The Clark model involves routing of rainfall excess through concentrated storages, which represent the storage effect of the basin. In this model a unit rainfall excess occurs uniformly and instantaneously over the basin and the inflow to the concentrated storage at the basin outlet is proportional to the time-area diagram.

The parameters of Clark model can be computed easily if adequate rainfall and runoff records are available. But for ungauged catchments, the geomorphological instantaneous unit hydrograph (GIUH) approach may be applied for the simulation of rainfall and runoff. The National Institute of Hydrology, Roorkee (India) recently developed a model in which the geomorphology of a basin can be used effectively for evaluation of parameters of Clark model. In the present study, this model has been applied in some selected watersheds.

Madhya Pradesh in spite of its good natural resources is considered as economically backward state. The people of this region mainly depend on agriculture for their living. About 80 % of cultivated area is rain fed. The Govt. of Madhya Pradesh in the year 1994 constituted the Rajiv Gandhi Watershed Mission with the aim of conservation of natural resources. The soil and water were considered the most important natural resources. Near about 500 watersheds have been developed till date. In order to conserve water in these watersheds, small structures are being constructed and it is strongly felt the need of development of some methods, which require minimum data for design of these structures.

In the present study, twenty small watersheds of Dhasan and Bebas basin have been selected for the analysis. The geomorphological characteristics of all these basins have been worked out using ILWIS software. The relationships between commonly used geomorphological parameters were determined. The time-area diagrams of all these basins were prepared using the capability of ILWIS. The small interval rainfall and corresponding discharge data for a few storms in four selected sites have been measured

to develop the relationship between velocity of flow and intensity of rainfall. A FORTRAN based computer program has been developed for the GIUH based Clark model as per the methodology suggested by National Institute of Hydrology. The model has been applied on five watersheds of the region. From the study, it has been observed that the GIUH based Clark model can be used conveniently for the simulation of rainfall and runoff in the ungauged or basins with very limited records.

CHAPTER 1.0 – INTRODUCTION

1.0 General

The water resources play an important role in the development of a country. The proper management of available resources has become the need of the hour for sustainable development of the society. In the developing countries, the increasing population and better living standard demand more and more water day by day. It is needless to emphasis to the need for the better management of available water resources and to explore new sources of water. The first requirement for management of water resources is the estimation of the available water in various water bodies. Even in this era of modern technology, the measurement of flow in the stream is not easy and cheep. Therefore, it is very important to model the rainfall-runoff process so that using rainfall and some other characteristics of the catchment as the inputs to the model one can estimate the available water in the stream.

Generally, models can be classified as either prototype or mathematical. The mathematical models may be further classified as deterministic, probabilistic, conceptual and parametric. A deterministic model is formulated by using laws of physics and chemical processes, as described by deferential equations. A probabilistic model, whether statistical or stochastic, is governed law of chance or probability. Statistical models deal with observed samples, whereas stochastic models focus on the random properties of certain hydrologic time series. A conceptual model is a simplified representation of the physical processes, obtained by lumping spatial and/or temporal variations, and described in terms of either differential equations or algebraic equations. A parametric model represents hydrologic processes by means of algebraic equations that contain key parameters to be determined by empirical means.

1.1 Geomorphology

The hydrological response of a basin is dependent on its geology, soil characteristics, topography, vegetation and climate. A part of the precipitation occurring over any part of surface of the earth flows over it through streams/rivers as surface runoff. Some portion of it enters the earth's surface in the form of sub-surface water and joins the river after sometime or percolates down to join the ground water. This apportioning of precipitation in surface runoff, sub-surface flow or contribution to ground water etc. is dependent upon surface of a basin and is reflected in the indices that are described by geomorphology of the basin such as its linear, aerial and relief aspects.

The linear aspects such as main channel length, total length of channels, wandering ratio, basin perimeter, channel slope etc; aerial aspects such as drainage area, drainage density, constant of channel maintenance, elongation ratio etc. and relief aspects such as basin relief, relief ratio and relative relief etc. play a dominant role in runoff formation and describe hydraulics of the flow of water from a basin. For example, the slope is related to rate at which the potential energy of water at higher elevation is converted into kinematics energy and the travel time in hydrologic system is inversely related to the slope. So the hydrological response of a basin is mainly influenced by its geomorphological and climatic characteristics. The development of relationships between the geomorphological characteristics and the hydrological variables serve as useful tool to determine the hydrological response of the basin. It attains greater importance particularly in case of ungauged basins, where lack of data poses problems in optimal planning of water resources development activities. In the present day world, geomorphological characteristics have been used in various fields such as hydrology, flood management planning, terrain evolution, energy resources and other engineering project. Geomorphology has strong relationship with the other disciplines like geology, pedology, forestry, land use and archaeology etc.

1.2 Unit hydrograph (UH)

In the category of conceptual model, the unit hydrograph theory first proposed by Sherman in the year1932. The unit hydrograph may be defined as the hydrograph of direct surface runoff resulting from one unit of effective rainfall, which is uniformly distributed over the basin at a uniform rate during a specified period of time known as unit time or the unit direction. The unit hydrograph is expressed by U(d, t), where the U(d, t) is an ordinate of direct runoff at any interval of t resulting from 1 cm of rainfall uniformly distributed in the catchment in d hour duration.

1.3 Instantaneous Unit Hydrograph (IUH)

If the duration of the rainfall excess becomes infinitesimally small, the resulting unit hydrograph is called the instantaneous unit hydrograph (IUH), and is expressed by U (0, t), or simply U(t). In other words, the instantaneous unit hydrograph is the hydrograph of the runoff that would result if 1 cm of water were spread uniformly over an area and then allowed to runoff.

The major advantage of the IUH in comparison with a unit hydrograph is that the IUH is independent of the duration of the rainfall excess, resulting thereby in an elimination of one variable in the hydrograph analysis. Moreover, the use of the IUH is better suited for the needs of theoretical investigations on the rainfall- runoff relationship in drainage basins.

1.4 Geomorphological Instantaneous Unit Hydrograph (GIUH)

The basic idea behind the development of geomorphological instantaneous unit hydrograph (GIUH) is that when the unit rainfall occurs in the basin instantaneously, its arrival and intensity at outlet is mainly affected by the underlying natural order in the morphology of the catchment and the hydraulic characteristics of the channel. One advantage of the geomorphological instantaneous unit hydrograph approach is the potential of deriving the UH using only the information obtained from topographic maps or remote sensing, possibly linked with Geographical Information System (GIS) and Digital Elevation Model (DEM). Hence, in case of ungauged catchment, geomorphological based model or regional synthetic unit hydrograph can be used to estimate the hydrologic response of a catchment.

1.5 Statement of the Problem

The Bundelkhand region of Madhya Pradesh lies in the central part of country. The average rainfall in this region is about 1200 mm. The region falls in the Ganga and Narmada basin. The Narmada, Ken, Dhasan, Betwa, Bearma, Bina etc. are the important rivers passing through the area. It has been observed that due to poor water management and lack of irrigation scheme, the region suffered from drought and water scarcity problem regularly. The runoff data are seldom available in the region to put forward the proper water management plan. Hence, the development of rainfall runoff relation with the help of ancillary data such geology, geomorphology, land use and other information which can be obtained easily from topographic maps may be very useful for planning irrigation and water retaining structures. The various objectives of the study are as follows:

- Determination of geomorphological characteristics for small basins using GIS.
- Development of the relationships between the geomorphological characteristics.
- Collection of short interval rainfall and runoff records for some basins.
- Development of Digital Elevation model for these basins.
- Application of GIUH based Clark model for some of the basins.

CHAPTER 2.0 – REVIEW OF LITERATURE

2.1 Geomorphology

The hydrologists have been faced with many problems especially in respect of ungauged catchments where hydrological data are rarely available. For ungauged basins it has been the endeavor of many hydrologists and earth scientists to quantify and relate the geomorphological parameters of a naturally shaped basins to its hydrologic response characteristics. The quantification of the geomorphology of the drainage basins was first started by Horton (1945) and suggested the method of classification of channels in terms of order. Strahler (1952) proposed a modification in Horton's ordering procedure. Strahler's method is now generally preferred because of its simplicity and greater and subjective decisions (Smart, 1972), Miller (1953), Maxwell (1960), Schumm (1956), Morisawa (1959) and several other scientists developed quantative methods by adding new parameters.

Shreve (1967) introduced a network classification system, which used the stream link as the fundamental compositional unit. A link is a section of a stream that extends from tip to junction, junction to junction, or junction to mouth. A link is, therefore, a stream segment lying between a source and first junction downstream, between two consecutive junctions, or between the outlet and the first junction upstream (Smart et al. 1967). Scheidegger (1967) showed that the Shreve link magnitude system and his consistent stream order method are identical, but the former is simpler to understand and easier to use in any large-scale basin studies. The stream length is an important parameter in hydrograph time characteristics (Snyder, 1938; Gray, 1961 a; 1961 b; 1962) and is closely related to other watershed parameters, such as size and shape. Several other geomorphological parameters such as drainage area, basin perimeter, basin relief, relief ratio, sinuosity ratio, circulatory ratio (Miller, 1932), form factor, (Horton, 1932), basin centroid (Snyder, 1938), drainage density (Horton, 1945), fineness ratio (Melton, 1957), relative relief (Melton, 1957), ruggedness number (Melton, 1957) and Strahler (1958), shape factor (Wu et. al, 1964), wandering ratio (Smart et al, 1967), elongation ratio (Schumm, 1956) have been defined and their effect on runoff have been studied. Recent studies on application of geomorphology to watershed runoff modeling have explicitly employed bifurcation ratio (Rodriguez- Iturbe and Valdes, 1979; Rodriguez-Iturbe et al. 1979: Valdes et al. 1979; Gupta et al., 1980: Singh, 1983, etc.).

2.2 Application of Geomorphology in UH studies

Snyder (1938), analysed a large number of hydrograph from drainage basins in Appalachian mountainous region in United States and developed the relationships, wherein, he related the time lag of unit hydrograph (t_p) with the product of length of main channel (L_{ca}) and length of the stream from a point on the stream nearest to the centroid of the catchment to the outlet (L_{ca}). Linsley (1975) suggested some modification in the relationships suggested by Snyder.

McCarthy (1938) related the geomorphological characteristics with unit hydrograph parameters. Clark (1945) developed IUH model by assuming that the outflow hydrograph for any storm is characterized by the translation and storage effect of separable basin sub-areas. Pure translation of the direct runoff to the outlet viz. the drainage network is described using the channel travel time, giving thereby an outflow hydrograph which ignores water storage effects. Nash (1957) proposed a conceptual model by considering a drainage basin comprising of a series of identical linear reservoirs. By routing a unit inflow through the reservoirs, a mathematical equation for IUH has been derived.

Rodriguez and Valdes (1979) first introduced the GIUH in which the runoff ordinates are interpreted in the framework of travel time distribution using geomorphological characteristics of the basin. The structure of the hydrologic response is found to be intimately linked to the geomorphologic parameters of a basin when the hydrologic response is represented by the unit hydrograph. The geomorphologic parameters have also been found to have very good relationship with the parameters representing Instantaneous Unit Hydrograph.

Gupta et al (1980), Panigrahi (1991), NIH (1993), NIH (1995), NIH (1996), Jain et al. (1997), Yen and Lee (1997), Lee and Yen (1997), Bhaskar et al. (1997), Lee (1998), NIH (1998-99), NIH (1999-2000) and several other investigators have analysed various issues of GIUH and application of GIS in this field.

A new approach of rainfall-runoff modeling has been developed at the National Institute of Hydrology (NIH, 1993) in which geomorphological parameters have been used with conceptual modeling of IUH. This methodology has been applied in different small to medium size basins and found suitable where rainfall and runoff record are very scarce. In the present study, this new approach has been applied on some watersheds of Dhasna and Bebas river basin.

CHAPTER 3.0 – STUDY AREA AND DATA USED

In the present study, the twenty small watersheds have been selected which fall in Dhasan and Bebas basin.

3.1 River Dhasan

The river Dhasan is an interstate river flowing between Madhya Pradesh and Uttar Pradesh with total length of 365 km. The Dhasan river rises in the Raisen district of Madhya Pradesh at an elevation of 721 m. above mean sea level with Latitude $23^0 26'$ and Longitude $78^0 33'$. The river flows 240 km. in Madhya Pradesh, 71 km. in Uttar Pradesh and besides this forms a common boundary of 54 km. between Madhya Pradesh and Uttar Pradesh. It joins river Betwa at an elevation of 135m near Deer village in Jhansi district of Uttar Pradesh. The catchment area of the basin is about 2049 sq. km.

The soil in the Dhasan basin is predominantly covered by clay and clay loam type. These soils are black in color, deep to very deep and are spread on nearly leveled to gently sloping plains. Various geological formations are exposed from east to west in the basin. The area is covered by Deccan Trap, which is basaltic lava flow and is made up of horizontal basalt. Sandstones are spread in northern part of the basin. Wheat and Pulses are the major crops cultivated in most of the area of basin in Rabi season. Kharif season crops are mainly oilseeds, pulses, Jawar, Maize and Paddy. Double cropping is being practiced under the rainfed cultivation, which indicates that much higher cropping intensities can be achieved with proper irrigation and application of fertilizers.

3.2 River Bebas

The river Bebas is an important tributary of river Sonar. The Bebas river originates from the Vindhyan range near Siarmau village (Elevation 600 m above MSL) in Silvani sub-division of Raisen district in Madhya Pradesh and joins Sonar river near village Barkhera in Damoh district. The Bebas river basin is located between $23^o 24'$ N to $23^o 46'$N latitudes and $78^o 31'$ and $78^o 45'$E longitudes. It is a leaf shaped elongated catchment.

The Bebas basin is bounded by Sonar basin on the east side, Dhasan basin on the west side and Vindhyan ranges on the south side. The basin fully lies in the Madhya Pradesh. The basin lies in the medium rainfall zone with more than 90% of rainfall occurs during June to October due to southwest monsoon. The stratography of the local formation encountered in the basin consists of Deccan trap, Lameta beds Vindhyan systems and alluvial soils. The black cotton soils are mostly found in the basin.

The drainage maps of all twenty watersheds have been presented in Fig 3.1 to 3.4. The catchment area of selected watersheds ranges from 0.75 to 30.0 sq. km. All the watersheds fall in the 55 I/9, 55 I/10 and 55 I/13 of Survey of India toposheets. The general information regarding all these basins has been given in the Table 3.1.

3.3 Data Used

In the study, the selected watersheds fall in the 55 I/9, 55 I/10 and 55 I/13 Survey of India toposheets. These toposheets have been used to compute the geomorphological parameters and generation of digital elevation maps. A preliminary survey of the area has been conducted and twenty sites have been selected on the basis of suitability in measurement. A self-recording rain gauge (SRRG) has been installed in the study area and daily mass curve of rainfall have been collected throughout the monsoon period of 2003. The cross-sectional details of all twenty sites have been measured. Stages have been installed in some selected basins for measurement of runoff. The runoff data of eight storms have been measured by area-velocity methods for the basins 1,2,3,4 and 5 in the monsoon season. The float method has been used for estimation of velocity. These data have been used for development of velocity and intensity of rain relationship and application of Clark model.

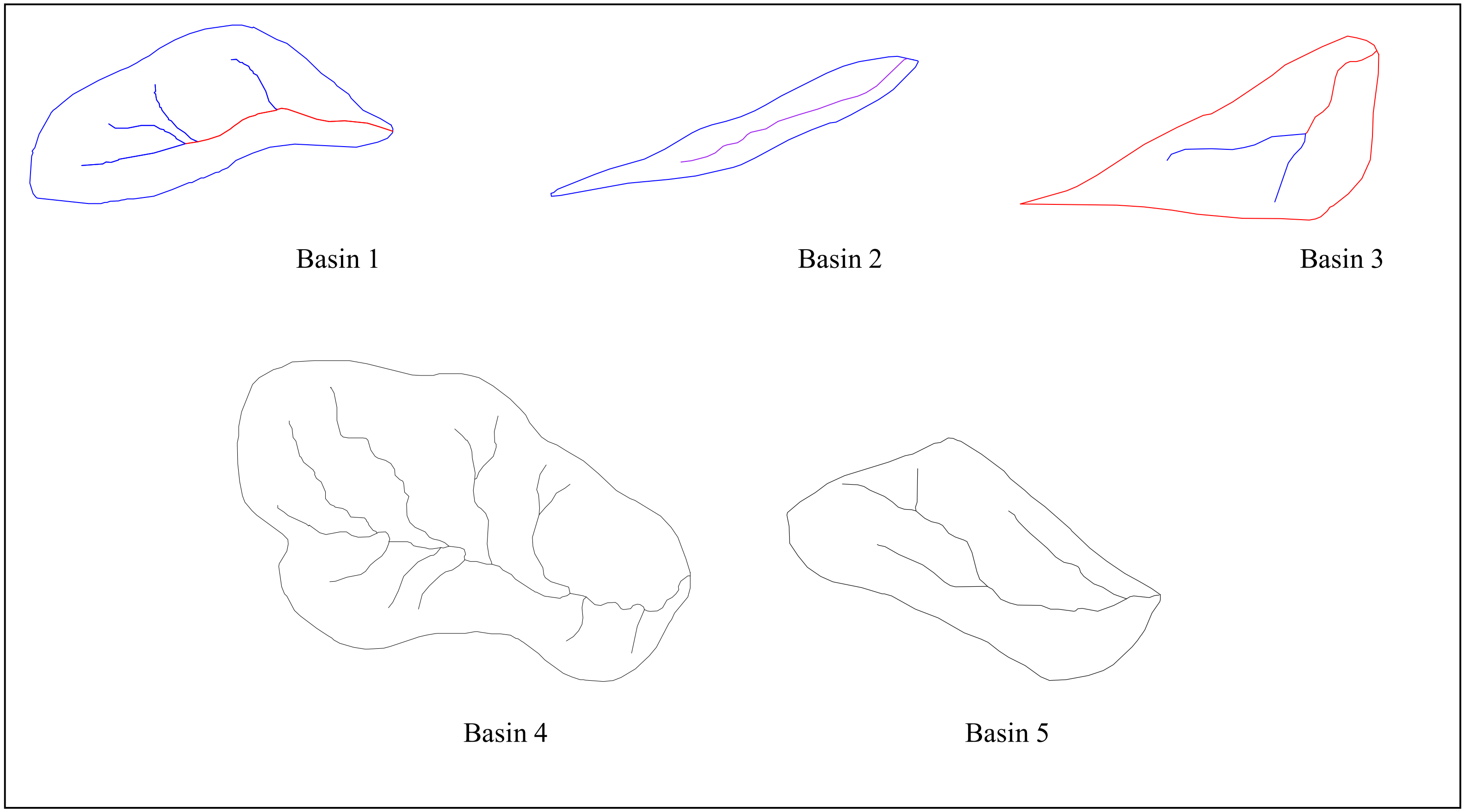

Fig 3.1: Drainage map of basin 1 to basin 5.

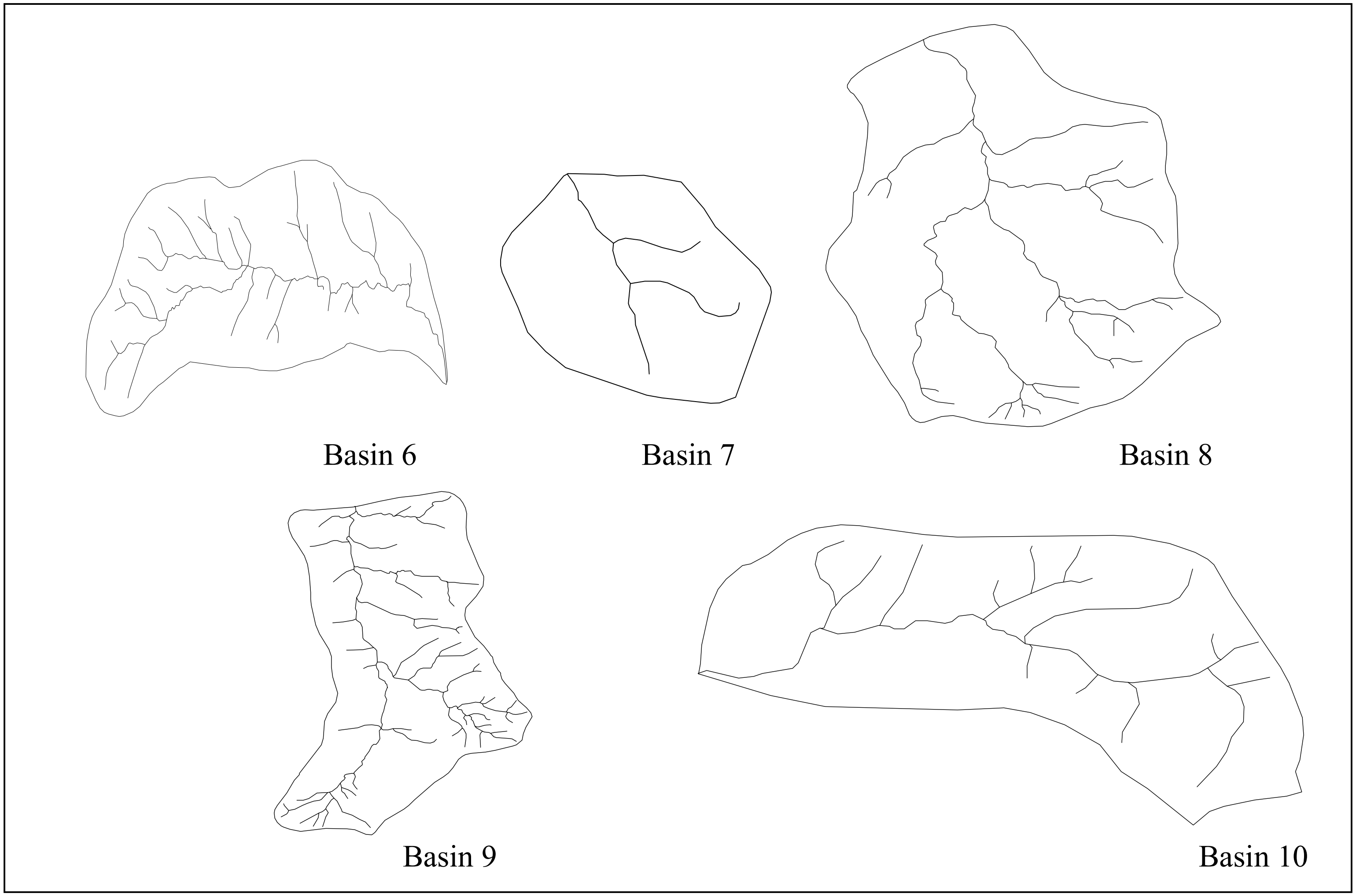

Fig 3.2: Drainage map of basin 6 to basin 10.

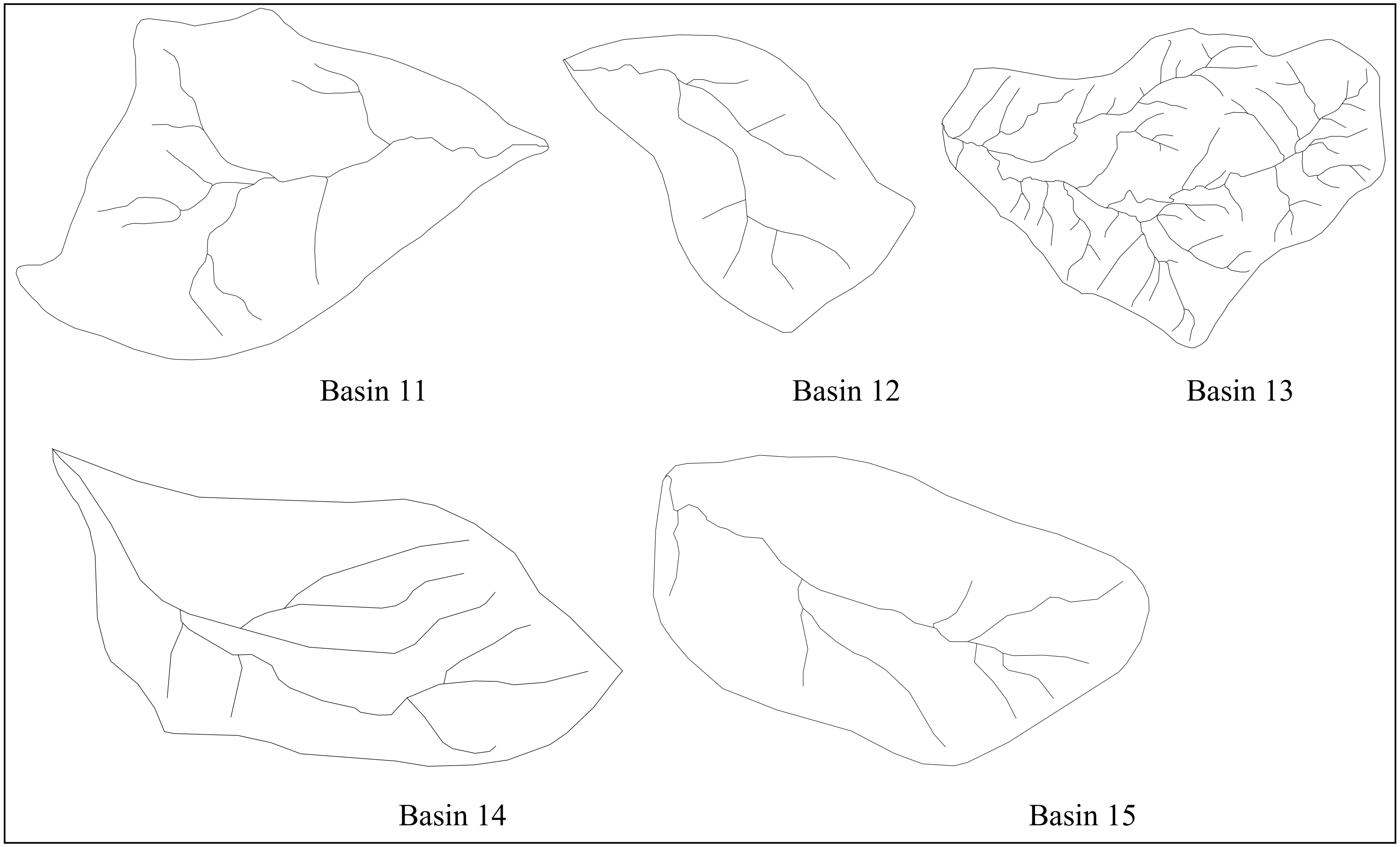

Fig 3.3: Drainage map of basin 10 to basin 15.

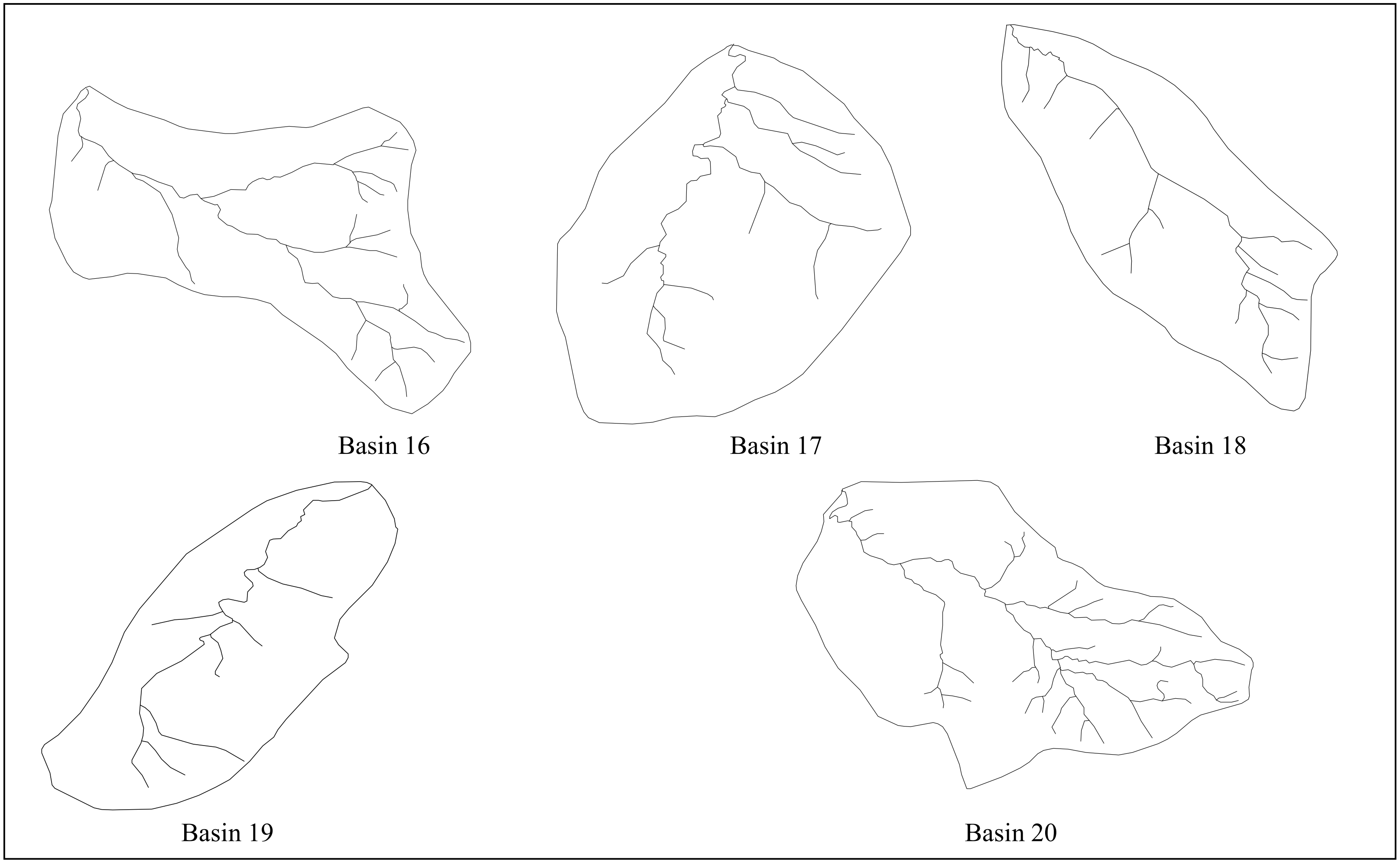

Fig 3.3: Drainage map of basin 16 to basin 20.

Table 3.1: General information of selected basins

Basin No.	Tributary of river	Survey of India Toposheets in which fall	Catchment area of the basin (sq. km)	Order of the basin	Perimeter of the basin (km)	Length of main channel (km)	No. of drains of 1st order	No. of drains of 2nd order	No. of drains of 3rd order	No. of drains of 4th order	Total no. of drains of all orders	Total length of all channels (km)	Elevation of the highest point (m)	Elevation of the lowest point (m)
1	Bebas	55-I/13	1.01	2	4.33	1.57	4	1	-	-	5	2.78	605.00	535.00
2	Bebas	55-I/13	0.75	1	5.27	1.72	1	-	-	-	1	1.72	565.00	515.00
3	Bebas	55-I/13	0.77	2	4.13	1.23	2	1	-	-	3	1.65	560.00	515.00
4	Bebas	55-I/13	4.08	3	8.13	3.41	12	3	1	-	16	10.54	565.00	515.00
5	Bebas	55-I/13	1.87	2	5.54	2.19	4	1	-	-	5	4.11	520.00	500.00
6	Bebas	55-I/13	18.59	4	20.85	10.43	28	8	2	1	39	31.12	570.00	500.00
7	Dhasan	55-I/9	4.13	2	7.56	2.51	3	1	-	-	4	4.30	560.00	520.00
8	Dhasan	55-I/9	28.06	4	21.04	8.73	21	9	2	1	33	32.81	590.00	520.00
9	Dhasan	55-I/9	27.54	4	25.18	10.03	47	12	2	1	62	47.64	560.00	520.00
10	Dhasan	55-I/10	4.06	3	8.70	4.10	15	4	1	-	20	10.27	600.00	520.00
11	Bebas	55-I/13	5.41	3	9.70	3.58	10	4	1	-	15	10.18	600.00	520.00
12	Dhasan	55-I/10	2.39	3	6.36	2.70	7	2	1	-	10	5.78	600.00	540.00
13	Dhasan	55-I/10	14.93	4	15.73	7.22	58	15	3	1	77	47.09	666.00	520.00
14	Dhasan	55-I/10	2.51	3	6.69	3.07	8	2	1	-	11	8.31	600.00	520.00
15	Dhasan	55-I/10	3.66	3	7.52	3.26	8	2	1	-	11	7.65	560.00	506.00
16	Dhasan	55-I/10	9.07	4	13.72	5.72	17	5	2	1	25	16.96	580.00	520.00
17	Dhasan	55-I/9	8.53	3	10.94	4.51	10	3	1	-	14	12.87	495.00	480.00
18	Dhasan	55-I/9	8.35	3	12.74	5.91	13	2	1	-	16	12.80	560.00	480.00
19	Dhasan	55-I/9	11.25	2	14.62	6.92	7	1	-	-	8	12.34	560.00	486.00
20	Dhasan	55-I/9	15.82	3	16.54	7.71	27	8	1	-	36	27.01	512.00	460.00

CHAPTER 4.0 – METHODOLOGY

In the present study, the new approach developed by NIH has been used to develop the GIUH. The geomorphological parameters of 20 small catchments have been determined using ILWIS 3.0 GIS software. It has been observed that the bifurcation ratio of a river system can be estimated easily, but the computation of length ratio and area ratio require lot of time and skill. Hence, in the study, an attempt has been made to develop the relationship between these parameters, which are used in the development of GIUH. The digital elevation model for these basins have been developed which is used as a input for the model. A computer program has been developed for the computation of ordinates of IUH. The detailed methodology can be seen in the reference of NIH (98-99), NIH (99-2000) etc. Here, methodology for the development of GIUH is being presented in short.

4.1 Determination of Geomorphological Parameters

Survey if India toposheets of scale of 1:50,000 have been taken and the boundaries, catchments, drainage and contour maps were prepared. All these maps were then digitized in ILWIS 3.0 software for further operations. All these maps were corrected for any errors such as proper joining of the stream, proper overlaying of the segments etc. Using the ILWIS facilities, the number of segments, lengths, perimeters, average catchment areas of each order, length of the main channel, total length of all channel, Maximum length of run, the highest point, the lowest point of each of the basins have been determined.

For computation of geomorphological characteristics, Strahler's ordering system has been used. The bifurcation ratio, length ratio and area ratio can be computed using following equations:

$$R_b = \frac{N_w}{N_{w+1}} \qquad \text{.... 4.1}$$

$$R_L = \frac{L_w}{L_{w-1}} \qquad \text{.... 4.2}$$

$$R_A = \frac{A_w}{A_{w-1}} \qquad \text{.... 4.3}$$

Where, N_w and N_{w+1} are the number of stream of w and w+1 order respectively. Similarly, L_w, L_{w-1} are the average length and A_w, A_{w-1} are the average area of w and w-1 order respectively. The R_b, R_L and R_A can also be determined with the help of plotting the graph between the N_w, L_w and A_w verses order of the drainage on semi log paper. The slope of the best-fit line gives R_b, R_L and R_A.

Horton (1945) defined the drainage density as the ratio of total length of all orders to the area of the basin. Miller (1953) introduced a dimensionless term circularity ratio, which may be defined as the ratio of the basin area to the area of a circle having circumference equal to the perimeter of the basin. Schumm (1956) used the term constant of channel maintenance as the inverse of drainage density.

The wandering ratio may be defined as the ratio between mainstream length along the course to the valley length (straight line distance between two extremes). Melton (1957) defined the fineness ratio as the ratio of channel lengths to the basin perimeter, which indicates the fineness of the topography. The stream channel frequency may be defined as the number of steam segment per unit area of the basin. Horton (1945) defined the length of overland flow is approximately half the average distance between stream channel and is therefore approximately equal to half the reciprocal of drainage density. The elongation ratio used by the Schumm (1956) as the ratio of diameter of the circle of the same area as the basin to the maximum basin length. Horton (1932) used form factor as a dimensionless ratio of basin area to the square of basin length. The compactness ratio may be defined as the ratio of catchment perimeter to that of the equivalent circle having area as that of the basin. The shape factor is the ratio of mainstream length to the diameter of a equivalent circle having same area as the basin.

The geomorphological parameters have been computed for all the basins. It has been observed that the bifurcation ratio, length ratio and area ratio are commonly used in the various hydrological studies. The estimation of bifurcation ratio is easy, but length ratio and area ratio estimation requires lots of time and effort. Therefore, in the study an attempt has been made to develop the relationship between these parameters for the region. Using catchment area, bifurcation ratio, length ratio and area ratio of all these basins, graphs have been plotted between catchment area v/s bifurcation ratio, bifurcation ratio v/s length ratio and length ratio v/s area ratio. The best-fit curves for each of the case were determined to compute theses parameters for any basin in the region.

4.2 Development of Time Area Diagram

The time area diagram is used as an input in the Clark based GIUH model. For preparation of time area diagram, digital elevation model for the region has been generated using the contour lines. The time of travel may be calculated as:

$$t = \frac{kL}{\sqrt{S}} \quad \text{.... 4.4}$$

where, t = time of travel,

L = length of stream,

S = slope of the stream,

K = proportionality constant

The initial estimate of time of travel can be obtained by Kirpich's formula, which may be given as:

$$T_c = 0.0195 L^{0.77} S^{-0.385} \quad \text{.... 4.5}$$

where, T_c = time of concentration in min,

L = length of main stream in meters,

S = mean slope of the main stream.

Using the length of mainstream and mean slope of the basin, time of concentration may be calculated using equation 4.5. The value of k in the equation 4.4 may be obtained by putting the values of T_c, L and S. After knowing the constant k, the time of travel for different points in the basin can be estimated using equation 4.4.

All the values of time of travel in the basin are marked as a point map in the ILWIS environment. Interpolation technique of ILWIS software may be used to obtain the isochronal map for each basin. Using the isochronal map of a basin, contributing area at any time interval can be found out. Similarly, a relationship can also be developed between the ratio of contributing time to time of concentration (T/T_c) and contributing area to total area of the basin (A/A_c). This relationship is used as an input in the Clark based GIUH model.

4.3 Excess Rainfall Estimation

The rainfall amount which produces surface runoff is termed as rainfall excess. For any rainfall- runoff modeling, the initial step is to estimate rainfall excess by separating the hydrological abstractions from the rainfall hyetograph. Although a number of methods are available for the separation of abstractions, the phi- index method has been used.

4.4 Geomorphology Based Clark Model

Clark model based on GIUH assumed that the rainfall excess first undergoes pure translation and then attenuation. The translation is achieved by a travel time-area histogram and the attenuation by routing through the results of the above through a linear reservoir at the outlet of the catchment.

The storage of the linear reservoir assumed at the outlet of the catchment can be described by:

$$S = RQ \quad \text{.... 4.6}$$

where, R = storage time constant,

Q = outflow.

The Clark model uses the Muskingum equation for routing the inflows at various times. The outflow (Q_2) for Muskingum method can be written as:

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1 \quad \text{.... 4.7}$$

For Clark model,

$$C_0 = \frac{0.5\Delta t_c}{R + 0.5\Delta t_c},$$

$$C_1 = \frac{0.5\Delta t_c}{R + 0.5\Delta t_c},$$

$$C_2 = \frac{R - 0.5\Delta t_c}{R + 0.5\Delta t_c},$$

I_1 and I_2 = inflows at time t_1 and t_2,

Q_1 and Q_2 = outflows at time t_1 and t_2,

$\Delta t_c = t_1 - t_2$

Here, it can be seen that C_1 and C_2 are same, also since the inflows are derived from the histogram I_1=I_2 for each time intervals, the equation 4.7 will become:

$$Q_2 = 2C_1 I_1 + C_2 Q_1 \quad \text{.... 4.8}$$

The equation 4.8 may written in more general form as:

$$u_i = CI_i + (1 - C)u_{i-1} \quad \text{.... 4.9}$$

where, u_i = i^{th} ordinate of IUH,

C = routing coefficient, $C = \frac{\Delta t}{R + 0.5\Delta t}$,

Δt = time interval in hours,

I_i = i^{th} ordinate of time area diagram.

Rodriguez – Iturbe and Valdes (1979) introduced the application of geomorphological parameters in IUH. They gave two equations for computation of peak flow and time to peak using geomorphological coefficients. The expression given by them are:

$$q_p = \frac{1.31 R_L^{0.49} V}{L_\Omega} \qquad \text{…. 4.10}$$

$$t_p = 0.44\left(\frac{L_\Omega}{V}\right)\left(\frac{R_B}{R_A}\right)(R_L)^{-0.38} \qquad \text{…. 4.11}$$

where, t_p = time to peak in hours,

L_Ω = length of the highest order stream in km,

q_p = peak flow in units of inverse hours,

V = expected peak velocity in m/sec,

R_B = bifurcation ratio,

R_L = length ratio,

R_A = area ratio

By multiplying q_p and t_p, we can get;

$$q_p * t_p = 0.5764\left(\frac{R_B}{R_A}\right)^{0.55}(R_L)^{0.05} \qquad \text{…. 4.12}$$

The term given in equation 4.12 is not dependent on storm characteristics and only a function of catchment characteristics.

4.5 Relationship Between Excess Rainfall and The Velocity

In the GIUH based Clark model expected peak velocity is used as an input in the model. This dynamic parameter at any given moment during the storm may be considered as constant through out the basin (Rodriguez et al, 1979). The velocity at peak runoff is used for the derivation of GIUH. A relationship between intensity of excess rainfall and peak velocity can be developed for the basin. Two different approaches are available for gauged and ungauged catchments.

4.5.1 Gauged catchment

This approach is used when the discharges and corresponding velocities at different depths at the outlet of the watershed are available. The discharge (Q) and velocity (V) at any depth may be considered as equilibrium discharge and equilibrium velocity respectively. The intensity of excess rainfall (i) can be calculated by:

$$i = \frac{Q_e}{0.2778A} \qquad \text{…. 4.13}$$

Using different pairs of V and i, a relationship can be developed in the form of $V=ai^b$.

4.5.2 Ungauged catchment

In case of ungauged catchment, the geometric properties of gauging section, bed slope and Manning's roughness coefficient should be known with adequate degree of accuracy. At different depths of a section, cross sectional area, wetted perimeter and hydraulic mean depth may be estimated. The velocities and corresponding discharges may be computed using Manning's equation and cross sectional areas. Graphs may be plotted between depth v/s area of cross section and depth v/s discharge. Equilibrium discharge may be calculated for an intensity of rainfall (i);

$$Q_e = 0.2778 iA \qquad \text{.... 4.14}$$

Where, A = catchment area in km^2,

Q_e = equilibrium discharge in cumecs.

The depth corresponding to that intensity may be calculated by the relationship between depth v/s discharge. For this depth, calculate the cross sectional area using the relationship of depth v/s area of cross section. Using the equilibrium discharge and cross sectional area, velocity at an intensity of rainfall can be computed. Similarly, velocity may be calculated for various intensities and a relationship between intensity of rainfall and equilibrium velocity in the form of $V=ai^b$ can be developed.

4.6 Application of New Approach in Clark Model

A new approach has been developed in National Institute of Hydrology, Roorkee in the year 1993, in which the parameters of the Clark model may be computed using geomorphological characteristics of the basin. Using the relationship developed between V and I earlier, the peak velocity may be estimated for the highest rainfall intensity of a storm. The peak discharge (Q_{pg}) of IUH may be calculated with the help of equation 4.10. The length ratio and length of highest order stream are used, as inputs in this equation. The time of concentration is calculated using following equation:

$$T_c = \frac{0.2778L}{V} \qquad \text{.... 4.15}$$

Two trial values of storage coefficients R_1 and R_2 may be assumed. The ordinates of two instantaneous unit hydrographs may be computed at very small time interval (0.1 or 0.05 hrs) with two assumed values of storage coefficients (R_1 and R_2) using equation 4.9. In this computation, the time of concentration (T_c) computed by equation 4.15, equation of time area diagram and storage coefficients will be used as inputs. The peak of both the computed instantaneous unit hydrographs may be find out as Q_{pc1} and Q_{pc2}.

The objective functions (FCN_1 and FCN_2) may be worked out using the following equations:

$$FCN_1 = \left(Q_{pg} - Q_{pc1}\right)^2 \qquad \text{.... 4.16}$$

$$FCN_2 = \left(Q_{pg} - Q_{pc2}\right)^2 \qquad \text{.... 4.17}$$

The first derivative FPN of the objective function FCN with respect to storage coefficient R can be calculated as:

$$FPN = \frac{(FCN_1 - FCN_2)}{(R_1 - R_2)} \qquad \text{.... 4.18}$$

The increment (ΔR) and next trial value of storage coefficient (R_{new}) can be computed by following equations of Newton-Raphson method:

$$\Delta R = \frac{FCN_1}{FPN} \qquad \text{.... 4.19}$$

$$R_{new} = R_1 + \Delta R \qquad \text{.... 4.20}$$

Again the ordinates of two IUH's may be computed considering $R_1 = R_2$ and $R_2 = R_{new}$ and the FCN1, FCN2, FPN, ΔR, R_{new} may be calculated using the same procedure till any one of the following conditions satisfy.

$$FCN_2 = 0.000001 \qquad \text{.... 4.21}$$

$$\frac{ABS(\Delta R)}{R_1} = 0.001 \qquad \text{.... 4.22}$$

Number of trials exceeds 1000 .... 4.23

With the help of final value of storage coefficient (R_2), time area diagram and time of concentration, the ordinates of IUH can be computed for a particular storm. The ordinates of a D-hour unit hydrograph (U_i) can be obtained for IUH using the following equation:

$$U_i = \frac{1}{n}\left[0.5\left(u_{i-n} + u_i\right) + u_{i-n+1} + - - - - - - + u_{i-1}\right] \qquad \text{.... 4.24}$$

This unit hydrograph may be use to estimate the direct surface hydrograph for that particular storm. A computer program in FORTRAN has been developed to compute the ordinates of IUH using the above procedure.

CHAPTER 5.0 – RESULTS AND DISCUSSION

In the present study, an attempt has been made to apply the geomorphological approach of rainfall-runoff modeling in the small watersheds in Dhasan and Bebas river system in Sagar district. It has been observed that the runoff measurements in Madhya Pradesh is limited only on big river that to only once a day. Hence, it is very important to develop some other methods, which may use basin characteristics and other easily available ancillary information for rainfall-runoff modeling. The geomorphological characteristics based Clark model may be used to determine the peak flow for design of small hydraulic structures such as barrage, weirs, bridges etc.

5.1 Geomorphological Parameters and their relationships

The different geomorphological parameters of all twenty basins, which are commonly used, have been estimated using ILWIS 3.0 GIS software. All these parameters have been given in Table 5.1 and 5.2. The bifurcation ratio (R_b), length ratio (R_l) and area ratio (R_a) are the most commonly used geomorphological parameters in many hydrological studies. Hence, an attempt has been made to develop relationship between catchment area, number of channels, bifurcation ratio (R_b), length ratio (R_l) and area ratio (R_a).

The bifurcation ratio, length ratio and area ratio of all these basins have been computed by graphical method. In this method, the order of the basin has been plotted on x-axis and no of drains, average length and average area of corresponding order have been plotted on y-axis on a semi log graph paper. The slopes of the best-fit lines give R_b, R_l and R_a respectively. The graphical representation for estimation of R_b, R_l and R_a for basin 16 has been given in Fig. 5.1.

In order to develop relationship between geomorphological characteristics and bifurcation ratio, numbers of combinations have been tried and catchment area v/s bifurcation ratio and sqrt (cat. area*total no. of channel) v/s bifurcation ratio have been found the most suitable. These relationships have been presented in Fig. 5.2 and 5.3. For developing the relationship, the basins of higher than second order have been considered. It is recommended that the bifurcation ratio should be measured using the drainage map as it can be computed easily if the drainage map of the basin is available.

Table 5.1: Geomorphological characteristics of basin 1 to Basin 10.

Basin No.	1	2	3	4	5	6	7	8	9	10
Order	2	1	2	3	2	4	2	4	4	3
Catchment Area (sq. km)	1.01	0.75	0.77	4.08	1.87	18.59	4.13	28.06	27.54	4.06
Perimeter (km)	4.33	5.27	4.13	8.13	5.54	20.85	7.56	21.04	25.18	8.70
Length of main channel (km)	1.57	1.72	1.23	3.41	2.19	10.43	2.51	8.73	10.03	4.10
Max length of run (km)	1.85	2.54	1.88	3.77	2.27	10.71	2.85	8.90	10.22	4.38
Length of Highest order stream (km)	1.06	1.72	0.61	1.52	1.73	6.20	1.24	3.34	4.62	3.10
Straight length	1.75	2.47	1.72	3.02	2.08	8.52	2.66	7.08	9.04	2.74
Bifurcation ratio	4.00	-	2.00	3.46	4.00	3.12	2.99	2.90	3.80	2.83
Length Ratio	2.46	-	1.18	1.64	2.91	2.19	1.82	1.89	2.16	2.73
Area ratio	6.97	-	3.61	4.26	7.40	3.73	5.04	4.40	5.02	8.69
Drainage density	2.75	2.29	2.15	2.59	2.19	1.67	1.04	1.17	1.73	2.53
Stream Channel Frequency	3.96	1.33	2.60	2.94	2.14	1.51	0.73	0.75	1.71	3.70
Wandering Ratio	0.90	0.70	0.72	1.13	1.05	1.22	0.94	1.23	1.11	1.50
Fineness Ratio	0.64	0.33	0.40	1.30	0.74	1.49	0.57	1.56	1.89	1.18
Farm factor	0.33	0.12	0.26	0.45	0.44	0.26	0.59	0.56	0.34	0.54
Length of overland flow	0.18	0.22	0.23	0.19	0.23	0.30	0.48	0.43	0.29	0.20
Channel maintenance	0.36	0.44	0.47	0.39	0.46	0.60	0.96	0.86	0.58	0.40
Circulatory ratio	0.68	0.34	0.57	0.77	0.77	0.54	0.91	0.80	0.55	0.67
Compactness ratio	1.22	1.72	1.33	1.14	1.14	1.36	1.05	1.12	1.35	1.22
Elongation ratio	0.33	0.12	0.26	0.45	0.44	0.26	0.59	0.56	0.34	0.54
Shape factor	0.69	0.88	0.62	0.75	0.71	1.07	0.55	0.73	0.85	0.90

Table 5.2: Geomorphological characteristics of basin 11 to Basin 20.

Basin	11	12	13	14	15	16	17	18	19	20
Order	3	3	4	3	3	4	3	3	2	3
Catchment Area (sq. km)	5.41	2.39	14.93	2.51	3.66	9.07	8.53	8.35	11.25	15.82
Perimeter (km)	9.70	6.36	15.73	6.69	7.52	13.72	10.94	12.74	14.62	16.54
Length of main channel (km)	3.58	2.70	7.22	3.07	3.26	5.72	4.51	5.91	6.92	7.71
Max length of run (km)	3.75	2.81		3.22	3.43	5.95	4.96	6.36	7.29	7.88
Length of Highest order stream (km)	2.22	0.81	5.63	1.00	1.16	2.17	1.47	2.69	6.06	5.04
Straight length	3.74	2.41	5.17	2.74	2.96	5.11	4.05	5.56	6.27	5.90
Bifurcation ratio	3.16	2.65	4.05	2.83	2.83	2.56	3.16	3.61	7.00	5.20
Length Ratio	1.99	1.37	2.02	1.22	1.36	1.77	1.47	2.34	6.75	3.46
Area ratio	4.08	3.71		3.95	4.06	3.74	4.15	6.12	17.34	7.59
Drainage density	1.88	2.42	3.16	3.31	2.09	1.87	1.51	1.53	1.10	1.71
Stream Channel Frequency	1.85	2.93	3.89	3.18	2.19	1.87	1.17	1.56	0.62	1.71
Wandering Ratio	0.96	1.12	1.40	1.12	1.10	1.12	1.12	1.06	1.10	1.31
Fineness Ratio	1.05	0.91	2.99	1.24	1.02	1.24	1.18	1.01	0.84	1.63
Farm factor	0.39	0.41	0.56	0.34	0.42	0.35	0.52	0.27	0.29	0.45
Length of overland flow	0.27	0.21	0.16	0.15	0.24	0.27	0.33	0.33	0.46	0.29
Channel maintenance	0.53	0.41	0.32	0.30	0.48	0.53	0.66	0.65	0.91	0.59
Circulatory ratio	0.72	0.74	0.76	0.71	0.81	0.60	0.90	0.65	0.66	0.73
Compactness ratio	1.18	1.16	1.15	1.19	1.11	1.29	1.06	1.24	1.23	1.17
Elongation ratio	0.39	0.41	0.56	0.34	0.42	0.35	0.52	0.27	0.29	0.45
Shape factor	0.68	0.77	0.83	0.86	0.75	0.84	0.68	0.91	0.91	0.86

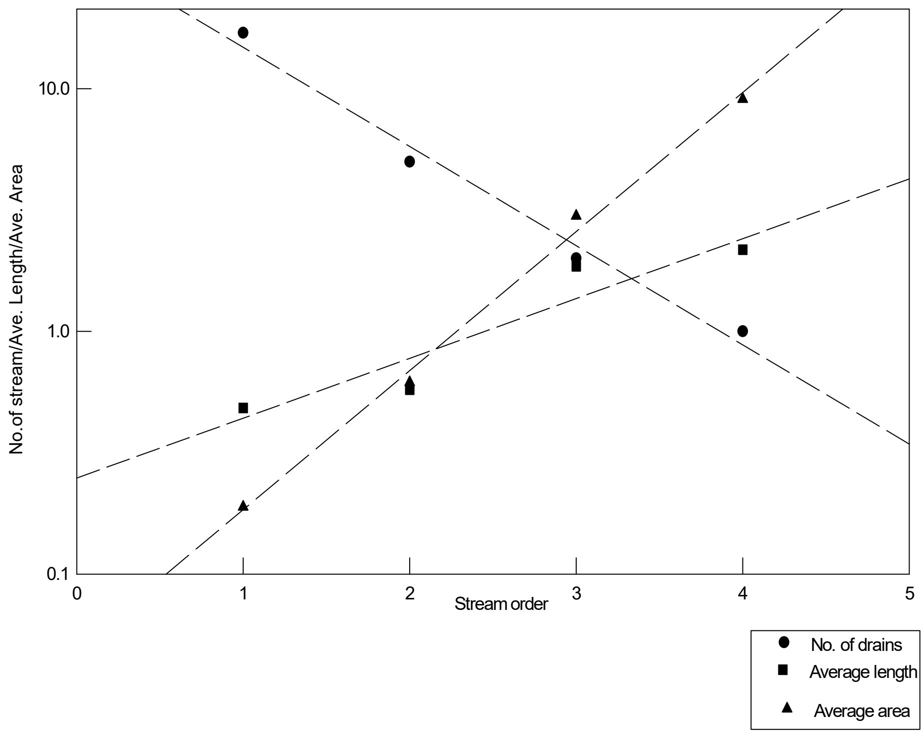

Fig. 5.1: Graph showing Stream order v/s No. of stream/Ave. length/Ave. Area for Basin 16

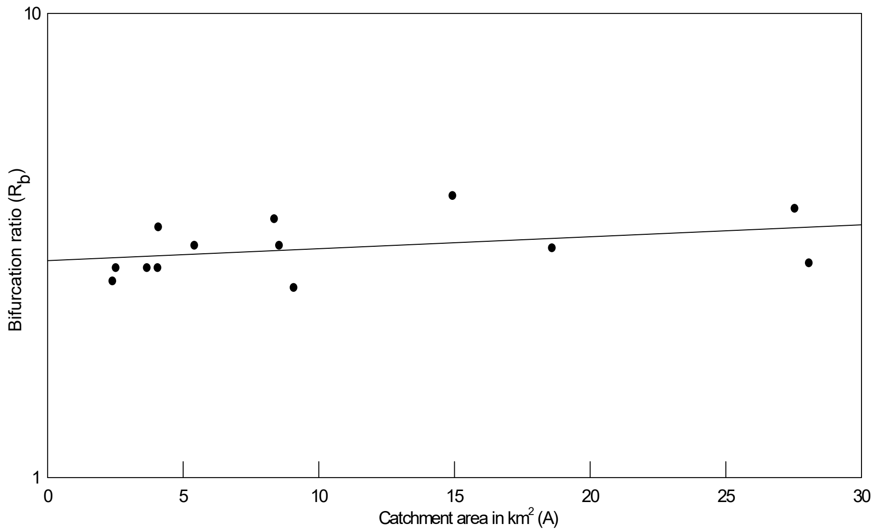

Fig. 5.2: Relationship between catchment area (A) and bifurcation ratio (R_b)

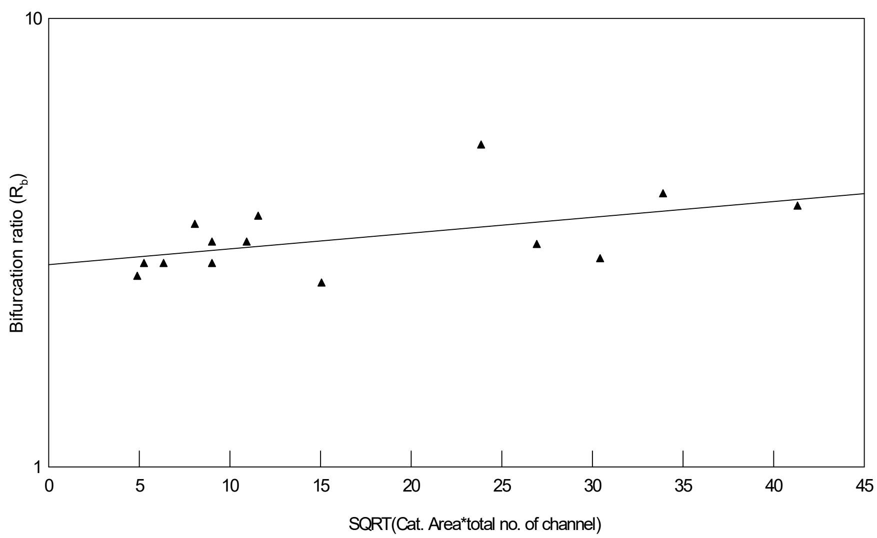

Fig.5.3: Relationship between sqrt(cat. area*total no. of chonnel) and bifurcation ratio (R_b)

The relationship between bifurcation ratio and length ratio has been given in Fig 5.4. Similarly, a relationship between length ratio and area ratio for the region has been presented in the Fig. 5.5. These relationships may give some idea regarding the geomorphological characteristics in the region.

5.2 Time Area Diagram

The time area diagram, which is used as an input in the Clark model, has been prepared for all the basins. The time area diagrams have been generated using ILWIS software. The time area diagrams of basin 4 and basin 9 have been given in the Fig. 5.6 and 5.7 respectively. The Relationship between T/Tc and A/Ac have been developed for all the basins. A graphical representation of relationship between T/Tc and A/Ac for basin 3 has been presented in Fig. 5.8.

5.3 Development of Relationship Between Excess Rainfall and The Velocity

In this study, both the methods of gauged and ungauged catchments have been used. The observations of runoff have been made for basin 1,2,3,4 and 5. While, the methodology of ungauged catchments have been used for other basins. The Manning roughness coefficient (N) has been taken as 0.035. The cross-sectional details of river at the outlet of basin have been used for development of the relationship in case of ungauged watersheds. The relationships between excess rainfall and velocity for basin 1 and basin 3 have been presented in the Fig 5.9 and Fig 5.10.

5.4 Application of GIUH based Clark Model

For development of the GIUH based Clark model, a program in FORTRN has been developed using the methodology given in chapter 4. For analysis basin 1, 2, 3,4,5 and 11 have been selected. The Self-recording rain gauge has been installed to collect rainfall information, while the runoff data have been collected by measuring the stage and velocity. Measurement of runoff was done on basin 1,2,3,4 and 5. While, the basin 11 has been considered as ungauged basin. The basin 2 has not been considered for analysis because it was a single order basin and it was not possible to compute geomorphological parameters of this basin. The Basin wise analyses of runoff hydrographs are being given below.

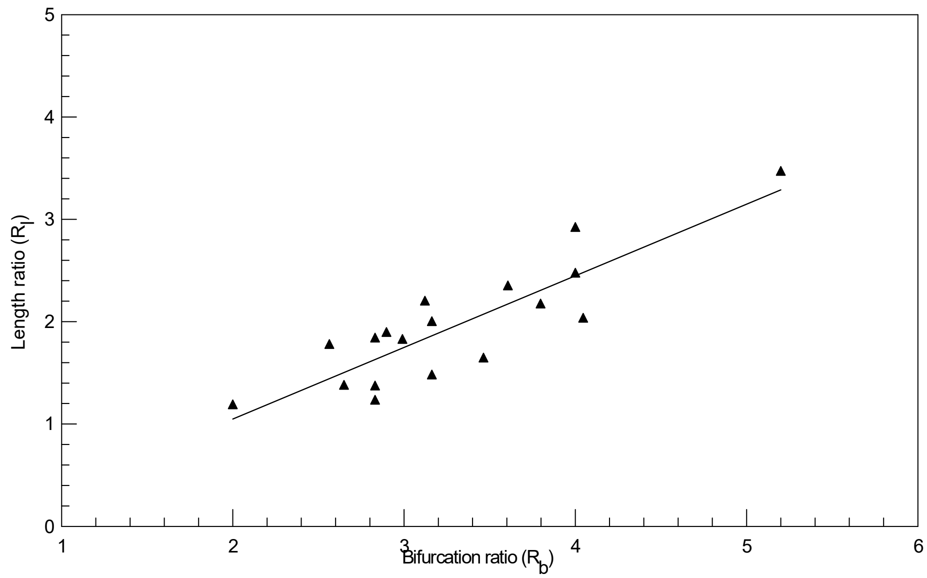

Fig. 5.4: Relationship between bifurcation ratio (R_b) and length ratio (R_l)

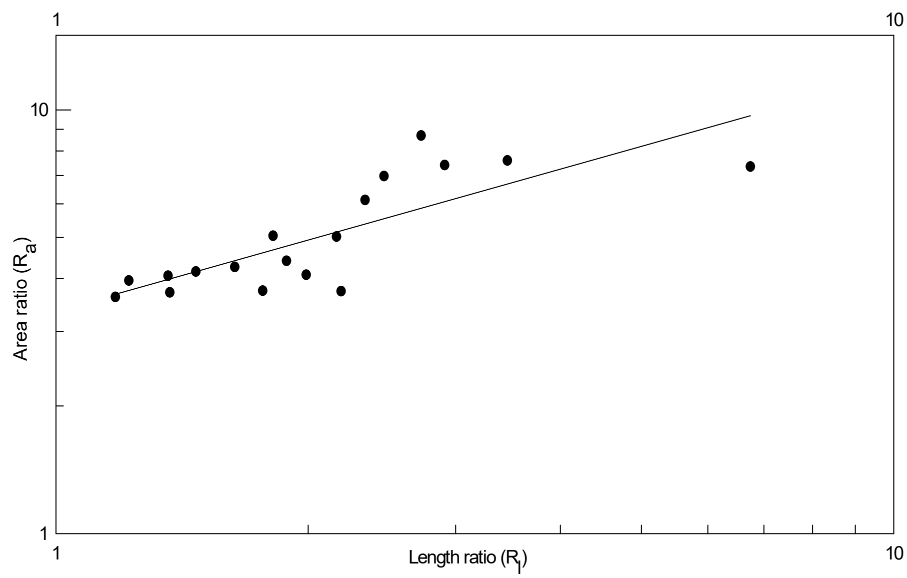

Fig 5.5: Relationship between length ratio (R_l) and area ratio (R_a)

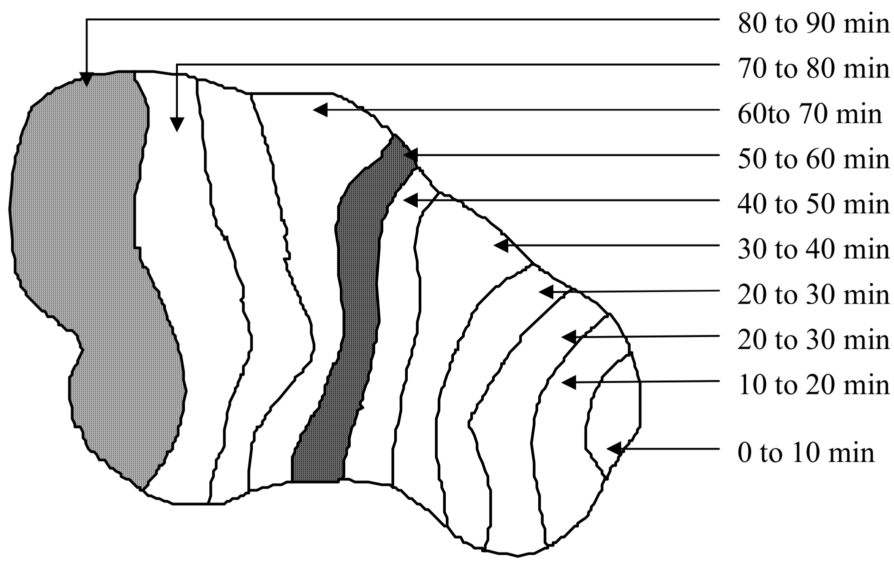

Fig 5.6: Time-area diagram for basin 4.

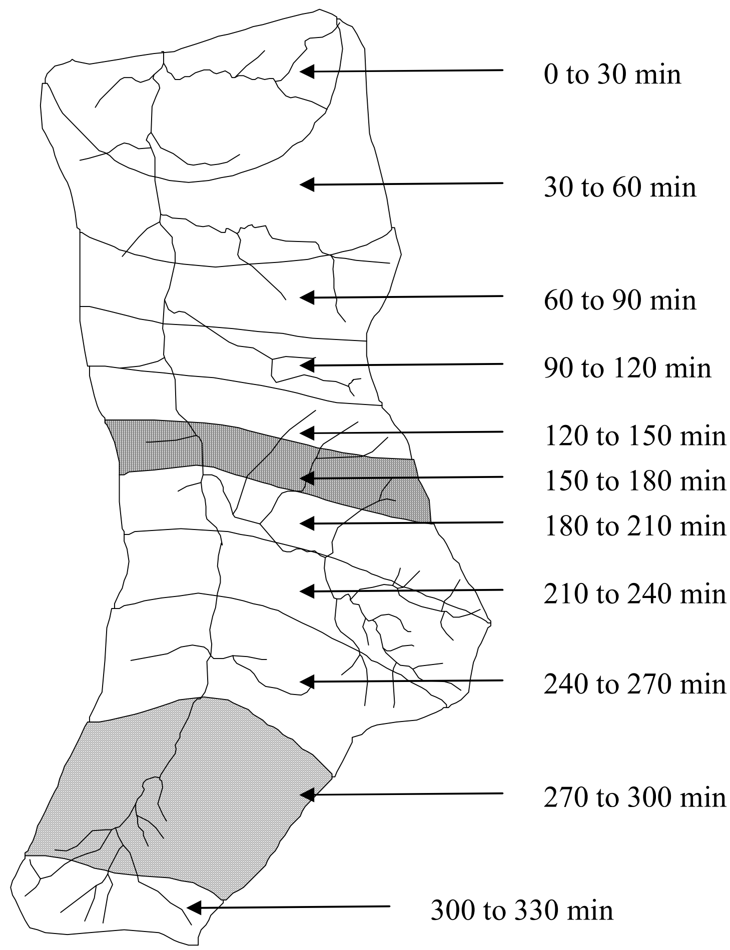

Fig. 5.7: Time-area diagram for basin- 9.

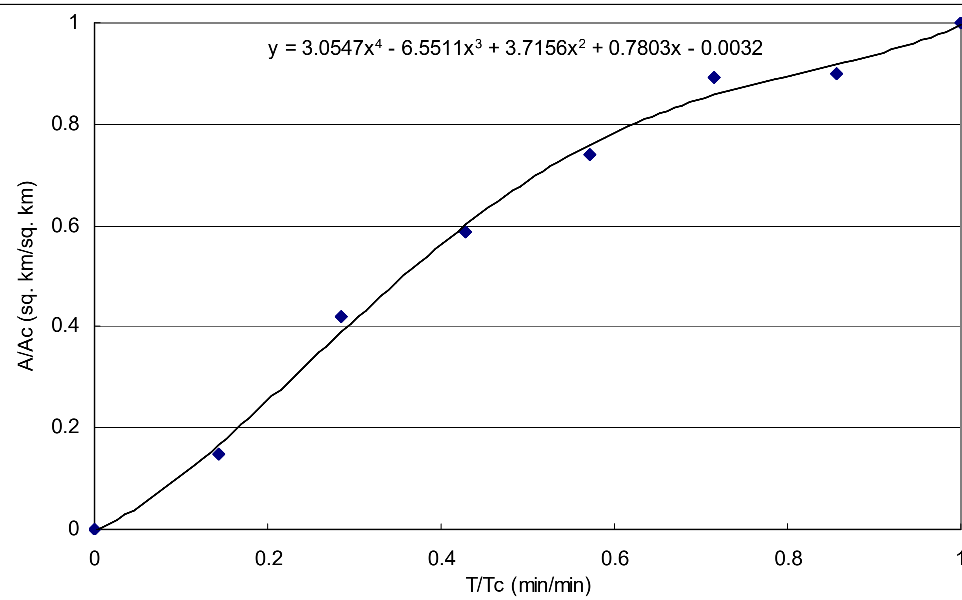

Fig 5.8: Relationship between T/Tc and A/Ac for basin 3.

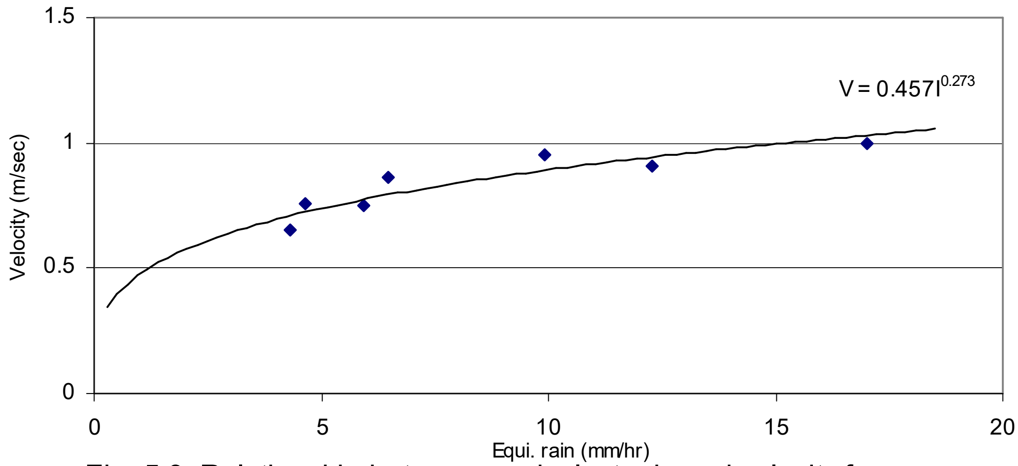

Fig. 5.9: Relationship between equivalent rain and velocity for basin 1

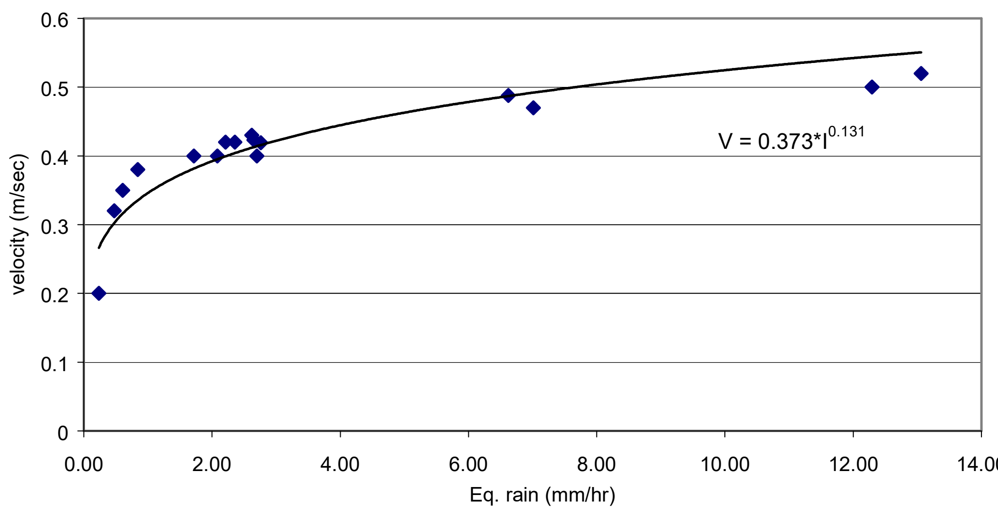

Fig. 5.10: Relationship between velocity and eq. rain for basin 3

5.4.1 Basin 1

For basin 1, two storms of Sept 15, 2003 and Sept 24, 2003 have been considered. Using the rainfall and runoff data collected for the basin, the following relationship between excess rainfall and equivalent velocity has been found fit.

$$V = 0.457 i^{0.273} \qquad \text{....5.1}$$

A graph has been prepared between T/T_c (on x-axis) and A/A_c on (y-axis) and used as an input in the model. The maximum rainfall intensity has been computed with the help of chart of SRRG installed in the region.

The time of concentration (T_c), storage coefficient (R), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) have been given in Table 5.3. A comparison of computed and observed direct surface runoff for an event on Sept 15, 2003 has been presented in Fig. 5.11.

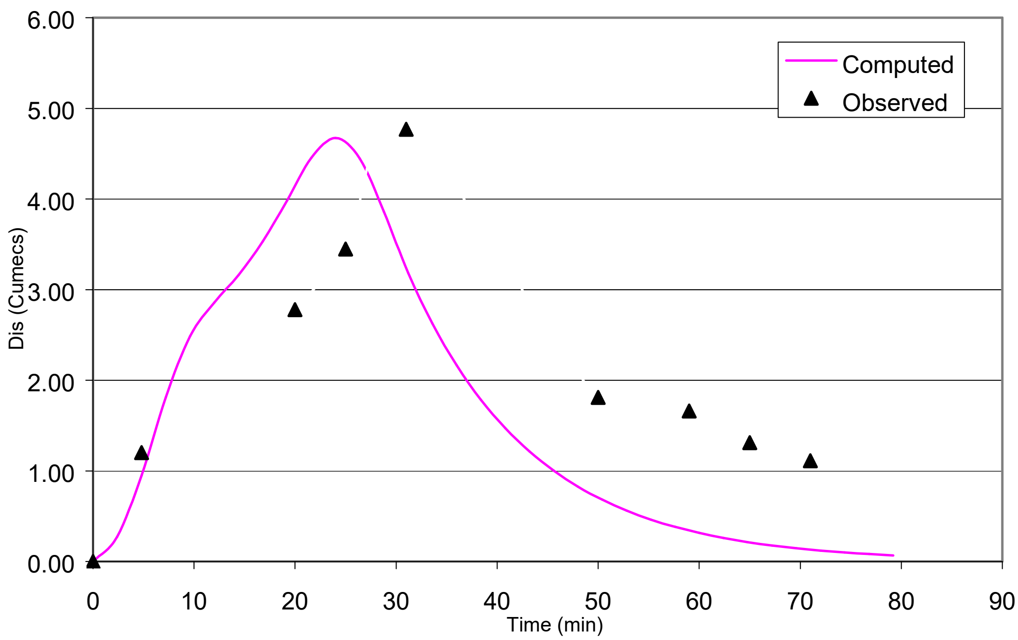

Fig 5.11:Comparision of observed and computed discharge for basin 1 (15-09-2003)

Table 5.3: Parameters of GIUH based Clark model.

S. N	Date	I	V	Q_{pg}	T_{pg}	Q_{pc}	T_{pc}	R	T_c
BASIN 1									
1.	15-09-03	40	1.25	6.73	21.72	6.75	21.6	0.21	0.35
2.	24-09-03	24	1.09	5.87	13.44	5.87	16.4	0.24	0.40
BASIN 3									
1.	14-08-03	7	0.48	2.39	22.77	2.41		0.44	0.71
2.	29-08-03	32	0.59	2.93	18.52	2.94	20.4	0.36	0.58
3.	15-09-03	40	0.61	3.04	17.92	3.03	19.2	0.38	0.56
4.	24-09-03	24	0.57	2.84	19.17	2.83	24.0	0.37	0.60
BASIN 4									
1.	14-08-03	7	1.17	14.56	25.35	14.6	52.8	0.83	0.81
2.	29-08-03	32	1.29	16.05	22.99	16.01	48.0	0.72	0.74
3.	15-09-03	40	1.30	16.18	22.81	16.22	48.0	0.75	0.73
4.	24-09-03	24	1.26	15.68	23.54	15.73	48.0	0.78	0.75
BASIN 5									
1.	14-08-03	7	0.67	4.45	32.39	4.48	55.2	1.4	0.90
2.	29-08-03	32	1.43	9.49	15.17	9.51	26.4	0.79	0.43
3.	15-09-03	40	1.60	10.62	13.56	10.62	28.8	0.69	0.38
4.	24-09-03	24	1.24	8.23	17.50	8.25	31.2	0.86	0.49
BASIN 11									
1.	14-08-03	7	0.38	4.94	103.79	4.78	101	4.11	2.58
2.	15-09-03	40	1.12	14.58	35.21	13.95	38.1	1.41	0.88

I Peak Rainfall Intensity in mm/hr,
V Peak Velocity in m/sec,
Q_{pg} Peak discharge using geomorphological parameters in cumecs,
T_{pg} Time to peak of IUH using geomorphological parameters in min
Q_{pc} Computed peak of IUH with Clark model in cumecs
T_{pc} Computed time to peak of IUH with Clark model in min
R Storage coefficient in hrs^{-1}
T_c Time of concentration in hrs

5.4.2 Basin 3

For basin 3, four storms of Sept 15, 2003, Sept 24, 2003, Aug 14, 2003 and Aug 29, 2003 have been considered. Using the rainfall and runoff data collected for the basin, the following relationship between excess rainfall and equivalent velocity has been found fit.

$$V = 0.373 i^{0.131} \qquad \text{....5.2}$$

A graph has been prepared between T/T_c (on x-axis) and A/A_c on (y-axis) and used as an input in the model. The maximum rainfall intensity has been computed with the help of chart of SRRG installed in the region.

The time of concentration (T_c), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) have been given in Table 5.3. A comparison of computed and observed direct surface runoff for an event on Sept 15, 2003 has been presented in Fig. 5.12.

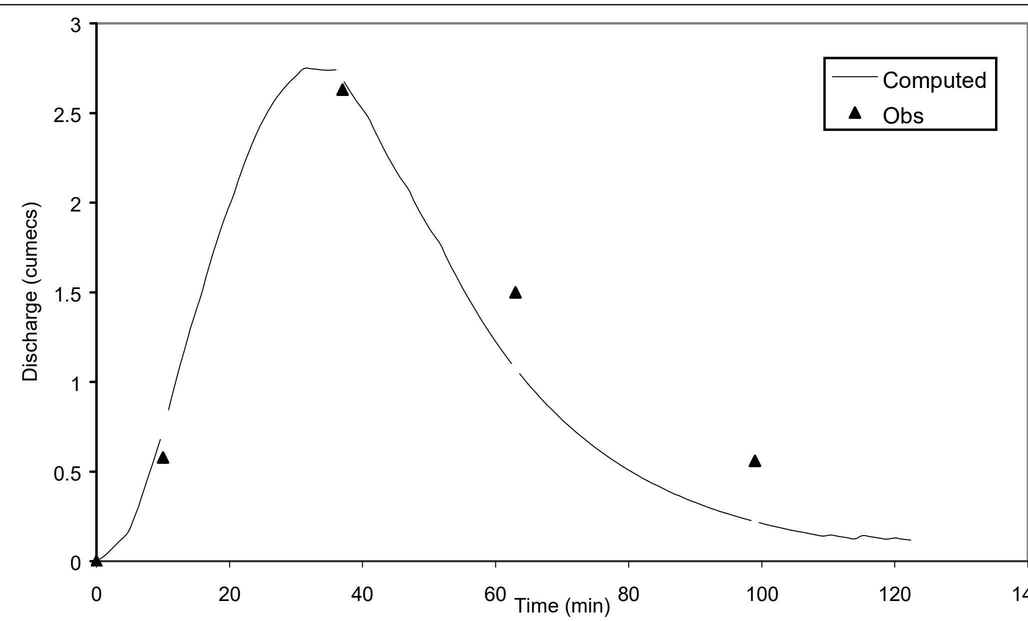

Fig.5.12: Comparision of observed and computed discharge for basin 3 (15-09-2003)

5.4.3 Basin 4

For basin 4, four storms of Sept 15, 2003, Sept 24, 2003, Aug 14, 2003 and Aug 29, 2003 have been considered. Using the rainfall and runoff data collected for the basin, the following relationship between excess rainfall and equivalent velocity has been found fit.

$$V = 1.045 i^{0.60} \quad \ldots.5.3$$

A graph has been prepared between T/T_c (on x-axis) and A/A_c on (y-axis) and used as an input in the model. The maximum rainfall intensity has been computed with the help of chart of SRRG installed in the region.

The time of concentration (T_c), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) have been given in Table 5.3. A comparison of computed and observed direct surface runoff for an event on Aug 29, 2003 has been presented in Fig. 5.13.

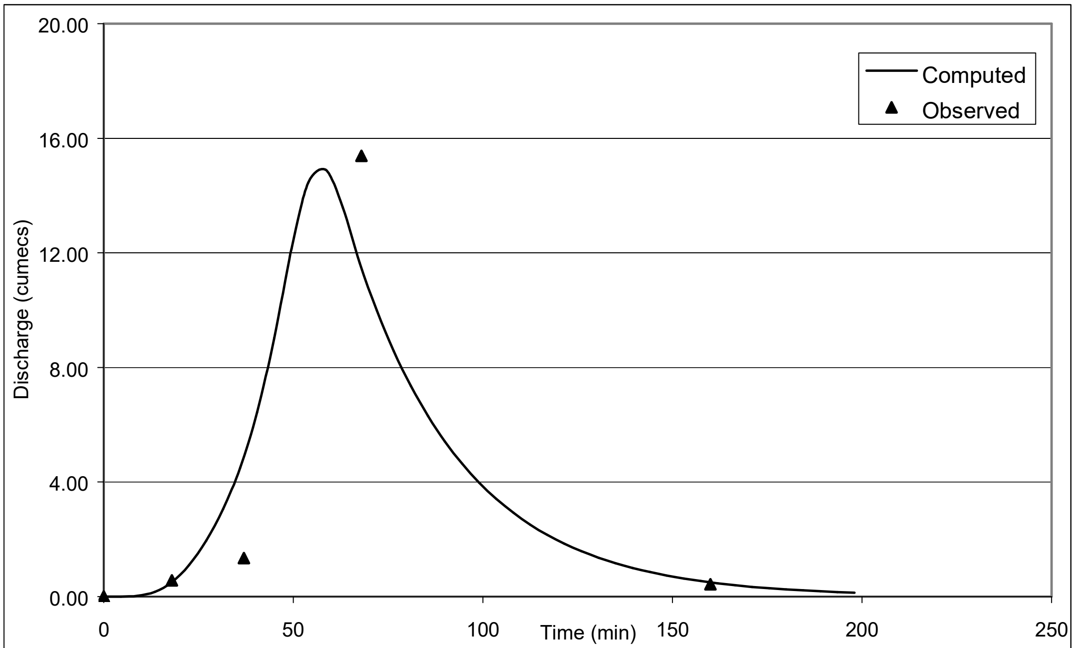

Fig.5.13: Comparision of observed and computed discharge for basin 4 (29-08-2003)

5.4.3 Basin 5

For basin 5, four storms of Sept 15, 2003, Sept 24, 2003, Aug 14, 2003 and Aug 29, 2003 have been considered. Using the rainfall and runoff data collected for the basin, the following relationship between excess rainfall and equivalent velocity has been found fit.

$$V = 0.257 i^{0.495} \quad \text{....5.4}$$

A graph has been prepared between T/T_c (on x-axis) and A/A_c on (y-axis) and used as an input in the model. The maximum rainfall intensity has been computed with the help of chart of SRRG installed in the region.

The time of concentration (T_c), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) have been given in Table 5.3. A comparison of computed and observed direct surface runoff for an event on Aug 14, 2003 has been presented in Fig. 5.14.

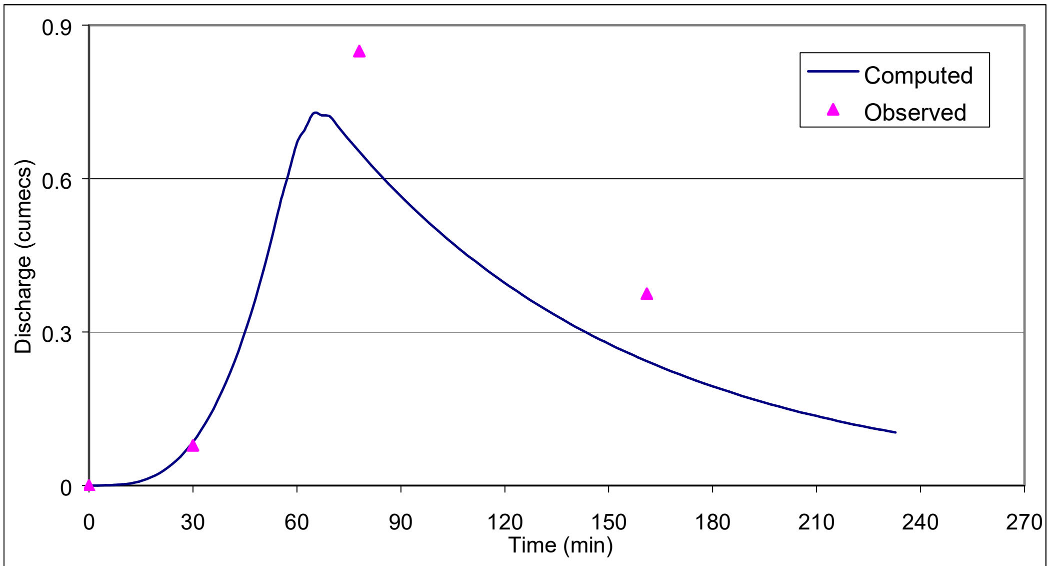

Fig.5.14: Comparision of observed and computed discharge for basin 5 (14-08-2003)

5.4.3 Basin 11

For basin 11, the IUH and corresponding hydrographs have been computed considering as the basin as an ungauged catchment. Using the cross-sectional area, the following relationship between excess rainfall and equivalent velocity has been found fit.

$$V = 0.116 i^{0.616} \qquad \text{….5.5}$$

A graph has been prepared between T/T_c (on x-axis) and A/A_c on (y-axis) and used as an input in the model. The maximum rainfall intensity has been computed with the help of chart of SRRG installed in the region.

The time of concentration (T_c), peak rainfall intensity (i), peak velocity (V), computed peak (Q_{pc}) and its time to peak (T_{pc}), also the peak using GIUH characteristics (Q_{pg}) and its time to peak (T_{pg}) have been given in Table 5.3. An observed direct surface runoff for an event on Aug 14, 2003 has been presented in Fig. 5.15.

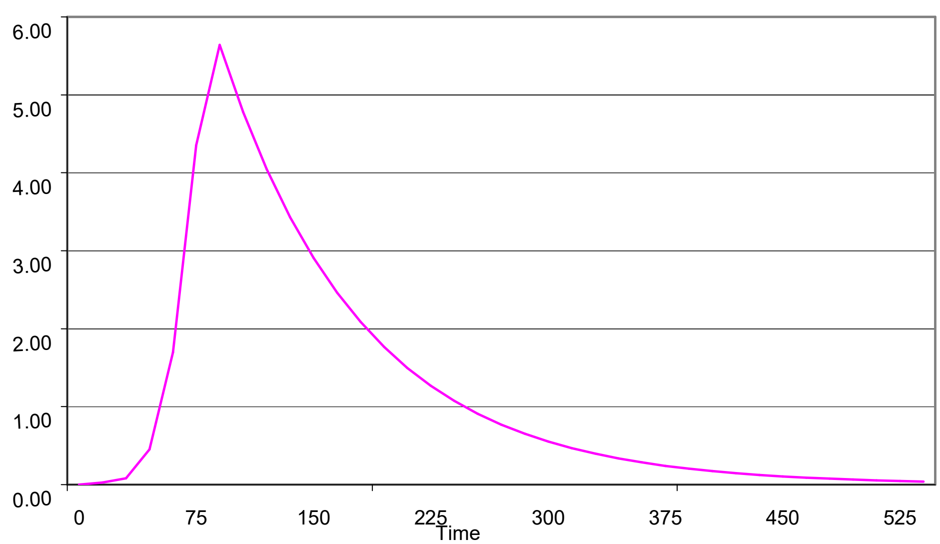

Fig.5.15: Computed DSRO for basin 11 (24-09-2003).

CHAPTER 6.0 – CONCLUSIONS

The geomorphology based Clark model has a wide application for estimation of runoff, flood forecasting and design flood estimation, design of small structures like weir, barrage, bridge etc, particularly in ungauged catchment or catchment with limited data. The data availability in the Bundelkhand region of Madhya Pradesh is very poor and discharge data are seldom available, therefore, the application of such models, which require minimum data, may be useful in this region. The geomorphological based models may have an edge because of requiring only geomorphological information, which can be extracted from topographic maps and field information. The following conclusions can be drawn from the study:

- The geomorphological characteristics of a basin and time area diagram can be determined easily using GIS software ILWIS. The application of GIS software gives the more accurate information in lesser time.
- The bifurcation ratio may be computed easily if the drainage map is available. The length ratio and area ratio can be computed using the relationships given, if the facilities for measuring lengths or areas are not available.
- The relationships of velocity and intensity of rainfall may be determined using the past record or cross-sectional information.
- A computer program for the development of IUH has been formulated using the methodology suggested by National Institute of Hydrology, Roorkee.
- The methodology suggested by National Institute of Hydrology, Roorkee for development of IUH using Clark model provides different hydrographs for different events using storm characteristics. This indicates that the methodology is capable of simulating the non-linear response to different events. But this method uses the highest block of rainfall intensity.
- From the study, it has been observed that the GIUH based Clark model has potential application for the estimation of design floods in the catchments with limited or no data.
- As this methodology has been applied on small basins in the region, it is recommended that the same should also be applied on large basins in the region.
- In this report, the float method has been used for measurement. The results could be improved if the current meter is used for measurement of velocity.

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DIRECTOR	**:**	**Dr. K. D. SHARMA**
HEAD & CO-ORDINATOR	**:**	**Dr. A. K. BHAR**
STUDY GROUP	**:**	**R. K. JAISWAL**
		T. THOMAS
		R.V. GALKATE