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Estimation of Instantaneous Unit Hydrograph with Clark's Method Using GIS Techniques

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Abstract: Determination of basin Instantaneous Unit Hydrograph (IUH) is important for design of hydraulic structures. Instantaneous Unit Hydrographs can be derived from rainfall runoff data, if those data are available. But if those data were not available, the IUH can be constructed from Synthetic Unit Hydrographs (SUH). In IUH the effective precipitation is applied to the drainage basin in zero time. Various methods were provided for determination of IUH, from which Clark's SUH method is more applicable compared with the other methods. Clark's method requires estimation of three basin parameters for the derivation of IUH, time of concentration (Tc), storage attenuation coefficient (K) and time-area histogram of the basin. In this study the required parameters for Clark's SUH were derived using geographic information system (GIS), techniques. The results show good agreements between observed data hydrographs and Clark's SUH which was derived by GIS techniques. This model was applied to the Kardeh river basin, in Khorasan province located in the northeast part of Iran. The results show that the Arcview GIS software is a powerful tool for IUH estimation.

Key words: Instantaneous unit hydrographs, Clark, Kardeh Basin, digital elevation model

INTRODUCTION

One of the most important steps toward hydrology analysis and construction of the hydrographs for a given project is the development of Unit Hydrograph concept. Unit hydrograph is a hydrograph for which the height of runoff is equal to one. It means that if we divide the volume of the runoff to the related basin area we get "one" for height of the runoff. The special thing about the Unit Hydrograph is that it enables us to derive the Hydrograph of design flood, based on which the hydraulic structure is to be designed. In Instantaneous Unit Hydrograph the effect of time is neglected (duration=0 h) and a unique Unit Hydrograph for the given basin would be constructed[1]. The advantage of using Instantaneous Unit Hydrographs over the Unit Hydrographs is that Instantaneous Unit Hydrographs are only related to the effective rainfall, therefore in the process of analysis one of the parameters would be eliminated. As the result, using Instantaneous Unit Hydrographs, for investigation on the rainfall-runoff of a basin, is much suitable than using Unit Hydrographs. Making use of GIS in river engineering has gained extreme development in recent decays, in such a way that all softwares used in this branch has the direct capability of GIS, or the capability of connecting to one of the softwares that GIS has provided[2]. On contrary to classic methods, GIS records the collected data digitally and uses different methods for super imposing the data from different sources. The most important capability of GIS is its ability to analyze the complicated data of location and none location. At present the concept of GIS has changed from a primarily of being a data bank, for saving different data, to a software for helping on decision making process. Therefore many believe that instead of using usual word of GIS the word GIM (Geographic Information Management) should be used[3]. With respect to what has been said and taking into consideration the importance of the two subjects of Instantaneous Unit Hydrograph and GIS, it is possible to provide an instrument with the ability of combining the two mentioned subjects as a unique and compatible system. This can be considered as an important step toward developing data systems, which can be used to improve the quality of services given to the clients. The aim of this research was to derive the Clark's Instantaneous Unit Hydrograph for the Kardeh river basin, in Khorasan province located in the northeast part of Iran, using the arcview GIS software.

Clark's instantaneous unit hydrograph: Different methods have been proposed for deriving Unit Hydrographs. From which the Clark's method is known to be the most practical. Clark has proposed a model for deriving Instantaneous Unit Hydrograph by using the idea of that the outflow hydrograph from any rainstorm will be transported directly in the river path while taking

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into account the storage effects of separate sub basins. By modeling the transportation of runoff directly through the river path up to the outflow point and using the results for finding the travel time, we can derive a hydrograph for which the storage effects has been eliminated. Then using this hydrograph for an imaginary basin having linear storage characteristic will include storage effects. Using these assumptions and the principal of continuity, Clark has derived an Instantaneous Unit Hydrograph for a basin while the value of inflow is provided by the following equations[1]:

$$Q_2 = CI_2+(1-C)Q_1 \quad (1)$$

$$C = \frac{2\Delta t}{2k + \Delta t} \quad (2)$$

In which I_2 is the flow rate at the end of time period Δt while Q_1 and Q_2 are inflow and outflow rates during this time period. The inflow rate during the i th period can be estimated from the following equation[1]:

$$I_1 = 0.278\frac{a_i}{\Delta t} \quad (3)$$

where, a_i is the drainage area at the end of i th period which is calculated from Digital Elevation Model (DEM). For deriving Clark's synthetic hydrograph we need to estimate the flow parameters:

- Time of basin concentration (Tc) is provided by the capabilities of arcview GIS software.
- The time-area diagram is derived from the basin (DEM).
- "K" parameter which is referred to the amount of outflow from the river channel storage after cutting the inflow of water into it.

Investigation area: Kardeh basin was studied under this research. This basin is located in Khorasan province in the northeastern part of Iran with least elevation of 1300 m above the sea level and the highest elevation of 2960 m. The average elevation is calculated to be 2021 m above the see level. The area of the basin is 542 square kilometers and Kardeh is the main river.

MATERIALS AND METHODS

Preparing Digital Elevation Model (DEM): The Digital Elevation Model is a digital topographic map, which contains the elevation of all the points located at the region. For constructing this model, first the elevation becomes digitized by using 1:500000 topographic maps and AutoCAD software. This separates all the

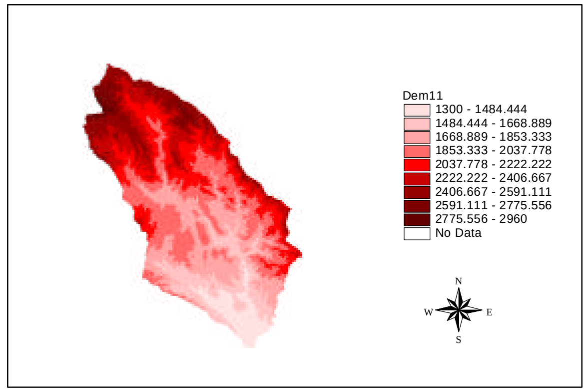

Fig. 1: DEM map in arcview

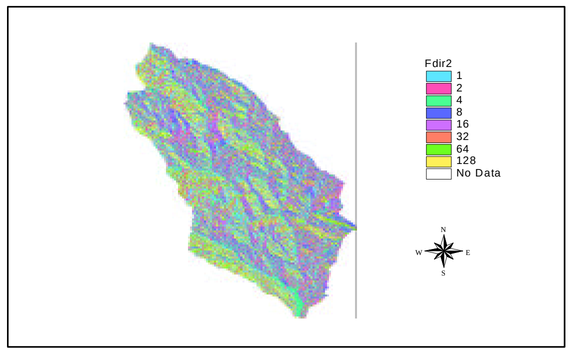

Fig. 2: Flow direction map

topographic lines. Then the Triangular Irregular Network (TIN) is drown and at the end (DEM) is constructed. After construction of (DEM) it is rendered by arcview (Fig. 1).

Preparing layers of flow direction and flow length: According to the method being used the function of the flow direction determines the runoff direction. Based on the flow direction the collective flow is calculated. In preparing layers of flow direction by using the Digital Elevation Model, calculation for each grid is carried out based on its value compared with the eight neighboring grids. After that the direction of flow for each grid is defined by specifying a code to it. Arcview uses this flow-direction map as an input for construction of the flow-length map. Flow-direction and flow-length maps for Kardeh basin are shown at Fig. 2 and 3.

Construction of curve number map: For constructing curve-number map (CN), two types of maps, land-use and soil, were used. By, using soil hydrologic type classifications with soil maps and land use type classification tables with land-use maps, the curve-number (CN) map was constructed. The curve-number (CN) map for the Kardeh basin provided by arcview has shown on Fig. 4.

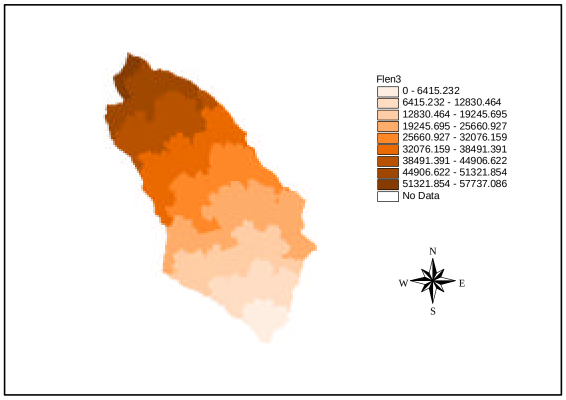

Fig. 3: Flow length map

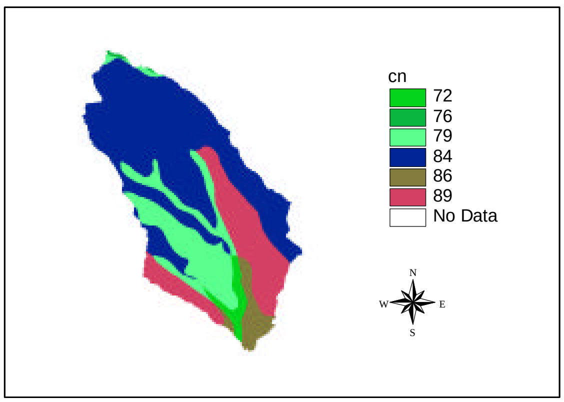

Fig. 4: Curve number map (CN)

Basin concentration time: Since the area of the Kardeh basin is very large, the method proposed by soil conservation society (SCS), which is known as long-time method, was used to obtain the concentration time of the basin. In this method the lag time is calculated using the following equation:

$$t_{Lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900y^{0.5}} \quad (4)$$

where, t_L is lag time in hour, "L" is the length of the main flow path in feet, "y" is the average slope of the basin in percent and "S" is an index of saving water in the basin which can be calculated from the following equation :

$$S = \frac{1000}{CN} - 10 \quad (5)$$

Arcview gets values of "L" from length of flow for each grid (FLGrid) and "y" average slope of the basin from the slop map and CN the average of Curve-Number for the basin from the CN map. By using CN map (Fig. 4) and the equations of (4) and (5), the concentration time of the Kardeh basin found to be 11.86 h.

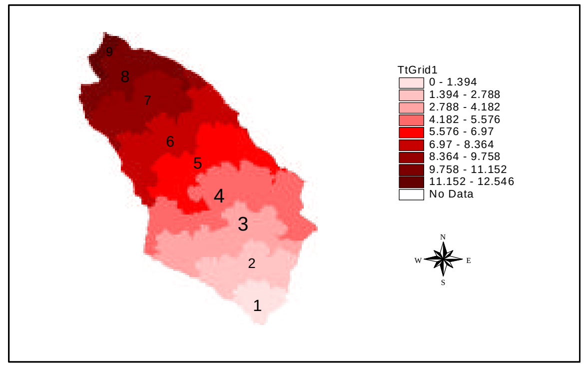

Fig. 5: Travel time (isochronal) map

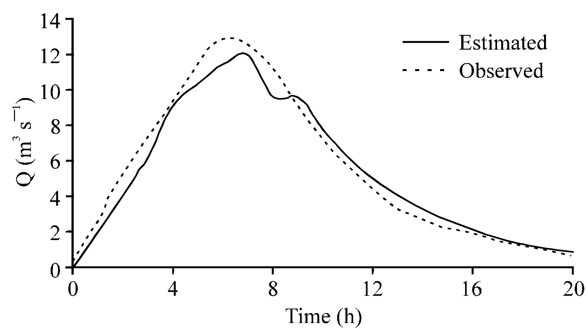

Fig. 6: Observed hydrograph and estimated Clark IUH

Travel time grid (TtGrid): After computing the travel distance of each grid, (FLGrid), the next step is calculating the travel time values, (TtGrid). The maximum value of the (FlGrid) belongs to the remotest grid of the basin to the outlet. Travel time of flow from that grid to outlet gives the time of concentration value of the basin, T_c . Equation 6 is used to prorate the values of (FlGrid) and to convert it to time values. The travel time grid of the basin is then determined from eq. 6 and named as (TtGrid).

$$TtGrid = \frac{T_c}{Max\ of\ cell\ travel\ lengths} * FlGrid \quad (6)$$

Travel-time maps or isochrones for Kardeh basin are shown in Fig. 5. After getting isochrones (TtGrids), the areas between isochrones are then calculated by arcview.

Determining attenuation coefficient (K): The storage attenuation coefficient, which represents the storage characteristic of stream channel, is calculated from an observed flood hydrograph of the basin. Therefore there is no need to consider the rising limb of the hydrograph, since the value of "K" is only related to the falling limb, which analytically is a power function with a negative slope.

Table 1: Calculation of Clark's IUH

Time (h)	Number of rsochrones regions	Area of time concentration steps (km^2)	Ii (m^3s^{-1})	IUH Qi (m^3s^{-1})
0	0	0.00	0.00	0.00
1	1	35.73	9.93	1.91
2	2	47.08	13.08	4.06
3	3	53.28	14.81	6.14
4	4	76.05	21.14	9.03
5	5	54.77	15.22	10.23
6	6	61.72	17.10	11.33
7	7	57.34	15.94	11.81
8	8	49.00	13.80	9.53
9		33.02	9.17	9.46
10				7.63
11				6.16
12				4.97
13				4.01
14				3.21
15				2.59
16				2.09
17				1.60
18				1.29

$$Q_1 = Q_0 e^{-t/k} \quad (7)$$

$$K = t/\ln(Q_0/Q_t) \quad (8)$$

where, Qt is inflow rate at time "t", Q_0 is the outflow rate at the start of a drought curve and "K" is the storage attenuation coefficient, "K" can be calculated by plotting outflows vs. time on a semi logarithmic scale. "K" coefficient for Kardeh basin was calculated as being 4.68 h. By selecting the one-hour duration and using equation (2), the value for "C" was calculated as being equal to 0.193. The results of calculations, which are needed to construct Clark's unit hydrograph, are given in Table 1. After determination of the outflow for one hour duration by Clark's hydrograph using the abilities of GIS techniques, the calculated values were compared by the observed values. This comparison is highlighted in Fig. 6. As it is shown there is a good match between calculated values using Arcview GIS software and observed values, from observation hydrograph.

CONCLUSION

In this study Instantaneous Unit Hydrograph was obtained using the capabilities of GIS. Time of basin concentration and slope of the basin were calculated more easily and accurately using GIS techniques in comparison with traditional methods. Curve-Number map was constructed using two types of maps, land-use and soil. Required parameters for determination of Clark's IUH were calculated with high precision using GIS techniques. Finally by comparison of calculated values by real observed values it was shown a good match between the two results.

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