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A REVIEW STUDY OF DIFFERENT METHODS OF SYNTHETIC UNIT HYDROGRAPH

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Abstract: In this review paper, we have studied different methods of SUH which can be used for the ungauged catchments for this we have studied few traditional methods i.e. Snyder method, Taylor and Schwarz model, Soil Conservation Service method. Geomorphological models in which we have studied GIUH model, Width Function Based GIUH model, GIUH Based 2PGD Nash model. We studied probability distribution function- based SUH method i.e. Transmutation method. We have also studied the traditional method from Akshay Thorvat research paper. During our study, we found that calculation by using of Traditional methods gives us the same results as we can expect from other methods.
Traditional methods can be used by the students for their calculation purpose which can give same results same as by other methods. The other methods need study of conceptual models as well as need of the study of GIS Software for the GIUH model study which is not needed for the traditional methods if the topographic features which required for the catchment area are known to the hydrologist.

***Index Terms* - Synthetic unit hydrograph, Ungauged basin, Unit hydrograph, Peak discharge, Time to peak.**

I. Introduction

Water is the basic requirements of all life on Earth. The origin of life has been caused due to water along with other basic elements water the source of life is passionate. To passionate to manage excess of, it leads to flood and lack of its results in drought and famine. So the Rainfall- runoff should be properly managed to avoid those conditions.

Rainfall and runoff calculation is very important for planning and designing of any water structure or water management. The rainfall and runoff data are sometimes not adequate for planning and designing of water structure or for water management. The use of unit hydrograph is used for calculating or estimating the rainfall-runoff and is widely accepted tool for calculating rainfall-runoff of at the gauged stations. This is one of the first tool which was used for determining the rainfall-runoff of the area with gauged station. As the unit hydrograph needs the observed rainfall runoff data from the gauging station for plotting the hydrograph. It is essential to study the concept of Synthetic unit hydrograph (SUH) for the area where the gauging station are not available. The Synthetic unit hydrograph methods are used to determine the rainfall and runoff data for the ungauged area. So the basic study of the different methods of SUH is been done in this review paper.

II. Study of Different Methods of SUH

We have studied different methods for calculating the discharge and runoff by referring various reference books, research papers, guidance of our professor. Following are various methods:

1. Traditional Methods of SUH

1.1 Soil Conservation Service Method

The SCS (1957) method of the US Department of Agriculture (USDA), developed by Victor Mockus, synthesizes the UH using a specific average dimensionless UH derived from the analysis of a large number of natural UHs for watersheds of varying size and geographic location. To enable definition of the time base (t_b) in terms of time to peak (t_p) and time to recession (t_{rc}) the SCS method represents the dimensionless UH as a triangular UH, which further facilitates the computation of the runoff volume (V) and peak discharge(q_p) as:

$$V = 0.5(q_p t_b) = 0.5 q_p (t_p + t_{rc})$$

$$t_{rc} = 1.67 \times t_p$$

$$q_p = 0.749 \left(\frac{V}{t_p}\right)$$

where,q_p is in mm h^{-1} mm^{-1}; V is in mm; t_p and t_{rc} are in hours. To determine the complete shape of the SUH from the non-dimensional (q/q_p versus t/t_p) hydrograph, the time to peak is computed as:

$$t_p = t_L + t_r/2$$

where,t_L is lag time (h) from the centroid of rainfall- excess to peak discharge (q) and t is the excess rainfall duration (unit duration) (h). The lag time (t_L) can be estimated from the watershed characteristics using the curve number (CN) procedure as

$$t_L = \frac{L^{0.8}(2540-22.86CN)^{0.7}}{14104CN^{0.7}Y^{0.5}}$$

where, L is the length of the main stream or hydraulic length of the watershed (m) CN is the CN (50 ≤ 95) and Y is the average catchment slope in (m/m).Alternatively, equation can be expressed as:

$$Q_P = 2.08 \left(\frac{A_w}{t_p}\right)$$

where, $Q_P$is peak discharge in m^3 s^{-1} cm^{-1} of rainfall - excess, and$A_w$is watershed area in km^2. Thus with known q_p, t_p and a specified dimensionless UH, the SUH can be easily derived.

1.2. Taylor and Schwarz Model

The Taylor and Schwartz (TS) model was proposed by Taylor and Schwarz (1952) for SUH derivation using the data of 20 watersheds having drainage areas varying from 20 to 1600 mi^2 (52–4144 km^2). While deriving the SUH, the model specially considers the average slope of the main channel of the watershed and the other watershed characteristics, i.e. A_w, $L$and L_c similar to those in Snyder's method. The average slope of the main channel can be calculated by:

$$S_C = \left(N \Big/ \sum_{I=1}^{N} (1/Si)^{0.5}\right)^2$$

where, S_C is the average slope of the main channel, S_i is the slope of the i th reach of the main channel and N is the total number of reaches. The empirical equations relating the UH characteristics to watershed characteristics are expressed as:

$$t_p = [0.6/{S_C}^{0.5}]e^{(m_1 D)}$$

$$Q_P = [382/(L\,L_C)^{0.36}]e^{(m_2 D)}$$

$$t_b = 5[t_p + t_r/2]$$

$$m_1 = 0.212(L\,L_c)$$

$$m_2 = 0.121{S_c}^{0.142} - 0.05 - m_1$$

where, D is rainfall duration, and t_p,L, L_c, t_b, t_r are the same as in Snyder's method. However, the peak discharge rate (Q_P) is expressed in units of ft^3 s^{-1} mi^{-2}. Similar to Snyder's method, the TS model also estimates W_{50} and W_{75} using the equations pro- posed by USACE (1940) for smooth sketching of the SUH. From equation,$t_b$appears to be lose to five time t_p. However, the basic in consistencies associated with the TS model remain the same as with Snyder's method.

1.3. Snyder Method

Snyder (1938) was perhaps the first to establish a set of empirical relations among watershed characteristics, such as area (A_w) (km^2); length of main stream (L) (km); and the distance from the watershed outlet to a point on the main stream nearest to the centre of the area of the watershed (L_C) (km) and the three basic parameters of the UH i.e. the lag or peak time (t_p) (h), the peak discharge (Q_P) (m^3/s), and the base time (t_b) (day), to describe the shape of the UH. These relationship can be expressed as:

$$t_p = C_t (L L_C)^{0.3}$$

$$Q_P = 2.78 \left(\frac{A_W C_P}{t_p}\right)$$

$$t_b = 3 + 3\left(\frac{t_p}{24}\right)$$

where, C_t and C_P are non-dimensional constants. The t_p and Q_P were obtained from the study of catchments varyingin size from 10 to 10000 square miles (26 – 25900 km^2) in the USA. Snyder (1938) found C_t to vary from 1.8 to 2.2 and C_P from 0.56 to 0.69. More recently, Das (2009) reported C_t and C_P as 0.65 and 0.94, respectively, for the Ramganga catchment in the Himalayan range, India Rainfall-excess duration (or unit duration) is given by,

$$t_R = \frac{t_p}{5.5}$$

however, if the duration of rainfall-excess, say t_{R1}, differs from the above defined duration (t_R), a modified lag time (t_{MP})is determined as:

$$t_{MP} = t_p + (t_{R1} - t_R)/4$$

One can sketch any number of UHs through the three known characteristic points of the UH, i.e. Q_P, $t_p$and t_b with its specific criteria, i.e. that the area under the SUH be unity. To overcome this ambiguity associated with Snyder's method, the US Army Corps of Engineers (USACE 1940) proposed empirical relations between widths of the UH at 50% (W_{50}) and 75% (W_{75}) of Q_P as a function of $Q_P/A_W = q_p$ expressed as:

$$W_{50} = 830/q_p^{1.1}$$

And

$$W_{75} = 470/q_p^{1.1}$$

The units of W_{50} and W_{75} are hours. Thus, one can draw a smooth curve through the seven points (Q_P, t_p,t_b, W_{50} and W_{75}) relatively more easily with less degree of ambiguity, and can keep the area under the SUH as unity. However, in practical applications, this procedure is very tedious and involves a great degree of subjectivity and error due to the manual fitting of the points and simultaneous adjustments for the SUH area.

2. GIUH Based Methods of SUH

2.1 The GIUH Model

Rodríguez-Iturbe and Valdés (1979)expressed the initial state probability of one droplet of rainfall in terms of geomorphological parameters as well as the transition state probability matrix. The final probability density function (pdf) of droplets leaving the highest-order stream into the trapping state is nothing but the GIUH. An exponential holding time mechanism, equivalent to that of an LR was assumed in its conceptualization, as discussed here.

Let $f_{Ts,i}(t)$ be an exponential pdf of travel time $T_{s,I}$ which is a subset of T_s, the part of the travel time of the specific paths through Strahler state *i* within the catchment, and *P*(*s*) the probability that a water droplet will follow that specific path. The latter depends upon the product of the probability that a droplet will originate from a segment draining to a stream of a particular order, and the transition probabilities of moving between different orders of streams within the network. Thus, $f_{Ts,i}(t)$ is expressed as:

$$f_{Ts,i\,(t)} = K_{s,i}\, exp(-K_{s,i}t)$$

where $K_{s,i}{}^{-1}$ is the mean travel time in channels of order*i*of the path s. The convolution of $f_{Ts,i\,(t)}$ for I = (1; Ω)givesf_{Ts}which can be used to complete *q*(t) as follows:

$$q(t) = \sum_{All\ paths\ s} f_{Ts,i(t)} . P(s)$$

Thus, for a catchment of order Ω, according to the Strahler ordering scheme of drainage net- works, the Rodríguez-Iturbe and Valdés (1979) formulation of the IUH takes the form:

$$q(t) = (a\Omega t + b\Omega)\ exp\ (-2VL^{-1}t) + \sum_{i=1}^{\Omega-1} bi\ exp(-2vL^{-1}tR_L{}^{\Omega-1})$$

where *q*(*t*) is the geomorphological IUH or GIUH [T^{-1}]; a_Ω and b_Ω are functions of R_A, R_B, R_L, λ_Ω, λ_*[T^{-2}]; *v* is the mean stream flow velocity or characteristic velocity [L T^{-1}]; *L* is the mean length of the highest-order stream or length of the main stream [L]; b_i is a function of R_A, R_B, R_L, λ_i [T^{-1}]; λ_i is the inverse mean waiting time in the *i* th-order stream equal to vL^{-1}[T^{-1}]; λ_m is the modified higher-order inverse mean waiting time [T^{-1}]; and L_i is the mean length of the *i*th-order stream[L].

The expression derived by Rodríguez-Iturbe and Valdés (1979) yields full analytical, but complicated expressions for the IUH. Therefore, they suggested that it is adequate to assume a triangular IUH and only specify the expressions for the time to peak (t_p) and peak value (q_p) of the IUH.These expressions were obtained by regression of t_p as well as q_p of IUH derived from the analytic solutions for a wide range of parameters with those of the geomorphological characteristics and flow velocities. The model was parameterized in terms of Horton's order laws of drainage network composition and Strahler stream ordering scheme. The expressions for peak flow (q_p), time to peak (t_p) and time to base (t_B) of the IUH are given as:

$$q_P = \left(\frac{1.31}{L}\right) R_L{}^{0.43} v$$

$$t_p = 0.44\left(\frac{L}{v}\right) R_B{}^{0.55} R_A{}^{-0.55} R_L{}^{-0.38}$$

$$t_p = 2/q_p$$

where, *L* is the length of main channel or length of highest-order stream in km, *v* is the average peak flow velocity or characteristic velocity in m/s; q_p and t_p are in units of h^{-1} and h, respectively. Note that equations of q_P and $t_p$are based on regression withlimiteddeterminismandglobalproperties.

Regarding the geomorphological basis itself for UH identification, Rodríguez-Iturbe and Valdés (1979) formulated the geomorphological IUH (GIUH) trying to reach universality "with the conviction that the search for a theoretical coupling of quantitative geomorphology and hydrology is an area which will provide some of the most exciting and basic developments of hydrology *in the future*". The roots can be traced back to Horton (1945) who originated the quantitative study of channel networks and developed a system for ordering stream networks and derived laws relating the stream numbers (*N*), stream lengths (*L*) and catchment area (*A*) associated with streams of different order. The quantitative expressions of Horton's laws are:

Law of stream number : $N_W/N_{W+1} = R_B$

Law of stream length : $\bar{L}_W/\bar{L}_{W-1} = R_L$

Law of stream areas: $\bar{A}_W/\bar{A}_{W-1} = R_A$

where N_w is the number of streams of the order w, L_w is the mean length of stream of order w and A_w is the mean area of basin of order w. R_B, R_L and R_A represent the bifurcation ratio, length ratio and area ratio, respectively, whose values in nature are normally between 3 and 5 for R_B, between 1.5 and 3.5 for R_L and between 3 and 6 for R_A.

Further, Rodríguez-Iturbe and Valdés (1979) defined a non-dimensional term β (shape factor) as the product of q_p and t_p :

$$\beta = 0.584 \left(\frac{R_B}{R_A}\right)^{0.55} R_L^{\,0.05}$$

In above equation, β is independent of the characteristic velocity v and length of highest-order stream or scale variable L, i.e. the storm characteristics, and hence is a function of only the catchment characteristics. If one of the IUH parameters q_p or $t_p$is known, say from observed records or some regional IUH analysis, the terms vL^{-1} and $v^{-1}L$ in the right-hand side of equations of q_P and t_p respectively, can be computed from the geomorphological data of the catchment. And, on substituting the values of vL^{-1} and $v^{-1}L$, the other IUH parameter (q_p or t_p) can be obtained. Thus, with q_p and t_p known, a suitable two-parameter pdf can be used to describe the complete shape of the UH. Thus, the GIUH provided a scientific basis for the hydrograph fitting and yielded a smooth and single-valued shape corresponding to unit runoff volume.

2.2 GIUH-based 2PGD Nash model

The possibility of preserving the form of the SUH through a two-parameter gamma pdf was analyzed by Rosso (1984), and Nash model parameters were related to Horton's order ratios using equation of (β). For this, the problem was approached by equating the dimensionless products (β) of the peak (q_p) and time to peak (t_p) resulting from the two formulations, i.e. equations of (β) and also equations of (β) from Transmutation method. Rosso used an iterative computing scheme and proposed the following equations for n and K:

$$n = 3.29(R_B/R_A)^{0.78} R_L^{\,0.07}$$

$$K_* = 0.70\,[R_A/(R_B R_L)]^{0.48}$$

where $K_* = KvL^{-1}$ is a dimensionless scale parameter. Thus, for an observed v, the parameters of 2GPD and the shape of UH can be computed from the geomorphological parameters of the catchment. It seems that under the same framework, a similar approach can also be applied to other suitable probability distribution functions for development of SUH models from ungauged catchments. Jin (1992) developed a GUH based on a gamma distribution and suggested a way to parameterize the distribution based on path types and a stream flow velocity. In Jin's GUH, the initial estimate of velocity is based on a peak observed discharge for a basin, thus some kind of stream flow record would be required.

2.3 Width function-based GIUH model

One of the most important hydrological characterizations of geomorphology can be represented by the geomorphological width function $W(x)$, defined as the probability measure obtained by dividing the number of links at a given distance x from the outlet by the total number of links in the network, x being the distance to the outlet of the i th link measured along the network and normalized by the maximum path distance along the streams from source to outlet (Rinaldo and Rodriguez-Iturbe1996). The width function $W(x)$ provides a good first step in quantifying the influence of the network geometry on the runoff response of a basin. The form of the width function also reflects the shape of the GIUH.

From the mathematical standpoint, the width function $W(x)$ can be represented as:

$$W(x) = \sum_{i=1}^{n} b(x; x_i^{\,u}, x_i^{\,d})$$

where n is the number of links in the network, $x_i^{\,u}$ and $x_i^{\,d}$ the distances of the upstream and downstream ends of link i from the outlet, and the function $b(x)$ is denoted as follows:

$$b(x; x_i^{\,u}, x_i^{\,d}) = \begin{Bmatrix} 1, x_i^{\,d} \le x < x_i^{\,u} \\ 0, otherwise \end{Bmatrix}$$

As discussed above, to compare the width functions of different networks, it is convenient to put $W(x)$ in the normalized form as:

$$w(\bar{x}) = \frac{W(\bar{x}L)}{l} L$$

where $x = l/L$, L is the length of the longest flow path and l is the total network length. Using the $W(x)$ approach, different formulations of GIUH.

3. Traditional Method Of Synthetic Hydrograph By Akshay Thorvat

3.1 Snyder's Method

Snyder(1938)was the first to develop empirical formulas to derive SUH for a catchment area with inadequate data by using the catchment characteristics of the basin (Subramanya2008).

$$t_p = C_t(L.L_C)^n$$

$$Q_p = 640C_pA/t_p$$
$$T_B = 5\,[(t_p/11)+t_p]$$

$$W_{50} = 2.14(q_p)^{-1.08}$$

$$W_{75} = 1.22(q_p)^{-1.08}$$

where, time of lag to peak is $t_{p(\text{hours})}$, the regional constant of storage effects and watershed slope is C_t, the length of the main channel is L (kilometers), the length between the outlet and centroid of the watershed is L_{c1} (kilometers),the superscript "n" refers to the basin constant used in the calculation of the basin lag t_p (in Snyder's method, the value of n is taken as 0.3), the peak discharge of a UH is Q_p (cubic meters per second), C_p is an indication of the retention and storage capacity of the watershed, A (square kilometers) is the drainage area, T_B(hours) is the base period, W_{50} and W_{75} (hours) are the widths at50 and 75%, respectively, of peak discharge of an SUH, and q_p (cubic meters per second per square kilometer) is the peak discharge per unit catchment area (Subramanya 2008).

3.2 Soil Conservation Service Method.

The land use, soil type, and hydrological and antecedent moisture conditions are utilized by SCS method of the catchment to estimate Q_p and T_p; from that the SUH shape is determined from an average dimensionless hydrograph, to avoid manual fitting (Bhunya et. al. 2009).The SCS dimensionless UH is assumed to be invariant (regardless of catchment shape, size, and location), although such an assumption may not be justified. A peak rate factor of 484 (McCuen & Bondelid 1983) is used to apply SCS method. Following formula gives relation of Q_p and T_p

$$Q_p = 484AV_q/T_p$$

where, A is drainage area of the basin (Km^2), V_q is runoff volume (m^3) distributed uniformly over the drainage basin.

4. Probability Distribution Function Based Methods of SUH

4.1 Transmutation Approach

Singh (2000) transmuted the traditional methods of SUH, e.g. Snyder, SCS, and the Gray method into a gamma distribution in a very lucid and simplified manner. The approach gives a smooth-shaped SUH and the area under it is guaranteed to be unity. Specifically, the possible unified conceptual interpretation of the popular SUHs in line with the conceptual models of IUH was presented. Assuming that the following equation represents a UH of unit duration,

$$q(t) = \frac{1}{K\Gamma(n)}\left(\frac{t}{K}\right)^{n-1} e^{-\frac{t}{K}}$$

the condition at the peak (t = tp) dq(t)/dt, yields:

$$K = tp/(n-1)$$

Using above two equations, a simple analytical expression relating the number of LRs n and a dimensionless term β was developed as:

$$\beta = \frac{(n-1)^{(n-1)}e^{-(n-1)}}{\Gamma(n-1)}$$

where, β is a product of peak flow rate q_p and time to peak flow rate t_p. The parameter β is also known as the *shape factor* and has generally been observed to vary between 0.35 and 1.25. Its value is greater for steep and fast-responding catchments and is less for slow-responding catchments in flat regions. Inversion of above equation gives the value of n for a known value of β.

Substituting the approximate expression for the gamma function in above equation, the following simple analytical equation for inverting equation of above was obtained as:

$$n = 7/6 + 2\pi\beta^2$$

the above equation can be used to calculate β, if n is known from other sources. It was found that above equation gives slightly higher values of n than its true value and the percentage error in n decreases with an increase in the value of β.

III. Conclusion

In this study of review paper we got to know about the different methods of SIU, there use and limitations. Each method can be classified as 1) Traditional methods 2) GIUH models 3) Traditional method of synthetic hydrograph by Akshay Thorvat 4) Probability distribution function based SIUH method. These different methods require different parameters for calculation. So, the results may vary a bit during the calculation by using these methods. The traditional methods formulae are easy to understand but requires large mathematical calculations. Where as other methods are made simplified by using the relation among the traditional methods. The GIUH model method need study of GIS software and its parameters may vary according to the resolution of the DEM used for calculating the parameters.

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