"Prediction of Runoff in Ungauged Basin Using CWC Method"

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Abstract— Drainage basins in the most parts of world are either partly gauged or fully ungauged. Prediction in ungauged basins is a serious challenge in hydrologic sciences, and there is still abundant work needed to appreciate sturdy and reliable predictions for such basins. Errors in the prediction of hydrological parameters are seen because of inaccessibility of sufficient discharge information. Geomorphologic instant unit hydrograph (GIUH) method will be used as a transfer function for modelling the rainfall – runoff development. The current study delivers an effective approach which deals with the geomorphologic structures of the ungauged drainage basin and derives the GIUH based transfer function and consequently geomorphologic unit hydrograph (GUH) for the study area. For this research work Sub-basin of Kundalika River has been taken as the study area. To validate the derived GUH of the Kundalika River basin, a comparison was executed with the synthetic unit hydrograph (SUH) attained using the Central Water Commission (CWC) procedure. After modeling we developed the unit hydrograph of basin and we predict the discharge of basin.

Keywords: Ungauged basin, IUH, SRTM DEM, Central Water Commission (CWC)

I. INTRODUCTION

Hydrological modeling is a technique of hydrologic system investigation for both the research hydrologists and practicing water resources engineer involved in the planning and development of an integrated approach for management of water resources. Hydrologic models are a symbolic or mathematical representation of known or assumed functions expressing various components of the hydrologic cycle. The term hydrological model is often misunderstood to be only as a computer-based mathematical model. The main function of these models are a hydrologic prediction and to understand various hydrologic processes.

Hydrologic models for ungauged basins try to simulate the catchment behavior by solving the equations that govern the physical processes occurring within the catchment. Therefore hydrologic models are usually used to simulate the catchment response for a given input. The hydrologic models take time series data and produce another time series as output. The importance of hydrological modeling in a catchment is

– To understand the spatial rainfall distribution over the catchment.
– To get information about catchment characteristics such as slope, soil type, land use, underlying geology, etc.
– Surface-groundwater interactions, water allocation, wetlands modeling, etc. can be better understood through hydrological modeling.
– Accurate streamflow forecasts are an important component of watershed planning and sustainable water resource management.

One of the most frequently used events in hydrology is the relation between rainfall and runoff. It determines the runoff signal which leaves the watershed from the rainfall signal received by the basin. In it, a part of the hydrological cycle has been studied to express the runoff from the catchment as a function of the rainfall and other catchment characteristics. It helps to extend stream flow time series both spatially and temporally to estimate management strategies and catchment response to climate.

There are various popular flood hydrograph modeling techniques for ungauged basins, like the synthetic unit hydrograph (SUH). The SUH models are grouped into four main classes, as follows: (a) conceptual models (b) traditional or empirical models (c) probabilistic models (d) geomorphologic models. The unit hydrograph (UH) theory is a potentially powerful tool in watershed hydrology similar to the unit-impulse response function in fields such as electrical, electronics and telecommunication or and structural engineering.

A. *Objectives of Study:-*

As mentioned above, hydrological modeling in any catchment; gauged, partially gauged or ungauged helps to understand the catchment features and its responses. The specific objectives of the present study are:

1) DEM processing by using ArcGIS
2) Extracting the geomorphological characteristics of the study area.
3) Development of SUH by CWC method, and GIUH using Nash based GIUH model

II. STUDY AREA

River Kundalika is a small river which originates at longitude $73^0 24'$E and latitude $18^0 31'$N near a small village Hirdewadi, Tal. Mulshi, Dis. Pune. It originates at hills of Sahyadri mountain and flows to the Arabian Sea. The length of the river is 83.97 Km. and catchment area of the river is 786.5 Km^2. Maximum elevation above means sea level is 1140m. There are five rain gauge stations Bira, Sudhagad, Roha, Sulkodi, and Alibaug.

Up to 90% of Kundalika river water is consumed by the industries. There for the hydrological study of the river catchment is important.

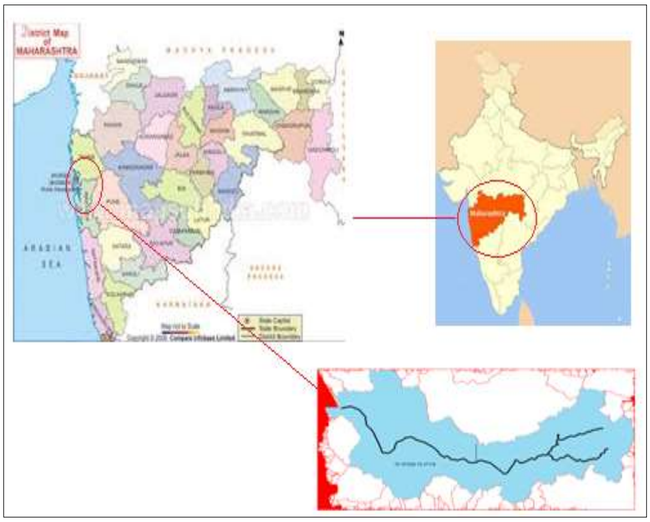

Fig. 2.1: Location of the study area.

A. Problem statement:

Comparison of runoff calculation from Nash based GIUH with traditional methods for calculate accurate discharge to solve various problems in practical applications like design of drainage structure and flood defenses, runoff forecasting and for catchment management tasks such as water allotment and climate impact analysis.

III. Methodology

The following methodology is followed for development, comparison of GIUH and GUH. By using this methodology, the discharge of the river is calculated.

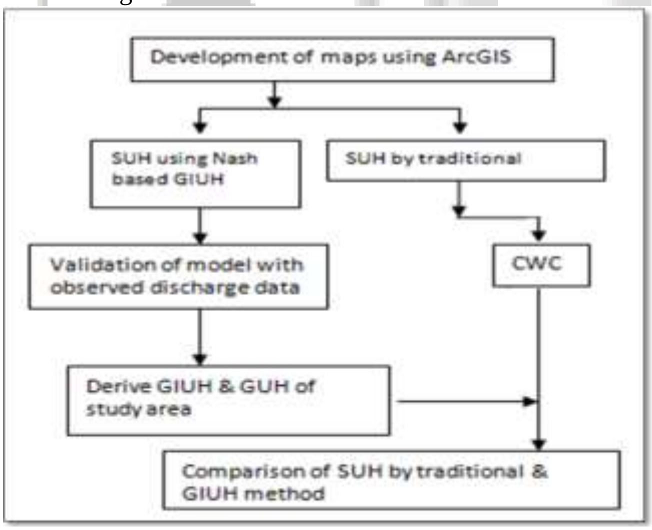

Fig. 3.1: Methodology- Tree diagram of project methodology

A. Derivation of Geomorphologic Unit Hydrograph (GUH)

This section describes the potential of GIUH for deriving the SUH, and solution procedure adopted to solve the Nash based GIUH and GUH.

The GIUH theory was introduced by Rodriguez-Iturbe and Valdes (1979) by relating the peak discharge and time to peak discharge with the geomorphologic characteristics of the catchment and a dynamic velocity parameter. This pioneering work of Rodriguez-Iturbe and Valdes (1979), which explicitly integrate the geomorphologic details and the climatologic characteristics of the basin, in a framework of travel time distribution, is a boon for stream flow synthesis in the basin having no or scanty information of flow data. This formulation of GIUH is based on the probability density function of the time history of a randomly chosen drop of effective rainfall arrived at the trapping state of a hypothetical basin, treated as a continuous Markovian process, where the state is the order of the stream in which the drop is located at any time. The value at the mode of this produces the main characteristics of GIUH. Rodriguez-Iturbe and Valdes (1979) derived the peak and time to peak characteristics of the IUH as function of Horton's order ratios (Horton, 1945)[5], and are expressed as follows

$$q_P=1.31R_i^{0.43}*V/L_\Omega \quad (1)$$

$$t_p=0.44(L_\Omega/V)(R_B/R_A)^{0.5}R_L^{-0.38} \quad (2)$$

Where q_P is the peak flow, t_p is the time to peak (h), L_Ω is the length of the highest order stream (Km), and V is the dynamic velocity parameter (ms^{-1}). Multiplying equation 1 and 2 a non-dimensional term $q_{P*}t_p$ is derived as

$$q_{P*}t_p=0.5764(R_B/R_A)^{0.5}R_L^{-0.38} \quad (3)$$

The term $q_{P*}t_p$ is independent of the velocity parameter and thus on the storm characteristics and therefore, it is a function of only the geomorphologic characteristics of the basin.[5]

B. The Nash model

The Nash model (Nash, 1957) is based on the concept of the routing of the instantaneous inflow through a cascade of linear reservoirs with equal storage coefficient. The Nash model can be expressed as follows

$$U(t)= [1/k\,\Gamma(n)]*(t/k)^{n-1}*e^{(-t/k)} \quad (4)$$

Where U (t) is the ordinates of IUH (cm/hour), t is the sampling time interval (hour), n and k are the parameters of the Nash model, in which n is the number of linear reservoirs and k is the storage coefficient (hour). A unit hydrograph (UH) of desired duration (D) may be derived by using the following expression:

$$U(D,t)= 1/D[I(n,t/k) - I(n, (t - D) / k)] \quad (5)$$

Where U (D, t) denotes the ordinates of D hour UH (hour-1), t is the sampling time interval (hour), I (n, t/k) is the incomplete gamma function of order n at (t/k), and D is the duration of UH (hour)

C. Geomorphological parameter estimation of Nash model based GIUH

The complete shape of the GIUH can be obtained by linking the of the GIUH with scale (k) and shape (n) parameters of the Nash model. By equating the first derivative with respect to t of eq (4) to zero, t becomes the time to peak discharge. Thus, taking the natural logarithm of both sides of eq. (4), differentiating with respect to t and by simplification eq. (6) is derived.

$$\frac{\partial}{\partial t}\text{In}[u(t)] = [-\frac{1}{k}+\frac{(n-1)}{t}] \quad (6)$$

Equating eq. (6) to zero results in by replacing t with tp,

$$t = t_p= k(n-1) \quad (7)$$

Simplifying the value of tp from eq. (7) in eq. (4) and simplifying yields

$$q_p=\frac{1}{k\,\Gamma(n)}\,e^{-(n-1)}\,(n-1)^{n-1} \quad (8)$$

Combining eqs. (7) and (8) results:

$$q_p * t_p = \frac{1}{k\,\Gamma(n)}\, e^{-(n-1)}\, (n-1)^{n-1} \quad (9)$$

Equating eq. (9) with eq. (3) results in:

$$\frac{(n-1)}{\Gamma(n)} * e^{-(n-1)} * (n-1)^{n-1} - 0.5764\left(\frac{Rb}{Ra}\right)^{0.55} * Rl^{0.05} = 0 \quad (10)$$

The Nash parameter n can be obtained by solving eq. (10) using the Newton-Rapson method. The Nash's parameter k for the given velocity V is obtained using eqs. (2) and (7) and the known value of the parameter n as follows:

$$K = \frac{0.44L_\Omega}{v} * (R_B/R_A)^{0.5} R_L^{-0.38} * \frac{1}{(n-1)} \quad (11)$$

The derived values of n and k are used to determine the complete shape of the Nash based GIUH using eq. (4). Subsequently, the D-hour UH can be derived from eq. (5). The direct runoff hydrograph (DRH) is estimated by convoluting the excess rainfall hyetograph with the UH.

D. Derivation of 1-hour synthetic unit hydrograph by CWC process

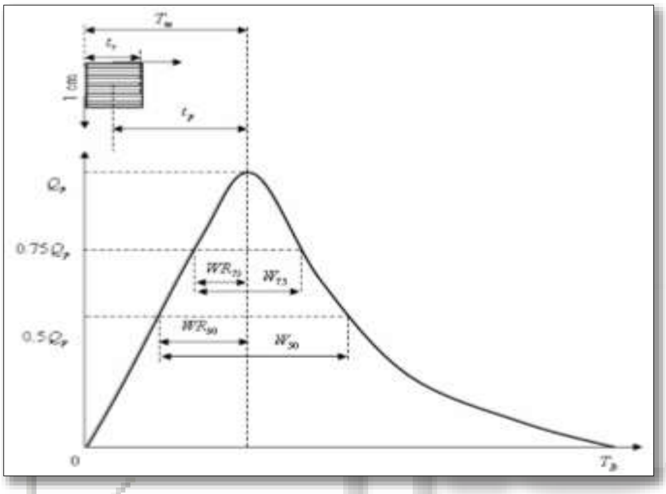

Fig. 3.2: Componants of SUH for CWC procedure

1) $q_p = 0.9178(\frac{L}{S})^{-0.4313}$
2) $t_p = 1.5607(q_p)^{-1.0814}$
3) $W_{50} = 1.925(q_p)^{-1.0896}$
4) $W_{75} = 1.0189(q_p)^{-1.0443}$
5) $WR_{50} = 0.5788(q_p)^{-1.1072}$
6) $WR_{75} = 0.3469(q_p)^{-1.0538}$
7) $T_B = 7.380(t_p)^{0.7343}$

Where,

L = Length of longest main stream along the river course in km S = Equivalent stream slope in m/km

q_p = Peak discharge of unit hydrograph per unit area in cumecs per sq. km

t_p = Time from the centre of unit rainfall duration to the peak of unit hydrograph in hours

W_{50} = Width of UH measured at 50% peak discharge ordinate (Q_p) in hours

W_{75} = Width of the UH measured at 75% peak discharge ordinate (Q_p) in hours

WR_{50} = Width of the rising side of UH measured at 50% of peak discharge ordinate (Q) in hours.

T_B = Base width of unit hydrograph in hours.

IV. RESULTS

A. Central Water Commission (CWC) method:

The Kundalika subbasin lies in Konkan and Malabar Coast 5(a) & 5(b) as per CWC. By using these formulas the values for hydrograph are developed as follow.

Q_p = 125.84 m^3/s

t_p = 11.32 hrs

T_b = 43.84 hrs

In Fig.4.1 X axis Indicates- time in hrs. and Y axis Indicates- discharge in m^3/sec

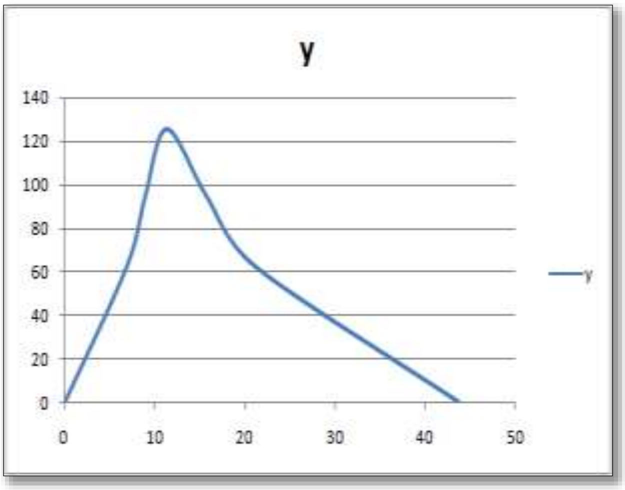

Fig. 4.1: Hydrograph by CWC Method for Kundalika River

B. Equivalent slope:-

$$S = \frac{\sum L_i\,(D_{i+1} + D_i)}{L^2}$$

= 1.35m/km

C. Synthetic unit graph parameters are computed bellow:-

$q_p = 0.9178(83.97/1.35)^{-0.4313}$

$= 0.154\ m^3/s/Km^2$

$t_p = 1.5607(0.154)^{-1.0814}$

=11.8 hrs.

$T_B = 7.380(11.8)^{0.7343}$

=45.24 hrs.

$W_{50} = 1.925(0.154)^{-1.0896}$

= 14.17

$W_{75} = 1.0189(0.154)^{-1.0443}$

=6.9

$WR_{50} = 0.5788(0.154)^{-1.1072}$

=4.4

$WR_{75} = 0.3469(0.154)^{-1.0538}$

=2.1

D. GIUH method:-

Using the aforementioned approach of Nash based GIUH and estimated Horton's ratios (i.e. Rb, Rl, and Ra) the parameter n of the Nash model was optimized using the Newton-Rapson method. The optimized value of n was found to be 3.02. The parameter k of the Nash model was estimated for the derived Horton's dimensionless parameters (i.e. Rb, Rl, and Ra) at a different dynamic velocity of flows using equation 11. Using the estimated values of the n and k at a different velocity of flows V, the ordinates of instantaneous unit hydrograph (IUH) was computed using equation4, and finally, the 1-hour

UHs were derived for the different velocity of flow using the relationship given by equation 5. The 1 h-UH at different velocities are depicted in Figure 4.7. To validate the derived GUH for the Kundalika River basin, a comparison was presented with the UH computed from the procedure adopted by CWC (Rai et al., 2009).

$$U(t)= [1/k\ \Gamma(n)]*(t/k)^{n-1} *e^{(-t/k)}$$

$$U(10)= \frac{1}{5.27\ X\ 2.027} *(1.89)^{3.02-1} *e^{(-1.89)}$$

$$=110\ m^3/s$$

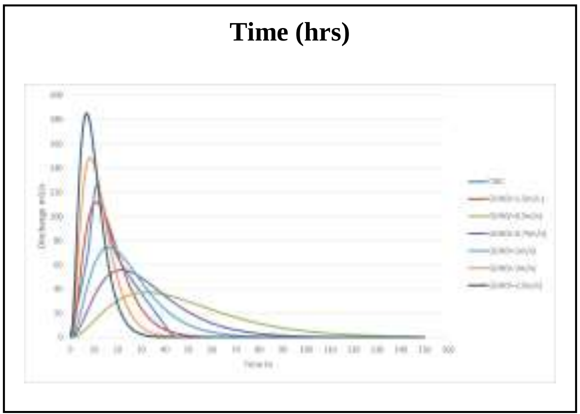

Fig. 4.2: GUH at different velocities for Kundalika River.

V. CONCLUSION

This study encircle of geomorphological investigation and development of GUH for Kundalika River basin of Maharashtra. The main purpose of the study is to generate a GUH for the Kundalika River basin for the estimation of flood hydrograph.

In CWC method the first parameter which is equivalent slope is calculated and its value is 1.35m/km. The topography of the study area within the first 15 to 20 km, has a very steep slope as compared to next 60 to 65 km.

The obtained GUH with a dynamic flow velocity of 1.5 m/s (roughly) shows closer contact with SUH derived from CWC approach. Meanwhile CWC approach is independent of the climatic parameter and geomorphologic characteristics other than the slope, drainage area and length of main stream; therefore, the resulting UH may have a higher computational error. Hence, the GUH based approach will be superior to the CWC approach.

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