Suitability of Synthetic Unit Hydrograph Methods for Micro Watersheds

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Abstract— Flood hydrographs are graphs that show how a drainage basin responds to a period of rainfall and it is important to plan for flood situations and time of drought. One of the admired tools to derive these hydrographs is the unit hydrograph, which requires the site-specific concurrent rainfall and runoff data. But the collection of such data for every site especially micro watersheds however is neither practicable nor economically feasible. In the absence of such data, a synthetic unit hydrograph can be used which relates the watershed characteristics with the unit hydrograph parameters. In the present study, the most suitable synthetic unit hydrograph method for a micro watershed is derived. For this, unit hydrograph will be derived for watershed within which micro watershed lies, and using precipitation data, the flood hydrograph was derived by the process of convolution. The simulated discharge hydrograph was then compared with the observed ones to determine the suitable method. Since area of concern i.e., micro watershed lies within watershed it can be assumed that most suitable method derived is applicable to the micro watershed as well. The method was then used to derive the flood hydrograph of the micro watershed.

Index Terms— Hydrograph, Microwatershed, Rainfall, Runoff, Synthetic unit hydrograph, Unit hydrograph, Watershed.

1 INTRODUCTION

Rainfall-runoff modelling was an important tool developed in response to many engineering problems. It is of paramount importance from engineering point of view for design of hydraulic structures, flood management and control and also to understand how catchment responds to a rainfall event. Absence of such data especially in case of micro watersheds which is ungauged stresses on the need for other methods to derive runoff data. One such method was the unit hydrograph developed by L.K. Sherman in 1932 to derive runoff for a rainfall event.

Unit hydrograph method is the most admired and accepted tool for the derivation of flood hydrograph. In order to develop a unit hydrograph for catchment, detailed information regarding rainfall and runoff data is required. But such information would normally be scanty due to unavailability of gauge stations especially in case of remote areas or smaller watersheds. Hence planning and designing of water management facilities and hydraulic structures are done with lack of such data in the case ungauged catchments. In such cases the concept of Synthetic unit hydrograph came into existence.

Synthetic unit hydrograph(SUH) as the name suggests consists of set of empirical equations that relate the watershed characteristics such as area of catchment, length of main stream etc. with the salient point of hydrographs such as peak discharge, time to peak etc. Various methods are available for deriving synthetic unit hydrographs which are classified as traditional, probabilistic, conceptual and geomorphological.

Traditional methods such as Snyder's , Soil Conservation Service(SCS) etc. are characterized by their simplicity and ease in development as it requires less data and yield smooth and single valued shape corresponding to one unit runoff volume, which is essential for derivation of unit hydrograph. It is based on set of empirical equations relating physical characteristics of watershed to salient points of hydrograph.

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In this study an effort is made to compare and determine the most suitable synthetic unit hydrograph method for microwatershed, where stream flow and rainfall data are not available for planning and designing of water management facilities and other structures due to lack of gauging stations.

2 STUDY AREA AND DATA USED

The area of concern is the microwatersheds within Kurumali watershed, which is a subwatershed of Karuvanur. The Karuvanur river is located in the state of Kerala, lieing between $10^0 15'$ to $10^0 40'$ N and$76^0 0'''$ to $76^0 35'''$ east. . It is the fourth largest river in Thrissur district having a length of 48kms and watershed area of 1054km^2.It has its origin at Pumala Hills in Chimmony Wildlife Sanctuary of Thrissur district and is formed by the confluence of Kurumali and Manali, which joins together before Arattupuzha to form Karuvanur river and then flows into Kole wetlands. The Kurumali river, which forms a major tributary of Karuvanur originates from Pumala hills and is formed by the confluence of Mupli and Chimini rivers. It has a dam and various irrigation projects. The Chimini dam is a main irrigation dam on the upstream. It is a seventh order stream having length of 29.523km and watershed area of 369.559km^2. Another major tributary is Valiyathodu, which is the area considered for this study. It is a fifth order stream having length of 12.52kms and watershed area 61.11km2. There are various structures constructed mainly for the purpose of irrigation such as check dams, sluices, gully plugs,weirs etc. Since it is a ungauged catchment, most of the designs were based on preliminary survey and participatory.

The data required for the study area are SRTM data , which is processed in ArcGIS platform to obtain various watershed characteristics, daily/hourly rainfall and runoff data of Kurumali and inflow outflow data of Chimini reservoir.

3 METHODOLOGY

3.1 Development of Snyder's unit hydrograph

The Snyder's method was one of the first method that established a set of empirical equations which relates the watershed characteristics such as area, length of main stream and distance from watershed outlet to a point on main stream nearest to the centre of watershed to the three basic parameters of unit hydrograph i.e., lag time or time to peak, peak discharge and time base. These are required to obtain the shape of unit hydrograph.

The peak discharge(Q_p), time to peak(t_p) and base width of unit hydrograph(T_b) are determined as follows

$t_p=C_t(LL_c)^{0.3}$ (1)

$Q_p=2.778(C_pA/\ t_p)$ (2)

$q_p= Q_p/A$ (3)

$T_b=5.56/q_p$ (4)

Where L is the length of main stream in kms, L_c is distance from watershed outlet to a point on main stream nearest to the centre of watershed in kms, A is the area of watershed in km^2, C_t is a regional constant representing watershed slope and storage effects and C_p is regional constant which indicates the retention and storage capacity of watershed. The values of C_p and C_t adopted in this study are 0.65 and 1.8 respectively which was considered from a study conducted by Amaranatha et.al (2018) in West coast region.

The above equations hold good for rainfall excess duration or unit duration as

$t_r= t_p\ /5.5$ (6)

If the duration of rainfall excess is different from above mentioned duration, say t_{r1} then the modified lag time(t_{pm}) is determined using the following equation,

$t_{pm}= t_p+(t_{r1}-t_r)/4$ (7)

Many unit hydrographs can be plotted using the three known characteristic points (Q_p,t_p,T_b) with specific criteria that the area under the curve need to be unity. So in order to overcome this ambiguity other parameters are considered for plotting the unit hydrograph i.e. widths of unit hydrograph at 50% and 75% of peak discharge.

$W_{50}=2.14q_p^{-1.08}$ (8)

$W_{75}=1.22q_p^{-1.08}$ (9)

where W_{50} and W_{75} are in units of hour and is proportioned on each side of the peak in the ratio 1:3 with the short time side on left of the synthetic unit hydrograph peak.

3.2 Development of SCS unit hydrograph

This method uses a specific average dimensionless unit hydrograph from the analysis of large number of natural unit hydrographs of different watersheds to synthesize the unit hydrograph. For the generation of Triangular Unit Hydrograph the time to peak and peak discharge can be calculated using the below mentioned equations.

$T_p=t_l+t_r/2$ (10)

Where t_l is lag time (hours) from centroid of excess rainfall to peak discharge (q_p) and t_r is excess rainfall duration(hours).

The lag time can be estimated using a relation with time of concentration and is given by

$t_l=0.6t_c$ (11)

where t_c is time of concentration in hours.

As mentioned in study by Bondelid et. al (1982), 75% of error in estimation of peak discharge occurs due to errors in determination of time of concentration. So it is important to use the right equations for its determination.

Bransby Williams formula was considered to determine the same as it is mentioned in the Bridges and Flood Wing Report No. 16 that this formula was developed based on Indian catchments and was suitable for Western Ghats.

$t_c=14.467LS^{-0.2}A^{-0.1}$ (12)

where L is the length of main stream (km), S is watershed gradient or slope (m/m) and A is watershed area (km^2)

Peak discharge can be estimated by

$Q_p=2.08A/\ T_p$ (2.12) (13)

Where Q_p is the peak discharge in cumecs for one centimeter of excess rainfall , A is area of watershed in km^2.

3.3 Determination of Average Hourly Rainfall

In order to determine the average hourly rainfall, initially the average daily rainfall is computed by using Theissen polygon option in ArcGIS. For this the rain gauges lying within the Kurumali watershed was considered and theissen polygon was drawn. Then the average daily rainfall obtained was disaggregated to average hourly rainfall using the CWC method.

3.4 Convolution

The discharge hydrograph is then derived by multiplying the ordinates of the unit hydrograph with the rainfall excess values.

[P][U]= [Q] (14)

Where P is the excess rainfall in cm

U is the unit hydrograph ordinates

Q is the runoff ordinates in cumecs

Multiply the first one hour effective rainfall with the ordinates of unit hydrograph to get the corresponding runoff ordinates and similarly repeat the procedure for the remaining hourly excess rainfall values by giving a lag of 1 hour to successive direct runoff ordinates. And then add these direct runoff ordinates at 1 hour interval to get total runoff hydrograph. The convolution was done for the period from July to September 2003.

4 RESULTS AND DISCUSSIONS

4.1 Delineation of watershed

The watershed was delineated along the stream network after removing the area of reservoir. The actual watershed area of Kurumali is 369.45km ^{2} , from which the area of reservoir was removed which is around 68.32km². This was done as the Kurumali discharge station did not have any influence of reservoir i.e., there was no outflow during the period of study considered as per the data obtained for year of 2003. This implies that the discharge was a contribution of remaining area after removing the reservoir.After delineation various watershed parameters are determined for Kurumali.

Similarly the parameters of Valiyathodu micro watershed was also determined

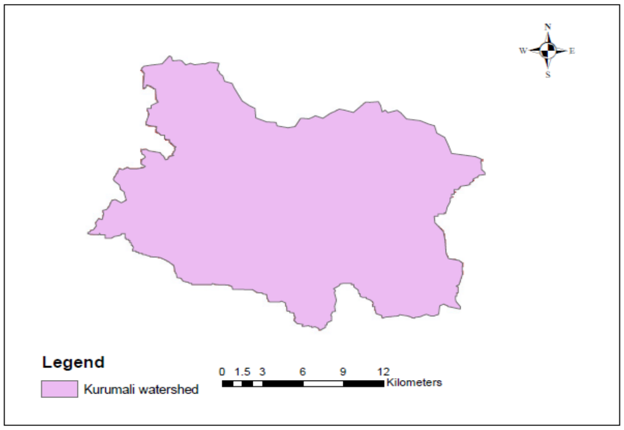

Fig.4.1 Kurumali watershed

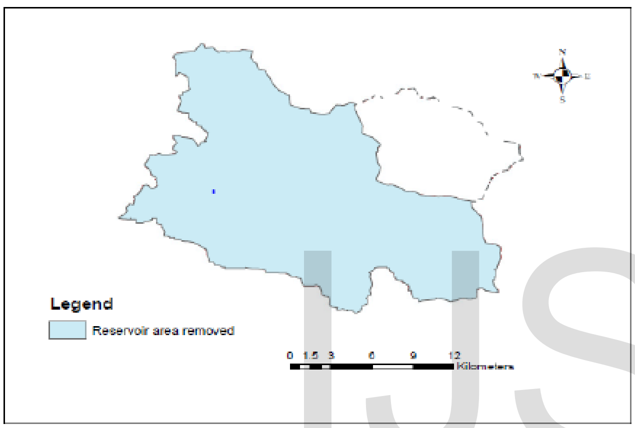

Fig.4.2.Kurumali watershed after removing the reservoir area

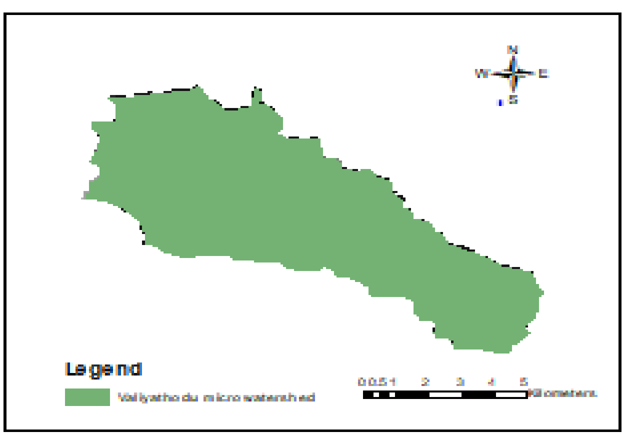

Fig.4.3.Valiyathodu micro watershed

Using the watershed characteristics, the various parameters required to plot unit hydrograph using the two methods are computed and are shown in table 4.1 and 4.2 .

TABLE 4.1 RESULTS OF SNYDER'S METHOD

Parameter	Values
Peak discharge $Q_p(m^3/s)$	62.03
Peak time t_p (hrs)	8.83
Base time T_b (hrs)	27.2
Width at 50% discharge W_{50} (hrs)	11.9
Width at 75%discharge W_{75}(hrs)	6.79

TABLE 4.2 RESULTS OF SCS METHOD

Parameter	Values
Peak time t_p(hr)	5.27
Peak discharge Q_p(m3/s)	120
Base time T_b(hrs)	14.07
Lag time,t_l (hrs)	4.77
Time of concentration, t_c(hrs)	7.95

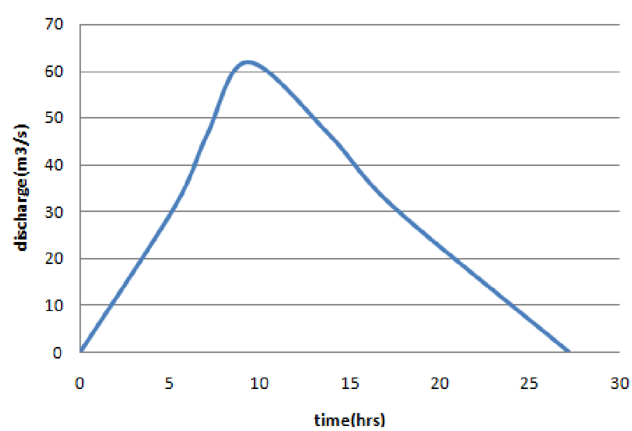

Fig.4.4 Snyder's unit hydrograph for Kurumali

4.2 Results of Snyder's and SCS unit hydrograph

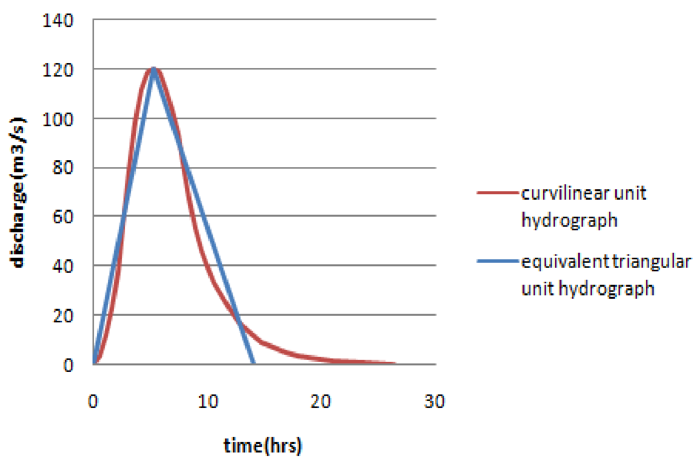

Fig.4.5 SCS unit hydrograph for Kurumali

4.3 Generation of discharge hydrograph

After developing unit hydrograph, the discharge hydrograph is simulated for the year 2003 by convolution. A comparison of actual discharge hydrograph with the simulated one for the period July to September 2003 is shown in fig 4.6 and 4.7 For this hourly rainfall value obtained by dissagregation of daily values were used after removing the loss rate.

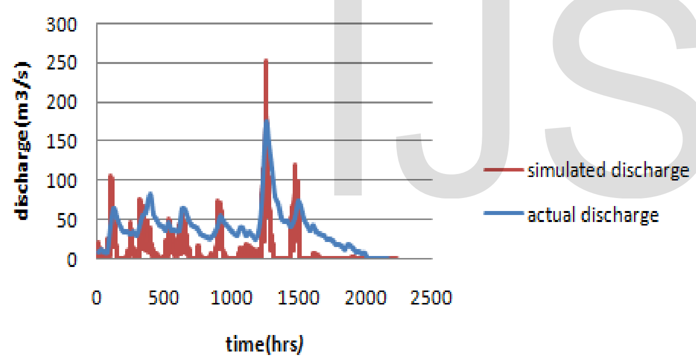

Fig.4.6 Simulate discharge v/s Actual discharge –Using Snyder"s unit hydrograph

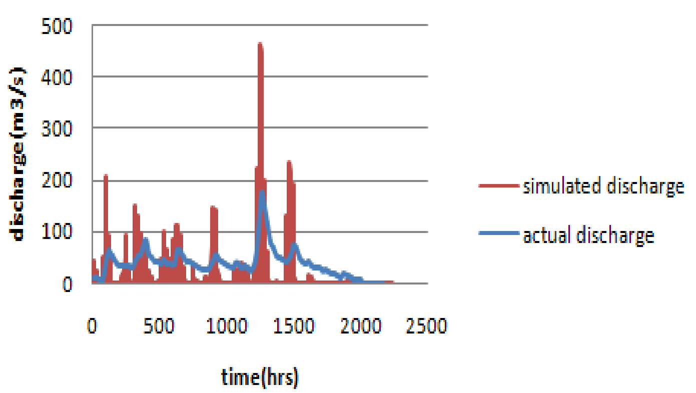

Fig.4.7 Simulate discharge v/s Actual discharge –Using SCS unit hydrograph

It was found that the simulated values were higher than the actual values in both cases. Kurumali river caters number of irrigation structures. The inflow outflow processes of these structures were not incorporated in this study. So this could be the reason of overestimation of simulated discharge.

From the study conducted, it was found that discharge hydrograph developed using Snyder's method gave promising results when compared to other method. Thus it can be concluded that Snyder's method may be a suitable method for developing unit hydrograph for Kurumali watershed. Since Valiyathodu lies within this watershed and since the catchment characteristics are same, the suitable method derived, can be applied here to derive unit hydrograph since it is an ungauged catchment.

4.4 Application to micro watershed

As mentioned earlier, Valiyathodu is a microwatershed that lies within Kurumali watershed. Thus it can be assumed that the most suitable synthetic unit hydrograph method derived for Kurumali i.e, Snyder's method, may also be suitable for this microwatershed.Thus using this method the synthetic unit hydrograph was derived for Valiyathodu and the results are as follows.

Using the unit hydrograph derived and the rainfall, the discharge hydrograph was simulated for Valiyathodu for the period of july to September 2003 and is shown below.

TABLE 4.3 RESULTS OF SNYDER"S METHOD

Parameter	Values
Peak discharge Q_p (m3/s)	20.89m3/s
Peak time t_p ,(hrs)	5.28
Base time T_b (hrs)	16.3
Width at 50% discharge W_{50} , (hrs)	6.8
Width at 75%discharge W_{75} (hrs)	3.89

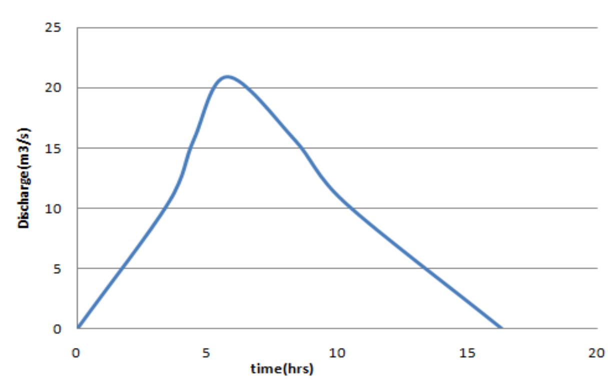

Fig.4.8 Snyder's unit hydrograph for Valiyathodu micro watershed

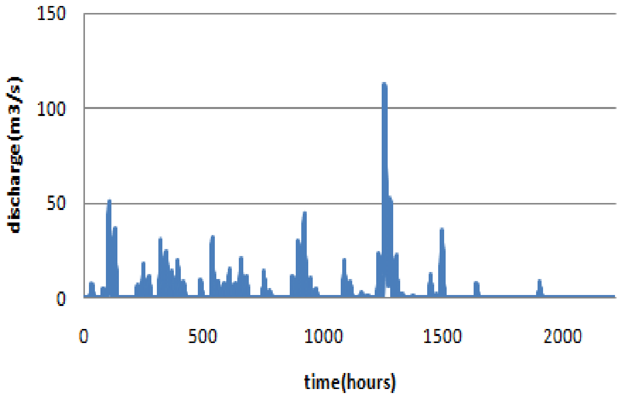

Fig.4.8 Simulated discharge for Valiyathodu using Snyder"s unit hydrograph

Very often it is required to predict the flood hydrograph resulting from known storm. Flood hydrograph are the graphs that show how a drainage basin responds to a period of rainfall and are used to plan for flood situations and times of drought. They show the river discharge that occurs as a result of precipitation from an earlier storm. Thus from this study it can be concluded that Snyder's unit hydrograph method may be a suitable method to derive unit hydrograph for Valiyathodu and can be used to derive flood hydrograph for the same which can be used to plan for flood situations and time of drought.

5 CONCLUSION

The unit hydrograph is developed by the Synder's and SCS method, both of which depend on the watershed characteristics rather than the rainfall-runoff data. Both these methods are significant as it uses most of the unit hydrograph and watershed characteristics to derive the unit hydrograph.
Some of the results observed in the study are:

- 1. The unit hydrograph developed by the both methods satisfied unit hydrograph criteria i.e, the area under the curve is unity.
- 2. Snyder gave a lesser peak discharge and higher time to peak when compared to other method.
- 3. SCS method gave higher peak discharge and lesser time to peak. This can be due to the limitations in this method regarding the area.
- 4. Discharge hydrograph was simulated by convolution using Snyder's and SCS unit hydrograph and showed that simulated discharge does not match with the observed discharge. This mismatch can be attributed to various physical characteristics relating to the study area. Firstly Kurumali caters many irrigation strctues of whisch inflow outflow parameters couldn't be incorporated in the model for discharge computation. And another reason could be the lack of hourly data due to which daily data was dissagregated using CWC method, which is an assumption that rainfall occurs in every hour.
- 5. Comparison of simulated and actual discharge hydrograph showed Synder's gave promising result compared to SCS method. Since area of concern Valiyathodu lies within Kurumli it can be assumed that Synder's method may be a suitable method for the microwatershed as well.

Thus Synder's method can be used to derive the flood hydrograph of Valiyathodu, which is ungauged, to understand how catchment responds to rainfall event as well as for planning during flood situations and time of drought.

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