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Determination of the best method of estimating the time of concentration in pasture watersheds (case study: Banadak Sadat and Siazakh Watersheds, Iran)

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Abstract

Temporal parameters are used in most of hydrological and hydraulic models. The most common temporal parameter in hydrology is time of concentration which is required for spillway design, flood volume estimation, producing flood hydrograph and much other hydrological analysis. Therefore, in this research, 10 estimation methods have been calculated for each sub-basin of both studied watersheds. Ultimately, equations of estimating the time of concentration were evaluated using mean deviation, mean difference, relative error percentage and mean square error tests and comparison method of mean by Tukey method and their categorization in Minitab software. The results of analysis of variance table showed that, there is a significant difference at the level of 1% between the equations. The results of analysis of variance by Tukey method for Banadak Sadat watershed showed that, Passini Model (which has the minimum amount of MD, BIAS, RE, RMSE by 0.001, 0.0031, 0.0043, 1.892 respectively) is the best approach, and after this model, Ventura model and Rational Hydrograph were respectively the best equations to estimate the time of concentration in the considered watershed. For Siazakh Watershed also, results showed that, the best method for concentration method estimation which has the minimum difference with observed values, is logistic hydrograph (also it has the minimum amount of MD, BIAS, RE and RMSE by 0.085, 0.0092, 0.068 and 5.83 respectively) and after this model, Kirpich and Chow models were respectively the best equations to estimate the time of concentration. Overall results demonstrated that, Rational Hydrograph equation is the most appropriate equation and Bransly-Williams equation is not recommended because of very much difference with observed data.

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Introduction

Temporal parameters are used in most of hydrological and hydraulic models. The most common temporal parameter used in hydrology is the time of concentration (Alizadeh, 1997). Time of concentration of a watershed is defined as required time within which a raindrop passes the longest path of the watershed and arrives to the station of discharge measurement (Ziaei, 2001). Time of concentration is a temporal parameter which is used widely for estimating the peak discharge in hydrologic plans (Fang *et al*., 2008). Time of concentration is calculated via numerous ways which give different results, which its cause is to ignore the situation of water flow direction in terms of roughness, vegetative cover and hydraulic radius in various points and other factors. Therefore, it is better to consider environmental conditions in addition to use theoretical relationships, and required modifications to be conducted (Mahdavi, 2007). By understanding the importance of in hydrologic evaluations and designs, the researchers have presented various methods to estimate time of concentration which are divided into three categories: field method based on travel time of water, using of flood hydrograph and precipitation hydrograph, and empirical methods (Najmaei, 1990). Considering that, determination of time of concentration depends on physiographic and climatic conditions of the watershed, some equations and relationships have been used to estimate the time of concentration in various points throughout the world. While, Iran has different climates and these equations cannot be used considering only some parameters. Therefore, these equations are required to be tested in different watersheds in Iran to select the best approach (Motamed Vaziri, 2004). Goitom (1989) investigated the time of concentration in a watershed of Arizona and indicated that, Kirpich equation can be an appropriate equation for the mentioned watershed. Motamed Vaziri (2005) compared some empirical equations of estimating the time of concentration by measured time of concentration in Shahrestanak Watershed and concluded that, in low slopes, Kirpich, California and Chow propose relatively acceptable results, and Mockus (SCS) proposes the best result in steep slopes. Currently, multiple linear regression technique depending on the main waterway length and slope has been recommended for estimation of time of concentration in Iran (Eslamian & Mehrabi, 2005). Pilgrim (1989) by investigating 96 watersheds in the southern region of Australia proposed an equation for the region time of concentration which only was a function of watershed area. Sheridan (1994) evaluated existent equations for estimating the time of concentration, delay time and time of peak in flat watersheds, he evaluated Kirpich equation in his study which was conducted for 9 watersheds in the southern United States, and concluded that, this equation underestimates time of concentration. McCuen *et al.* (1984) evaluated 7 empirical equations of time of concentration for 5 urban watersheds. They concluded that, measuring the time of concentration through mean waterway velocity presented by Soil Conservation Service (SCS) had the minimum error. Azadnia *et al.* (2010) compared some empirical estimation methods of time of concentration in Meymeh watershed in Ilam province and concluded that, Kirpich, Chow and Rational Hydrograph proposed relatively results. Kowsari *et al.* (2010) accomplished sensitivity analysis of four equations of estimating the time of concentration (Kirpich, Bransby-Wiliams, California and SCS). They suggested that, partial variations of slope especially in low slopes have high effect on the increase of time of concentration. Sensitivity analysis is a method by which the effects of existing variations in models on their results can be investigated. The results of this investigation can be used at calibration stage so that, it leads to increase accuracy and save time and money (Avarand *et al.,* 2007). Kang *et al.* (2008) predicted the existence of the first eventual runoff flow by time of concentration. Currently in Iran, most of research plans for estimating the time of concentration in mountainous watersheds use empirical equations such as Kirpich, Bransby-Wiliams and SCS, and there is no scientific and proper investigation about application of these equations and other empirical equations since, each empirical equation has been written consistent with regions with specific climatic traits. Therefore, the purpose of this study is to select the best equation for estimating the time of concentration in the studied watershed while applying various empirical methods to estimate time of concentration in Banadak Sadat and Siazakh watersheds and their evaluation with regard to the amounts of mean deviation, mean difference, relative error percentage and mean square error, and comparison of mean through Tukey method.

The aim of this study is determination of the best method of estimating the time of concentration in pasture watersheds in Banadak Sadat and Siazakh Watersheds in Iran

Materials and methods

Study area

In this research, boundary of the study area was determined on a 1:50000 topography map using interpretation of aerial photos, satellite images and field visit, and all main branches of the watershed having permanent water were distinguished. After providing the region digital map in Arc GIS9.3 software, area of each sub-basin was determined, and the future researches and measurement were concentrated in these sub-basins. Banadak Sadat watershed is located in Yazd province with an area by 39.32 km². In terms of geographical, the watershed has been located between latitudes of northern 31° 31' 8.8'' and 31° 36' 30.6'' and longitudes of eastern 54° 10' 8.9'' and 54° 14' 7.5'' and major part of hill slopes is pasture lands. Siazakh watershed is located in Kurdistan province in Zagros hill slopes. The area of this watershed is about 1058 km². Location of this watershed is between northern 682300 to 647334 and eastern 3933099 and 3992199 (UTM). Mean slope of the watershed is 21.92% and mean annual precipitation is 530 mm. Fig (1) shows position of the study area in the provinces and Iran.

Methodology

Introducing the investigated equations

1. Passini

This method has been presented to estimate time of concentration and is applicable for watersheds larger than 40 km² (Islamian and Mehrabi, 2005).

$$Tc = 0.108\sqrt{\frac{A.L}{S}} \quad (1)$$

Where A is watershed area (km2), L is length of the longest waterway and S is mean slope of waterway (m/m) and TC is time of concentration (hr).

2. Kirpich

This equation is used to calculate time of concentration in small watersheds and is as below:

$$Tc = \frac{0.0195L^{0.77}}{S^{0.385}} \quad (2)$$

Where L, S, Tc are waterway length (m), waterway slope (m/m) and time of concentration (min) respectively (Mahdavi, 2007).

3. California

This equation is used to estimate time of concentration especially in large watersheds and is as below:

$$Tc = \left[0.885\frac{L^3}{H}\right]^{0.385} \quad (3)$$

Where L, H, TC are length of longest waterway (km), elevation difference of the highest and lowest points of the watershed (m) and time of concentration (hr) (Kowsari *et al.* 2010).

4. Bransby-Wiliams

This equation also is applied to calculate time of concentration in large watersheds but, it can be used in small watersheds too.

$$Tc = \frac{L}{1.5D}\times\left(\frac{A^2}{S}\right)^{0.2} \quad (4)$$

Where A, D, S, L and TC are watershed area (mile2), ضریب گردی, waterway slope (%),length of waterway (m) and time of concentration (hr) respectively, and ضریب گردی is achieved by the following equation (Ziaei, 2001).

5. Basoo

This equation has been proposed as below:

$$D = \sqrt{\frac{4A}{\pi}} \quad (5)$$

6. Ventura

This equation is applicable for small watershed as below:

$$Tc = 0.067\left(\frac{L^{1.155}}{H^{0.385}}\right) \quad (6)$$

Where L, H are length of main waterway (km) and elevation difference of watershed (km) respectively.

7. Giandoty

This equation has been proposed for large mountainous watershed as below:

$$Tc = 0.1272\sqrt{\frac{A}{S}} \quad (7)$$

Where A is watershed area (km^2) and S is mean slope of waterway (m/m) and time of concentration is as hour. Limit of these methods is that, area should be more than 10 km^2 and watershed slope should be low to moderate (Eslamian & Mehrabi, 2005).

8. Chow

$$Tc = \frac{(4\sqrt{A}) + (1.5L)}{0.8\sqrt{H}} \quad (8)$$

Where A, L, H and TC are watershed area (km2), length of waterway (km), mean height of watershed (km) and time of concentration (hr) respectively (Eslamian & Mehrabi, 2005).

9. Rational Hydrograph

Rational Hydrograph another equation to estimate time of concentration is as below:

$$Tc = 0.00032L^{1.15}H^{-0.385} \quad (9)$$

Where H, L and TC are elevation difference of watershed (m), length of waterway (m) and time of concentration (hr) respectively (Azadnia *et al.*, 2009).

10- Carter

It is the last equation to estimate time of concentration explained in this study and is as below:

$$Tc = M\left(\frac{L}{S^{0.5}}\right)^{0.66} \quad (10)$$

Where M is constant and equal with 0.057, S is watershed slope (m/m), L is length of waterway (m) and T_C is time of concentration (min) (Azadnia *et al.*, 2009).

$$Tc = 2.833L^{0.6}S^{-0.3} \quad (11)$$

Where L is length of waterway (mile), S is waterway slope (ft/mile) and TC (hr) (Eslamian & Mehrabi, 2005).

After obtaining the results of all 10 estimation methods of time of concentration which have been shown in Tables (1), (4), finally the best model was determined to estimate time of concentration in Banadak Sadat and Siazakh pasture watersheds using BIAS, RE, RMSE and MD methods and comparison of means.

Statistical tests

In order to evaluate and determine suitable model in this study, mean deviation test (MD), mean difference (BIAS), relative error percentage (RE), mean square error (RMSE) and comparison of mean by Tukey method were used in Minitab software. Ten, the graphs related to each method was drawn for more proper comparison with observed values.

Mean Deviation (MD)

$$MD = \frac{1}{n}\sum_{i=1}^{n}[Q_o - Q_e] \quad (12)$$

Where Q_o is observed value, Q_e is estimated value and n is the number of sample.

Mean Difference (BIAS)

$$BIAS = \frac{1}{n}\sum_{i}^{n}\frac{E_o - E_e}{E_o} \quad (13)$$

Eo is observed value, Ee is estimated value and n is the number of sample.

Relative Error percentage

$$RE = \left|\frac{Q_o - Q_e}{Q_e}\right| \times 100 \quad (14)$$

Where Q_o is observed value and Q_e is estimated value.

Mean Square Error (RMSE)

$$RMSE = \left| \frac{1}{n} \sum_{i=1}^{n} \frac{(Q_o - Q_e)^2}{Q_o} \right|^{\frac{1}{2}} \quad (15)$$

Where Q_o is observed value, Q_e is estimated value and n is the number of sample.

Results

Main and required characteristics of the studied watersheds have been presented in Tables (1) and (2). According to the explained equations in the past sections, time of concentration was calculated for each sub-basin of Banadak Sadat and Siazakh watersheds and the results have been shown in Tables (3) and (4).

Table 1. Physiographical characteristics of each hydrological unit for Banadak Sadad watershed.

Coefficients of watershed shape			Length of main waterway (km)	Waterway slope (m/m)	Minimum elevation (m)	Maximum elevation (m)	Area (km^2)	Precipitation (cm)	Hydrological unit
Miller	Gravelius	Horton							
0.53	1.35	0.32	4.98	0.2	2280	3500	7.36	31.7	A
0.4	1.56	0.2	4.46	0.28	2300	3960	3.99	34.8	B
0.51	1.38	0.22	3.99	0.29	2260	3700	3.76	33.74	C
0.54	1.34	0.33	8.68	0.07	1880	3020	23.94	28.66	INT
0.14	2.57	0.28	12.25	0.12	1880	3960	39.32	31.1	TOTAL

Table 2. Physiographical characteristics of each hydrological unit for Banadak Sadat watershed.

Sub-basin number	Elevation difference of sub-basin (m)	Sub-basin area (km^2)	Waterway slope (m/m)	Length of waterway (km)	Mean elevation of watershed (m)
M1	1140	132.9424	0.009647	14.512	2.368869
M2	940	157.6527	0.004546	65.991	2.278473
M3	900	62.953	0.024079	14.951	2.310238
M4	860	254.6157	0.006663	34.517	2.231043
M5	800	65.772	0.014987	13.345	2.166583
M6	960	380.6379	0.002672	52.389	2.069618

Table 3. Estimation of time of concentration in Banadak Sadat watershed.

Sub-basin		A	B	C	INT	TOTAL
Empirical method						
Passini	Time of concentration(hr)	0.086	0.060	0.053	0.215	0.316
Kirpich	Time of concentration(hr)	0.014	0.0129	0.0116	0.0224	0.0285
California	Time of concentration(hr)	0.395	0.3088	0.2868	0.7702	0.9097
Bransby-Wiliams	Time of concentration(hr)	1.303	1.141	1.033	2.286	2.917
Basoo	Time of concentration(hr)	0.027	0.021	0.020	0.054	0.063
Ventura	Time of concentration(hr)	0.154	0.120	0.123	0.211	0.227
Giandoty	Time of concentration(hr)	0.655	0.450	0.452	1.206	1.191
Chow	Time of concentration(hr)	0.370	0.289	0.269	0.720	0.849
Rational hydrograph	Time of concentration(hr)	0.068	0.064	0.058	0.102	0.125
Carter	Time of concentration(hr)	0.0367	0.0343	0.0315	0.052	0.063
Observed	Time of concentration(hr)	0.11	0.08	0.07	0.19	0.43

Results of statistical tests

The results of used statistical methods in this study have been presented in Tables (5) and (6) for all tested empirical models. The results from comparison of mean by Tukey method using Minitab have been shown in Tables (9) to (13) and the results of other statistical methods including MD, BIAS, RE, RMSE have been indicated in Tables (5) and (6). In tables (7) and (8), the best model is that has the lowest amount of MD, BIAS, RE, RMSE (Mobaraki, 2006; Esmaeili Ori, 2012).

Evaluation of empirical methods for estimating the time of concentration

With regard to the comparison criteria, low rank has been considered for the most suitable method and high rank has been considered for the most unsuitable method. The method having the highest rank in all criteria can be considered as the most suitable method. The results have been shown in Tables (7) and (8) (Esmaeili Ori, 2011).

Table 4. Estimation of time of concentration in Siazakh watershed.

Sub-basin		M1	M2	M3	M4	M5	M6
Empirical method							
Passini	Time of concentration(hr)	48.314	163.488	21.387	124.063	26.212	295.150
Kirpich	Time of concentration(hr)	3.107	13.325	2.235	6.983	2.458	13.688
California	Time of concentration(hr)	0.0232	0.143	0.0263	0.0704	0.0241	0.109
Bransby-Wiliams	Time of concentration(hr)	57.123	219.681	76.149	118.225	61.552	143.586
Basoo	Time of concentration(hr)	0.0233	0.144	0.0264	0.0707	0.0242	0.1097
Ventura	Time of concentration(hr)	0.154	0.245	0.0673	0.257	0.0872	0.497
Giandoty	Time of concentration(hr)	1.0633	2.203	0.836	1.785	0.8239	2.438
Chow	Time of concentration(hr)	0.620	6.4799	0.7105	2.536	0.6270	4.5466
Rational hydrograph	Time of concentration(hr)	2.452	8.5420	1.8495	4.909	2.0065	8.740
Carter	Time of concentration(hr)	0.054	0.168	0.0420	0.1021	0.0452	0.1725
Observed	Time of concentration(hr)	2.89	7.68	1.92	3.85	2	9.25

Table 5. The results of statistical methods MD, BIAS, RE and RMSE for the used empirical models in Banadak Sadat watershed.

Tested method	MD	BIAS	RMSE	RE
Passini	0.001	0.0031	0.0043	1.8927
Kirpich	0.0491	0.01520	0.2115	1033.3333
California	0.0978	0.03027	0.4214	64.4938
Bransby-Wiliams	0.432	0.03385	1.8633	88.9270
Basoo	0.0432	0.1337	0.1862	406.2696
Ventura	0.0160	0.0495	0.0690	42.2907
Giandoty	0.1447	0.4479	0.6235	72.8799
Chow	0.0877	0.2714	0.3778	61.9552
Rational hydrograph	0.0330	0.1022	0.1422	158.4000
Carter	0.0433	0.1340	0.1865	409.4637

Table 6. The results of statistical methods MD, BIAS, RE and RMSE for the used empirical models in Siazakh watershed.

Tested method	MD	BIAS	RMSE	RE
Passini	47.65	5.151	38.37	96.86
Kirpich	0.73	0.08	0.595	32.422
California	1.523	0.1647	1.55	8386.23
Bransby-Wiliams	22.38	2.42	18.032	93.55
Basoo	1.523	0.164	1.2269	8332.087
Ventura	1.458	0.157	1.17	1761.167
Giandoty	1.135	0.122	0.914	279.409
Chow	0.784	0.084	0.63	103.47
Rational hydrograph	0.085	0.0092	0.068	5.83
Carter	1.512	0.163	1.21	5262.31

From the tables above, it can be concluded that, the best method for estimating the time of concentration in Banadak Sadat watershed is Passini method considering RMSE, BIAS, MD, RE and after that, Ventura and Rational Hydrograph are also the best methods respectively. Passini equation has a more accurate estimation because, it considers three parameters of slope, length and area while, most of other methods consider only two or one parameter for estimating the time of concentration. According to Table (8) it can be concluded that, the best equation for estimating the time of concentration in Siazakh watershed id Rational Hydrograph equation and after this equation, Kirpich and Chow had the best estimation for time of concentration and this conclusion is consistent with Azadnia *et al.* (2010) who introduced Rational Hydrograph, Chow and Kirpich as the best equations to estimate time of concentration. Since slopes are very low in Siazakh watershed, so it can be found that, Chow, Kirpich and Rational Hydrograph equations have the best estimations in low slope areas which is consistent with Motamed Vaziri (2004). According to the tables of estimating the time of concentration it can be concluded that, Kirpich equation underestimates the time of concentration which is consistent with Sheridan (1994).

Table 7. Final results of ranking the empirical methods of estimating the time of concentration in Banadak Sadat watershed.

Evaluation criterion	Passini	Kirpich	California	Bransby-Wiliams	Basoo	Ventura	Giandoty	Chow	Rational hydrograph	Carter
RMSE	1	6	8	10	4	2	9	7	3	5
BIAS	1	6	8	10	4	2	9	7	3	5
MD	1	6	8	10	4	2	9	7	3	5
RE	1	10	4	5	8	2	6	3	7	9
Total	4	28	28	35	20	8	33	24	16	24
Rank	1	6	6	8	4	2	7	5	3	5

Table 8. Final results of ranking the empirical methods of estimating the time of concentration in Siazakh watershed.

Evaluation criterion	Passini	Kirpich	California	Bransby-Wiliams	Basoo	Ventura	Giandoty	Chow	Rational hydrograph	Carter
RMSE	10	2	8	9	7	5	4	3	1	6
BIAS	10	2	8	9	7	5	4	3	1	6
MD	10	2	8	9	7	5	4	3	1	6
RE	4	2	9	3	10	7	6	5	1	8
Total	34	8	33	30	31	22	18	14	4	24
Rank	10	2	9	7	8	5	4	3	1	

Table 9. Analysis of variance table for Banadak Sadat watershed.

Variations source	Freedom degree	Sum of squares	Mean of squares
Equation	10	7.36	0.736
Error	33	1.72	0.052
Total	43	9.08	

Table 10. Categorization of equations in Banadak Sadat watershed.

Equation	Mean	Category	
Bransby-Wiliams	1.4	A	
Giandoty	0.7	B	
California	0.4	B	C
Chow	0.4	B	C
Ventura	0.2	B	C
Passini	0.1		C
Observed	0.1		C
Rationa Hydrograph	0.1		C
Carter	0		C
Kirpich	0		C
Basoo	0		C

Table 11. Analysis of variance table for Siazakh watershed.

Variations source	Freedom degree	Sum of squares	Mean of squares
Equation	10	30421.6	3042.2
Error	33	8379.5	253.9
Total	43	38801.1	

Analysis of variance table

The results of analysis of variance and their categorization in Minitab software based on completely randomized layout indicated that, there is a significant difference at the level of 1% between the tested equations. The results of comparison of mean by Tukey for Banadak Sadat watershed showed that, the best equation is Passini which has the lowest difference with observed values (Table 9). According to table (10), Bransby-Wiliams and Giandoty are unsuitable equations and have the highest difference with observed results but, Passini and Rational Hydrograph equations have the maximum consistency with observed data. In Fig (2), the graph of different equations were drawn based on their average in Minitab software to have more complete evaluation for the equations.

Table 12. Categorization of equations in Siazakh watershed.

Equation	Mean	Category
Bransby-Wiliams	77.1	A
Passini	60.5	A
kirpich	3.9	B
Rational Hydrograph	2.9	B
Observed	2.9	B
Giandoty	1.2	B
Chow	1.1	B
Ventura	0.2	B
Carter	0.1	B
Basoo	0	B
California	0	B

Results of analysis of variance between tested equations at the level of 1% showed that, there is a significant difference between the equations, and Rational Hydrograph equation was determined as the most suitable equation in Siazakh watershed based on the results of comparison of mean by Tukey method (Table 11). Both Passini and Bransby are placed in a same category and are unsuitable equations (Table 12).

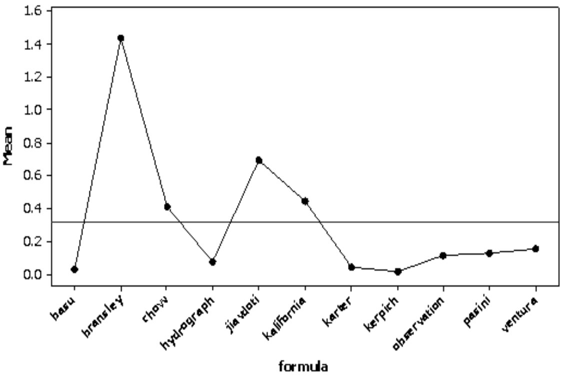

Fig. 1. Graph of equations comparison based on their mean in Banadak Sadat watershed.

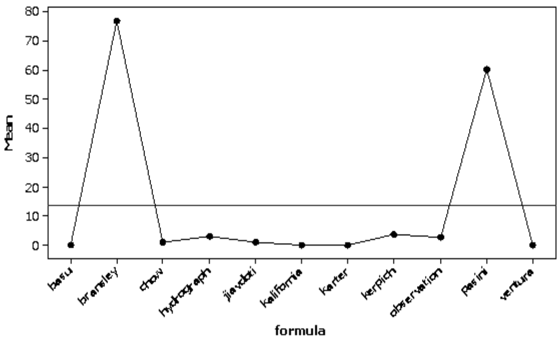

Fig. 2. Graph of equations comparison based on theirmean in Siazakh watershed.

Conclusion

In this research, 10 empirical models of estimating the time of concentration were evaluated in Banadak Sadat located in Yazd province and Siazakh located in Kurdistan province, Iran. The purpose of this study is to determine the most suitable model among tested models which was done using comparisons of mean (Tukey methods) and MD, BIAS, RE and RMSE. The results of all tables and graphs for

Banadak Sadat watershed indicates that, Passini model is the best model (MD, BIAS, RE and RMSE are 0.001, 0.0031, 0.0043 and 1.892 respectively) and after this model, Ventura, Rational Hydrograph are the best equations for estimating the time of concentration respectively). The results for Siazakh watershed demonstrated that, the most suitable equation for estimating the time of concentration is Rational Hydrograph (MD, BIAS, RE and RMSE are 0.085, 0.0092, 0.068 and 5.83 respectively) and after this equation, Kirpich and Chow are used as the best equations. The results of this section is consistent with Azadnia *et al.* (2010) in Meymeh watershed. According to the drawn graphs, Bransby-Wiliams equation has the highest difference with observed values and is not recommended. Kirpich and Rationa Hydrograph methods also present more valid in low slopes that is completely consistent with Motamed Vaziri (2004). Considering that, Rational Hydrograph are the best equations in Siazakh watershed as well as in Banadak Sadat watershed, it can be concluded that, this equation is the most suitable approach to estimate time of concentration and after this equation also, Kirpich equation can be used as the second suitable method which is consistent with Azadnia *et al.* (2010).

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