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Geomorphic Instantaneous Unit Hydrograph (GIUH) Approach for Runoff Estimation in an Ungauged Basin from Western Upland Maharashtra, India

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Abstract
Geomorphic Instantaneous Unit Hydrograph (GIUH) of a specified duration has many applications in water resources development. It can be used to determine the watershed response to a given rainfall event if an estimate of the abstractions can be made which are not contributing to the runoff. Runoff within the basin is controlled by basin geomorphology, especially the drainage network of the river basin. The present paper describes the computation of GIUH based on Clark and Nash models for runoff estimation in an ungauged hilly catchment of River Shivganga, located in southwestern part of Pune district, Western Maharashtra, India. Variety of factors may account for differences between estimated and actual runoff such as vegetation (type and density), soil, impervious surfaces, land use immediately adjacent to streams, and seasonal fluctuation in the rainfall. Such factors have not been considered in this study but may have important implications for future water-resource management. The derived value of u (t) for time't' of 1 hour = 10572.3 m3/s. The effect of velocity on the Shivganga river basin at temporal scale shows that higher velocity causes significant increase in hydrograph peak and decrease in time to peak.
Keywords: *Hydrograph, Impervious surface, Peak discharge, Runoff, Ungauged catchment, Watershed*

Introduction

Hydrological response of a river basin is defined by the production of run-off against a given rainfall, which in turn is characterized by soil characteristics and basin geomorphology. Soil characteristics control the infiltration loss, whereas the distribution of the remaining 'rainfall excess' is governed by basin geomorphology. Run-off variability within the basin is therefore controlled by basin geomorphology, especially the drainage network of the river basin (Dey et al 2006).

The concept of Geomorphic Instantaneous Unit Hydrograph (GIUH) is essentially based on this fundamental idea and has provided the first analytically developed model to calculate river hydrograph from Horton's morphometric parameters. GIUH approach has many advantages over the regionalization techniques as it avoids the requirement of flow data and computations for the neighboring gauged catchments in the region as well as updating of parameters. GIUH of a specified duration has many applications in water resources development. It can be used to determine the watershed response due to a given rainfall event if an estimate can be made of the abstractions not contributing to the runoff. This approach has also been followed up in India and some recent works have successfully used GIUH to compute the runoff of ungauged basins (Bhatia 2006). Thus linking of geomorphological parameters with hydrologic characteristics of the basin can provide a simple way to understand the hydrologic behavior of different catchments, particularly the ungauged basins. The present paper describes the computation of GIUH based on Clark and Nash models for runoff estimation in an ungauged hilly catchment of River Shivganga, located in southwestern part of Pune district, Western Maharashtra, India.

Study Area

The drainage basin taken up for the present study is situated in southwestern part of Pune district, Maharashtra. Geographically it extends between 18° 13' north to 18° 24' north latitude and 73°45' east to 73°56' east longitude. Total geographical area of the basin is 131.25 km2. The climate of the study area is tropical and semi arid type. The basin receives about 600 mm of rainfall annually, about 90 percent of which occurs during June to September. July and August are the rainiest months. The drainage in the study area is mostly dendritic to subdendritic in nature.

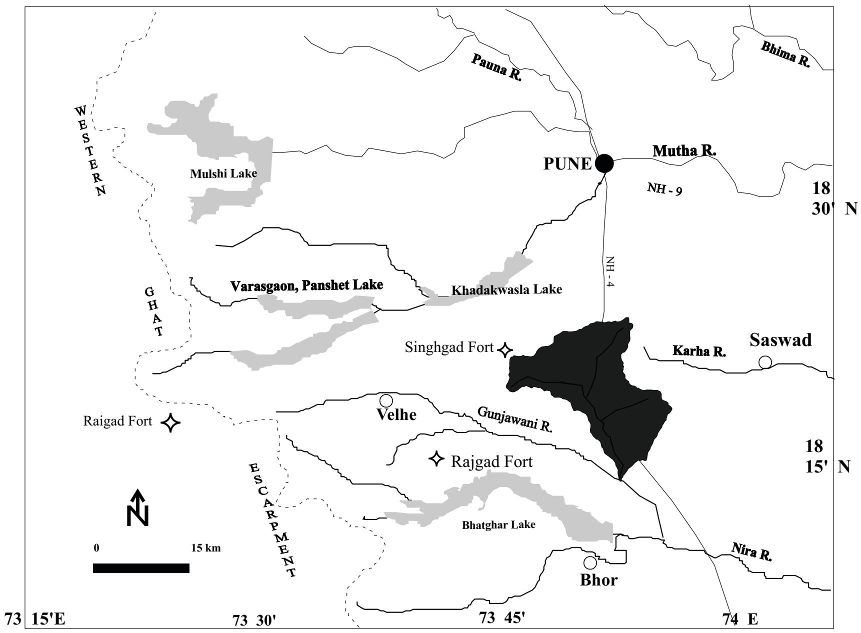

Figure1. Location Map of the Study Area

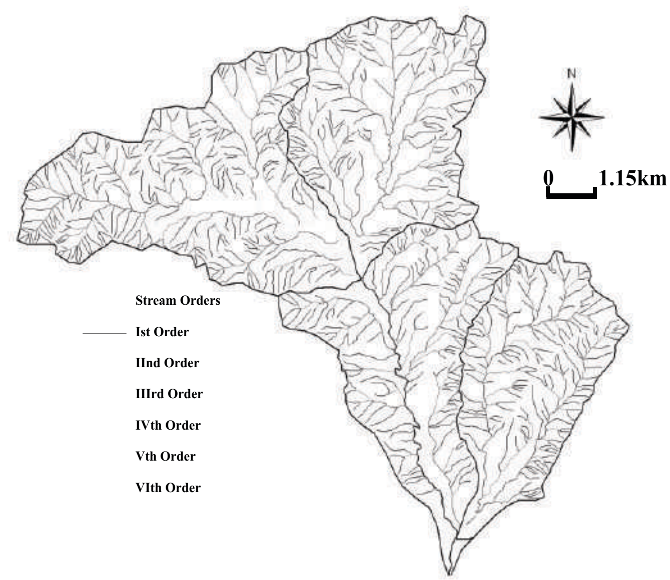

Figure 2: Drainage Map of the Shivganga Basin

Runoff predictions in an ungauged basin have been the subject of investigation since last three decades. It is well known that most of the runoff related studies have been done on the rivers that have fair amount of hydrological and meteorological data (Kumar et. Al. 2006). The present work encompasses hydrology, geomorphology, geology, watershed management, and water economics to have an overlook on the predictions in ungauged basins from India. Lohani et al. (2006) presented a procedure for the computation of Geomorphological Instantaneous Unit Hydrograph (GIUH) based on Clark and Nash models. It highlights the application of the GIUH and GIS based approach for design flood estimation of an ungauged hilly catchment or catchments with limited observed discharge data. Sahoo et al. (2006) developed an applied geomorphologic instantaneous unit hydrograph (GIUH) based on Clark and Nash model for the Ajay River Basin at Jamtara in northern India for flood estimation from ungauged basins.

Assumptions & Postulates of GIUH Model

In the GIUH model, uniform distribution and instantaneous is assumed. Thus, GIUH is independent of rainfall characteristics and loss parameters. Further assumption is made that the incoming discharge due to this rainfall excess is filling a bucket at the outlet and the rate of filling of a bucket at the outlet of a basin will give the hydrograph. The GIUH is defined as the probability density function for the time of arrival of a randomly chosen drop to the trapping state (bucket). The bucket at the outlet will start empty and will reach a final volume equal to the total volume of rainfall excess over the basin. The total volume yielded as output up to a certain time 't' will be given by, volume [V (t) = q (t) dt]. The derivative of the observed V (t) gives the hydrograph of discharge q (t) resulting from the rainfall input. This hydrograph q (t) is the IUH of the river.

The general equations of GIUH are a function of Horton's numbers, i.e. bifurcation ratio (Rb), Area ratio (Ra), length ratio (Rl), length of highest-order stream (LW) and mean velocity of stream flow (V). Therefore, it provides a theoretical link between hydrology and geomorphology, and can be used to analyze the geomorphic control on basin hydrology. This has immediate application in flood forecasting and warning.

With the knowledge of the time distribution of runoff response, both the flood peak and its time of occurrence can be well estimated.

For the maximum possible rainfall, the maximum possible flood can be determined. Thus the GIUH can serve as an indicator of the flood producing characteristics of a given watershed.

If sediment concentration for a given watershed is known, the unit sediment graph for a specified duration can be constructed. This, in turn, can be utilized to estimate erosion due to a specified rainfall on the watershed.

The basic postulates of the Instantaneous Hydrograph are:

The effective rainfall should be uniformly distributed within its duration with the same intensity throughout the drainage basin.

The hydrologic losses must be uniform over the entire drainage basin.

The duration of surface runoff should be constant for all uniform-intensity storms of the same length, regardless of differences in total volume of surface runoff.

The time distribution of surface runoff from a given storm period is independent of concurrent runoff from antecedent storm period.

Requirements of GIUH

1. Contour map, stream orders, stream length, bifurcation ratio, stream length ratio and stream area ratio are the geomorphological parameters of the watershed.
2. The flow velocity is considered as the dynamic property of the watershed.
3. Computation of Nash parameters (n and K), which are determined on the basis of above mentioned geomorphological parameters.

4. Computation of Peak runoff (Qp) and time to peak (tp).

Basin Area (RA)	= 131.25 Sq. km
Stream order	= 6th order
Length of main stream (L)	= 30.5 km
Bifurcation Ratio (Rb)	= 3.17
Stream Length ratio (Rl)	= 1.75 km/km
Stream Area Ratio (Ra)	= 6 streams/sq. km
Flow velocity (V)	= 18.0 m/sec
Time of concentration (TC)	= 96 minutes (1 hr. 36 minutes)
Effective Rainfall intensity	= 10.5 mm/hr (Source: field measurements for different rainfall events)
Effective rainfall duration	= 3600 sec (1 hr or 60 minutes)
Rainfall Excess	= 1.44 mm

Empirical results indicate that for natural basins, the values of Ra, Rb, Rl ranges 3 to 6, 3 to 5, 1.5 to 3.5. Here, controlled morphometric parameters have been analyzed for runoff generation through GIUH analysis. The main characteristics of GIUH are its peak (qp) and time to peak (tp) which have been expressed as

Peak (qp) = 1.31Rl 0.43 V/L……………… ……………..……..(Eq. 1)

& Time to peak (tp) = 0.44 (L/V) (Rb A) 0.55 (Rl)- 0.38 …….……… (Eq. 2)

Therefore, qp derived from equation 1 is 3.293 m3/s and time to peak tp derived from equation 2 is 2.32 hours.

To compute ordinates of GIUH, other parameters used are as follows

Manning's roughness coefficient (n)	= 0.5
Width of main stream (b΄Ω)	= 51 m
Slope of mainstream (m/m)	= 0.05
Kinematic wave parameter (ά΄Ω)	= (m-1/2. S-1/2)

Computation of Nash parameters (n & K) –

Nash parameters are determined on the basis of geomorphological parameters of the watershed, such as bifurcation ratio, stream length ratio, stream area ratio and flow velocity. Computations of n and K is given as under:

n = 3.29 [Rb / RA] 0.78 . Rl 0.07………………………………… (Eq.3)

The derived value of n = 5.96

K = 0.70 [(RA) 0.48 / Rb .Rl] . L / V…………………………… (Eq. 4)

The derived value of K = 0.29

Computation of ordinates of GIUH

u (t) = [1 /K (n)] . [t/K] n-1. e – (t/K)……………………..…… (Eq. 5)

Thus the derived value of u (t) for time't' of 1 hour = 10572.3 m3/s.

Following table shows rainfall, runoff and loss data for the storm of Sept 29-30, 2009 on Shivganga Basin. The data was obtained by having actual measurements using conventional methods such as rain gauging, effective depth of rainfall after deducting the initial losses, total runoff at the basin outlet for aforesaid storm duration. Before storm event started, the base flow was also measured for every 20 minutes duration in order to separate it from total runoff as it is contribution of previous rainfall event occurred in the basin. The period of unit hydrograph considered for the event was 20 minutes.

Table 1: Actual Rainfall, Runoff, and Loss of Shivganga Basin Data for Single Storm Event (Sept 29-30, 2009)

Time	Rainfall (cm)	Loss (cm)	Effective Rainfall (cm)	Total Runoff (m^3/s)	Base flow (m^3/s) (for Previous Day for same duration and time)	Direct Runoff (m^3/s)
14.00– 14.20pm	0.8	0.8	0	50	35	15
14.40	0.95	0.5	0.45	311	38	273
15.00	1.18	0.5	0.68	1568	36	1532
15.20	1.35	0.3	1.05	4359	35	4324
15.40	1.76	0.10	1.66	6765	35	6730
16.00	1.89	0	1.89	7370	32	7338
16.20	1.50	0	1.50	7934	37	7897
16.40	1.23	0	1.23	8648	36	8612
17.00	0.7	0	0.7	9358	35	9323
17.20	0.56	0	0.56	8850	34	8816
17.40	0.0	0	0	7687	33	7654
18.00	0.0	0	0	7393	35	7358
18.20	0.0	0	0	6891	35	6856

Draina ements)

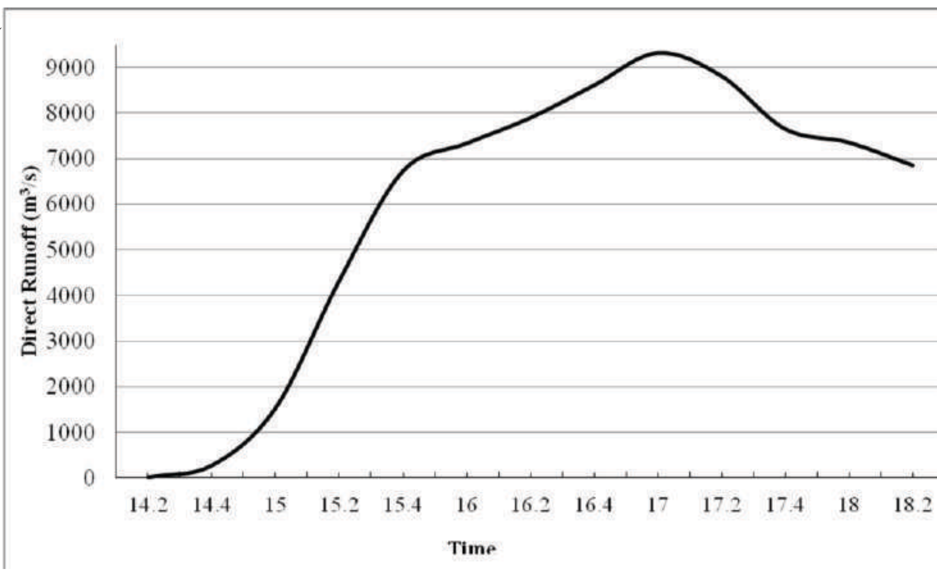

Figure 3: Hydrograph for Single Storm Event (Sept 29-30, 2009)

The effect of velocity on the Shivganga river basin at temporal scale shows that higher velocity causes significant increase in hydrograph peak and decrease in time to peak. Topographic, soil, and land-use information was used to estimate runoff of the Shivganga Basin. Results indicate that nearly the whole basin had a large percentage of potentiality of contributing to runoff.

The spatial distribution of potential contributing areas within the individual sub basin shows considerable variability. Kondhanpur sub basin has higher potential for runoff than Kelawade sub basin. This study had some limitations. The estimation of runoff may overestimate or underestimate in contrast to actual runoff for a particular location and precipitation event. A variety of factors may account for differences between estimated and actual runoff such as vegetation (type and density), soil, impervious surfaces, land use immediately adjacent to streams, and seasonal fluctuation in the rainfall. Such factors have not been considered in this study but may have important implications for future water-resource management.

Conclusions

Higher values of length ratio make the condition favorable for flooding in the downstream region. Any decrease in the main channel length of a river basin due to channelization or natural processes increases the flood hazard significantly at downstream region. Further, the scale of basin not only determines the length of the highest-order stream but also channel slope. The basin slope has affected the GIUH because of change in velocity. However, as mentioned earlier, the velocity in a river basin at any particular time remains constant from upstream to downstream. Therefore, the effect of velocity on the GIUH needs to be considered only for computing the hydrological response of a river basin for different time periods or for comparison of hydrological response of two river basins. The effect of velocity on the Shivganga river basin at temporal scale shows that higher velocity causes significant increase in hydrograph peak and decrease in time to peak. The derived value of u (t) for time't' of 1 hour = 10572.3 m3/s.

Results indicate that nearly the whole basin had a large percentage of potentiality of contributing to runoff. The spatial distribution of potential contributing areas within the individual sub basin shows considerable variability. Kondhanpur sub basin has higher potential for runoff than Kelawade sub basin.

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