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Analysis of hydro morphometric characteristics using GIS and statistical analysis (Case study: Maragh basin, Esfahan province, center of Iran)

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ABSTRACT

In present research, the relation between stream rank and each of stream parameters such as stream length, slope, area, bifurcation ratio and stream branch number have been determined using GIS and statistical analysis. This study determines the best method of stream ranking in Maragh basin (located in Kashan city, Esfahan province, Iran) using four stream ranking systems (Horton, Strahler, Shidger and Shreve). The results showed that 1- there was the well-organized relation between the rank and the stream branch number and the rank and the area. They decreased as a result of increasing the rank. 2- The basin slope decreased as a result of the rank increasing. Also, according to the results of regression analysis and the correlation among different factors, there were the most correlation between stream rank and parameters of branch ratio, stream branch number, slope, basin area and stream length in Strahler method withR^2*=1, 0.993, 0.960, 0.906 and0.879, respectively. Therefore, Strahler method is more appropriate than other methods, but in this method, total number of existent streams in drainage system is not showed. Hence, Then, one of Shreve or Shidger methods can be used to show the stream number.*

Keywords: Hydro morphometric, stream rank, ranking system, Maragh basin

INTRODUCTION

Physical parameters such as linear characteristics and hydro-morphological relations are measured and analyzed in basins. It is clear that this analysis is done by mathematic and statistic models and it needs some data, geological and topography information [1]. Hydro-morphologic and morph-dynamic properties of the basin are related to the hydrology. These properties are used in environmental management. In order to recognize the hydrological system of basins, their drainage situation should be studied[8].The topology of stream system has been widely examined during the last decades using quantitative methods provided by Horton, Shreve, Strahler and Tokunage. Also, the relation between topology of stream system and hydrological reactions in a basin has been studied by different researchers [4, 12, 14, and 15]. On the other hands, the stream network has been studied in order to recognize the process structure of the sediments transport (in form of bed load), nutrients, coast plant cover and food needed for aquatic organism by many researchers [2, 3, 5, 6, 7, 9, 10, 11, 13, and 16].The research results show that morphometric parameters play an important role in hydrologic behavior of the basin. So, they should be involved in environment management plans. Ignoring these factors lead to increase the costs and non-accessibility to the complete succeeds in environment management. As a result, these studies will play the important role in terms of environment, economic and society. Therefore, the development of a systematic frame in order to study the dynamic processes in the stream system can be effective in terms of hydrology, geomorphology, watershed management and ecology. In this study, Maragh basin has been investigated using statistical tests. In the other words, this study is the investigates hydro-morphometric properties and different methods of the stream ranking (Horton, Strahler, Shreve and Shidger).

MATERIALS AND METHODS

Study area

Maragh basin with an area of 5309.09 ha is located in 51° 00´ to 51° 30´ eastern longitude and 33° 30´ to 34° 00´ northwest latitude and about 35 km of west of Kashan city (in Esfahan province, Iran). The maximum and minimum height of the region is 3450 and 1600 m from sea level, respectively. The average annual rainfall and average slope in this basin is 250 mm and 24%, respectively. The geological formations of Q^{al}, gd, K_2^1, di E_5^t and $K_1^m$are observed in this region (tab. 2).

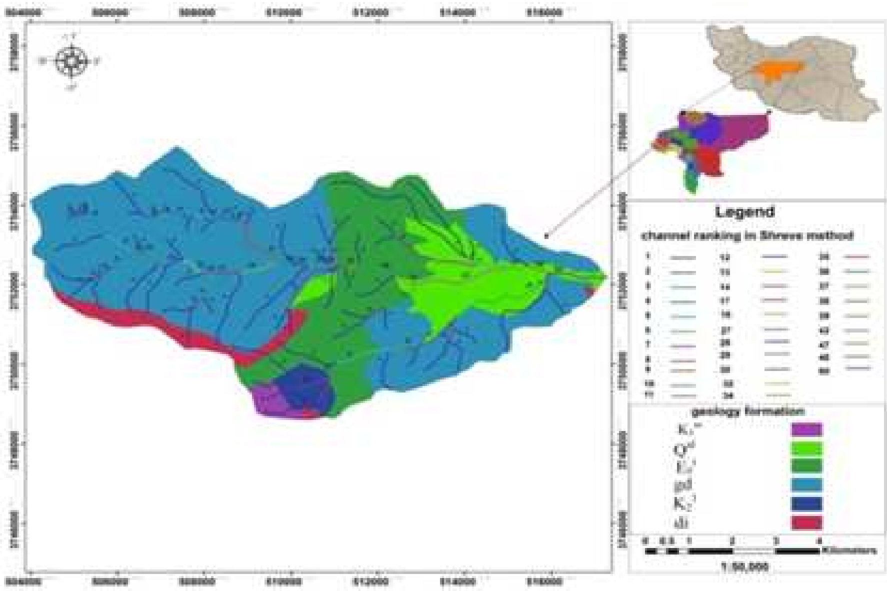

Figure 1: location of study area in Esfahan province and Iran

Study methodology

In this study, the correlation relation between the stream rank and parameters of stream length, slope, area, bifurcation ratio and stream branch number were determined using four ranking systems(Horton, Strahler, Shreve and Shidger) and Arc $GIS_{9.3}$and $SPSS_{16}$software's.First, maps of drainage network, geology and slope were prepared using Arc $GIS_{9.3}$. Then, the stream network was ranked using stream ranking methods (Horton, Strahler, Shreve and Shidger). In next stage, the boundary of the basin was determined for each of the stream branches and the average slope, slope ratio, area, area ratio, drainage density, stream length, length ratio and bifurcation ratio were estimated for each basin. Finally, the relations between different parameters with the stream rank were analyzed using statistical analysis, regression and correlation between different parameters by stream ranking methods.

Also, in order to determine the bifurcation ratio, (stream number with specific rank ($\sum n$) to the stream number with higher ranks ($\sum_{n+1}$), eq. (1)was used.

eq. (1) $$R=\frac{\Sigma n}{\Sigma(n+1)}$$

The area ratio (Ra) was obtained by eq.(2)

eq. (2) $$R_a=\frac{Au}{A(u-1)}$$

Where Au is the average area of the region in the rank of u. The relation between lower ranks obtained using eq. (3)

Eq. (3) $i = \bar{L}. R_L^{i-1}$

Where i am the stream rank number, L_i is the average area of the basin branches with rank of i, $\bar{L}$ is the average stream length with rank 1 and R_L is the ratio of stream lengths in the basin. The relation between rank and stream slope obtained using eq. (4). [2, 5].

Eq. (4) $\bar{S}_u = \bar{S}_1 R_{s(u-1)}$

The slope ratio obtained using eq. (5)

Eq. (5) $R_s = [\bar{S}_u / (S_{u-1})]$

RESULTS AND DISCUSSION

The results of the physiography, parameters related to the morphometric properties in stream ranking methods (Horton, Strahler, Shreve and Shidger), the correlation and regression between stream rank with the parameters of stream branch number, bifurcation ratio, slope, area and stream length were determined.

Form of watershed basins

The basin form affects flood hydrograph. Also, maximum flow of flood is higher in round basin rather than expanded ones, as the concentration time in round basins is shorter and their reaction to the flood is more severe. Regarding to the results of table (1) and field observations, the studied basin has been almost round. Hence, the basin has a lower concentrate time. In this region, the (Q^{al}) formation has a good potential to make runoff. Also, the formations of gd, K_2^1,di and low permeability of $E_5^t$and K_1^mformations will lead to significant flood in the basin, during severe rainfall (tab (2)).

Table 1: Physiographic properties in Maragh basin

Parameters	value
Basin length (Km)	13.39
Stream length (Km)	91.72
Basin area (ha)	5309.9
Drainage density	1.72
Basin Perimeter (Km)	34.99
Compactness coefficient	1.34
Circulatory coefficient	0.54
Elongation coefficient	0.61
Mean slope (%)	24

Table 2: Geology formation in Maragh basin

symbol	age	Lithofacies	Area (ha)
Q^{al}	Quaternary	Recent alluvium	612.79
K_2^1	Middle Miocene to upper Miocene	Gray to yellowish cream limestone, silty marl and sandy limestone (coniacian- santonian)	125.12
gd	Post. M. Oligocene to lower Miocene	Granite- Granodiorite	3135.90
di	Lower Oligocene	Diorite and quartz diorite	230.51

Table 3: Used models and equations to study the correlation relation among morphometric parameters

Model	Equation
Linear	$Y= b_0+ b_1X$
Logarithmic	$Y=b_0+b_1\ln X$
Inverse	$Y = b_0+ \frac{b1}{X}$
Quadratic	$Y= b_0+b_1X+b_2X^2$
Cubic	$Y= b_0+b_1X+b_2X^2+b_3X^3$
Power	$Y= b_0 X^{b1}$
Compound	$Y= b_0+ b_1^T$
S	$Y= e^b o^{+\frac{b1}{X}}$
Growth	$Y= e^b o^{+b1T}$

Investigation of correlation and regression relation among parameters in system ranking methods:

In many cases, the linear regression cannot show the alteration among variables, thoroughly. In every issue where the simultaneous increase of the variables show no constant increase in independent variables, these statues will be observed. In many cases, the nature of the nonlinear relation is in such way that the common linear convertors miss their usual efficiency. In this study, models of table (2) have been used to study the alterations among independent and dependent variables.

Hence, according to the mentioned models in table (3), the relation between stream rank with parameters of the stream branch number, bifurcation ratio, stream length, area and the slope were investigated. Then, the model with the maximum $R^2$was selected using the R square obtained from each of the current models. This model shows the existent variance in data, properly. According to the results presented in table(4), the most number of stream branches and stream length were related to rank 1. Therefore, as a result of increasing the stream rank, number of the stream branch decreases. Also, the more increases the stream rank, the more decreases the stream drainage. This issue occurs because of young age of the region.

Table 4: Drainage network quantities in Maragh basin- (Horton method)

Rank	1	2	3	4
Rank number	60	12	2	1
Bifurcatio ratio	0	5	6	2
Stream length	56153	14919	7105	13548
Stream Length ratio	1.32	2.85	3.81	0
Area ratio	0.2	0.6	2.39	0
Area(ha)	3261.64	670.72	405.54	971.99
Slope ratio	0.76	0.64	1.25	0
Mean slope	65	50	32	40

Table (5) shows the selected models between the variables of physiographic properties and drainage characteristics in the studied basin. According to tab. (5), models are nonlinear. Also, the relation between rank and stream branch number is in form of Power equation with the R^2= 0.982. The relation between the rank and bifurcation ratio is in form of Cubic equation with R^2= 1. The relation between the rank and slope is in form of compound equation with R^2= 0.826. The relation between the rank and area is in form of Cubic equation with R^2= 0.736.Finally, the relation between the rank and the stream length is in form of compound equation with R^2=0.791.

Table 5: Results obtained from regression test in Horton method

	Variables	Stream rank and stream branch number	Stream rank and bifurcation ratio	Stream rank and slop	Stream rank and area	Stream rank and stream length
Model summary	Equation	Power	Cubic	Compound	Cubic	Compound
	R Square	0.98	1	0.82	0.73	0.79
	F	106.17	---	9.48	1.39	7.58
	Df2	1	3	1	2	1
	Df1	2	0	2	1	2
	sig	0.009	0.000	0.09	0.51	0.11
Parameter estimates	constant	3.98	1	13.33	2.11	3.82
	b1	-0.32	3.78	0.96	0	1
	b2	---	-1.42	---	2.3	---
	b3	---	0.14	---	-7.39	---

Table 6: Drainage network quantities in Maragh basin- Strahler method

rank	1	2	3	4
Rank number	60	12	3	1
Bifurcatio ratio	0	5	4	3
Stream length	56153	14919	18028.43	2624.57
Stream Length ratio	1.32	4.83	0.43	0
Area ratio	0.26	1.03	0.35	0
Area(ha)	3261.64	852.00	880.51	315.74
Slope ratio	0.64	0.85	0.41	0
Mean slope	65	42	36	15

As it can be seen in table (6), maximum number of the stream branch in Horton method was related to streams with rank 1. In this method, the more increases the stream rank, the more decreases the area slope. Of course, the bifurcation ratio increases as a result of increasing the stream rank.

Table (7) shows the models selected between the variables of physiographic properties and the drainage properties in the studied basin. So, models were nonlinear and the relation between the rank and stream number is in form of a logarithmic quartier model with R^2= 0.993. Also, the relation between the rank and bifurcation ratio is in form of Cubic model with R^2= 1. The relation between the rank and the slope is in form of Quadratic model with R^2= 0.960. The relation between the rank and area is in form of Cubic model with R^2= 0.906 and the relation between the rank and the stream length is in form of compound model with the R^2 = 0.879.

Table 7: Results obtained from the correlation test in Strahler method

	Variables	Stream rank and stream branch number	Stream rank and bifurcation ratio	Stream rank and slop	Stream rank and area	Stream rank and stream length
Model summary	Equation	Logarithmic	Cubic	Quadratic	Power	Compound
	R Square	0.99	1	0.96	0.90	0.87
	F	285.51	---	11.93	19.24	14.46
	Df2	1	3	2	1	1
	Df1	2	0	1	2	2
	sig	0.003	0.000	0.20	0.04	0.06
Parameter estimates	constant	3.89	1	5.07	131.98	3.870
	b1	-0.72	3.7	-0.7	-0.59	1
	b2	---	-1.2	---	---	---
	b3	---	0.1	---	---	---

Table 8: drainage network Quantities of Maragh basin- Shreve method

rank	Rank number	Bifurcation ratio	Stream length	Stream Length ratio	Area ratio	Area(ha)	Slope ratio	Mean slope
1	60	0	56153	0.71	0.12	3261.64	0.63	65
2	13	4.61	8611.76	0.72	0.24	407.19	1.21	41
3	6	2.16	2863.76	1.21	1.57	99.64	1.2	50
4	4	1.5	2313.76	1.53	1.7	156.95	0.93	60
5	4	1	3545.76	0.51	0.19	267.42	0.98	56
6	2	2	902.76	1.95	1.32	52.49	0.65	55
7	2	1	1759.76	0.41	0.17	69.79	0.86	36
8	1	2	358.76	2.04	10.27	12.02	2.06	31
9	2	0.5	1461	0.44	0.68	123.50	0.5	64
10	2	1	636.76	0.87	0.07	84.14	1.06	32
11	1	2	276.76	1.12	7.29	6.01	0.82	34
12	2	0.5	619.59	2.19	0.29	43.87	1.85	28
13	1	2	678.76	0.60	2.41	12.74	0.92	52
14	1	1	409.76	1.62	0.86	30.75	0.37	48
17	1	1	664.76	1.59	2.65	26.49	1.94	18
18	1	1	1056.76	0.47	0.15	70.22	0.85	35
27	1	1	493.76	0.74	1.52	10.73	0.8	30
28	1	1	367.76	1.52	0.46	16.36	1.5	24
29	1	1	557.76	0.35	0.09	7.64	0.86	36
30	1	1	192.76	0.84	0.73	0.72	0.93	31
32	1	1	161.76	1.07	0.59	0.53	1	29
34	1	1	172.76	0.89	1.27	0.31	1.03	29
35	1	1	153.76	1.66	25.84	0.40	1.16	30
36	1	1	254.76	1.58	0.95	10.37	0.6	35
37	1	1	403.76	2.52	5.50	9.88	1.28	21
38	1	1	1017.76	0.57	0.91	55.26	0.51	27
39	1	1	557.76	4.14	4.57	50.44	1.35	14
42	1	1	2393.76	0.24	0.07	230.959	0.73	19
47	1	1	557.76	1.08	3.29	17.845	1.42	14
48	1	1	619.76	2.37	1.94	58.837	0.9	20
60	1	1	1467.76	0	0	653.114	0	18

As it can be seen in table (8), maximum rank of the stream in Shreve method was 60 and the most bifurcation ratio in it was related to rank 2. In Shreve method, the maximum area of Maragh basin was under first rank drainage such as Horton and Strahler methods. Also, the slope decreases as a result of increasing the rank.

Table 9 shows the selected models between physiographic and drainage properties in the studied basin. As it can be seen in this table, models were nonlinear and the relation between the rank and stream branch number was in form of S model with R^2= 0.790. Also, the relation between the rank and bifurcation ratio was in form of Cubic model with the R^2= 0.397. The relation between the rank and slope was in form of Cubic model with R^2= 0.323.Finally, the relation between the stream length and rank was in form of Power model with R^2=0.513.

Table 9: results obtained from regression test in Shreve method

	Variables	Stream rank and stream branch number	Stream rank and bifurcation ratio	Stream rank and slop	Stream rank and area	Stream rank and stream length
Model summary	Equation	S	Cubic	Cubic	Power	Power
	R Square	0.79	0.39	0.62	0.32	0.51
	F	108.77	5.91	15.01	14.43	30.53
	Df2	1	3	3	1	1
	Df1	29	27	27	29	29
	sig	0.000	0.003	0.000	0.001	0.000
Parameter estimates	constant	0.614	-4.62	62.77	39.82	825.10
	b1	2.71	73.76	-1.10	-0.28	-0.59
	b2	---	-47.30	-0.013	---	---
	b3	---	6.853	0	---	---

Table 10: Drainage network quantities in Maragh basin- Shidger method

rank	Rank number	Bifurcation ratio	Stream length	Stream Length ratio	Area ratio	Area(ha)	Slope ratio	Mean slope
2	60	0	56153	0.7	0.12	3261.64	0.63	65
4	13	0.21	8611.76	0.72	0.24	407.19	1.21	41
6	6	0.46	2863.76	1.21	1.57	99.64	1.2	50
8	4	0.66	2313.76	1.53	1.7	156.95	0.93	60
10	4	1	3545.76	0.5	0.19	267.42	0.98	56
12	2	0.5	902.76	1.94	1.32	52.49	0.65	55
14	2	1	1759.76	0.4	0.17	69.79	0.86	36
16	1	0.5	358.76	2.03	10.27	12.02	2.06	31
18	2	2	1461	0.43	0.68	123.50	0.5	64
20	2	1	636.76	0.86	0.07	84.14	1.06	32
22	1	0.5	276.76	1.11	7.29	6.01	0.82	34
24	2	2	619.59	2.19	0.29	43.87	1.85	28
26	1	0.5	678.76	0.6	2.41	12.74	0.92	52
28	1	1	409.76	1.62	0.86	30.75	0.37	48
34	1	1	664.76	1.58	2.65	26.49	1.94	18
36	1	1	1056.76	0.46	0.15	70.22	0.85	35
54	1	1	493.76	0.74	1.52	10.73	0.8	30
56	1	1	367.76	1.51	0.46	16.36	1.5	24
58	1	1	557.76	0.34	0.09	7.64	0.86	36
60	1	1	192.76	0.83	0.73	0.72	0.93	31
64	1	1	161.76	1.06	0.59	0.53	1	29
68	1	1	172.76	0.89	1.27	0.31	1.03	29
70	1	1	153.76	1.65	25.84	0.40	1.16	30
72	1	1	254.76	1.58	0.95	10.37	0.6	35
74	1	1	403.76	2.52	5.59	9.88	1.28	21
76	1	1	1017.76	0.56	0.91	55.263	0.51	27
78	1	1	557.76	4.14	4.57	50.44	1.35	14
84	1	1	2393.76	0.24	0.07	230.95	0.73	19
94	1	1	557.76	1.07	3.29	17.84	1.42	14
96	1	1	619.76	2.36	1.94	58.83	0.9	20
120	1	1	1467.76	0	0	653.11	0	18

According to table 10 the minimum rank of the stream in Shidger method was related to rank 2 and the maximum rank was rank 120. Therefore, the stream rank increases significantly in Shidger method, in spite of other methods. Consequently, the determination of stream ranking is very time-consuming through Shidger method. In this method, the most bifurcation ratio was related to rank 8 and 24, but the most area of the basin like the other three methods was under the drainage of the streams with the least rank. This issue is derived from high slope and mountainous condition. Therefore, as a result of decreasing the region slope, the stream rank increases.

Table11 shows the selected models between variables of physiographic properties and drainage properties in studied basin. According to this table, the models were non-linear. Also, the relation between the rank and the stream branch number was in form of S model with R^2= 0.790, the relation between the rank and the bifurcation ratio was in form of Cubic model with R^2= 0.416. The relation between the rank and slope was in form of Cubic model with R^2= 0.625. The relation between the rank and area was in form of Power model with R^2= 0.323. Finally, the relation between the rank and the stream length was inform of Power model with R^2= 0.513.

Table 11: Results obtained from regression test in Shidger method

	Variables	Stream rank and stream branch number	Stream rank and bifurcation ratio	Stream rank and slop	Stream rank and area	Stream rank and stream length
Model summary	Equation	S	Cubic	Cubic	Power	Power
	R Square	0.79	0.41	0.62	0.32	0.51
	F	108.77	7.69	15.01	14.43	30.53
	Df2	1	3	3	1	1
	Df1	29	27	27	29	29
	sig	---	0.001	---	0.001	---
Parameter estimates	constant	1.30	4.37	125.55	79.64	1.65
	b1	2.71	-48.79	-2.20	-0.28	-0.59
	b2	---	181.17	-0.025	---	---
	b3	---	-76.60	---	---	---

CONCLUSION

Obtained results from quantifying of morphometric parameters have showed in tables of(4), (6), (8) and (11) and the results obtained from regression and correlation analysis between different factors have showed in tables of (5), (7), (9) and (11).According to the obtained results from morphometric parameter analysis, it can be concluded that: 1- there is a well- organized relation between the rank and the stream branch number and it decreases as a result of increasing the rank. 2- There is a significant relation between the rank and the area. Therefore, regarding to the young status of the studied region, the amount of area decreases because of increasing the rank. 3- The relation between the rank and the basin slope shows that the more the rank increases, the less becomes the slope. Also, according to the results of regression and correlation analysis between different factors, in Strahler ranking methods, there is the most correlation between stream rank with parameters of branch ratios, stream branch number, slope, basin area and stream length withR^2= 1, 0.993, 0.960, 0.906 and0.879, respectively. According to the results of correlation status in Horton method and the stone variety in this region, it can be noted that the existent deviation in Horton method was related to the amount of the stone Strength. So, according to the mountainous situation of the area and the lack of land use change, land use changes have had no effect on this deviation. Therefore, the Strahler method is more suitable than others, but Strahler method doesn't show total number of the streams in drainage system. Hence, it is recommended that the morphometric properties of the basin would be determined using Strahler method and in order to show the number of streams and the comparison of the stream changes during different years, either Shreve or Shidger methods have been used. According to the increasing of the rank in Shidger method, it seems that Shreve method is more appropriate for this aim.

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