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DEVELOPMENT OF GEOMORPHOLOGICAL INSTANTANEOUS UNIT HYDROGRAPH OF HARIDRA RIVER WATERSHED USING RS AND GIS

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***Abstract:**The use of physically dependent precipitation-runoff calculation methods such as the geomorphological hydrograph of the instantaneous unit has evolved to mitigate these difficulties. The basin's geomorphological parameters have been calculated using ARC-GIS from SRTM DEM. This approach's disadvantage is that the GIUH only provides the peak discharge (qp) and time to peak (tp) but not the hydrograph's full form. The main aims of this study are to determine the geomorphological characteristics of the watershed and to define certain useful parameters of drainage basins in numerical terms Mathematical computation of the Nash model parameter and to establish the instantaneous unit hydrographic geomorphology. In this study, a method was created for the extraction of the full form of GIUH by linking it to the Nash model. The Nash Model ' n ' and ' k ' parameters are extracted from the GIUH peak discharge and peak time for this reason. The problem with the GIUH is its reliance on peak velocity V and the use of these values n and k, and these two parameters of the Nash equation are extracted from the entire GIUH process.*

Keywords: *ArcGIS, GIUH,UH, Nash model.*

1. INTRODUCTION

The sustainable development and management of natural resources is possible through the implementation of a watershed-based soil and water protection system. Soil and water are very important for sustainable agriculture. India's average annual rainfall is about 120 cm and 80 per cent of it falls only during the monsoon season, i.e. from July to October.

The annual volume of precipitation by four types of weather phenomena: South-West monsoon (74%), north-east mountain (3%), pre-monsoon (13%), post-monsoon (10%). The distribution of rainfall varies with time and space, the analysis of rainfall become more important for soil conservation point of view. Estimation of runoff is important for designing the soil and water conservation structures.

Satellite imaging remote sensing methods are a powerful tool for morphometric analysis and groundwater research. The morphometric study of the watershed is playing an important role for understanding the geo-hydrological parameters and it is reflecting the climate change, geology, and geomorphology of the watershed. This morphometric analysis gives the physical characteristics of the watershed and helps to determine the parameters within the watershed area.

The benefit of the GIUH technique is its ability to generate a unit hydrograph (UH) using geomorphological characteristics derived from a topographic map or remote sensing is related to the GIS and DEM. Using the GIUH method, the direct runoff and direct runoff hydrograph (DRH) are measured. After measuring the DRH, it is possible to obtain the flood hydrograph simply by adding the element of the base flow.

2. Details of the Study Area

The study area is Haridra River catchment, which is a small catchment in Karnataka State, India. Figure shows map of Catchment area of Haridra River, which is a main tributary of Tungabhadra. Tungabhadra is a Sub-Basin of Krishna River. The study area is located between 14º07′12″ N to 14º31′12″ N Latitude and 75º41′24″ E to 76º13′12″ E Longitude.

The study area covers an area of 1416.44 km2, and having maximum length of 83.334 km and the study area elevation varies from 518 m to 993 m. Catchment area is delineated from DEM Data using Arc GIS software 10.1

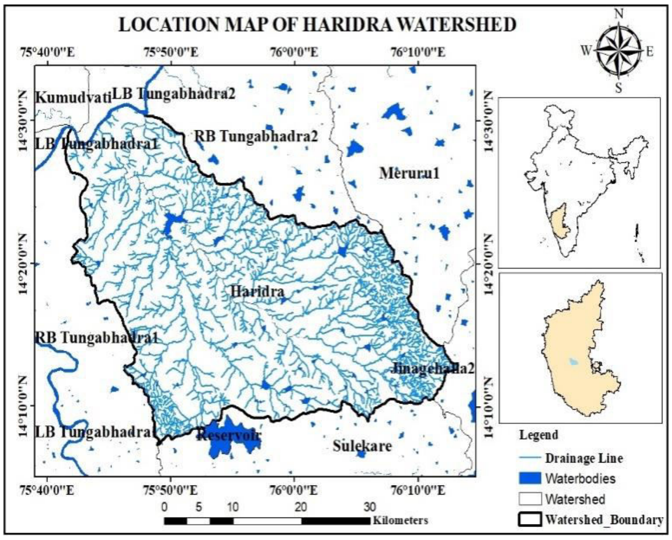

Fig.1. Study area Location map

3. METHODOLOGY AND MATERIAL

The methodology plays an important role in the current studies. The methodology was classified as follows to achieve the goals of this study:

i. Methodology for morphometry analysis and
ii. Methodology for GIUH.

3.1 Morphometric analysis

The morphometric analysis of the basin is carried out via the linear, aerial and channel network gradient and the ground slope basin. In this analysis, the Geographical Information System (GIS) is used to analyze the various fields and morphometric parameters of the change more readily and more precisely. Satellite data and GIS tools have been widely used to generate data on spatial variations in drainage characteristics, thereby providing insight into the hydrological conditions necessary for the design of watershed management strategies, GIS being a powerful tool for the interpretation and evaluation of spatial information and providing a versatile framework for morphometric analysis.

Geomorphological characteristics of watershed:

Morphological characterization is the systematic description of watershed geometry. Geometry of drainage basin and its stream channel system required the following measurements:

(I) Linear aspect of drainage network

(II) Areal aspect of drainage basin

(III) Relief aspect of channel network and contributing ground slopes

❖ **Linear Aspects of Drainage Networks:**

The linear aspects include the measurement of linear aspects of drainage such as stream order (N_u), bifurcation ratio (R_b), stream length (L_u), length of overland flow and drainage pattern.

❖ **Areal Aspects of Drainage Networks:**

Area of a basin (A) and perimeter (P) are the important parameters in quantitative morphology. The area of the basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all order of basins. Perimeter is the length of the boundary of the basin which can be drawn from topographical maps.The aerial aspects of the drainage basin such as drainage density (D_d), stream frequency (F_s), elongation ratio (R_e), circularity ratio (R_c) and form factor ratio (R_f)

❖ **Relief Aspects of Drainage Networks:**

Relief aspects of drainage basin relate to the three-dimensional features of the basin involving area, volume and altitude of vertical dimension of landforms. Relief is the elevation difference between the highest and lowest point on the valley floor of the region. Relief aspects is an indicator of flow direction of water as it is an important factor in understanding the extent of denudational process that have undergone within the catchment. Relief Aspects are, Relief (H), Relief ratio (Rn), Relative relief (Rr), Ruggedness number (H_D).Morphometric parameters are shown Table 1.0a

3.2 Geomorphological Instantaneous Unit Hydrograph

❖ **Unit Hydrograph Development:**

The unit hydrograph approach was used only with simple storm event, in which the storm hydrograph had a smooth shape. The 1- hour unit hydrograph were computed by multiplying each ordinate of the direct runoff hydrograph by the reciprocal of the depth of rainfall excess for each event. Depth of rainfall excess was used as proportionality constant to convert the direct runoff hydrograph to a unit hydrograph.

❖ **Instantaneous Unit Hydrograph (IUH):**

An Instantaneous Unit Hydrograph (IUH) is a conceptual unit hydrograph representing the direct runoff hydrograph resulting from an instantaneous precipitation of one cm effective rainfall of infinite similarly small duration in the watershed. It is a single peak with finite base width.

The relationships developed by them are,

$qp=i\times v$……………………………..….. (1)

$tp=k/v$…………………………………...(2)

Where i and k depend on the geomorphological parameters R_b, R_L, R_A and $L_w$as given by the following equations and derived by Rodriguez-Iturbe and Valdes (1979) using regression analysis.

3.3 Derivation of Nash model parameters

Nash (1957) proposed a conceptual model in which catchment impulse response can be represented as the outflow obtained from routing the unit volume of the instantaneous excess rainfall input through a series of n successive linear reservoirs having equal delay time.

The equation for the Nash IUH model is given as

$$U(0,t)=\frac{1}{K}\cdot\frac{1}{\Gamma(n)}\cdot e^{(-t/k)}\cdot(t/K)^{n-1}$$ ………. (3)

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,

$$t_p = 0.44\left(\frac{L_\Omega}{V}\right)\left(\frac{R_B}{R_A}\right)^{0.55} R_L{}^{-0.38}$$ ……………. (4)

$$q_p = 1.31 R_L{}^{0.43}\left(\frac{V}{L_\Omega}\right)$$ ………… (5)

Where,

q_p =Peak discharge, hour-1, R_L= Stream length ratio V = Dynamic velocity parameter, m/s

t_p = Peak time, hour-1 Ω = stream order of the catchment, L_Ω= length of highest order stream, km R_b = Bifurcation ratio, R_A = Stream area ratio

The assumption for shape of IUH with increasing q_p and decreasing t_p was verified with available data. Multiplication of equation (4) and (5) 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 was asfollows.

$$q_p . t_p = 0.5764 . R_B^{0.55} R_A^{-0.55} R_L^{0.05}$$ …. (6)

On the other hand, the derivative of equation (3) gives the time to peak as follows

t_p= (n-1) k …………….......... (7)

Substituting this equation (7) of in equation (3) the peak discharge q_p of the IUH was obtained as

$$q_p = \frac{(n-1)^{n-1}}{K\times\Gamma(n)}\times e^{-(n-1)}$$ ……….. (8)

The product of equation (7) and equation (8) gave equation for Nash model in terms of n Thus,

$$q_p \times t_p = \frac{(n-1)^n}{\Gamma(n)} \times e^{-(n-1)} \quad \text{...... (9)}$$

Equating the equation (6) and equation (9), the following relationship was arrived

$$\frac{(n-1)}{\Gamma(n)}.e^{-(n-1)}.(n-1)^{n-1} = 0.5764.R_B^{0.55}.R_A^{-0.55}.R_L^{0.05} \quad \text{...... (10)}$$

Using the Newton Raphson Method for non-linear optimization for equation (10), The IUH parameter Nash model n was obtained (Karegoudar A. V. et. al., 2013 and Ashwini N. et.al.,2014).

The Nash model parameter k for the given velocity (V) was obtained using equation (5) and equation (7) and the value of the parameter k is as follows;

$$K = \frac{t_p}{n-1} = \frac{0.44}{v} L_w.R_B^{0.55}.R_A^{-0.55}.R_L^{-0.38}.\frac{1}{n-1} \quad \text{.... (11)}$$

The derived values of n and k were used to determine the complete shape of the Nash based GIUH from equation (10) and equation (11). In this methodology the proper estimate of velocity (V) which is dynamic parameter was also needed while calculating the value of k.

3.4 Estimation of Nash Model Parameters for GIUH:

- **Estimation of n parameter by Newton-Raphson method:**

The estimation of Nash model parameter n is determining using equation (10) and Use of Newton-Raphson method of non-linear optimization was made to solve the equation (10).

In this equation all the right-hand side parameters values are known and by substituting their obtained value we estimate the n value.

$$f = \frac{(n-1)}{\Gamma n} \exp[-(n-1)^{n-1}] 0.5764 \left[\frac{Rb}{Ra}\right]^{0.55} [Rl]^{\wedge} \quad 0.05$$

.... (i)

The first derivative of *f* with respective n can be expressed as follows:

$$f' = \frac{1}{\Gamma n}\exp[-n+1]\,(n-1)^{n-1} - \frac{1}{\Gamma n}\exp[-n+1]\,(n-1)^{n-1} \times \psi(n) - \frac{(n-1)}{\Gamma n}\exp[-n+1]\,(n-1)^{n-1} + \frac{(n-1)}{\Gamma n}\exp[-n+1]\,(n-1)^{n-1} \times \{\ln(n-1)+1\}$$

.... (ii)

The optimization algorithm for Newton –Raphson Method is expressed as follows:

n _new = n_old-[*f*(n_old) /*f'*(n_old)] .... (iii)

The optimization terminated when the following condition is achieved.

(n _new - n_old) ≤0.01

The above values substituting in the equation (v) and from this n new value is obtained. This is a Nash model parameter n =3.93 value.

Calculation of n value:

If n=4 and substituting the values of Horton's morphometric ratio. Then, from equation (i) gives the value *f* = 0.283 and equation (ii) gives the value *f'*=4.008.

Estimation of Nash model parameter K values:

From the geomorphological parameters (q_p and t_p) and velocity (v) as estimated in the preceding, parameters of the Nash model k are determined using (11).

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4. RESULTS AND DISCUSSION

4.1 Delineation of the Watershed

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. To extract the geomorphologic features of the basin, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Digital Elevation Model (DEM) data of 30m×30m resolution was used is Shown in Fig.2. Watershed delineation was performed in ArcGIS 10.1

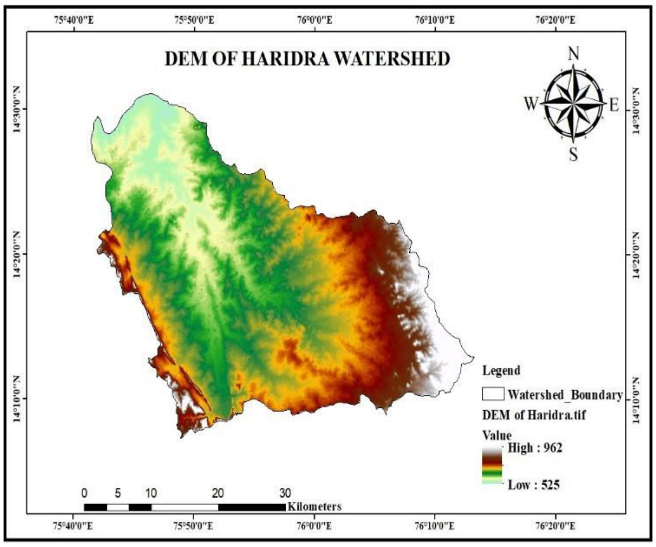

Fig.2. SRTM DEM

Slope Map: The topographic characteristics of area have its own importance in affecting the runoff, recharge and movement of surface water. Slope is one of the important parameters for developmental activities. The slope map of the study area was developed from the Digital Elevation Model (DEM) acquired for watershed delineation is shown in Fig.3.

Stream order and Drainage Map: Stream order map of the study area was extracted using the DEM. SOI Toposheets of the study were used for validation of stream order map prepared using DEM. The Strahler's stream ordering system was adopted for stream ordering (Singh, 1992). Drainage map of watershed is shown in Fig.4.

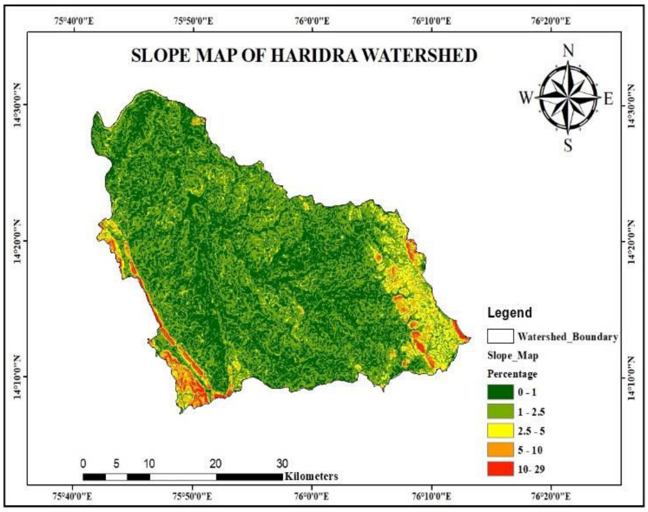

Fig.3. Slope Map of Watershed

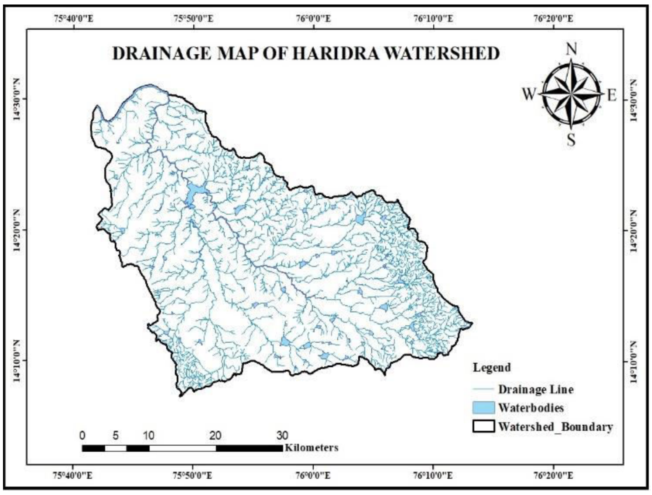

Fig.4. DrainageMap of Watershed

For calculation of geomorphological parameters following two methods has been adopted:

- **Arithmetic average method:** Geomorphological parameters R_b, R_L, and R_A were calculated for consecutive order channels using Horton's laws.R_b, R_L, and R_A for the whole basin were obtained by averaging the preceding values.

- **Graphical method**: After plotting the values of Nw, Lw and Aw in a logarithmic scale verses the order of the channel on a linear scale, a visual fit was performed in each one of the plots.

Stream order	Stream Count	Total Length (km)	Avg. length (km)	Total Area (km^2)	Avg. Area (km^2)	Bifurcation ratio (R_B)	stream length ratio (R_L)	stream area ratio (R_A)
1	853	727.433	0.853	703.937	0.825	4.988	0	0
2	171	396.854	2.321	1061.378	6.207	4.622	0.546	1.508
3	37	229.022	6.190	1240.712	33.533	3.700	0.577	1.169
4	10	88.950	8.895	1318.748	131.875	5.000	0.388	1.063
5	2	66.360	33.180	1392.114	696.057	2.000	0.746	1.056
6	1	19.650	19.650	1416.440	1416.44	0.000	0.296	1.017

Table 1.0a Results obtained by morphometric analysis

Table 1.0b Results obtained by morphometric analysis.

Sl. No	**Morphometric parameters**	**Formulae**	**Result (range)**	**Remarks**
		Drainage Network		
1	Stream Order (S_u)	Hierarchical rank	1-6	-
2	Stream number (N_u)	$N_u = N_1 + N_2 + N_3 + --- + N_n$	1108	-
3	Stream length (L_u) km	$L_u = L_1 + L_2 + L_3 + ---- + L_n$	1052.50	-
4	Stream length ratio (L_{ur})	$L_{ur} = L_u / L_{u-1}$	0.16-6.39	-
5	Mean stream length ratio (L_{urm})	$\sum L_{ur}$	2.553	-
6	Mean bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$	2.00 - 4.988	<5 , hence structurally controlled
7	Main channel length (L_Ω) km	Using ARCGIS Software	83.334	-
8	Equivalent stream slope (Se) m/km	$Se = (\sum Li\ (Di\text{-}1+Di))/L_\Omega^2$	0.157	-
		Basin Geometry		
9	Basin length (L_b) km	Using ARCGIS Software	56.5	
10	Basin area (A) km	Using ARCGIS Software	1416.44	-
12	Shape factor (S_f)	$S_f = L_b^2 / A$	2.25	> 0.9, hence circular in shape
13	Form ratio (F_f)	$F_f = A / L_b^2$	0.443	
14	Elongation ratio (R_e)	$R_e = 2/L_b * (A/\pi)^{0.5}$	0.752	Circular and less elongated
15	Circularity ratio (R_c)	$R_c = 4\pi A/P^2$	0.365	Circular catchment, more and uniform infiltration

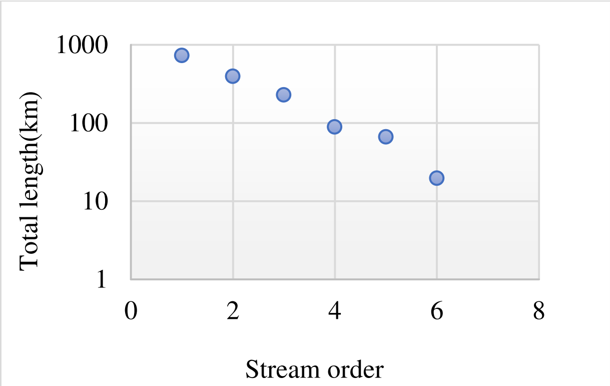

Fig.5. Stream order v/s Number of streams

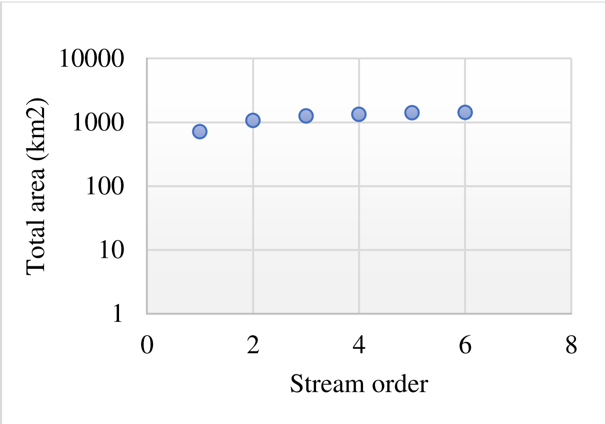

Fig.6. Stream order v/s Total length(km)

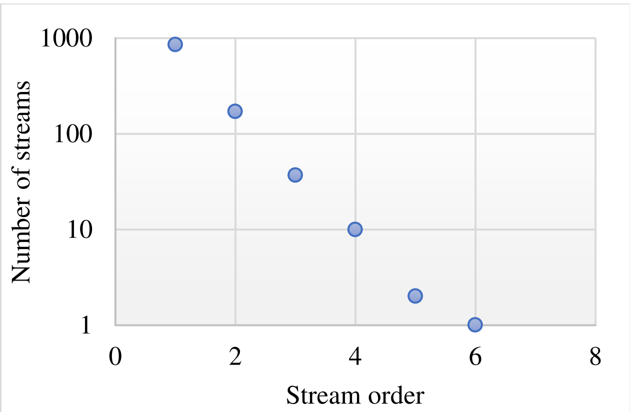

Fig.7. Stream order v/s Total area (km^2)

- The values obtained by arithmetic average method are considered in the analysis. The values of R_b, R_L, and R_A found from arithmetic average method are 3.385, 0.426 and 1.05 respectively. As shown in Fig.5, Fig.6, Fig.8.

Estimated of Ordinates of GIUH of Haridra river at different velocities:

The Nash model parameters n, k and t (hrs) values are substituting in below equation then we get the discharge in m^3/s with respective time in hrs.The GIUHs of Haridra River at different velocities as shown in Fig.8.

Watershed	Nash parameter "n"	Nash parameter "k" at different velocity "V"		
		V =1.0 m/s	V=1.5 m/s	V=2.0 m/s
Haridra	3.93	1.978	1.318	0.989

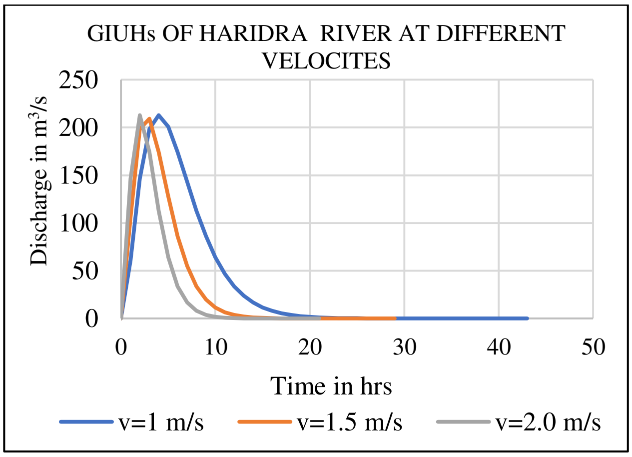

Fig.8. GIUH of Haridra river at different velocities

5. CONCLUSIONS

The morphological parameters like stream order, stream length, area perimeter, basin length, bifurcation ratio, circulatory ratio, elongation ratio, relief ratio, relative relief, basin shape factor, ruggedness number, average slope of the watershed and length of overland flow of the watershed etc. can be extracted using various thematic maps of the watershed and by the standard procedure.

Using the values of Nash parameters n (the number of linear reservoirs) and k (catchment storage coefficient) derived from geo-morphological parameters, the complete shape of IUH can be estimated.

Thus, GIUH technique is applicable for the estimation of the direct runoff component of the stream flow using the Nash model and hence, can be used to generate the direct runoff hydrograph (DRH). Once the DRH is computed, the flood hydrograph can be simply obtained by adding the base flow component.

It is the fact that most of the Indian as well as the watersheds of developing countries do not have enough historical records and detailed watershed information needed for physically based distributed models.

In these cases, GIUH can provide a better solution for flood management programs. The technique of GIUH based Nash model is very useful in prediction/forecast of the temporal variation of the surface runoff at the outlet of the ungauged basin, which is useful in the hydrologic/environmentalengineeringapplications.

The described technique is cost effective and quite accurate for determining the flood hydrograph for any basin /catchment (gauged or ungauged) as it requires DEM of the catchment that can be freely obtained from SRTM or ASTER source.

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