RAINFALL RUNOFF ANALYSIS BY GIUH METHOD ON OM CHU RIVER BASIN

Chokey Yoezer[1] Jit Bahadur Mongar[1] Sangpo Tamang[1] Tenzin Phuntsho[1] Tshering Tashi[1] Kirtan Adhikari[1]

Civil Engineering and Architecture Department, College of Science and Technology, Royal University of Bhutan

E-mail: Adhikari.cst@rub.edu.bt[1]

Abstract

It is critical to quantify runoff that would be generated due to rainfall in a catchment which would in turn help in predicting the nature of response from a catchment that can be used to come up with a strategic planning and implementation to prevent from certain foreseen or unforeseen calamities. Most of the sub-catchments in Bhutan are un-gauged, which results in the insufficient hydrological data for validating the accuracy of any hydrological model. The current study is approached with identification of reliable hydrological model with the help of real data obtained through customized gauging stations developed using Arduino chip that works on batteries, using sonar sensors. To overcome the issue of insufficient data sets, Om chu river, situated at Phuentsholing is chosen to be gauged for the study. This practical approach towards the analysis of intensity and response of catchment, would help engineers to foresee the possible calamities if any and design the structures accordingly with the reasonable costing.

Key words: *quantify, runoff, catchment response, ungauged, hydrological models, arduino*

1. INTRODUCTION

Water is the most important resource of Himalayan countries like Bhutan as hydro power is one of the major sources of revenue. On the other hand, it can also be the major cause of problems prevailing in the country especially during monsoon. According to UNDP, Bhutan's climatic conditions vary considerably from one region to another owing to mountainous topography that influences every sphere of the environment due to drastic difference in altitude. Rainfall in the country is attributed to Indian monsoon that begins by early June and lasts till end of October. During the rainy season, the southern region of the country, often witnesses calamities like damages to infrastructures such as bridges and river training structures, because of the considerable flow.

To counteract these problems, it is critical to quantify runoff that would be generated due to rainfall in a catchment. Further, this can be helpful to manage runoff adequately thereby predicting the nature of response from a catchment which would in turn, can be used to come up with a strategic planning and implementation to prevent from certain predicted calamities.

Geomorphological method has been implemented as it does not require past runoff data and uses the catchment geomorphological characteristics to quantify runoff (Gehbrehiwot & Kozlov, 2019).

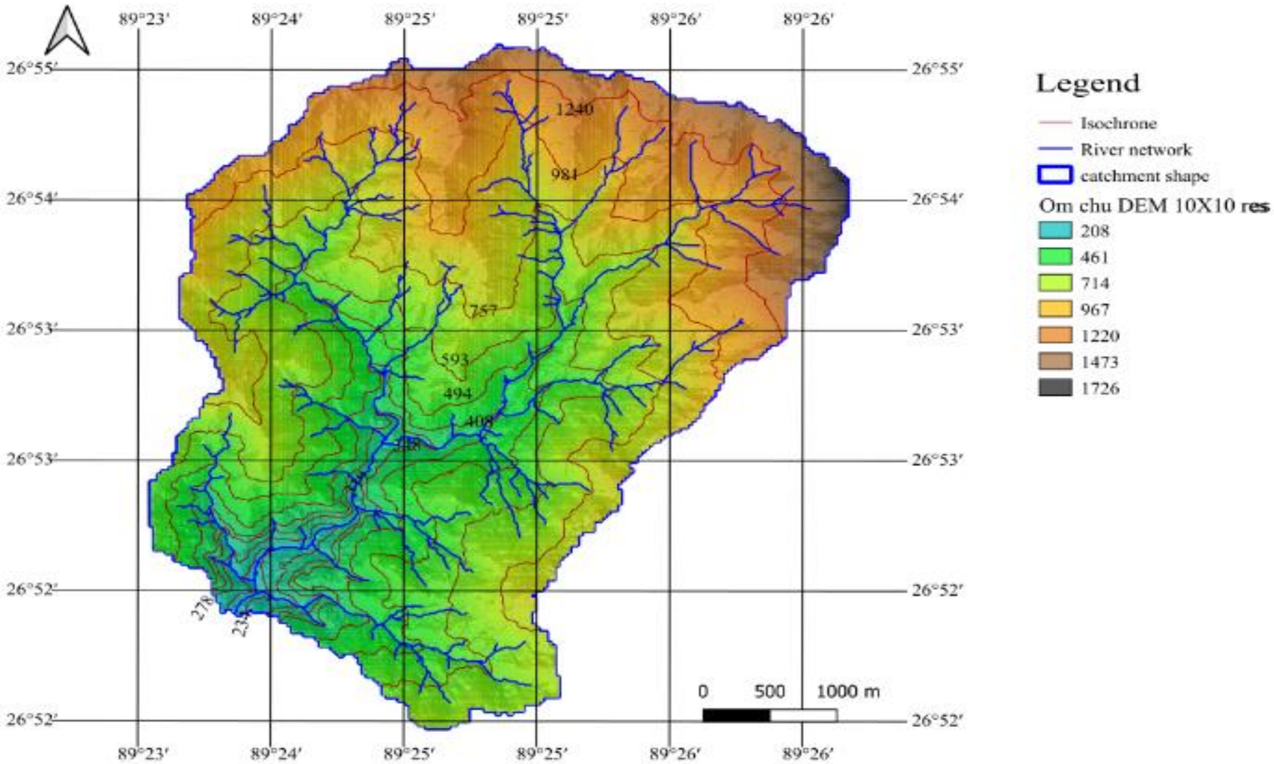

Figure 1: Drainage map of Om chhu river basin with outlet at Karbayter (Phuentsholing, Bhutan)

2. STUDY AREA

The Om Chu is a perennial river originating from the slope of Sorchen area near Kamji and flows through Phuentsholing town, Bhutan. The drainage area is about 18.06 km^2 with the varying elevation between 264m to 1420m above the sea level. The catchment area falls under the moist temperate zone and receives about 4383mm of average annual rainfall. The maximum precipitation is observed within the month of July and October (NCHM).

3. DEVELOPMENT OF GUIH MODELS

The development of GIUH based clerk and Nash model includes the extraction of the catchment geomorphological characteristics, estimation of the parameters. Procedure to develop GIUH models are mentioned below.

3.1. GIUH based Clerk model

Clerk instantaneous unit hydrograph (IUH) due to instantaneous rainfall excess is based on a concept that the catchment acts like a linear channel. Parameters of the Clerk IUH are time of concentration (Tc) and the storage coefficient (R) expressed in hour.

GIUH based Clark model has two parameters, time of concentration (T_c) and catchment storage coefficient (R). These parameter estimation are explained in detail in (Timothy D. Straub, Charles S. Melching, 2000). In brief,

$$T_c = 1.54L^{0.875}S^{-0.181} \text{ (h)} \quad (1)$$

$$R = 16.4L^{0.342}S^{-0.79} \text{ (h)} \quad (2)$$

Determination of time area diagram is a mandatory for development of Clark model. Clark based IUH can be obtained using the following equation

$$U_i = 2C_1L_i + C_2U_{i-1} \quad (3)$$

Where Ui is ith ordinate of the IUH, $C_1 = \frac{2\Delta t}{R+0.5\Delta t}$ and $C_2 = \frac{R-0.5\Delta t}{R+0.5\Delta t}$, Δt is computational interval. Li is inflow rate between an inter-isochronal area.

3.2. GIUH based Nash model

The instantaneous unit hydrograph from Nash model was developed on a conceptual consideration that the catchment response can be linked through a linearly arranged reservoir in series that act as a cascade. Parameter of the Nash model are the number of n linear reservoir (n) and the storage coefficient (k). It is explained in detail in (Kumar, Chatterjee, Singh, Lohansi, & Kumar, 2007). It is calculated using the following equation

$$n = 3.29\left(\frac{R_B}{R_A}\right)^{0.78} R_L^{0.05} \quad (4)$$

$$k = \frac{0.44L_\Omega}{V}\left(\frac{R_B}{R_A}\right)^{0.55} R_L^{-0.38}\frac{1}{(n-1)} \quad (5)$$

Where n and k are Nash parameter, R_A, R_B and R_L are the Horton ratio.

The IUH by the GIUH based Nash model is obtained by the following equation,

$$Q(t) = \frac{1}{k\Gamma n}\left(\frac{t}{k}\right)^{n-1} e^{\frac{-t}{k}} \quad (6)$$

Where, Q (t) = IUH ordinate (per hour), t is time interval of the sample taken (hour), n and k are the Nash parameter.

3.3. Evaluation of the computed storm hydrograph with the observed storm hydrograph

Since the evaluation of two hydrograph deals with the checking in the variation of each ordinate of hydrograph, objective function has been applied for evaluation of observed and computed storm hydrograph by each model. The function includes (I) Efficiency (EFF), (II) Absolute average error (AAE) and (III) Root mean square error (RMSE).

$$EFF = \frac{\sum_{i=1}^{n}(Q_{oi}-Q)^2 - \sum_{i=1}^{n}(Q_{oi}-Q_{ci})^2}{\sum_{i=1}^{n}(Q_{oi}-Q)^2} * 100 \quad (7)$$

Where, Q_{oi} is i^{th} ordinate of observed discharge, Q is average of the ordinates of the observed discharge and Q_{ci} is I^{th} ordinate of computed discharge.

$$AAE = (Q_{oi} - Q_{ci})n \quad (8)$$

Where n is number of ordinates.

$$RMSE = \sqrt{\frac{\sum(Q_{oi}-Q_{ci})^2}{n}} \quad (9)$$

Table 1 Catchment charcteristics

4. EXTRACTION OF CATCHMENT GEOMORPHOLOGICAL CHARACTERISTICS THROUGH GIS AND DEM

GIUH method involves the use of the use of distinct catchment characteristics such as the catchment area, perimeter, slope of the catchment and the length of the river channel in flowing through the catchment. Surveying these data in the field is a tedious and labor-intensive work and hence QGIS tool provide an economic and efficient alternative to field surveying.

Table 2 Detail of stream segment of Om Chu river

Sl. No.	Geographical parameter	Symbol	Magnitude
1	Area (sq. km)	A	18.08
2	Perimeter (km)	P	24.69
3	Basin length (km)	L_b	5.9
4	Longitudinal slope	S	0.179 m/m
5	Channel stream order	O	5
6	Length of outlet from centroid of the catchment	L_c	3.565
7	Longest length of stream	L	7.024 km

stream order (U)	No. (N_U)	Stream Length (Km)	Mean Stream Length (Km)	Mean Stream Area (Km2)
1	108	24.959	0.231	0.079
2	21	11.706	0.225	0.391
3	6	6.32	0.175	1.781
4	2	3.805	0.238	6.770
5	1	2.096	0.140	18.808

Om chu river network has been shown in the figure 1. Strahler's method of stream order is applied in Om Chu and river has highest order 5. Using stream order data and table 1 data, R_A, R_B and R_L are 4.429, 1.924 and 1.882 respectively. Using the Aster DEM, geomorphological characteristics of the Om Chu has been obtained in progressive manner.

5. DEVELOPMENT OF HYDROGRAPH FROM COMPUTED IUH

A significant step for the validation and application of any hydrological methods involves the generation of the hydrograph from the model. For GIUH models, the final output is an IUH. It is converted to UH by taking the average of the IUH data with another same IUH data lagged by an hour to obtain 1D hour UH. To convert UH to H, the term effective rainfall and base flow comes in picture. Phi index for the Om chu river is obtained through experimental method where the infiltration of the soil in the catchment is determined and taken as the average which is the phi index of the catchment. For Om chu river it is 1.24 cm/h. Effective rainfall is the difference of the rainfall intensity and the phi index. To obtain the hydrograph, the excess rainfall intensity is multiplied to the UH ordinate to obtain the hydrograph.

5.1. Collection of the storm hydrograph from the field

Validation of the hydrological model requires an observed field data. For an ungauged data, obtaining field data mean to gauge the river at the catchment outlet. For Om chu river, since the catchment response to a rainfall is abrupt, manual recording prove to be hard and risky. Also, lack of any device to measure the velocity of the river made it harder. In this scenario, development of the data logger to collect the stage hydrograph and application of non-contact discharge measurement technique come in action. Chezy's method for discharge measurement for a small catchment produces a very high discharge, which is not accurate (Tazioli, 2011). An equation to compute discharge with only stage data. Simplifying the working by removing the need for measurement of the velocity. The method showed accuracy of 99% on a hypothetical test. Reasonable rating curve was obtained for the Chattahoochee river, USA (Perumal & Adhikari, 2019). The equation is known as Approximate Convection-Diffusion wave equation given by

$$Q_2 = \frac{Q_o^2}{2 S_o T_2 C_2^2 \Delta t} + \frac{1}{2}\sqrt{\left(\frac{Qo2}{S_o T_2 C_2^2 \Delta t}\right)^2 + 4\left(Q_o 2^2 + \frac{2Q_o^2 Q_1}{s_o T_2 c_2^2} + \frac{2Q_o^2}{s_o T_2 c_2}\left[\frac{A2-A1}{\Delta t}\right)\right.} \quad (9)$$

Where, T is top width, c is celerity, So is channel bed slope, Q1 is discharge at previous time step and Q_0 is steady discharge.

For Om Chu river, for a steady flow of by ACDW method, discharge obtained was to be fairly close to discharge obtained by area-volume method with variation of 3%.

6. RESULT AND ANALYSIS

For computation of the GIUH based Clerk model, inflow rate corresponding to each time area diagram was computed. Using the parameter and the inflow rate, ordinate of the IUH was obtained. For GIUH based Nash model is much simpler and uses the parameter and the computational time for the generation of the IUH. The IUH by GIUH based and GIUH based Nash model is shown below.

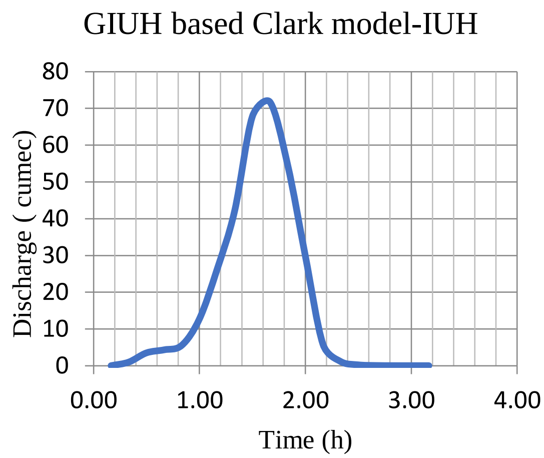

Figure 2 IUH by Clark model

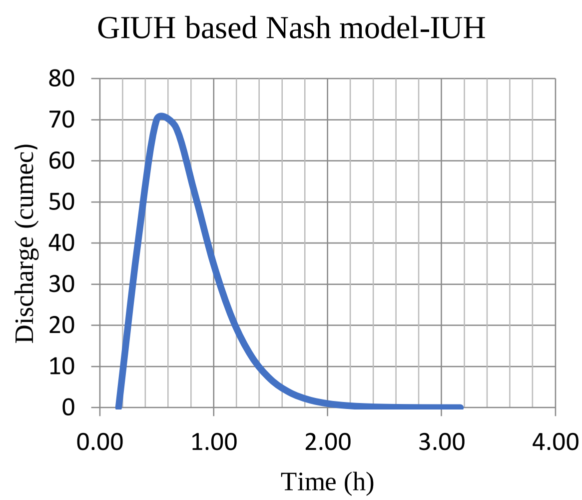

Figure 3: IUH by Nash model

For the validation of the work, the IUH is used to computed the storm hydrograph for the Om chu for a rainfall event with rainfall intensity of 22mm/h. Phi index for the catchment is 12.36mm/h. Base flow of the catchment was about 10 cumec. The result by both the method is displayed below

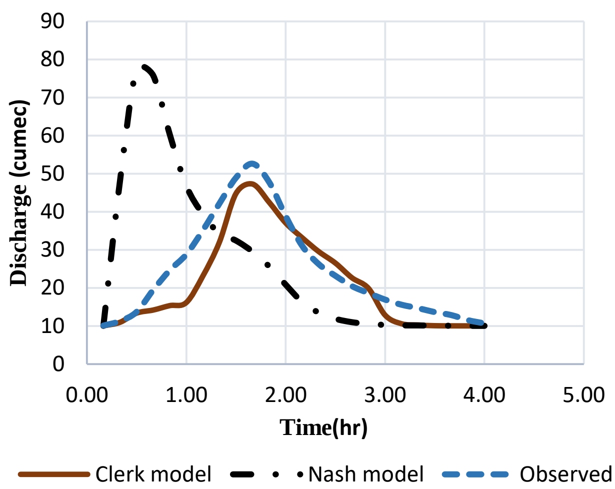

Figure 9 Comparison of Clark, Nash based hydrograph with observed hydrograph

Table 3 Magnitude of objective function for Clark model

Objective function	EFF	AAE	RMSE
Magnitude	82.3	0	5.46

Table 4 Magnitude of objective function for Nash model

Objective function	EFF	AAE	RMSE
Magnitude	-213.5	0	22.97

This is being clear in the Figure 9, that the catchment response for this particular event is shown better by GIUH based Clerk model. GIUH based Nash model is found to give the reasonable rainfall event duration but giving an early peak than expected. Empirical method of determining unit hydrograph is simple and easy to carry out the parameter estimation but the for-Om Chu river, the result is not reasonable both in peak discharge as well as the duration of catchment response.

7. CONCLUSION

Geomorphological IUH based hydrological models mainly uses geomorphologic parameters to construct IUH. GIUH is easy and cost effective because the geomorphological parameters can be easily obtained using QGIS and DEM. In addition to that, it doesn't require past hydrological rainfall runoff data and this particular reason makes it applicable in any sub-catchment gauged or ungauged. Based on the comparison between observed hydrograph obtained from field and the hydrograph through different hydrological models, it is concluded that geomorphological IUH can be applied in the Bhutan's river basin. Comparing the peak discharge, time of concentration and time to peak with field hydrograph, Clark model is displayed the reasonable accuracy for the Om chu river basin for an event.

REFERENCES

Adhikari K., (2019). Approximate convection diffusion wave method to compute discharge using only stage data. [MastersThesis] *Indian Institute of Technology Roorkee*

Anupam KS, S. B. (2015). Snyder unit hydrograph and GIS for estimation of flood for un-gauged catchments in lower Tapi basin,India. *Journal of Waste Water Treatment & Analysis*, 06(01). https://doi.org/10.4172/2157-7587.1000195

Bhaskar, N. R., Parida, B. P., &Nayak, A. K. (1997). Flood estimation for ungauged catchments using the GIUH. *Journal of Water Resources Planning and Management*, 123(4), 228–237. https://doi.org/10.1061/(asce)0733-9496(1997)123:4(228)

Boufadel, M. C. (2018). Unit hydrographs derived from the nash model nates. https://doi.org/10.1111/j.1752-1688.1998.tb05969.x

Brundra,G.S.,Pramod,M.P.&Sharathchand,U.B.(2016).Derivation of unit hydrograph & S curve for Haridra river catchment using CWC method,1(6),1-5

Gehbrehiwot, A., &Kozlov, D. (2019). GIUH-Nash based runoff prediction for debarwa catchment in Eritrea.

Gurung, A., Tshewang.,Lhachay, U., & Sharma, V. (2014). Hydrology modeling using SCS-CN and HEC-HMS in Omchu

Khaleghi, S., Monajemi, P., & Nia, M. P. (2018). Introducing a new conceptual instantaneous unit hydrograph model based on a hydraulic approach. *Hydrological Sciences Journal*, 63(13–14). https://doi.org/10.1080/02626667.2018.1550294

Kumar, R., Chatterjee, C., Singh, R. D., Lohani, A. K., & Kumar, S. (2007). Runoff estimation for an ungauged catchment using GIUH based Clark instantaneous unit *hydrograph (GIUH).* https://doi.org/10.1002/hyp.6318

Patra, K. C.,(2008). Hydrology and Water Resources Engineering (pp. 379 - 381). India, New Delhi: Narosa

Sahoo, B., Chatterjee, C., Raghuwanshi, N., & Singh, R. (2006). Flood estimation by GIUH-based Clark and Nash models. https://doi.org/10.1061/(ASCE)1084-0699(2006)11

Site, I., Surface, P., Discharge, W., To, M., Cross, C., & Once, S. (2016). A four-step guide to accurately calculating surface water discharge.

Sook, S., Deog, S., &Kyu, S. (2016). Measurement of flow velocity using video image of spherical float. *Procedia Engineering*, 154, 885–889. https://doi.org/10.1016/j.proeng.2016.07.464

Taylor, A. B., & Schwarz, H.E. (1952). Unit-hydrograph lag and peak flow related to basin characteristics, 33(2), 235-246

Timothy D. Straub, Charles S. Melching, K. E. K. (2000). A technique for estimating time of concentration and storage coefficient values for Illinois streams. 1–30. Retrieved from https://pubs.er.usgs.gov/publication/wri8222

Valdes, J. B., Fiallo, Y., & Rodriguez-iturbe, I. (1979). A rainfall-runoff analysis of the geomorphologic IUH. 15(6).