علـوم محیـطی سال نهم، شماره اول، پاییز ۱۳۹۰
ENVIRONMENTAL SCIENCES Vol.9, No.1 , Autumn 2012
39-50

Lag Time Forecasting in a River Basin

Afshin Honarbakhsh,[1*] Seyed Javad Sadatinejad,[1] Moslem Heydari[2] and Mohamadreza Mozdianfard[3]

1- Assistant Professor, Department of watershed management, Faculty of Natural Resources and Earth Sciences, University of Shahrekord.
2- Lecturer, University of Applied Science and Technology of Shahrekord.
3- Assistant Professor, Department of Chemical Engineering, Faculty of Sciences, University of Kashan

تاریخ دریافت: ۸۹/۱/۲۰ تاریخ پذیرش: ۹۰/۸/۲۹

Abstract
Lag time is a parameter that appears often in theoretical and conceptual models associated with river basin. The river basin lag time is an important factor in linear modeling of river basin response. Generally, all hydrologic analyses require at least one of the time parameters of river basin and, in the majority of cases, time of concentration or lag time are used. In this research, storm data from 6 stations in the North Karoon river basin (in Iran) were analyzed. From this analysis, 23 events were selected. Then, in one experimental sub-basin located in this river basin, the lag time was calculated using field method. In this method, performed in the Darehbeed-Samsami study area, lag time was computed from a hydrograph generated by discharge measurement of a triangular scaled spillway. After that, 23 events were divided into two groups, including, one for a newly developed empirical model (70 percent) and another for validation of this model (30 percent). The results obtained from this research based on coefficient of determination (R^2), root mean square error (RMSE) and relative error (%RE) statistical measures showed that the agreement between the computed(from new empirical model) and measured data is good.

Keywords: Lag Time, Flood, Hydrology, Empirical Model, North Karoon River.

پیش بینی زمان تاخیر در حوضه آبخیز

افشین هنربخش[۱*]، سید جواد ساداتی نژاد[۱]، مسلم حیدری[۲]، محمدرضا مزدیان فرد[۳]

۱-استادیار گروه مرتع و آبخیزداری، دانشکده منابع طبیعی وعلوم زمین، دانشگاه شهرکرد
۲-مربی دانشگاه جامع علمی کاربردی شهرکرد
۳-استادیار گروه مهندسی شیمی، دانشکده علوم، دانشگاه کاشان

چکیده
زمان تاخیر پارامتری است که اغلب در مدل های تئوری و مفهومی مرتبط با حوزه آبخیز نمایان است. زمان تاخیر حوزه آبخیز یک عامل مهم در مدل سازی خطی ناشی از واکنش حوزه آبخیز است. به طور کلی همه تحلیل های هیدرولوژیکی حداقل به یکی از پارامترهای زمانی حوزه آبخیز نیاز دارند که در اکثر مواقع از زمان تمرکز یا زمان تاخیر استفاده می شود. در این تحقیق، داده های رگبار شش ایستگاه در حوزه کارون شمالی مورد تحلیل قرار گرفتند. از این تحلیل ۲۳ واقعه انتخاب شدند. سپس در یک زیرحوضه آزمایشی واقع در این حوضه، زمان تاخیر با استفاده از روش میدانی محاسبه شد. در این روش که درمنطقه مورد مطالعه دره بید سمسامی انجام شد زمان تاخیر از یک هیدروگراف تولید شده بوسیله اندازه گیری دبی ناشی از یک سرریز مثلثی مدرج محاسبه شد. بعد از آن ۲۳ واقعه به دوگروه یکی برای توسعه یک مدل تجربی جدید(۷۰درصد) و گروه دیگر برای ارزیابی آن(۳۰درصد) تقسیم شدند. نتایج بدست آمده از این تحقیق برمبنای معیار های آماری R^2، RMSE و RE% نشان داد که مطابقت داده های محاسبه شده(از مدل تجربی جدید) با داده های اندازه گیری شده خوب است.

کلمات کلیدی: زمان تاخیر، سیلاب، هیدرولوژی، مدل تجربی، کارون شمالی.

* Corresponding author. *E-mail Address*: afshin.honarbakhsh@gmail.com

Introduction

From point of view of hydrology river basin lag time (TL) is defined as the time between the centroid of rainfall excess and the peak of the hydrograph (Loukas and Quick ,1996). Lag time is a variable that often used in hydrographical analysis (Sudharsanan *et al.*, 2010). This variable shows the hydrological response of river basin to a rainfall event (Thompson *et al.*, 2004 and Roussel *et al.*, 2005).

The shape of a flood hydrograph is primarily a function of the geometry of the river basin. This is due to the fact that the physical parameters of the river basin all affect outlet runoff of river basin. Where time distance between rainfall occurrence and runoff generation is small the flood hydrograph displays a small lag and a high, sharp peak discharge, otherwise, the flood hydrograph displays a longer lag and a lower, broader peak discharge.

Also it should be noted that urbanization can affect the shape of the flood hydrograph by increasing the area of impermeable substrate and by reducing the amount of soil infiltration. These changes typically produce a shorter lag and a higher, steeper peak discharge (Chow, 1964; Leopold, 1968; Anderson, 1970; Schulz and Lopez, 1974; Laenen, 1980;Singh and Agiralioglu, 1982).

Many empirical formulae have been proposed for estimating lag time. Usually, these formulae compute the watershed lag time as a function of the watershed parameters (Barnes, 1959;Gray, 1961; Eagleson, 1962;Diskin, 1964;Laureson, 1964;Bell and Kar, 1969; Rastogi and Jones, 1969; Anderson, 1970; Askew, 1970; Ragan and Duru, 1972;Rao and Delleur, 1974). According to soil conservation service (SCS) findings, for many cases the lag time could be related to the concentration time and so they used the relationship between lag time and time of concentration to compute lag time by the following formula (1)

$$Tc = 1.67\ TL \quad (1)$$

where :

Tc = time of concentration (hr)

TL = lag time (hr)

For small natural drainage basins with simple drainage patterns, the lag time may be very close to the time of concentration. However, it is sometimes difficult to measure the lag time in real world situations.

Materials and Methods

The studyarea of this research is located in the West of Iran and with latitude ranging from 3469326 to 3608955 and longitude between 397448 and 574474. Data used in this research are storm data that collected from gauged stations located in north Karoon river basin. The gauged stations used in this paper are listed in Table (1) and their positions are given in Figure (1).

Data Collection

Using data from a recording float type rain gauge at meteorology stations within sub-basins, 23 events indicating excessive and prolonged rainfall which yielded large floods, were selected. The hydrograph for each event was obtained using data from the hydrometric stations at the relevant sub-basin. Discharge

Table 1. Positions of basins.

Basin	Position of basins (x,y)
Khanmirza	3473377 - 3499677 N , 491826 - 520538 E
Dezak	3566141- 3608627 N , 397214 - 439538 E
Darkeshvarkesh	3550553 - 3595844 N , 439774 - 478695 E
Karebast	3469326 - 3526609 N , 503513 -574759 E
Beheshtabad	3522094 - 3603793 N , 440048 -542439 E
Armand	3470104 - 3608955 N , 397448 -574474 E
Samsami experimental micro basin	3574734 -3574840 N , 469063 – 469302 E

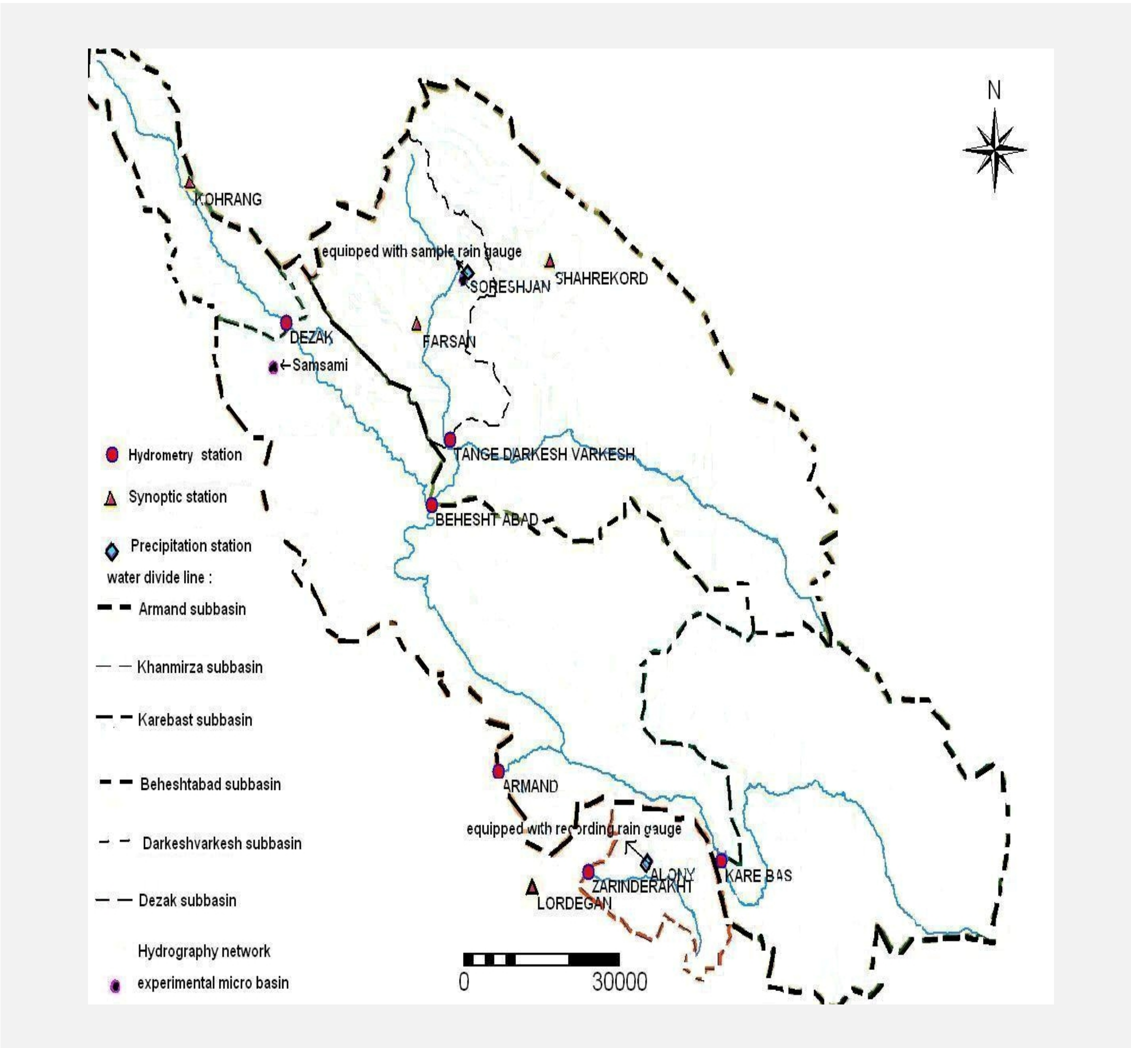

Fig.1. Positions of the sub-basins and stations studied.

flows were obtained from stage-discharge relation produced from the limnographs at these stations (see Figures 2 and 3).

In order to determine the centroid of rainfall excess, the Φ index (a loss function whose value results in a volume of direct run-off equal to that measured and distributed uniformly across the hydrograph) (Matreja, 1990) was calculated and superimposed on the histogram (see Figures 4 and 5). The Φ index is therefore matched up so that the amount of direct runoff from the hydrograph is equal to the amount of excess rainfall. Finally, by use of a hydrographic method the estimated lag time of events was calculated.

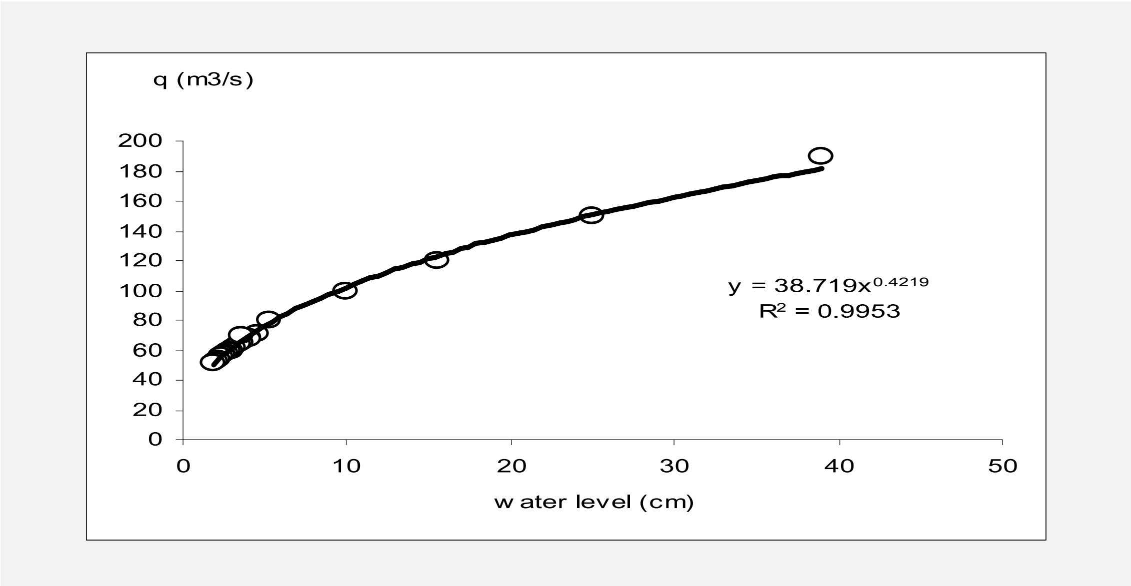

Fig. 2. A sample stage-discharge relationship from Khanmirza basin.

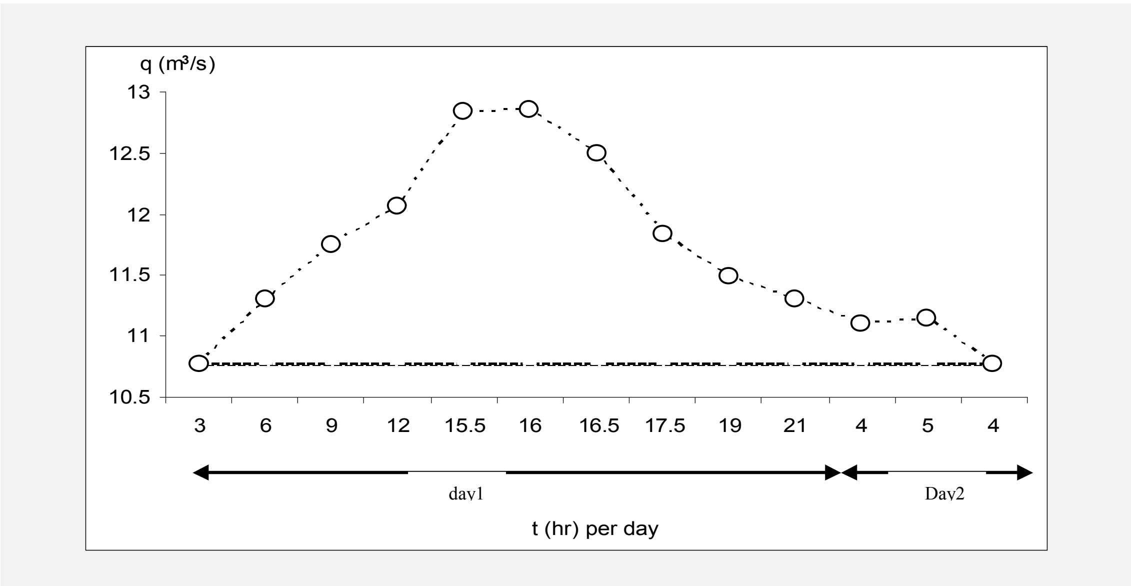

Fig 3. A sample hydrograph from Khanmirza basin.

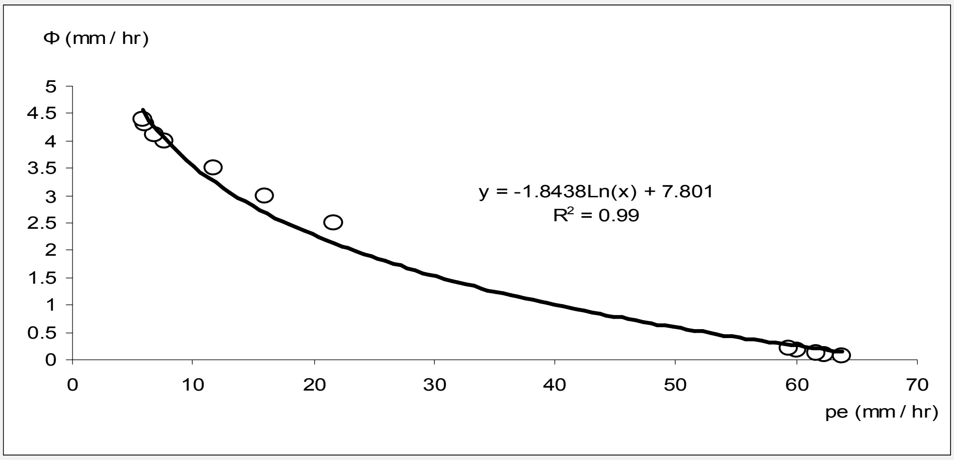

Fig. 4. Relationship between the Φ index and excess rainfall (pe) from Khanmirza basin.

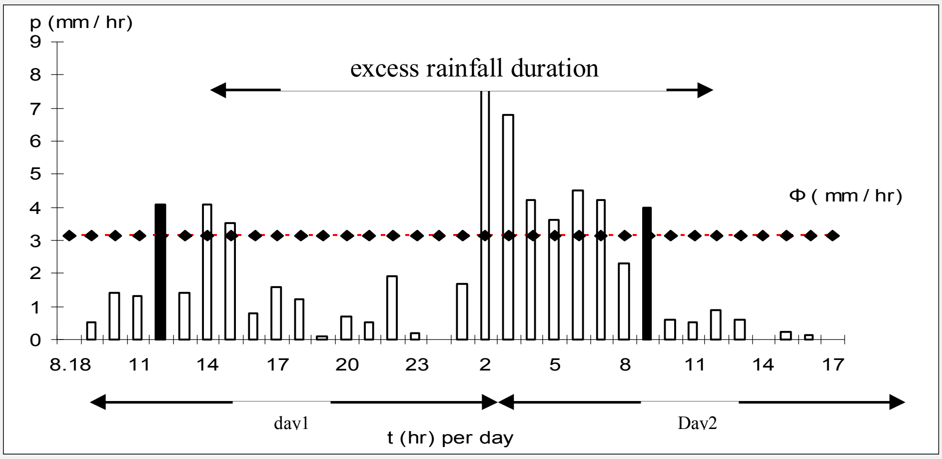

Fig. 5. Determination of excess rainfall using the Φ index from Khanmirza basin.

In order to apply more diverse data, lag time was also obtained in a rainfall-runoff event for a smaller experimental basin (Samsami experimental micro basin) using data obtained from a simple rain gauge and a triangular scaled spillway (see Fig. 6). Rainfall-runoff data was collected every five minutes from which the corresponding histogram and hydrograph were produced and lag time was extracted accordingly and was found to be 19 minutes (see Fig. 7).

Fig. 6. Triangular scaled spillway at Samsami experimental micro basin.

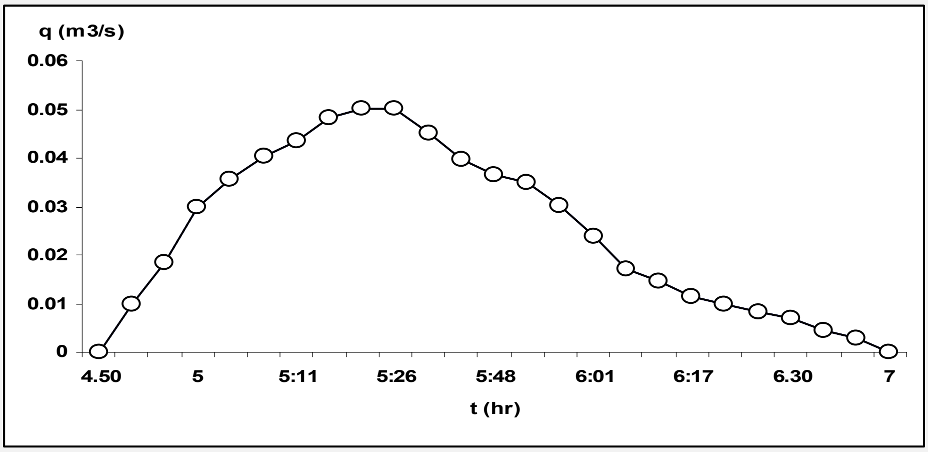

Fig. 7. Hydrograph generated in Darehbid Samsami experimental basin with lag time equivalent to 19 minutes.

Physical parameters of the sub-basins were determined using GIS software, including: area (A), perimeter (P), the longest route for water (L_f), main river length (L), the equivalent circle diameter or diameter of circle whose perimeter is equal to the perimeter of the basin (D_e), the watershed length (L_w), basin circularity (C_r), main river average slope (S_w), watershed average slope (S), mean basin elevation (E_m), distance between watershed gravity centre and outlet (L_c), elongation ratio (E_r), difference between minimum and maximum elevation (ΔH), bifurcation ratio (B_r) and height difference between the start and end of the main river (Δh) These are presented in Table 2.

Table 2. Physical parameters of the basins.

parameters	Basins						
	Armand	Beheshtabad	Karebast	Darkeshvaekesh	Dezak	Khanmirza	Samsami
Area (km^2)	10104	3880	2388	909	578	390	0.027
Perimeter (km)	647	242	256	153	141	110	0.674
Length of longest flow path (m)	199560	105808	78724	58398	64615	39597	304
Length of main water way (m)	199103	104261	77891	56898	64158	39320	254
Diameter of circle with area equal to area of basin (km)	113	70	55	34	27	22	0.185
Equivalent diameter (D_e) (km)	206	108	81	49	45	35	0.214
Basin length (m)	130661	53134	55274	45917	55280	29618	261
Basin circularity	0.302	0.416	0.455	0.482	0.362	0.404	0.748
Weighted slope of main water way(%)	0.954	0.757	1.502	1.221	1.41	2.12	30.47
Weighted slope of basin (degree)	21.47	13.6	30.48	23.59	31.27	15.51	33.98
Difference between min and max elevation in basin (m)	3000	1650	1760	1632	1925	1262	85.4
Mean basin elevation (m)	2265	2209	2206	2223	2725	1956	2280
Length from outlet to the centroid of basin (km)	42.2	59.3	23.02	22.79	28.15	12.72	0.17
Bifurcation ratio	3.66	3.96	3.18	3.75	4	4.22	1.5
Difference between outset and end of main water way (m)	1900	790	1170	695	905	835	77.7

In this study, in addition to the elongation coefficient which is the diameter of the circle whose 'area' is the same as that of the basin, another equivalent circle diameter, namely the equivalent diameter, was used. This is defined as the diameter of the circle whose 'perimeter' is the same as that of the basin (D_e). It is noted that the statistical measures used in this research are as follows:

$$\text{RMSE} = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(x_o - x_e)^2\right)} \qquad (2)$$

$$\%\text{RE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x_o - x_e}{x_o}\right| \qquad (3)$$

$$R^2 = \frac{\left(\sum xy - \frac{\sum x \sum y}{n}\right)^2}{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right]\left[\sum y^2 - \frac{(\sum y)^2}{n}\right]} \qquad (4)$$

where:

x_o = observed value

x_e = predicted value

n = the number of data

x = independent variable

y = dependent variable

Results

In the empirical method of estimating lag time, a meaningful relationship was sought between the real lag time and the parameters influencing it, which are generally presented in exponential equations. More than 12 relationships have been suggested so far in the literature, which are specific to a certain defined circumstances. In this research, considering the physical characteristics of the studied sub-basins and their real lag time, a new empirical model called the ShahreKord Model 2 (SKM2) has been proposed. SKM2 uses a new parameter (D_e) (which to the best of our knowledge does not exist in the literature to date) based on the diameter of the circle with the same 'perimeter' as that of the corresponding basin. It should be noted that this parameter is different from the elongation coefficient proposed by Schumm in 1956 as he used the diameter of a circle with the same 'area' of the basin. SKM2 was found to be able to estimate lag time more accurately than majority of other empirical models described in the literature.

As discussed earlier, in order to make the empirical model for estimating TL, the relationship between the real TL and the physical parameters of each sub-basin need to be investigated. Table 3 demonstrates this relationship and the associated determination coefficient, R^2. Table 3 demonstrates the

Table 3. R^2 for the relationship between lag time and physical parameters in the studied basins.

Parameter	R^2	Parameter	R^2
Length of main water way	0.992	difference between outset and end of main water way	0.969
Length of longest flow path within the basin	0.992	basin length	0.967
Perimeter	0.992	weighted slope of main water way	0.946
Equivalent diameter(D_e)	0.992	mean basin elevation	0.839
Diameter of circle with area equal to area of basin	0.988	bifurcation ratio	0.792
Area	0.988	basin circularity	0.733
Length from outlet to the centroid of basin	0.981	length of main water way from outlet to a point opposite the centroid of basin	0.635
Difference between min. and max. elevation in basin	0.974	weighted slope of basin	0.0016

relationship between TL and L as well as TL and D_e. The equations for these are:

$$TL = 0.0109\, L^{0.63651} \quad (5)$$

$$TL = 0.9661 {D_e}^{0.6261} \quad (6)$$

where R^2 equals to 0.9929 and 0.9922, respectively. As explained earlier D_e is introduced here for the first time and is defined as the diameter of the circle whose 'perimeter' is the same as that of the basin.

D_e is obtained from the following equation:

$$D_e = 0.3183954 p \quad (7)$$

where P is the basin perimeter (Km).

Using the hydrographic method, events were analysed in all sub-basins for calculation of the real lag time, which were then employed to produce and test the new model, SKM2.. For development of this model, 23 (22+1) events were divided into two groups, including one for constructing a new empirical model and another for validation of this model.

Therefore, using $\frac{2}{3}$ of events for constructing the model and $\frac{1}{3}$ of these for the validation of it. By using the above equations, the SKM2 model can therefore be written as follows:

$$TL = 0.102618175({D_e}^{0.30305}).(L^{0.31825}) \quad (8)$$

Where TL = lag time of basin (hour), D_e = equivalent diameter (in km^2) obtained from above formula (7) and L is main river length in meters. Based on the methodology applied by the SCS method for driving time of concentration and lag time equation a newly formula for estimation of lag time was developed. This new formula is named ShahreKord Model 3 (SKM3) and can be written as follows:

$$TL = 0.8849.(Tc^{0.9683}) \quad (9)$$

Where TL = lag time of basin (hour) and Tc = time of concentration (hour) obtained from SKM1 as follows:

$$TC = 0.1244({D_e}^{0.3151}).(L^{0.3205}) \quad (10)$$

Where Tc = time of concentration of basin (hour), D_e = equivalent diameter(km^2) obtained from above formula (7), and L is main river length in meter (Heydari, 2010).

Discussion

In order to evaluate and test the SKM models, the relationship between the calculated TL using the SKM and the real values were compared. Statistical analysis were carried out and presented in Fig. (8) and (9). With regard to results of the statistical analysis, the following statistical measures are obtained: for SKM2: R^2= 0.9, RMSE=1.78 and RE=8.64% and for SKM3: R^2 = 0.994, RMSE = 0.317 and %RE = 3.503.

It can be concluded that the proposed SKM models in this work are capable of estimating TL in a satisfactory manner. These models can be used for sub basins with different areas in the northern Karoon River, because their entry parameters were taken from various sub-basins as well as the area concerned. Another advantage of these models is that it is easy to obtain the required entry parameters for them.

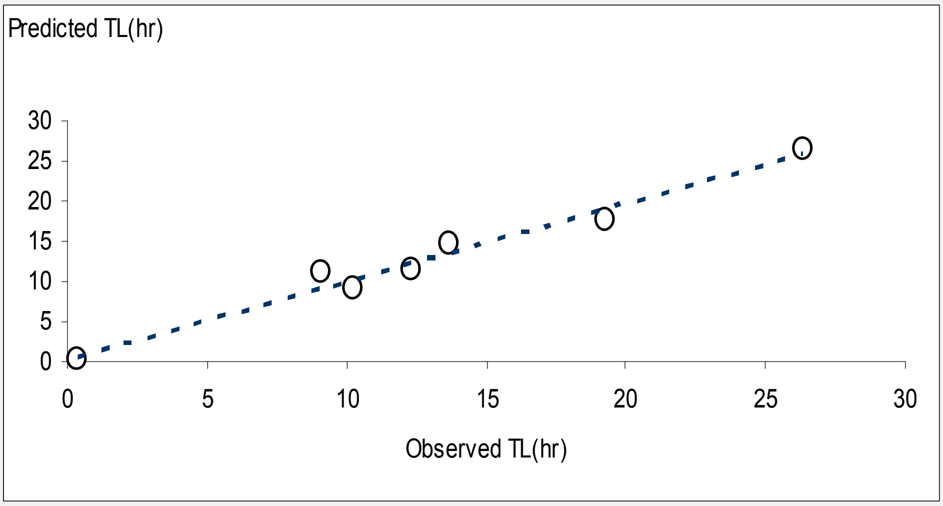

Fig 8. Comparison between predicted TL obtained from the SKM2 model and the real (observed) TL.

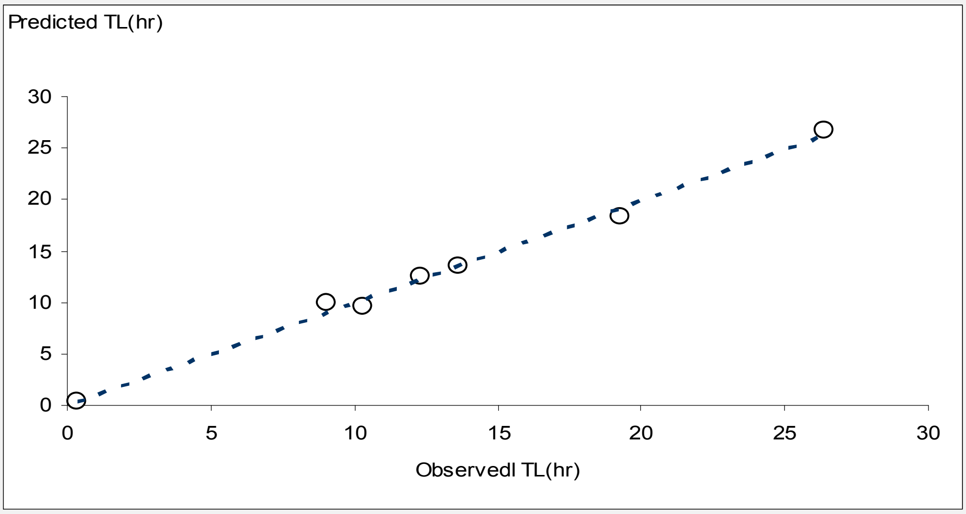

Fig. 9. Comparison between predicted TL obtained from the SKM3 model and the real (observed) TL.

The typical characteristics of the basins for which these formulas were applied, include the following:

– Area between 0.027 and 10104 (Km^2).

– Length of longest flow path between 304 and 19956 (m).

– Slope of longest flow path from 0.757 % to 30.47 %.

– Slope of basin from 13.6 to 33.98in degrees.

The SKM models could probably be used for areas up to 10,000 km^2, with more accuracy for similar geographical characteristics. It should be noted that the application of these models to other basins depends on evaluating its validity.

References

Anderson, D.G. (1970). Effects of Urban Development on Flood in Northern Virginia, U.S.G.S Water Supply Paper 2001-C .

Askew, A.J. (1970). Variation in lag time for natural catchments. Journal of the Hydraulics Division. Proceedings of the American Society of Civil Engineers. 96(2):317-329.

Barnes, B.S. (1959). Consistency in unitgraphs. Journal of the Hydraulics Division. Proceedings of the American Society of Civil Engineers, 8:39-61.

Bell, F.C., andS.O. Kar (1969). Characteristic response times in design flood estimation. Journal of Hydrology, 8:173-196.

Chow, V.T. (1964). Handbook of Applied Hydrology. Newyork: McGraw Hill.

Diskin, M.H. (1964). A basic study of the linearity of the rainfall-runoff process in watersheds. M.Sc. Thesis, University of Illinois, Urbana, IL.

Eagleson, P.S. (1962). Unit hydrograph characteristics for sewered areas. Journal of the Hydraulics Division. Proceedings of the American Society of Civil Engineers, 2:1-25.

Gray, D.M. (1961). Synthetic unit hydrographs for small watersheds. Journal of the Hydraulics Division. Proceedings of the American Society of Civil Engineers, 4:33-54.

Heydari, M. (2010). Revision of Some Empirical Model for Estimation of Time of Concentration and Survey the Efficiency of Fuzzy Regression Model to Estimate the Time of Concentration in North Karoon River Basin. M. Sc Thesis. Shahrekord University. Shahrekord, Iran.

Heydari, M. (2010). Survey of Lag Time in North Karoon River Basin. MSc. Seminar at Shahrekord University. Shahrekord, Iran.

Laenen, A. (1980). Storm Runoff as Related to Urbanization in the Portland, Oregon-Vancouver, Washington Area. U.S.G.S, Water Resource Investigations Open File Report 80-689.

Laureson, E.M. (1964). A catchment storage model for runoff routing. Journal of Hydrology, 2:141-163.

Leopold, L.B. (1968). Hydrology for Urban Land Planning: A Guidebook on the Hydrologic Effect of Urban Land Use. U.S.G.S, Circular 554.

Matreja, K.N. (1990). Applied Hydrology. Newdelhi: TaTa McGraw Hill.

Ragan, R.M., and J.O. Duru (1972). Kinematic wave nomograph for time of concentration. Journal of the Hydraulics Division. Proceedings of the American Society of Civil Engineers, 98(10):1765-1771.

Rao, A.R., and J.W. Delleur (1974). Instantaneous unit hydrograph, peak discharges,and time lags in urban areas. Hydrological Sciences Bulletin, 19(2): 185-198.

Rastogi, R.A, and B.A. Jones. (1969). Simulation and hydrologic response of a drainage net of a small agricultural drainage basin. Transactions of the American Society of Agricultural Engineers, 12: 899-908.

Roussel, M.C., D.B. Thompson, X. Fang, T.G. Cleverland and C.A. Garcia (2005). Time Parameter Estimation for Applicable Texas Watersheds. Department of Civil Engineering, Lamar University, Beaumont, TX 77710.

Schulz, E.F., and O.G. Lopez (1974). Determination of urban watershed response time. Hydrology Paper no. 71, Colorado State University, Fort Collins, CO.

Singh, V.P., and N. Agiralioglu (1982). Lag time for diverging overland flow. Nordic Hydrology, 13:39-48.

Sudharsanan, R.M. Krishnaveni and K. Karunakaran (2010). Derivation of Instantaneous Unit Hydrograph for a sub-basin using Linear Geomorphological Model and Geographic Information Systems 77710. Journal of Spatial Hydrology 10(1): 30-40.

Thompson, D.B., X. Fang and T.G. Cleverland (2004). Literature Review on Time Parametersfor Hydrographs. Department of Civil Engineering, Lamar Univercity.