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Case Report

Assessment of Empirical Methods of Runoff Estimation by Statistical Test (Case study: BanadakSadat Watershed, Yazd Province)

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ABSTRACT

Runoff estimation resulted from precipitation is the basis of more study in various develop and exploit design from water resource, then its measure and calculation due to environmental bottlenecks, always have a plenty problem. As a result of the importance of output runoff estimation and flood volume in watershed for the sake of country integrated watershed management in this study tried to 9 empirical methods of runoff estimation implemented in Banadaksadat and this provided result with observation runoff from Hydrometric station in watershed outlet have been evaluation by paired t-test, MD, BIAS, RE and RMSE tests then selected best model in Banadaksadat watershed to runoff height estimation that it's have a most efficiency and precision. After preparation of necessary maps in GIS environment and Statistical test implementation in SPSS software, result showed that LACEY method with MD, BIAS, RE and RMSE value 0.016, 0.007, 4.36 , 0.026 respectively and also no significant difference with observation data in 95%confidence level, with runoff height equal to 1.53 cm, 2.29 MCM runoff volume and 18.79%runoff coefficient , determine the best empirical model to runoff estimation in the case study. The sensitivity analysis using Excel software was used for LACEY model to determine the influential reachs, according to the get result, F/Z parameter in 6-8, 8-10 and 18-20 reachs have a most effect in the model output.

Keyword: Runoff Estimation, Empirical method, Banadaksadat Watershed, GIS, SPSS, Sensitivity Analysis.

Introduction

If rainfall intensity is more than the capacity of soil infiltration, a part of precipitation would stream along the slope on the watershed surface and will be emitted by water bodies. This part of precipitation which is measurable in the rivers is called surface runoff (Alizadeh, 2009). One of basic requirements in designing soil and water projects, is the estimation of runoff resulted from precipitation. In order to achieve this purpose, various methods can be used like (Coutagine, Turc, Khosla and etc.). Precipitation can be considered as the most important factor which is directly effective in hydrologic cycle. Determination of runoff resulted from precipitation is one of the most important factors in hydrologic problems analysis and water resources management. The relationship between precipitation and runoff is a complicated and non-linear relationship which is depended on several factors. Forecasting and determination of the quantitative amount of created and transported runoff to the outflow point of watershed are very important (Ghafari *et al.*, 2009; khayam and molavi, 2004; and velayati *et al.*, 2004). In order to control and conduct the runoff also, to discharge and transporting surface flows to a proper location which is out of the region, various models have been developed and used by a plenty of researchers of scientific organizations throughout the world (Minras, 1975; Neshat, 2001). With regard to provide water demands, the importance of surface floods and runoffs in arid areas is really high. Usually, the floods in arid and semi-arid regions are short-time and basic flows are too low and perhaps there is no basic flow at all because, the rivers mostly are temporary or a kind of torrent. Using empirical models for estimating annual runoff in those watersheds in which there is no hydrometric station, has been recommended since several years ago and each empirical model is developed for a special watershed (Bajalan, 2005). Also, the accuracy and efficiency of each model is needed to be tested before using in other watersheds (Jandaghi and Mohammadi, 2007). In arid regions, water cycle has more speed and is formed in the absence of vegetative cover, soil and water management (Rahbar and Maasoudi, 2006). Recent studies have shown that, soil erosion and runoff are related with rainfall intensity, amount of precipitation, ground surface cover and vegetative cover also, soil erosion is more affected than runoff (Nearing *et al.*, 2005). Davarirad (2006) evaluated the efficiency of some empirical methods and announced that, including Khosla, Coutgine, Turc , I.C.A,R, Justin and Lacey in the watershed of Namak lake and announced that I.C.A.R, Coutagine, Justin and Turc methods have more accuracy respectively comparing to other methods and Khosla method has not been proper. Zare *et al*. (2008) in addition to explain Khosla, Coutgine, Turc and Langbin formulations announced that, sometimes these methods have error compared to constant universal methods. Evaluation and measuring the amount of runoff and flow in watersheds is very important therefore, runoff estimation is needed for using empirical equations in the watersheds without measurement station. The purpose of this study is to apply various empirical methods of runoff estimation and to evaluate them with regard to observed amounts using statistical tests in Banadaksadat watershed. After determining a proper method, the other goal of this study is to apply sensitivity analysis on selected model and to determine the most effective parameter in the model in order to have more accuracy when the most effective parameter is being measured and achieving more proper results.

Materials and Methods

Study area

Area of the studied region is 39.32 km^2 located in western south of Mahriz city, Yazd province. Geographically, the watershed is located between latitudes of northern 31 31 8.8 to 31 36 30.6 and longitudes of eastern 54 10 8.9 to 54 14 7.5. The highest point of the region is 3960 m and the lowest point has about 1880 m height from sea level. There are and Rangeland Topographically, the up-slope part of watershed including stony and rocky heights with steep slopes and a few branches of water bodies and almost without soil. Figure 1 shows the situation of study area in the province and Iran.

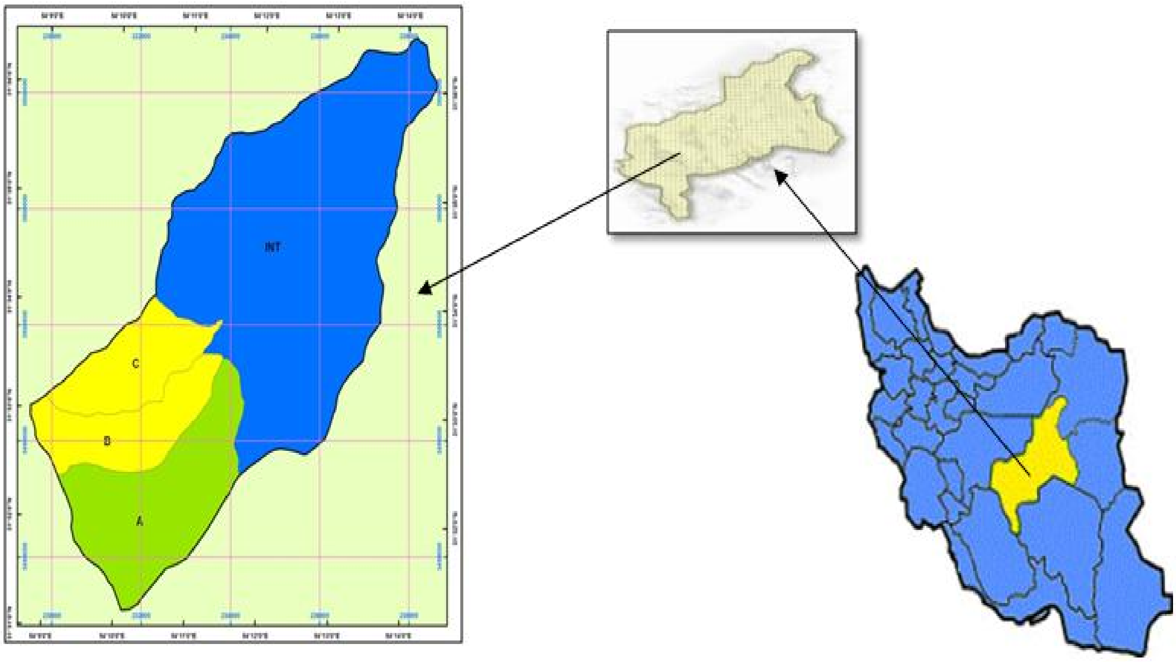

Figure 1. The situation of Banadaksadat in the province and Iran

Methodology of study

When the rain is occurring, runoff height in arid regions is achieved from the amount of precipitation minus evaporation and infiltrated water. Therefore, the mean precipitation of watershed area should be calculated firstly. For calculation of the mean precipitation of watershed area, the average of recorded precipitations by installed stations should be calculated. A method for calculating average is Tisen multi-aspects method (Jafari *et al.*, 2009).

Evaluation of empirical models in annual runoff estimation

Empirical models include relationships and equations which have been determined using analysis of limited data and the region characteristics, and the models are used to estimate some special probabilistic parameters. Most of these methods are useful for a special zone so, it is not possible to use them for other areas. But, some of these methods have more expanded domain and can be used for some same regions by applying some corrections and choosing proper coefficients. There are several empirical models have been developed in order to estimate surface runoff (extra flow). The mentioned methods are divided to four categories including:

1. Surface runoff coefficient
2. Relationships between precipitation and runoff
3. The methods about surface flow shortage
4. The methods about to use physiographic characteristics

Where, surface runoff coefficient and relationships between precipitation and runoff are local and are applicable only in some special physical and climatic situations. The methods about surface flow shortage and methods about to use physiographic characteristics present more acceptable results considering physical and climatic factors.

1- Surface runoff coefficient

The simplest method for surface runoff estimation is to use surface coefficients. In other words, in this method the surface runoff estimation is a percentage of precipitation considering the parameters affecting runoff. The most important coefficient of those have been presented in this method, were suggested by Strange, Barlu, Bini and Rudier in various regions and Barlo coefficient has been recommended for tropical regions (Bashul, 2002).

2- Relationships between precipitation and runoff

A number of hydrologists presented their achieved results as some relationships between precipitation and annual surface runoff with this suppose that physical characteristics of the watershed is constant. In this context, there are plenty of relationships including Engli D, Souza, Dehir-Ehiuja-Majumdar, Irrigation Department of India, Institute of Irrigation Research of India, Paker and etc.

2.1) Engli D, Souza

These two scientists presented the following relationships in plains and mountains of Maharshtera region located in India (Mutereja, 1986):

(1)For highlands:

$$R = 0.85 \times P - 30.5 \quad (1)$$

(2) For plain areas:

$$R = \frac{(P - 17.8) \times P}{254} \quad (2)$$

Where:
P is annual precipitation by cm, and
R is annual runoff by cm

2.2) Department of irrigation, India

Management of Reihand plan presented the following relationship between the amount of annual precipitation and runoff of Reihand River (Gupta, 1992):

$$R = P - 1.17 \times P^{0.86} \quad (3)$$

Where:

P is annual precipitation by cm and,

R is annual runoff by cm

3. Relationships about annual surface flow shortage

In these relationships it is assumed that, the amount of surface runoff flowing out from concentration point of a watershed is the difference between precipitation and annual surface flow shortage. Overlay, annual surface flow shortage includes physical and physiological evaporation which is affected by some factors like temperature, topography, geology and vegetative cover.
The most important methods in this context are Turc, Coutagine and Khosla.

3.1) Turc relationship

Mr.Turc presented following relationship for watersheds with the area less than 300 km^2 based on achieved results from doing a study on 254 watersheds in various climatic and weather conditions.

$$D = \frac{P}{\sqrt{0.9 + (\frac{P}{LT})^2}} \quad (4)$$

$$LT = 300 + 25T + 0.05T^3 \quad (5)$$

$$R = P - D \quad (6)$$

Where:

P is annual precipitation by cm, T is mean temperature by ˚C, R is annual runoff by cm and D is annual flow shortage.

3.2) Coutagine relationship

Coutagine also after doing many studies on various watersheds, presented a general relationship as below (Alizade, 2009):

$$D = P - l \times P^2 \quad (7)$$

$$l = \frac{1}{0.8 + 0.14 \times T} \quad (8)$$

$$R = P - D \quad (9)$$

Where:
P is annual precipitation by m, T is mean temperature by ˚C, R is annual runoff by m, and D is annual flow shortage.

Coutagine is applicable if $\frac{1}{2\lambda} < P < \frac{1}{8\lambda}$

3.3) Khosla method

In this method, the amount of mean annual runoff is calculated by following formula:

$$R = P - \frac{T}{3.74} \tag{10}$$

Where:
R is mean annual runoff of watershed by cm, P is mean annual precipitation by cm, and T is mean annual temperature by ˚C.

4) Runoff calculation using physiographic characteristics

Physiographic characteristics of each watershed including slope, length of main waterway, soil type and vegetative cover, are the most important controller factors of potential for producing surface runoff therefore, it is possible to determine a relationship between a watershed annual surface runoff and the factors mentioned above.
The most important presented relationships consist Indian Council of Agricultural Research (I.C.A.R), Justin, Lacy, World Meteorological Organization (WMO), and Soil Conservation Service (SCS) which estimates runoff resulted from individual precipitations so, this relationship is not concerned in this study.

4.1) Indian Council of Agricultural Research (I.C.A.R) method

This method has been presented based on studying the amount of 17 watershed annual runoff in Neilgiri region that was conducted by Indian Council of Agricultural Research:

$$R = \frac{P^{1.44} \times A^{0.63} \times \Delta H^{0.66}}{15.19 \times F_f^{2.05} \times L_a^{2.05} \times T^{1.34}} \tag{11}$$

Where:
P is annual precipitation by cm, R is annual runoff by cm, A is the watershed area by km^2, ΔH is maximum height difference of watershed, F_f is the factor of watershed shape, T is mean annual temperature by ˚C, and L_a is the length of main waterway by km.

4.2) Justin relationship

Justin conducted extensive researches on the relationships between annual precipitation and runoff in several watersheds with various climatic situations. He presented his achieved results as a general formula as below:

$$R = K \times S^{0.155} \times \frac{P^2}{(1.8 \times T + 32)} \tag{12}$$

$$S = \frac{\Delta H}{A^{0.5}} \tag{13}$$

Where: K is regional coefficient, A is the watershed area by m^2, ΔH is maximum height difference of watershed by m, S is watershed slope, T is temperature by ˚C, P,R are precipitation and runoff respectively by cm. Regional coefficient (K) can be calculated using available data from hydrometric stations of adjacent watershed. Concerned parameters for calculating (K) are mean annual precipitation (P) and mean annual temperature (T).

4.3) Lacey relationship

Lacy; the Indian scientist, presented following formula based on several studies in various watersheds in order to estimate annual runoff:

$$R = \frac{P}{1 + \frac{304.8}{P} \times (\frac{F}{Z})} \tag{14}$$

Where: R is annual runoff by cm, P is mean annual precipitation, F is a parameter related to durability of precipitation, and Z is a coefficient related to physiographic characteristics. Values of F/Z have been presented in Table1.

Table.1. Suggested coefficients of Lacey method

Durability of precipitation			Land type of the watershed
Long	Medium	Short	
6	4	2	Including plateaus, flat plains with deep soils and proper vegetative cover
2.5	1.67	0.83	Almost flat with semi-deep soil and vegetative cover of pasture plants
1.5	1	0.5	Relatively high hills with shallow soil weak vegetative cover
0.88	0.58	0.23	Sandy lands with lots of gravels and steep slopes in high lands
0.43	0.28	0.14	Rocky lands with high height and slope and without vegetative cover

4.4) World Meteorological Organization (W.M.O) relationship

This method is based on studies which were conducted in desert and arid regions of the US and is applicable for the other same areas around the world as WMO has recommended. In other words, this method is applicable for those regions with the temperature above zero.

$$LT = 10^{(0.027*T+0.886)} \tag{15}$$

Where: P is mean annual precipitation by cm, T is mean annual temperature by ˚C, and R is mean surface runoff by cm. Annual runoff can be calculated using estimated ratios in Table 2.

Table 2. Estimated ratios in W.M.O relationship

$\frac{P}{LT}$	0	1	2	3	4	5	6	7	8	10	12	14
$\frac{R}{LT}$	0.009	0.026	0.75	0.2	0.415	1	1.9	2.7	3.4	5	7	9

Statistical tests

In order to evaluate the results and to determine a proper model, in this research the coupled t-test, mean deviation (MD), mean deference (BIAS), percentage of relative error (RE) and Root mean square error (RMSE) were used that more will be explained.
The Paired Sampel t-Test
Overall relationship of this test is as below:

$$t = \frac{\bar{d}}{s_{\bar{d}}} \quad (16)$$

Where d is mean difference of Paired Sampel observations and Sd is standard deviation of differnces.
This test was carried out using SPSS 18 software.
- Mean deviation (MD):

$$\text{MD} = \frac{1}{n}\sum_{i=1}^{n}[\text{Qo} - \text{Qe}] \quad (17)$$

Where Q_O is observed values, Q_e is estimated values and n is the number of samples
- Mean difference (BIAS):

$$\text{BIAS} = \frac{1}{n}\sum_{i}^{n}\frac{\text{Eo}-\text{Ee}}{\text{Eo}} \quad (18)$$

Where E_O is observed values, $E_e$is estimated values and n is the number of samples
- Percentage of relative error (RE):

$$RE = \left|\frac{Qo - Qe}{Qe}\right| * 100 \quad (19)$$

Where Q_O is observed values and Q_e is estimated values
-Root Mean square error (RMSE):

$$RMSE = \left|\frac{1}{n}\sum_{i=1}^{n}\frac{(Qo-Qe)^2}{Qo}\right|^{\frac{1}{2}} \quad (20)$$

Where QO is observed values, Qe is estimated values and n is the number of samples. Permeability and slope are two factors which affect the amount of runoff flow. The maps of two mentioned factors have been produced in GIS environment (Figure 2, 3).

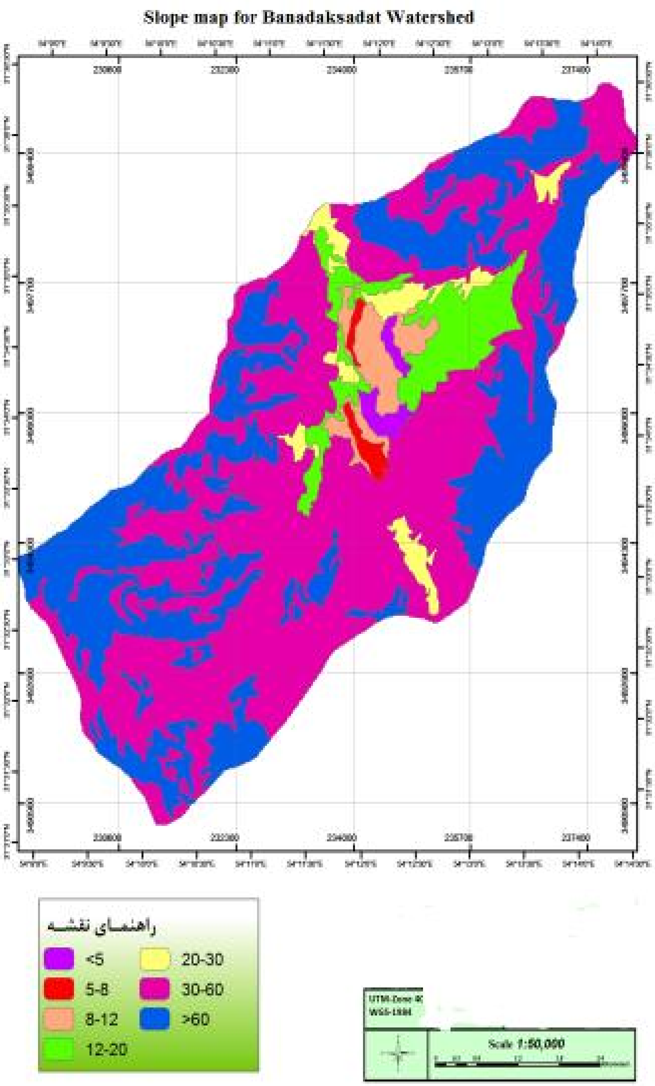

Figure 2. Slope map

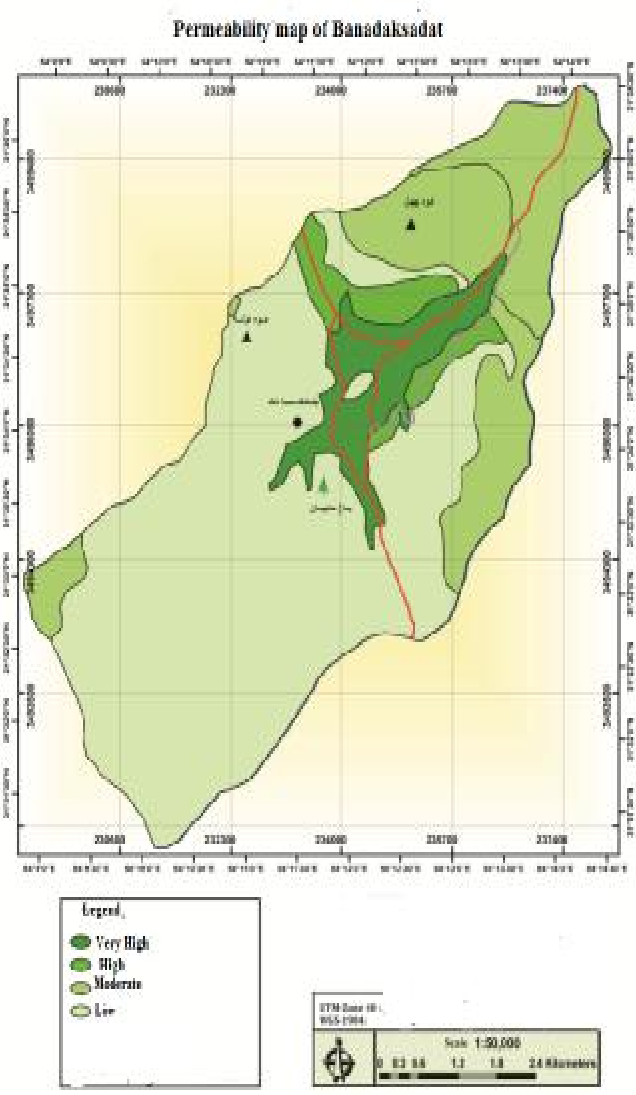

Figure 3. Permeability Map

Results

Required and main characteristics of the watershed have been presented in Table 3. With regard to previous explained formulas, calculation of runoff height, runoff volume and runoff coefficient were conducted for each sub-basins of Banadaksadat watershed. The results have been shown in Table 4.

Table 3. Physiographic characteristics of each studied hydrologic unit

Concentration time (min)	Coefficients of watershed shape			Length of main Stream (km)	Mean weight slope	Minimum height (m)	Maximum height (m)	Area (km^2)	Precipitation (cm)	Mean temperature (°C)	Hydrologic unit
	Miller	Gravelios	Horton								
23	0.53	1.35	0.32	4.98	57.17	2280	3500	7.36	31.7	15.5	A
18	0.4	1.56	0.2	4.46	57.24	2300	3960	3.99	34.8	14.8	B
17	0.51	1.38	0.22	3.99	61.06	2260	3700	3.76	33.74	15	C
52	0.54	1.34	0.33	8.68	52.36	1880	3020	23.94	28.66	16.2	INT
56	0.14	2.57	0.28	12.25	55.92	1880	3960	39.32	31.1	15.6	TOTAL

Table 4. The results of calculating empirical formulations in Banadaksadat sub-basin.

Empirical methods	Estimated Parameter	Sub-Basin				
		A	B	C	INT	TOTAL
Engli D,Souza	Runoff Height	1.73	2.32	2.11	1.22	1.62
	Runoff Volume	0.127	0.092	0.079	0.29	0.63
	Runoff coefficient	5.45	6.66	6.25	4.25	5.2
Department of irrigation, India	Runoff Height	8.83	10.02	9.61	7.69	8.61
	Runoff Volume	0.65	0.399	0.361	1.84	3.38
	Runoff coefficient	27.58	28.79	28.48	26.83	27.68
Turc	Runoff Height	49	123.45	96.73	0	38.08
	Runoff Volume	0.36	0.49	0.36	-	1.5
	Runoff coefficient	0.15	0.35	0.29	-	0.12
khosla	Runoff Height	27.55	30.84	29.72	24.32	26.92
	Runoff Volume	2.02	1.23	1.11	5/82	10.58
	Runoff coefficient	86.9	88.62	88.08	84.85	86.55
I.C.A.R	Runoff Height	3.64	4.59	4.33	2.76	3.16
	Runoff Volume	0.27	0.18	0.16	0.66	1.24
	Runoff coefficient	11.47	13.2	12.84	9.62	10.18
Justin	Runoff Height	9.41	12.74	11.70	6.80	8.61
	Runoff Volume	0.69	0.51	0.44	1.63	3.39
	Runoff coefficient	29.68	36.61	34.67	23.74	27.70
Lacey	Runoff Height	5.97	7.13	24.1	2.96	5.84
	Runoff Volume	0.439	0.284	0.903	0.710	20298
	Runoff coefficient	18.84	20.49	71.18	10.35	18.79
W.M.O	Runoff Height	1.51	1.44	1.46	0.54	1.53
	Runoff Volume	0.111	0.057	0.54	0.012	0.601
	Runoff coefficient	4.76	4.13	4.32	1.88	4.91
Coutagine	Runoff Height	3.38	4.22	3.93	2.68	3.24
	Runoff Volume	0.25	0.17	0.15	0.64	1.27
	Runoff coefficient	10.67	12.12	11.63	9.34	10.42

Results of statistical tests

The results found from used statistical methods in this research have been presented for all tested empirical models in following tables. Found results from Pairde Sampel t-test by

SPSS software have been shown in Table 6 and the results from other statistical methods including MD, BIAS, RE, and RMSE have been presented in Table 7. The results shown in Table 7 are significant by confidence of 95% and in table 8 the best model is the one with lowest amount of MD, BIAS, RE and RMSE.

Paired sampel t-test

Table 7. The statistical results of Paired sampel t- test for runoff estimation methods with observed data in Banadaksadat wate rshed

Methods	mean	Standard Deviation	Standard Error Mean	df	95%Confidence Iinterval of the Difference		t	sig
					Upper	Lower		
Engeli D, Souza	1.84	0.48	0.24	3	-1.31	0.22	-2.25	0.109
Department of irrigation, India	9.04	1.03	0.51	3	5.02	8.28	12.97	0.001
Turc	67.29	54.41	27.21	3	-21.68	151.45	2.37	0.017
khosla	28.11	2.87	1.44	3	21.15	30.29	17.92	0.000
I.C.A.R	3.83	0.82	0.41	3	0.14	2.74	3.52	0.039
Justin	0.82	0.55	0.28	3	-2.45	-0.69	-5.69	0.011
Lacey	10.04	9.53	4.77	3	-7.52	22.82	1.6	0.207
W.M.O	1.24	0.47	0.23	3	-1.89	-0.41	-4.95	0.016
Coutagine	3.55	0.68	0.34	3	0.8	2.24	3.43	0.042

Table 8. The results of statistical methods including MD, BIAS, RE and RMSE for used empirical models in Banadaksadat watershed.

Methods	MD	BIAS	RMSE	RE
Engeli D, Souza	0.038	0.016	0.060	8.778
Department of irrigation, India	1.036	0.435	1.642	72.24
Turc	5.948	2.488	9.424	93.72
khosla	4.088	1.710	6.477	91.12
I.C.A.R	1.191	0.080	0.303	92.58
Justin	1.035	0.434	1.643	72.25
Lacey	0.016	0.007	0.026	4.36
W.M.O	0.143	0.060	0.227	56.20
Coutagine	0.145	0.059	0.224	26.23

Evaluation of empirical runoff estimation equations in the watershed with regard to standards of comparison, in each standard for the most suitable method the lowest rank and for the worst method the highest rank is considered. By putting the ultimate resultsin the table, it is possible to consider the method with the lowest rank in all standards, as the most suitable method. The results is shown in Table 9 (Esmaeiliouri, 2011).

Table 9. Ultimate results of ranking various empirical runoff estimation methods in Banadaksadat watershed

Evaluation Standard	Engeli D, Souza	Department of irrigation, India	Turc	Khosla	I.C.A.R	Justin	Lacey	W.M.O	Coutagine
RMSE	2	6	9	8	5	7	1	4	3
BIAS	2	7	9	8	5	6	1	4	3
MD	2	6	9	8	7	5	1	3	4
RE	2	5	9	7	8	6	1	4	3
Total	8	24	36	31	25	24	4	15	13
Priority	2	5	8	7	6	5	1	4	3

Sensitivity analysis

In order to do sensitivity analysis a parameter varies between its up and down limits while, another parameter (parameters) remains on its average. So it is possible to find the effect of a variation on outputs. In fig.4 sensitivity analysis graph has been shown. The line with higher slope is more sensitive. As it is obvious from fig. 5, in sensitivity analysis of Lacey formula for parameter F/Z it can be seen that, in variations of 6-8, 8-10 and 18-20 percent, Lacey model is very sensitive about parameter F/Z.

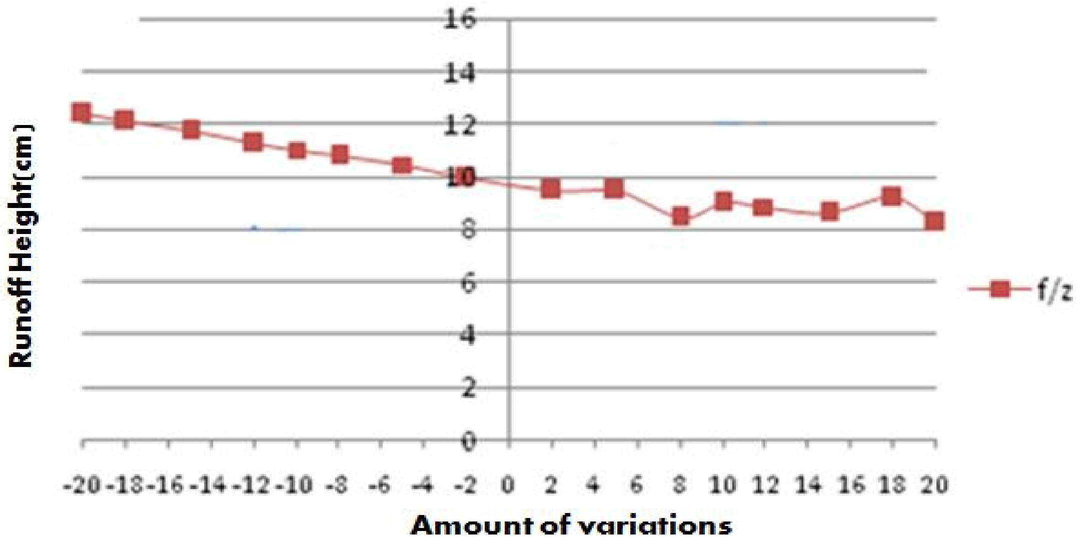

Figure 4. Sensitivity analysis of Lacey model

Discussion and Conclusion

In this research, nine runoff estimation models were performed in Banadaksadat watershed. Also these models were evaluated using observed and measured data in hydrometric station of the watershed. The purpose of this study is to determine the most suitable model among tested models in studied watershed that, was conducted using coupled t-test, MD, BIAS, RE and RMSE. The results shown in tables 7, 8, 9 show that, Lacey model with amounts of 0.016, 36.007, 4.0, 0.026 for MD, BIAS, RE and RMSE respectively, is the best model (with a runoff height by 1.53 cm, a runoff volume by 2.29 million m^3 and a runoff coefficient by 18.79%) for runoff height estimation in Banadaksadat and had the most efficiency and accuracy. Also with regard to coupled t-test performance, having no significant difference in a level of 95% confidence confirms the results above which is correspondent with Bashul(2002), Fath Zade (1999) and Ghazavi(2003) results. Ghazavi (2003)did not consider Coutagine method and corrected Langbin method, as suitable methods in arid regions and Khosroshahi(1991) has mentioned the estimation by I.C.A.R is more than observed varieties, this case is more obvious in the watersheds which are larger than 200 km^2. Also, FathZade (1999) considered classic Coutagine and Turc approaches as non-suitable methods with significant errors. In this research, according to the results of statistical tests Engli D, Souza method introduced as the best method after Lacy method, for runoff calculation in the studied area. Results above also, agree with achieved maps (Fig 1 and Fig2) which can be used for more accuracy of Lacy model results. The advantage of Lacey model is the application of combined effect of factors related to time interval of precipitation and physical characteristics of watershed. Flood nature of rivers of arid and semi-arid regions confirms the precipitation with high intensity and short time. Totally, the methods which are based on surface runoff coefficient and the relationship between precipitation and runoff are mostly local and are applicable by special physical and climatic conditions. But, considering physical and climatic results, the runoff estimation methods using surface shortage and physiographic characteristics present more acceptable results.

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