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Water Yield Estimation in Polrudwatershed Based on Empirical Methods and Modelling in Geographic Information System (GIS)

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ABSTRACT

Accurate estimation of basin discharge has been discussed by the experts in various construction projects and this important issue has considerable influence on the design of the required structures and their cost. Basin discharge can be calculated according to different methods. According to the conditions of the basins under study, the accuracy of these approaches varies and the obtained results often show relatively large differences. To estimate the annual average flow of the basin, the obtained results of discharge stations are analyzed by different methods and regional relations discharge are obtained. To this end, in this study four regional models consists of an area – discharge, area – standard deviation, area - specific discharge and height - discharge have been used. Also, basin discharge estimation is presented based on flow shortage methods. For this purpose, the method of empirical relations, like ICAR, Justin and Coutange catchment were used to calculate discharge then regional models were compared. The obtained results indicate the accuracy of the results of flow shortage methods to determine the discharge basin. In this research, Polrud basin co-discharge model has been developed in the Gilan province by using the capabilities of GIS model.

KEYWORD

Experimental methods, Justin, ICAR,Coutange, GIS, Regional methods

INTRODUCTION

Determining the annual and monthly amount of water Abdullahvand (2009)applied empirical methods like Justin, ICAR, Coutgine to estimate water yield in KuhBazu watershed located in Yazd, Iran. The results showed the remarkable inaccuracy in Coutgine and ICAR methods for arid areas and good accuracy of Justin method for such areas. Bashul (2009) compared Turc, Coutgine, ICAR, Justin, Lacey and WMO methods with the measured values to estimate the annual rivers' runoff in arid and semi-arid areas in Neishabour watershed. The obtained results showed acceptable accuracy of Lacey model compared to other methods. Shahmohammadi and Nikbakht (2004) used empirical relations Coutgine, Turc, Justin, and I.C.A.R to calculate the depth of annual runoff in the central and south east of watershed of Khuzestan plain. The results showed that at 90% level of confidence all three methods are equally acceptable and at 95% level of confidence ICAR is more suitable. In a study Tahmasebipour and Beiranvand (2002), evaluated the empirical formulas for estimation of water yield in watersheds without hydrometric stations. The results showed that Coutigne, ICAR, Turc, Irrigation Department of India relation and Khosla are prior to other methods. Some other studies about yield water volume estimation out of Iran have been done by Hawley and McCuen (1982), Babel, Gupta, and Nayak (2005), Laaha and Blöschl (2006) and CSIRO institute in Australia (2008).

CASE STUDY

The range under study is a part of the coastal area of Caspian watershed that has been from Northern slopes and the foothills of Alborz and includes mountainous areas and coastal plains. The mentioned range is located between Roudsar in the west and Chaboksar and Ramsar in the East and includes the East of Gilan province. The area of this part is 2746 km2, which about 90 percent area is located in Gilan province and 10 percent of it is located in Mazandaran

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province; its length is 43 km and its width is about 54 and its length is 5 km along the coast of the Caspian Sea. The largest river in this area is Polrud River. The area of Polrud River is 1345 square kilometers (the area output has been considered the next point of the junction area of Chakrud River) and the length of its main branch is 54 kilometers to the conjunction point of Chakrud River and 90 kilometers to the sea and general direction of the river is from south to north.

The most important sub-branch of Polrud River is Chakrood River, whose area of its basin is 770 square kilometers in the basin of "Ryab" and "TesehChal" and the length of its main branch is 51 km and important waterways were located such as. The range of basin and sub-basins of Polrud River have been presented In Figure 1.

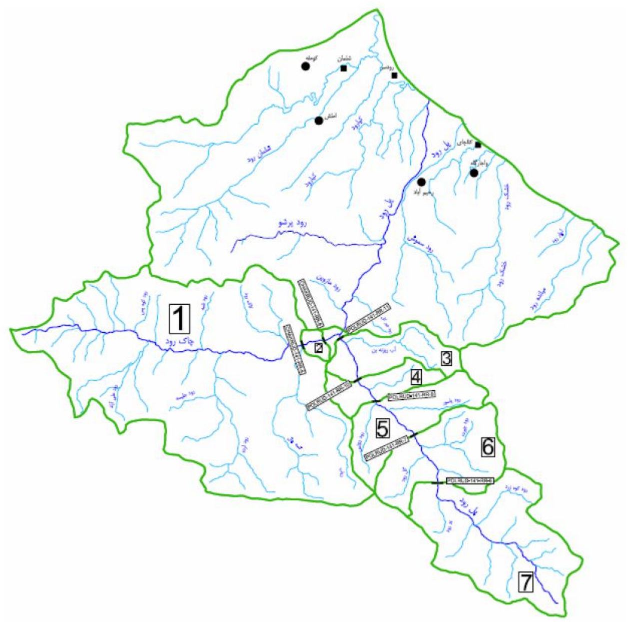

Fig.1.the study area

Analyzing the Results of Stations and Providing Regional Relations

To estimate the annual average flow of the basins of the stations under study, the obtained results of discharge stations are analyzed by different methods and logical relations of discharge was obtained (Table 1).

To estimate the annual average flow of the basins in the area, the regional models, (area– discharge), (area-standard deviation, discharge), (area-specific discharge), (height-specific discharge) have been used. Totally, 4 regional models have been examined in these studies. Table 1 presents the results of different models in estimating the discharge site under investigation.

As the results in Table 1 show, the percentage of estimation error, Q-A model has the lowest estimation error and SPR-Stdev model has the maximum estimation error. In examining the results of K2 test, it can be stated that Q-A model has been the most appropriate model and SPR-Stdev model has been the worst model. Overall, the examining Q-Stdev-A and SPR-Stdev shows they have been less accurate and practically, these models are not able to estimate discharge values of sites under study because of hydrometric stations are located in plains and the sites under study are located in the highlands and mountains.

Determination Basin Discharge based on Flow Shortage Method

Using the hydrological balance techniques can be useful to achieve an estimation of the volume of water flowing and rainfall losses in the considered scale. In order to perform the necessary estimations in the context of these studies, using the current experimental formulas in this field, the evaluation and calculation of the total annual rainfall losses are inevitable. To obtain necessary information regarding this process, the general form of the balance equation is used as follows:

$$P+S=Q+D=(S+\Delta S) \quad (1)$$

P: Annual rainfall height
S: storage at the beginning of the period (water year)
Q: the height equivalent to the surface flow
D: evaporation and transpiration and other losses
(S+ΔS): changes in the storage at the end of the period

If the changed balance has not happened in the flow storage during the period, it can be assumed the following equation is obtained in the simple form as follow:

$$P=Q+D \quad (2)$$

The goal is to determine the value of D as lack of flow or quantity of R as the surface runoff in experimental methods. The above parameters are considered as indicator for the amount of evaporation and finally precipitation for specific areas whose climate is not covered by permanent ice exposed to the intense and continuous sunshine and are calculated using 2 meteorological factors.

T: Annual average air temperature as a representative of the power evaporation of air
P: Average annual rainfall

Several formulas have been proposed calculated D that temperature is involved in some of them and this is where the rainfall exceeds certain limits. The following are some of the empirical relations for calculating basin discharge are studied.

ICAR Relation: Another experimental method used is the method of Indian Committee Agriculture (ICAR). In this method, the amount of annual runoff is calculated by using the following equation:

$$Q=\frac{CP^{1.44}}{T^{1.31}A^{0.613}} \quad (3)$$

In this relation:
Q: amount of runoff from annually rainfall (m)
A: area (km2)
P: average annual rainfall (cm)
T: average annual temperature versus (c)
C: coefficient of equation

The results of the ICAR method are presented in Table 2.

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Tab.1. Test results of various models to estimate the discharge site under review

Site Name	Average discharge	Area (km2)	StDev.		(Q-A) model	(Q-StDev-A) model	(SPR-A) model	(SPR-StDev) model	Evaluation
Chakrud-141-RR-5	6	760.9	2.95	Discharge *	9.04	9.07	9.06	10.38	Q-A model
				Error (%)	50.65	51.23	51.01	72.93	50.65
				K2	9.23	9.45	9.37	19.15	9.23
Chakrud-141-RR-6	6	770.1	2.97	Discharge *	9.10	9.13	9.12	10.45	Q-A model
				Error (%)	51.61	52.20	51.98	74.10	51.61
				K2	9.59	9.81	9.73	19.77	9.59
Polrud-141-RR-11	8	567.7	2.44	Discharge *	7.73	7.76	7.75	8.80	Q-StDev-A
				Error (%)	3.32	3.00	3.09	10.05	3.00
				K2	0.07	0.06	0.06	0.65	0.06
Polrud-141-RR-10	6.5	495.9	2.23	Discharge *	7.20	7.22	7.21	8.16	Q-A model
				Error (%)	10.73	11.7	11.00	25.55	10.73
				K2	0.49	0.52	0.51	2.76	0.49
Polrud-141-RR-9	5.5	450.	2.10	Discharge *	6.84	6.86	6.86	7.73	Q-A model
				Error (%)	24.37	24.71	24.66	40.62	24.37
				K2	1.8	1.85	1.84	4.99	1.80
Polrud-141-RR-7	4	349.8	1.78	Discharge *	5.98	5.99	5.99	6.71	Q-A model
				Error (%)	49.45	49.79	49.80	67.75	49.45
				K2	3.91	3.97	3.97	7.34	3.91
Polrud-141-RR-6	2	225.5	1.33	Discharge *	4.73	4.74	4.74	5.25	Q-A model
				Error (%)	136.64	139.98	137.18	162.27	136.64
				K2	7.47	7.51	7.53	10.53	7.47
Evaluation	Rating Model				1	3	2	4	
	The average error				46.68	47.00	46.96	64.75	
	The sum of K2				4.65	4.74	4.71	9.31	

* Discharge Estimation

Tab.2.the estimated results of C on ICAR relation

Site	Area (Km2)	Mean H. (m)	P (cm)	T (C)	Q estimated (cms)	c
Chakrud-141-RR-5	761	1836	46	9.4	6	0.26
Chakrud-141-RR-6	770	1828	47	9.4	6	0.26
Polrud-141-RR-11	568	2332	60	7.6	8	0.15
Polrud-141-RR-10	496	2353	58	7.5	6.5	0.12
Polrud-141-RR-9	451	2394	56	7.4	5.5	0.1
Polrud-141-RR-7	350	2466	54	7.1	4	0.06
Polrud-141-RR-6	222	2626	50	6.6	2	0.02
P1*	1345	2037	53	8.7	14	0.65

Justin Method: Justin's relationship is based on two factors of weather and one factor of physiographic that include:

T: Annual temperature as the power of evaporation in air
P: Average annual rainfall as a representative of required irrigation facilities in order to evaporate
S: Representing the basin physiographic conditions
Justin's relationship is as follows:

$$Q=\frac{KS^{0.152}P^2}{1.8T+32} \quad (4)$$

In this relation:
Q: The amount of annual runoff from rainfall (cm)
S: the average slope of the basin (m/m)
P: Average annual rainfall (cm)
T: Average annual temperature (C)
K: The coefficient of the equation is determined by the characteristics of the area under study.It has been attempted to obtain ratio coefficient to calibrate it in the area under study. By using the discharge information on the station and performed reviews on them, the amount for site basin under study has been is estimated at 0.72 times. The results of Justin method are presented in Table 3

CoutangeRelation: In this method, the flow annual deficit is calculated from the following equation.

$$D = P - \lambda p^2 \quad (5)$$

$$\lambda=\frac{1}{0.8+0.14T} \quad (6)$$

The lack of annual flow is in meters (m) and annual rainfall is in meters (m) and the average annual temperature is in degrees Celsius in this relation. The application of the above relation is just recommended for two extreme precipitations.

$$\frac{1}{8\lambda} \leq P \leq \frac{1}{2\lambda} \quad (7)$$

The results of Coutange relationship are presented in Table 4.

COMPARING THE RESULTS OF EMPIRICAL RELATIONSHIPS

ICAR and Justin relations, each of them, have specific calibration coefficients (K, C) which are possible to estimate using statistics or data from hydrometric stations or desert estimation. Since, regional variations of the above parameters with the correlation equations have not resulted in suitable equations, Based on hydrometric stations located in the basin Polrud and also the results of desert observations, above coefficients were calibrated in Polrud basin.

Tables 2 and 3 show the results of calculation of parameter values of equations of ICAR and Justin in the calculation C, K for potential and hydrometric stations located in the Polrud basin. Data used in the analysis of these results are extracted by using the form of lines of rainfall and temperature and slope in arc view and calculations have been applied. Also, Coutange relationship was directly used to calculate the amount of the site discharge and hydrometric stations by using the above information that the results did not correct. Table 5 shows the results of calculation via the above method.

In order to investigate the changes in the coefficients K, C in the basin under investigation, it was attempted to establish correlation between these parameters and the area and the average height of the basin in the sites under study and hydrometric stations which the results are given in Figure 2 and Figure 3. Evaluation of the obtained results show that the changes of these parameters have been greatly affected by the average height of the basin and according to it, the changes relationship between k, c was used as a function of height in the regional model in the whole basin.

PREPARATION OF BASIN CO-DISCHARGE MODEL

To calculate the discharge of the basin by this method, and by considering the more appropriate correlation between k relation and height, Dem layer of K coefficient was calculated in the basin under study and it was computed for each of potential Pixel for crating discharge.

Accordingly, the relationship between the independent variables of height, temperature, precipitation and surface was determined by discharge which this relationship is:

$$Q=\frac{0.72\, S^{0.155}P^2}{1.8T+32} \quad (8)$$

So using Arc View software capabilities, basin discharge co- lines were drawn by overlapping the layers of independent variables based on the above relation and the basin discharge values were calculated on the sites and hydrometric stations.

Tab.3.the estimated results of K coefficient on Justin relation

Site	Area (Km2)	Mean H. (m)	P (cm)	T (C)	S (m/m)	Q estimated (cms)	K
Chakrud-141-RR-5	761	1836	46	9.4	19	6	0.09
Chakrud-141-RR-6	770	1828	47	9.4	19.1	6	0.09
Polrud-141-RR-11	568	2332	60	7.6	25.7	8	0.06
Polrud-141-RR-10	496	2353	58	7.5	25.7	6.5	0.05

Polrud-141-RR-9	451	2394	56	7.4	25.2	5.5	0.05
Polrud-141-RR-7	350	2466	54	7.1	25.4	4	0.04
Polrud-141-RR-6	222	2626	50	6.6	25.3	2	0.02
P1*	1345	2037	53	8.7	22	14	0.15

Tab.4.the estimated results of D coefficient on Coutange relation

Site	Area (Km2)	Mean H. (m)	P (cm)	T (C)	λ	D (m)	Q estimated (cms)
Chakrud-141-RR-5	761	1836	46	9.4	0.5	0.36	6
Chakrud-141-RR-6	770	1828	47	9.4	0.5	0.36	6
Polrud-141-RR-11	568	2332	60	7.6	0.5	0.41	8
Polrud-141-RR-10	496	2353	58	7.5	0.5	0.4	6.5
Polrud-141-RR-9	451	2394	56	7.4	0.5	0.39	5.5
Polrud-141-RR-7	350	2466	54	7.1	0.6	0.38	4
Polrud-141-RR-6	222	2626	50	6.6	0.6	0.36	2
P1*	1345	2037	53	8.7	0.5	0.39	14

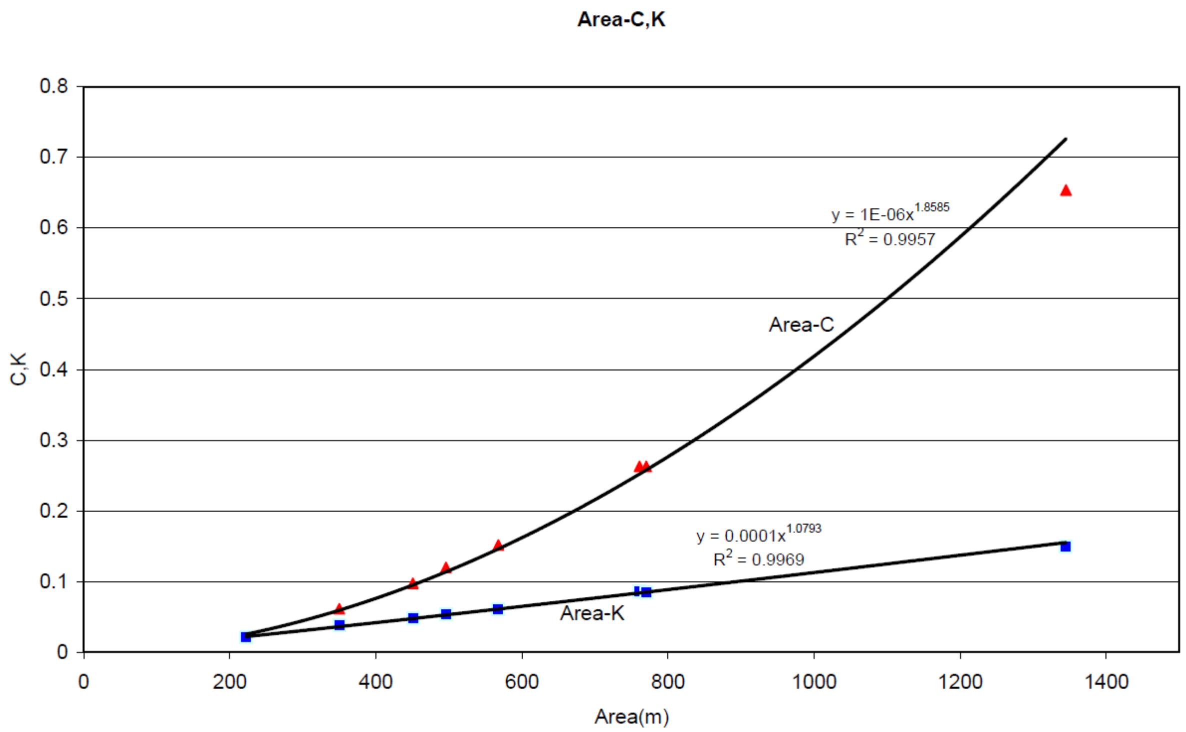

Fig 2 : The effect of the changing C and K coefficient on average height of the catchment

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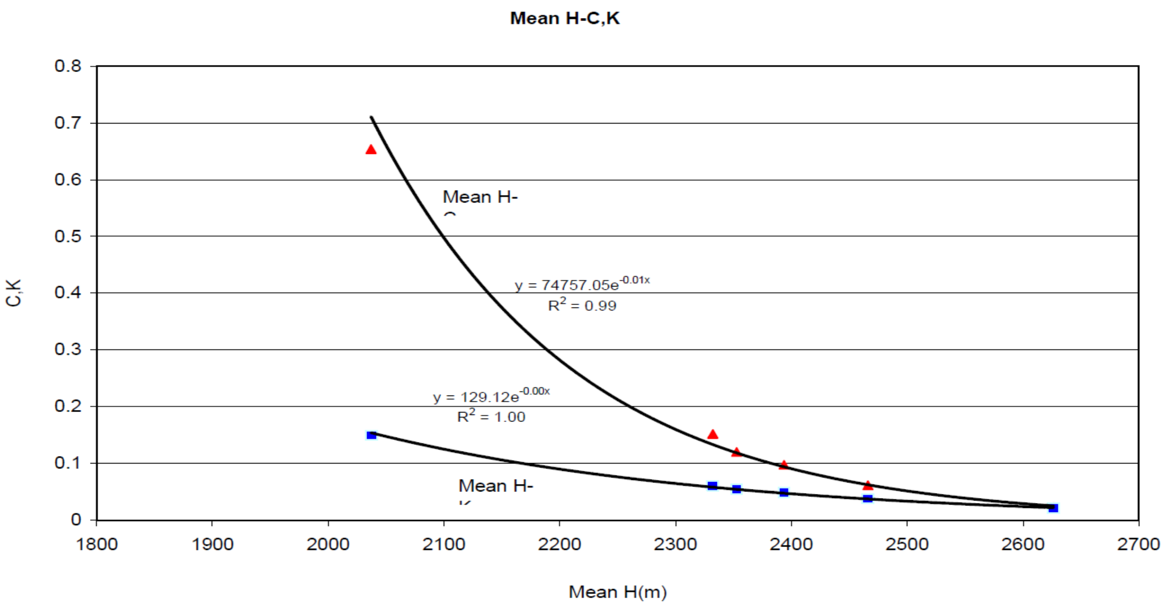

Fig 3. The effect of the changing C and K coefficient on watershed area

Tab.5.a comparison of the experimental methods used in the study

Empirical method	Variable	Q_{mean}(cms)	Mean H (m)	Area (Km2)	Site
Cotaigne	Q=f(T,P)	2.50	1835.98	760.93	Chakrod-5
		2.50	1828.13	770.13	Chakrod-6
		3.50	2332.15	567.68	Polrod-3
		2.80	2352.70	495.93	Polrod-4
		2.40	2393.60	450.64	Polrod-4-2
		1.80	2466.05	349.85	Polrod-5
		1.00	2626.19	222.46	Polrod-5-1
		5.80	2037.10	1344.70	P1
ICAR	Q=f(Area,T,P)	12.60	1835.98	760.93	Chakrod-5
		12.70	1828.13	770.13	Chakrod-6
		21.70	2332.15	567.68	Polrod-3
		19.40	2352.70	495.93	Polrod-4
		18.40	2393.60	450.64	Polrod-4-2
		16.40	2466.05	349.85	Polrod-5
		14.00	2626.19	222.46	Polrod-5-1
		20.80	2037.10	1344.70	P1
Justin	Q=f(T,P,S)	5.90	1835.98	760.93	Chakrod-5
		6.10	1828.13	770.13	Chakrod-6
		8.40	2332.15	567.68	Polrod-3
		6.70	2352.70	495.93	Polrod-4
		5.70	2393.60	450.64	Polrod-4-2
		4.10	2466.05	349.85	Polrod-5
		2.40	2626.19	222.46	Polrod-5-1
		14.10	2037.10	1344.70	P1

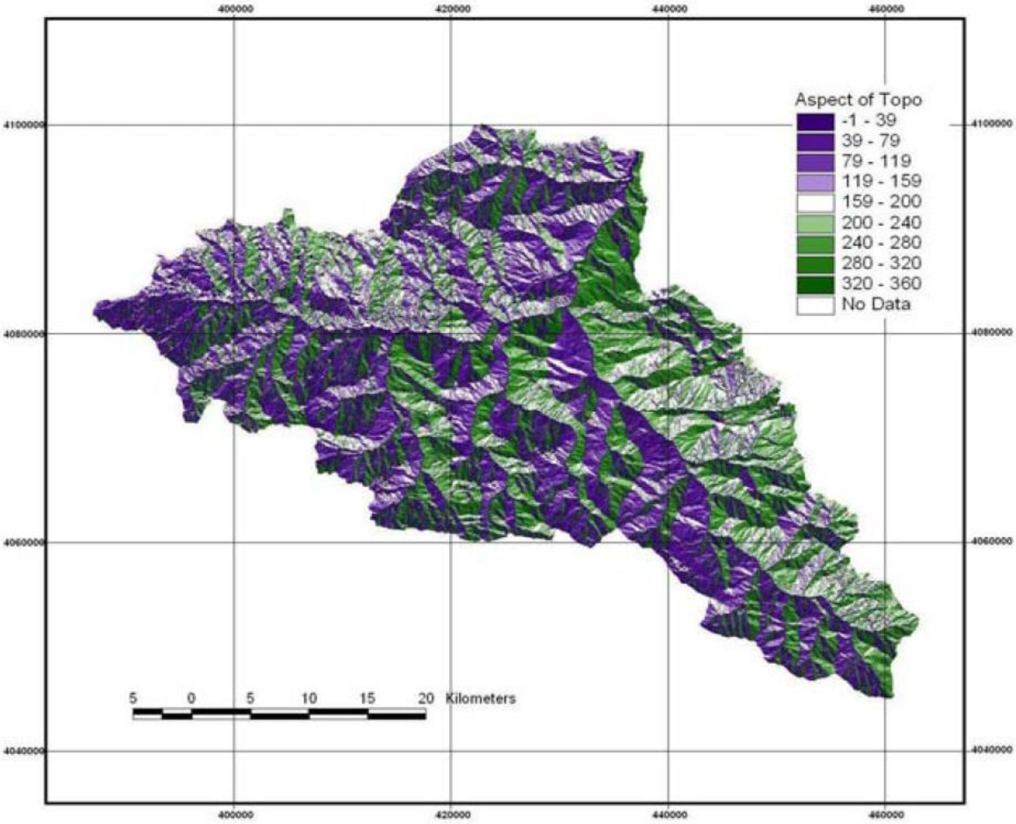

Fig 4. Slope in Polrud river basin

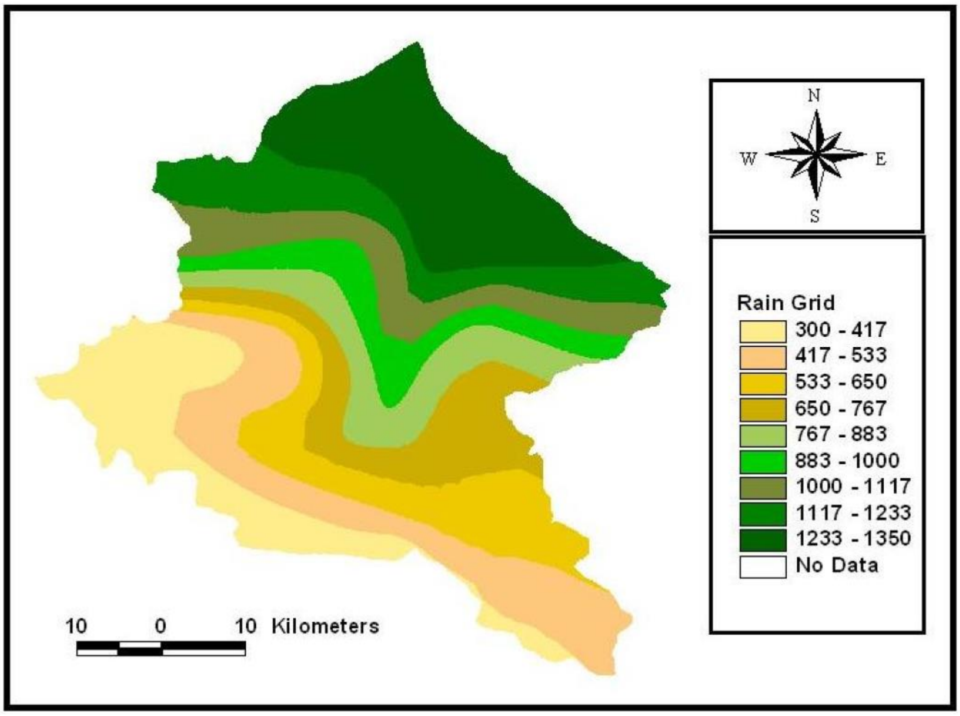

Fig 5.Precipitation curve in the Polrud river basin.

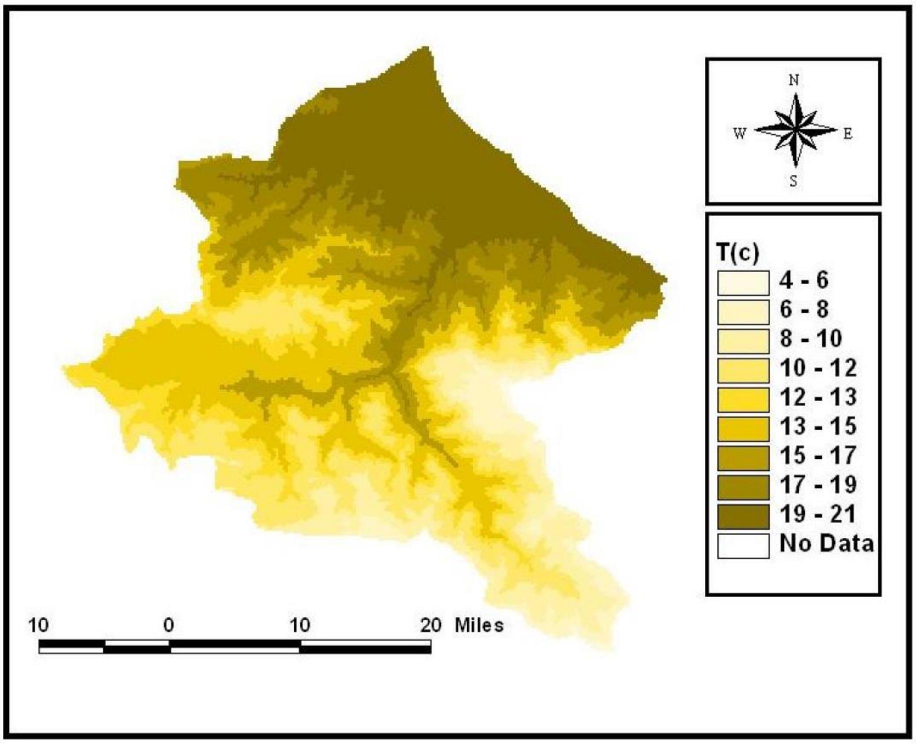

Fig 6. Isothermal curve in the Polrud river basin

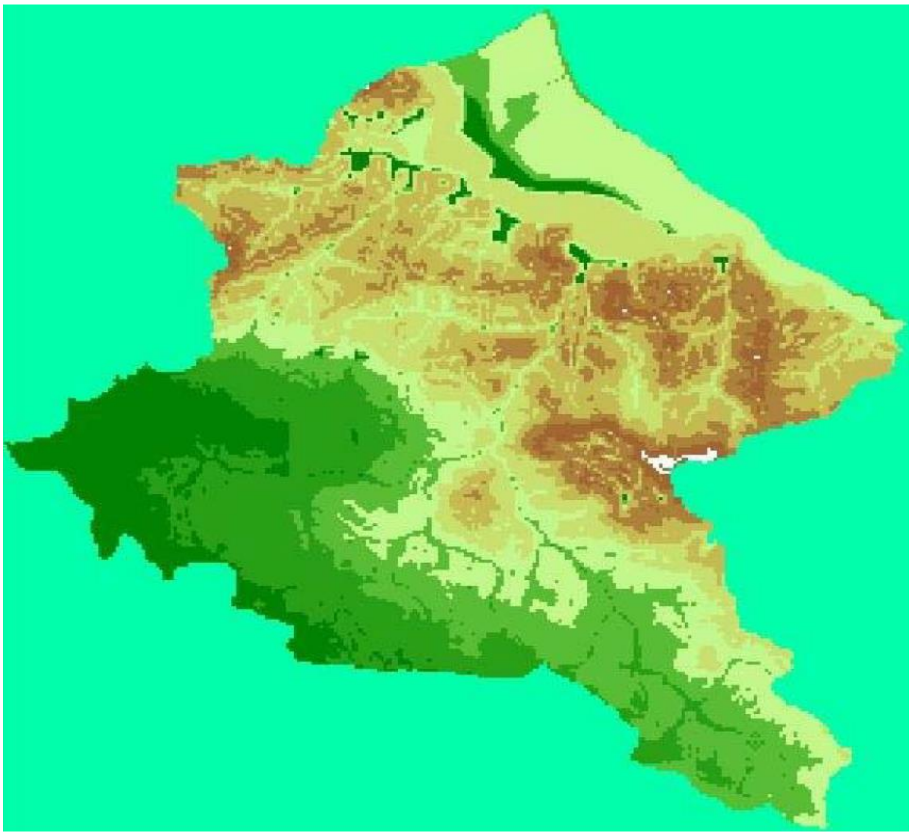

Fig 7. The discharge curves of the Polrud river basin

CONCLUSIONS

Survey results show that the amount of calculated discharge by this method, while having the possible highest accuracy regarding the values of hydrometric stations and sites, has structurally appropriate compatible with the general conditions of discharge basin. For example, the total outflow of the rivers Polrud and Chakrood, at the junction of the two branches together, have been estimated 8 and 6 cubic meters per second, respectively which the sum of these numbers is match while compared to the total amount of discharge at the site of Derazlat hydrometer station which is located lower than these two branches and the passed the connection between the two.

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