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Performance of Different Models for Curve Number Estimation (Case study: Bar Watershed in Khorasan Razavi Province, Iran)

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ABSTRACT Among different models for runoff estimation in watershed management, the Soil Conservation Services-Curve Number (SCS-CN) method along with its modifications have been widely applied to ungauged watersheds because of quickly and more accurate estimation of surface runoff. This approach has been widely accepted by hydrologists, water resources planners, foresters, and engineers, as well. Therefore, this work was aimed to estimate the curve number using CN-values through several methods viz. SCS, Sobhani (1975), Hawkins *et al.* (1985), Chow *et al.* (1988), Neitsch *et al.* (2002) and Mishra *et al.* (2008) in Bar Watershed, Iran. According to the results, the Neitsch formula showed the best performance for estimating the Curve Number in situation with low (CNI) and high (CNIII) antecedent moisture conditions. However, the weakest performance was related to Mishra (2008) in CNI and CNIII-conversions. The weakest performance was resulted from the exponential form of the Neitsch *et al.* formula and the variable meteorological conditions of the Bar Watershed over the year.

Key words: *Antecedent soil moisture, Flood estimation, North-Eastern Iran, Rainfall-runoff modeling*

1 INTRODUCTION

Nowadays, integrated watershed management (IWM) has an important function in many fields. In fact, it implies correct and appropriate use of water to land and other natural resources in a watershed for runoff estimation which is required for planning, developing and managing water resources. Runoff is one of the significant hydrological variables which is used in the water resources applications and planning management (Amutha and Porch Elvan, 2009). Relationship between rainfall-runoff is highly nonlinear, complex and complicated and dependent to many factors such as rainfall intensity and duration, soil type, antecedent soil moisture (AMC), land use, evaporation, infiltration, land cover, and slope (Elhakeem and Papanicolaou, 2009). Hydrologic models have been widely used to explain and predict complex behaviors associated with the

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management of environmental systems (Schulze, 2000; Bronstert *et al.*, 2002; Croke *et al.*, 2004; Siriwardena *et al.*, 2006; Lin *et al.*, 2007; Kalin and Hantush, 2009; Isik, *et al.*, 2012). In this way, there are many hydrologic models which are used to estimate runoff. However, physically based models are faced with some limitations because of their large number of input parameters and complicated calibration (Wu *et al.*, 1993; Kothyari and Jain, 1997; Xiao *et al.*, 2011). Regarding the numerous variables and uncertainties governing the rainfall-runoff process, the lumped-conceptual models are useful approaches for hydrological analysis (Ponce and Hawkins, 1996; McCuen, 2003; Mishra and Singh, 2003; Elhakeem and Papanicolaou, 2009). However, these models must be calibrated by using field measurements (Papanicolaou *et al.*, 2008). Due to the simplicity, high speed computing, correct estimation, and few data requirement, the Soil Conservation Service method (SCS) curve number (CN) is one of the best methods in small agricultural and urban watersheds (Ponce and Hawkins, 1996; Bhuyan *et al.*, 2003; Liu and Li, 2008; Xiao *et al.*, 2011). Additionally, many papers revealed that curve number has been incorporated into a wide range of single event and continuous computer models (Ponce, 1989). The SCS curve number is a function of the soils ability to allow infiltration of water with respect to the land use, land cover and AMC. According to the U.S. Soil Conservation Service classification, there are four hydrologic soil groups, i.e. A, B, C and D with respect to the rate of runoff potential and final infiltration rate (Amutha and Porch Elvan, 2009). Actually, this method is a dual parameter model for predicting surface runoff depth from rainfall depth of individual storm events and it has been widely accepted by scientists, hydrologists, water resources planners, agronomists, foresters, and engineers for surface runoff estimation (Patil *et al.*, 2008).

The SCS-CN (method SCS 1956, 1964, 1971, 1993) transforms rainfall to surface runoff (or rainfall-excess) by using curve number, which is derived from watershed characteristics and antecedent 5-day rainfall (Mishra *et al.*, 2008). Since a natural watershed is very dynamic and has different reaction versus storms, some parameters such as antecedent 5-day rainfall, interception and soil moisture show a variety in individual CN of a watershed even during a storm. Hjelmfelt (1980) has shown that the curve number equation is identical for the special case with the constant rainfall intensity and zero asymptotic infiltration rates. Moreover, this method has been used in ungauged rural watersheds and has been evolved well beyond its original objective for surface runoff prediction in urbanized and forested watersheds (USDA, 1986).

Some scientists such as Ponce (1989) believe that the CN method should not apply for the watersheds which are longer than 250 km^2 and are not subdivided. However, sometimes this method is used for the situation that is not applicable and appropriate (Suresh Babu *et al.*, 2008; Xiao *et al.*, 2011). Although this method has many advantages, some parameters such as spatial and temporal infiltration and time distribution are not considered in that. Furthermore, CNs are computed, empirically, but other factors such as soil and vegetation which effect on them are not empirically computed. The division of soils into hydraulic groups is very coarse and the definition of the antecedent moisture condition is not a quantitative variable (Ponce and Hawkins, 1996; Xiao *et al.*, 2011). Bhuyan *et al.* (2003) has studied event based watershed scale of the AMC values to adjust field-scale

CNs as well as to identify the hydrologic parameters that would provide the best estimate of the AMC. This study showed that the AGNPS (Agricultural Non-Point Source Model) watershed model (Heaney *et al.,* 2001) overestimated the runoff depth while using a CN based on AMC-II condition (Patil *et al.*, 2008; El-Hames, 2012). Thus, the universal assumption for applying AMC-II conditions under typical watershed conditions was observed to be invalid for many experimental watersheds (Patil *et al.,* 2008). Xiao *et al.* (2011) applied the SCS-CN model to estimate runoff in Loess Plateau of China, as well.

Carlesso *et al.* (2011) wanted to measure the runoff for different soils classes at different rainfall intensities in Southern Brazil. For this aim each class of soil, the initial time and runoff rate, rainfall characteristics, surface slope, crop residue amount and cover percentage, soil densities, soil porosity, textural fractions, and the initial and saturated soil water content were measured. The runoff measured was compared to Smith's modified and Curve Number (USDA-SCS) models. The Smith's modified model overestimated the cumulative runoff by about 4%. The SCS Curve Number model overestimated the cumulative runoff by about 34%. Smith's modified model better estimated the surface runoff for soil with high soil water content, and it was considered satisfactory for Southern Brazil runoff estimations. The SCS Curve Number model overestimated the cumulative runoff and its use needs adjustments particularly for no-tillage management system.

Deshmukh *et al.* (2013) used three different methods for three watersheds located in Narmada basin. In this work, the CN computed from the observed rainfall-runoff events was termed as CN (PQ), land use and land cover (LULC) was termed as CN (LU) and the CN based on land slope was termed as SACN2. The estimated annual CN (PQ) varied from 69 to 87 over the 26 years period with a median of 74 and an average of 75. The CN (PQ) ranged from 70 to 79 were the most significant values and truly represented the AMC-II condition for the Sher Watershed. The annual CN (LU) was computed for all three watersheds using GIS for the years 1973, 1989 and 2000. The computed CN (LU) values showed increasing trend with the time which was attributed to the expansion of agricultural area in whole watersheds. The predicted values of CN (LU) used to predict runoff potential under the LULC alterations. Comparison of CN (LU) with CN (PQ) values showed a close agreement which establish the validation of the LULC classification. In addition, results showed that for the micro watershed planning, SCS-CN method should be modified to incorporate the effect of change in land use and land cover along with land slope alteration. Lin *et al.* (2014) combined Xinanjiang model with the Curve Number (XAJ-CN model) to simulate the impact of land use change on water flow in Dongjiang River basin which constitutes the most important water source system for Guangdong Province and Hong Kong City. They calibrated and validated the model based on the 10 years data. It was observed that the simulated runoff matched the observed one, which indicated that the performance of the XAJ-CN model was satisfactory. Results showed that the impact of land use change on runoff was more obvious flood season compared to that in dry season. The impact of changes in the CN value on surface runoff was the highest flood season, while the change in the CN value mainly affected groundwater recharge dry season. Lal *et al.* (2015) used a large number of observed rainfall and runoff events occurred in India. The effects of land features such as slope and antecedent moisture was evaluated on the curve number parameters of the SCS-CN methodology. Results showed that the original assumption of the optimized initial abstraction ratio (λ) of 0.20 was unusually high. The median and mean λ values were respectively 0 and 0.034 for natural rainfall and runoff data and 0.033 and 0.108 for ordered rainfall and runoff data, respectively. In addition, CN or potential maximum retention (S) values showed a higher degree of dependence on the physically observed 1-day antecedent soil moisture than other duration antecedent soil moisture values. The AMC was introduced as the initial moisture condition of the watershed before storm event. Commonly, the AMC-II is considered as the base condition for CN determining.

Curve numbers was first calculated under the AMC-II condition, then they were adjusted based on the AMC-III or AMC-I depending on the 5-day antecedent amount of rainfall (Mishra *et al.*, 2008). There were three drawbacks with this assumption (Hope and Schulze, 1981). First, the relationship between antecedent rainfall and AMC was defined for discrete classes, rather than continuous (Hawkins, 1978; Mishra *et al.*, 2008). Second, the use of 5-day antecedent rainfall was more applicable on subjective judgments than physical reality. Third, evapotranspiration and drainage were not considered in depletion of moisture (Mishra *et al.*, 2008). After determination of the AMC and CN-values by NEH-4[1] (SCS, 1972), some scientists such as Sobhani (1975), Hawkins *et al.* (1985) and Chow *et al.* (1988) have shown other formulae about the same CN conversion. Neitsch *et al.* (2002) and Mishra *et al.* (2008) have also represented CN-conversion formulae entirely different in form and these are being used in the Soil and Water Assessment Tools (SWAT). Therefore, there are many formulae about this subject which are very different in terms of the techniques for CN estimation. While runoff estimation is very important factor for watershed management and planning; it is quite necessary to compare the mentioned conversion formulae for CN estimation and discuss their validity with regard to some evaluation criteria, which is the main purpose of this work.

2 MATERIALS AND METHODS

2.1 Study Area

The Bar Watershed is located in Khorasan Ravazi Province, northeastern Iran. The area of this watershed is about 111 km^2 which is located between 36º 27´ 38´´ to 36º 36´ 32´´ N-latitude and 58º 40´ 46´´ to 58º 49´ 31´´E-longitude. The mean annual rainfall and average altitude is about 330 mm and 2226 m, respectively with a semi-arid climate (Jafari *et al.*, 2012). The length of Bar main river is 22.5 km and its average slope is 4.2% which finally drains to the Neyshabur plain (Sadeghi *et al.*, 2010). Figure 1 shows a general view of the Bar Watershed.

1. National Engineering Handbook

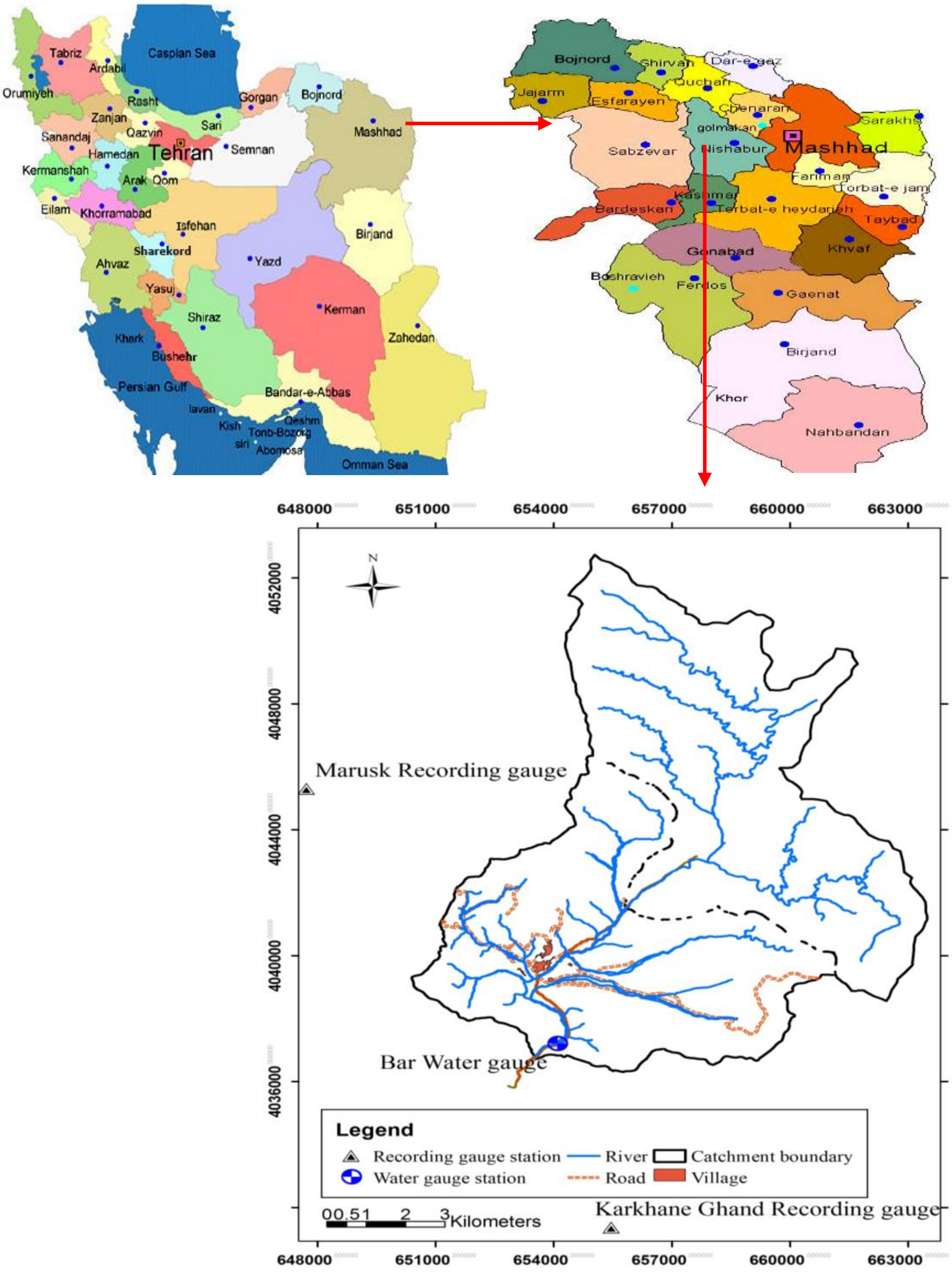

Figure 1 The study area location, rainfall stations and gauge site

3 METHODOLOGY

In order to conduct the study, daily discharge and precipitation data during the period 1951-2006 (56 years) was used. According to Xiao *et al.* (2011) and many other researcher's observations; by increasing the initial abstraction, the ratio of

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rainfall (I_a/S) increased gradually when it is lower than 50 mm, but when it is more than 50 mm, the I_a/S value increased rapidly. The popular form of the SCS-CN equation obtained through combining water balance and two fundamental hypotheses has been represented as the SCS approach (1972):

$$Q = \frac{(P - Ia)^2}{P - Ia + S} \qquad (1)$$

Where P is the total rainfall in mm, Q is the direct runoff in mm, S is the potential maximum retention and Ia is the initial abstraction which involve the interception, surface storage and initial infiltration and many other factors so that it is expressed as a function of S (Ia=λS). In this equation, λ is initial abstraction coefficient which depends on geological and climatic factor and it is between 0.1 and 0.3. However, many books and papers empirically assume λ is 0.2 (SCS, 1985). From the observed rainfall–runoff data and the SCS-CN parameter, S can be determined by solving Eq. 1 for λ = 0.2, as follows (Hawkins, 1978):

$$S = 5\left[(P + 2Q) - \sqrt{Q(4Q + 5P)}\right] \qquad (2)$$

Where S is related to the curve number (CN) which it is very variable from 0 up to 100. If it is 0, there is not any direct runoff and therefore 100 represents that all rainfalls turn into runoff. CN = 100 represents a theoretical lower bound of the potential retention storage, and CN = 0 denotes a theoretical upper bound of the potential retention storage (Jung *et al.*, 2012). The relation between two parameters is shown as:

$$CN = \frac{25400}{S + 254} \qquad (3)$$

Where S is in mm and CN is a non-dimensional factor and shows runoff potential which is controlled by the AMC, land use, soil type, and treatment (SCS, 1985). There are three antecedent moisture conditions (AMC), i.e. AMCI, AMCII and AMCIII which are defined in dry, medium or normal and wet soil conditions. In this formula median CN (CNII) selected as a representative CN which is valid for normal antecedent moisture condition of the watershed (Xiao *et al.,* 2011). This 'Median CN' approach is commonly adopted (Hjelmfelt, 1991; Hawkins *et al.,* 2002; Mishra *et al.,* 2005; Jung *et al.,* 2012).

In this work, runoff depth was calculated for every day in all of the months during 56 years through converting discharge to volume flood in Excel 2010. Then, for every daily runoff, potential maximum retention (S) and curve number (CN) was computed daily by using equations 2 and 3. It is noticeable that the curve number was defined in accordance with CNII which was the watershed's "average condition" in terms of wetness by using Table 1 and then adjusting to AMC III or AMC I depending on the 5-day depth of antecedent rainfall. This table belongs to the NEH-4 CN-values (SCS, 1972). In order to compare the performance of the discussed CN methods with the observed data from a gauged watershed; the recorded data at the watershed outlet were analyzed to obtain the CN with different methods by using Tables 1 and 2. These observed runoff depths of different rainfall events were utilized to compare with the CN based predictions to analyze their performances. All proposed CN-conversion formulae were represented in Table 2. Sobhani (1975), Hawkins *et al.* (1985), Chow *et al.* (1988), Nietsch *et al.* (2002), and Mishra *et al.* (2008) formulas were used for comparing their ability through three parameters indices for evaluation criteria viz. RE, RMSE and R^2.

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Table 1 Curve number (CN) and constants for the case Ia=0.2 S (SCS, 1972)

1	2	3	4	5	1	2	3	4	5
CN for AMCII	**CN for AMCI**	**CN for AMCIII**	**S (mm)**	**Curve starts where P= (mm)**	**CN for AMCII**	**CN for AMCI**	**CN for AMCIII**	**S (mm)**	**Curve starts where P= (mm)**
100	100	100	0	0	60	40	78	169.41	33.78
99	97	100	2.56	5.08	59	39	77	167.38	35.30
98	94	99	5.18	10.16	58	38	76	183.89	36.83
97	91	99	7.84	15.24	57	37	75	191.51	38.35
96	89	99	10.59	20.32	56	36	75	199.64	39.87
95	87	98	13.36	2.79	55	35	74	207.77	41.65
94	85	98	16.20	3.30	54	34	73	216.40	43.18
93	83	98	19.12	3.81	53	33	72	225.29	44.95
92	81	97	22.09	4.31	52	32	71	234.44	46.99
91	80	97	25.12	5.08	51	31	70	244.09	48.76
90	78	96	28.19	5.58	50	31	70	254.00	50.80
89	76	96	31.49	6.35	49	30	69	264.16	52.83
88	75	95	34.54	6.85	48	29	68	274.32	54.86
87	73	95	37.84	7.62	47	28	67	287.02	57.40
86	72	94	41.40	8.38	46	27	66	297.18	59.43
85	70	94	44.70	8.89	45	26	65	309.88	61.97
84	68	93	48.26	9.65	44	25	64	322.58	64.51
83	67	93	52.07	10.41	43	25	63	335.28	67.05
82	66	92	55.88	11.17	42	24	62	350.52	70.10
81	64	92	59.43	11.93	41	23	61	365.76	73.15
80	63	91	63.5	12.70	40	22	60	381.00	76.20
79	62	91	67.56	13.46	39	21	59	396.24	79.24
78	60	90	71.62	14.22	38	21	58	414.02	82.80
77	59	89	75.94	15.24	37	20	57	431.8	86.36
76	58	89	80.26	16.00	36	19	56	452.12	90.42
75	57	88	84.58	17.018	35	18	55	472.44	94.48
74	55	88	89.15	17.78	34	18	54	492.76	98.55
73	54	87	93.98	18.79	33	17	53	515.62	103.12
72	53	86	98.80	19.81	32	16	52	538.48	107.69
71	52	86	103.63	20.82	31	16	51	563.88	112.77
70	51	85	108.71	21.84	30	15	50	591.82	118.36
69	50	84	114.04	22.86	25	12	43	762.00	152.40
68	48	84	119.38	23.87	2	9	37	1016.00	203.20
67	47	83	124.96	24.89	15	6	30	1440.18	288.04
66	46	82	130.81	26.16	10	4	22	2286.00	457.20
65	45	82	136.65	27.43	5	2	13	4826.00	965.20
64	44	81	142.74	28.44	0	0	0	infinity	infinity
63	43	80	149.09	29.71					
62	42	79	155.70	31.24					
61	41	78	162.30	32.51					

[DOR: 20.1001.1.23222700.2015.3.3.7.5]

Table 2 Some methods about CN-conversion formulae

Methods	AMC I	AMC III
Sobhani (1975)	$CN_I = \frac{CN_{II}}{2.334 - 0.0133CN_{II}}$	$CN_{III} = \frac{CN_{II}}{0.4036 + 0.0059CN_{II}}$
Hawkins *et al.* (1985)	$CN_I = \frac{CN_{II}}{2.281 - 0.0128CN_{II}}$	$CN_{III} = \frac{CN_{II}}{0.427 + 0.0057CN_{II}}$
Chow *et al.* (1988)	$CN_I = \frac{4.2CN_{II}}{10 - 0.058\ CN_{II}}$	$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}}$
Neitsch *et al.* (2002)	$CN_I = CN_{II} - \frac{20\ (100 - CN_{II})}{\{100 - CN_{II} + \exp\ [2.533 - 0.063\ (100 - CN_{II})]\}}$	$CN_{III} = CN_{II} \exp\ \{\ 0.0067\ \ (100 - CN_{II})\}$
Mishra *et al.* (2008)	$CN_I = \frac{CN_{II}}{2.2754 - 0.0128CN_{II}}$	$CN_{III} = \frac{CN_{II}}{0.430 + 0.057CN_{II}}$

Root mean square error (RMSE), relative error (RE), and Pearson correlation coefficient (R^2) are defined as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Q_O - Q_e)^2}{N}} \qquad (5)$$

$$RE = \left|\frac{Qo - Qe}{Qo}\right| * 100 \qquad (6)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Qo - Qe)^2}{\sum_{i=1}^{n}(Qo - \overline{QO})^2} \qquad (7)$$

Where RMSE and RE are two evaluation criteria for indicating difference between the model simulation and observation, Q_o is observed flow, Q_e is simulated flow and N is the number of data records. RE is expressed in percent (%). In fact CN in NEH-4 (Table 2) is an observation and those derived from the above formulae are simulated, computed and presented in Table 2. So that, for daily runoff CNI and CNIII was computed with every method which was written in Table 1. Results are shown in Tables 3 and 4, respectively.

4 RESULTS AND DISCUSSIONS

As it was explained, CN in NEH-4 is an average of CNs and it is defined as the observation data, as well. For the period 1951 to 2006, the value of CNII was calculated and transformed to CNI and CNIII by using NEH-4 formula (SCS, 1972) as the target values

(56 common years) and after that Sobhani (1975), Hawkins *et al.* (1985), Chow *et al.* (1988), Nietsch *et al*. (2002), and Mishra *et al.* (2008) formulas were applied (Table 1). It is noticeable that, undesirable negative yield values of CNI in CNII results in negative S-values which are not conceptually rational indeed. For this reason, these results have been omitted from other results. In addition, when precipitation was less than discharge, the results was omitted, as well.

Since there is a record of data (about 20300) the average of relative CNI, II and III were written and therefore average of relative error, root mean square and correlation coefficient were presented in Tables 3 and 4. As it can be seen in Table 3, the lowest and the highest values of CNI in NEH-4 (observed data) was 77.94 and 92.29 in April and July, respectively while in computed data the lowest and the highest value of CNI was 78.41 and 93.12 in these months, in Neitsch *et al.* (2002) and Mishra *et al.* (2008) formulas respectively. Therefore, the range of observed data CNI in NEH-4 varied from 77.94 to 92.29 and in computed data from 78.41 to 93.12. Additionally, the lowest and the highest values of observed data CNIII in NEH-4 was 95.32 and 98.60 in April and July respectively while in computed data the lowest and the highest values of CNI were 90.15 and 98.60 in September and July in Mishra *et al.* (2008) and Neitsch *et al.* (2002) formulas respectively. Thus, the range of observed data CNIII in NEH-4 varied from 95.32 to 98.60 and from 90.15 to 98.60 in computed data.

Furthermore, the range of average relative error for CNI was (0.76-1.75), (0.92-2), (0.69-1.53), (0.48-0.82), and (0.93-2.02) and for CNIII was (0.21-0.47), (0.28-0.62), (0.31-0.71), (0.20-0.28) and (0.29-7.74) that were belonged to Sobhani (1975), Hawkins *et al.* (1985), Chow *et al.* (1988), Nietsch *et al.* (2002) and Mishra *et al.* (2008) formulas, respectively. According to Table 3, the lowest and the highest relative errors for CNI and CNIII belonged to Neitsch *et al.* (2002) and Mishra *et al.* (2008), in respective. In fact the Neitsch *et al.* (2002) formulae exhibited the narrowest range of RE-variation and as result it was the closest one to NEH-4 data (observation data). Therefore among all formulas, Mishra *et al.* (2008) and Neitsch *et al*. (2002) were the worst and the best models in this study which their results did not agree with Mishra *et al.* (2008) as can be seen clearly in Table 4.

Table 3 Comparison of average of various AMC dependent CN and their respective RE

	NEH-4			**Sobhani (1975)**				**Hawkins *et al.* (1985)**				**Chow *et al.* (1988)**				**Nietsch *et al.* (2002)**				**Mishra *et al.* (2008)**			
	Observed			**Computed**		**RE (%)**		**Computed**		**RE (%)**		**Computed**		**RE (%)**		**Computed**		**RE (%)**		**Computed**		**RE (%)**	
	CNII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII
Jan	91.53	82.37	96.49	83.56	96.19	1.66	0.46	83.83	95.99	1.91	0.61	83.32	95.92	1.50	0.67	82.83	96.55	0.78	0.28	83.86	95.96	1.94	0.64
Feb	91.06	81.80	96.22	82.93	95.94	1.53	0.38	83.20	95.73	1.76	0.54	82.69	95.66	1.43	0.61	82.30	96.29	0.76	0.24	83.20	95.70	1.74	0.56
Mar	91.43	82.53	96.43	83.56	96.12	1.49	0.39	83.83	95.92	1.73	0.55	83.33	95.85	1.34	0.61	82.94	96.47	0.72	0.25	83.83	95.89	1.70	0.57
Apr	89.01	77.94	95.32	79.10	95.01	1.63	0.41	79.43	94.75	1.90	0.62	78.81	94.66	1.51	0.71	78.41	95.44	0.76	0.28	79.47	94.71	1.94	0.66
May	93.31	85.57	97.30	86.81	97.02	1.53	0.34	87.03	96.86	1.74	0.47	86.61	96.81	1.38	0.52	86.15	97.33	0.74	0.21	87.06	96.84	1.77	0.49
Jun	95.04	89.05	98.06	90.19	97.79	1.37	0.32	90.36	97.67	1.52	0.41	90.04	97.63	1.26	0.45	89.64	98.02	0.71	0.21	90.38	97.66	1.55	0.43
Jul	96.46	92.29	98.60	92.99	98.44	0.76	0.21	93.11	98.35	0.92	0.28	92.88	98.32	0.69	0.31	92.69	98.60	0.48	0.20	93.12	98.34	0.93	0.29
Aug.	95.04	87.95	98.36	89.45	97.90	1.75	0.47	89.65	97.78	2.00	0.59	89.27	97.75	1.53	0.62	88.53	98.19	0.74	0.24	89.67	97.77	2.02	0.60
Sep	93.46	85.46	97.56	86.66	97.18	1.60	0.42	86.90	97.02	1.90	0.57	86.45	96.97	1.34	0.63	85.84	97.53	0.82	0.21	86.92	90.15	1.93	7.74
Oct	93.30	85.29	97.37	86.59	97.06	1.59	0.35	86.82	96.90	1.81	0.50	86.39	96.84	1.41	0.55	85.88	97.39	0.77	0.28	86.85	96.88	1.86	0.52
Nov	93.37	85.85	97.29	87.00	97.03	1.49	0.38	87.22	96.87	1.67	0.47	86.81	96.82	1.34	0.52	86.32	97.32	0.62	0.25	87.25	96.85	1.69	0.49
Dec	92.21	83.54	96.86	84.68	96.54	1.53	0.37	84.94	96.36	1.80	0.54	84.46	96.29	1.37	0.61	84.00	96.90	0.73	0.24	84.97	96.33	1.83	0.57

Table 4 Average of RMSE and R^2 values for different AMC dependent CN conversion formulae taking SCS (1972, 1985) CN value as target values

	Sobhani (1975)				**Hawkins *et al.* (1985)**				**Chow *et al.* (1988)**				**Nietsch *et al.* (2002)**				**Mishra *et al.* (2008)**			
	RMSE		**R^2**		**RMSE**		**R^2**		**RMSE**		**R^2**		**RMSE**		**R^2**		**RMSE**		**R^2**	
	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII	CNI	CNIII
Jan	1.62	0.73	0.998	0.995	1.81	0.84	0.998	0.995	1.49	0.89	0.998	0.955	0.99	0.64	0.998	0.998	1.83	0.86	0.998	0.995
Feb	1.51	0.43	0.996	0.994	1.70	0.60	0.996	0.994	1.40	0.67	0.996	0.994	0.90	0.30	0.999	0.997	1.70	0.63	0.996	0.997
Mar	1.46	0.46	0.995	0.994	1.64	0.63	0.995	0.994	1.35	0.70	0.996	0.994	0.87	0.32	0.998	0.997	1.64	0.66	0.995	0.994
Apr	1.51	0.46	0.998	0.997	1.73	0.66	0.998	0.997	1.37	0.75	0.998	0.997	0.79	0.33	0.999	0.996	1.75	0.69	0.998	0.997
May	1.49	0.39	0.992	0.967	1.67	0.55	0.992	0.967	1.35	0.61	0.993	0.967	0.78	0.26	0.997	0.978	1.70	0.57	0.992	0.967
Jun	1.41	0.38	0.992	0.991	1.57	0.49	0.992	0.991	1.28	0.54	0.992	0.991	0.77	0.24	0.994	0.992	1.59	0.51	0.992	0.985
Jul	0.79	0.22	0.996	0.992	0.89	0.34	0.996	0.992	0.74	0.39	0.997	0.991	0.50	0.21	0.999	0.998	0.90	0.36	0.996	0.991
Aug.	1.66	0.55	0.996	0.992	1.88	0.67	0.995	0.992	1.48	0.72	0.996	0.992	0.73	0.28	0.999	0.996	1.90	0.69	0.995	0.992
Sep	1.53	0.46	0.995	0.993	1.74	0.62	0.994	0.993	1.37	0.68	0.995	0.993	0.97	0.26	0.997	0.996	1.76	9.34	0.995	0.993
Oct	1.51	0.42	0.994	0.975	1.71	0.59	0.994	0.975	1.37	0.65	0.994	0.975	0.81	0.27	0.996	0.979	1.73	0.61	0.994	0.975
Nov	1.41	0.43	0.996	0.996	1.62	0.54	0.996	0.995	1.25	0.59	0.996	0.995	0.61	0.31	0.998	0.998	1.65	0.56	0.996	0.995
Dec	1.49	0.43	0.996	0.994	1.70	0.61	0.995	0.994	1.35	0.68	0.996	0.996	0.85	0.29	0.998	0.997	1.72	0.63	0.995	0.994

One of the evaluation criteria was RMSE. It is noticeable that the NEH-4 AMC and the Neitsch *et al.* (2002) definition Tables are not the same which was used to determine soil moisture content of a day as the latter adjusts CNs for AMCs. In the NEH-4 procedure, the season was considered as growing season. In Table 4 all the five methods compared based on average RMSE values which were derived from their application to P–Q data sets of the Bar Watershed during 56 years. These methods can be ranked as follows: The range of average root mean square for CNI was (0.79-1.66), (0.89-1.88), (0.74-1.49), (0.5-0.99) and (0.90-0.19) and for CNIII was (0.22-0.73), (0.34-0.84), (0.39-0.89), (0.21-0.64) and (0.36-9.34) that belonged to Sobhani (1975), Hawkins *et al.* (1985), Chow *et al.* (1988), Nietsch *et al.* (2002), and Mishra *et al.* (2008) formulas, respectively.

Generally these rankings were the performance of various methods as following (average of RE and RMSE-based):

(For CNII to CNI)
Neitsch> Chow > Sobhani > Hawkins > Mishra

(For CNII to CNIII)
Neitsch > Sobhani > Hawkins> Chow > Mishra

Since the number of figures about correlation coefficient are too many (N=120); only the figure of Neitsch *et al.* (2002) formulae was shown which illustrates the best performance among all other formulas. The results of correlation coefficient were shown in Figures 2 and 3.

As it was shown in figures 2 and 3 and table 3, according to Neitsch *et al.* (2002) formulae the lowest and the highest correlation coefficient in CNI, i.e., 997 and 0.999 were belonged to August and July and those for CNIII, i.e. 0.972 and 0.998 were matched to August and February, respectively. In addition, CNI had much higher correlation coefficient with observed data but much lower average relative error and root mean square especially in July. The results of RE and RMSE were the same which established that Neitsch *et al.* (2002) formulae had the best performance in both CNI and CNIII and in CNI Chow *et al.* (1988) had the second rank. Sobhani (1975) and Hawkins *et al.* (1985) were ranked as the third and the fourth in terms of performance. However, in CNIII calculations, Sobhani (1975) showed the second rank and Hawkins *et al*. (1985) and Chow *et al*. (1988) were the third and the fourth, respectively. Finally, in both of them (CNI and CNIII) Mishra *et al*. (2008) was the weakest model in this study. These results could be resulted from the form of formula. The form of formulae in Neitsch *et al*. (2002) is exponential while in Mishra *et al.* (2008) and the rest of formulas are linear. Furthermore, this finding showed that the differences between values in this watershed were very high. These findings were in conformity with Deshmukh *et al.* (2013). In fact this area was situated in semi-arid region and in this region there are much variability between rainfall and runoff in all over the year. Because precipitation in this area has not even distributed normally so that it may all rainfall amount fall in one place and in a short time with high intensity, therefore we may have a lot of errors. These results were agreed with Carless *et al.* (2011) and Lin *et al.* (2014) who revealed that this event may occur because of the greater kinetic energy of the rainfall which may cause more quickly alterations in the soil surface, surface seal forming and reduction in time of runoff. At last, increasing rainfall intensity and duration increase the total kinetic energy.

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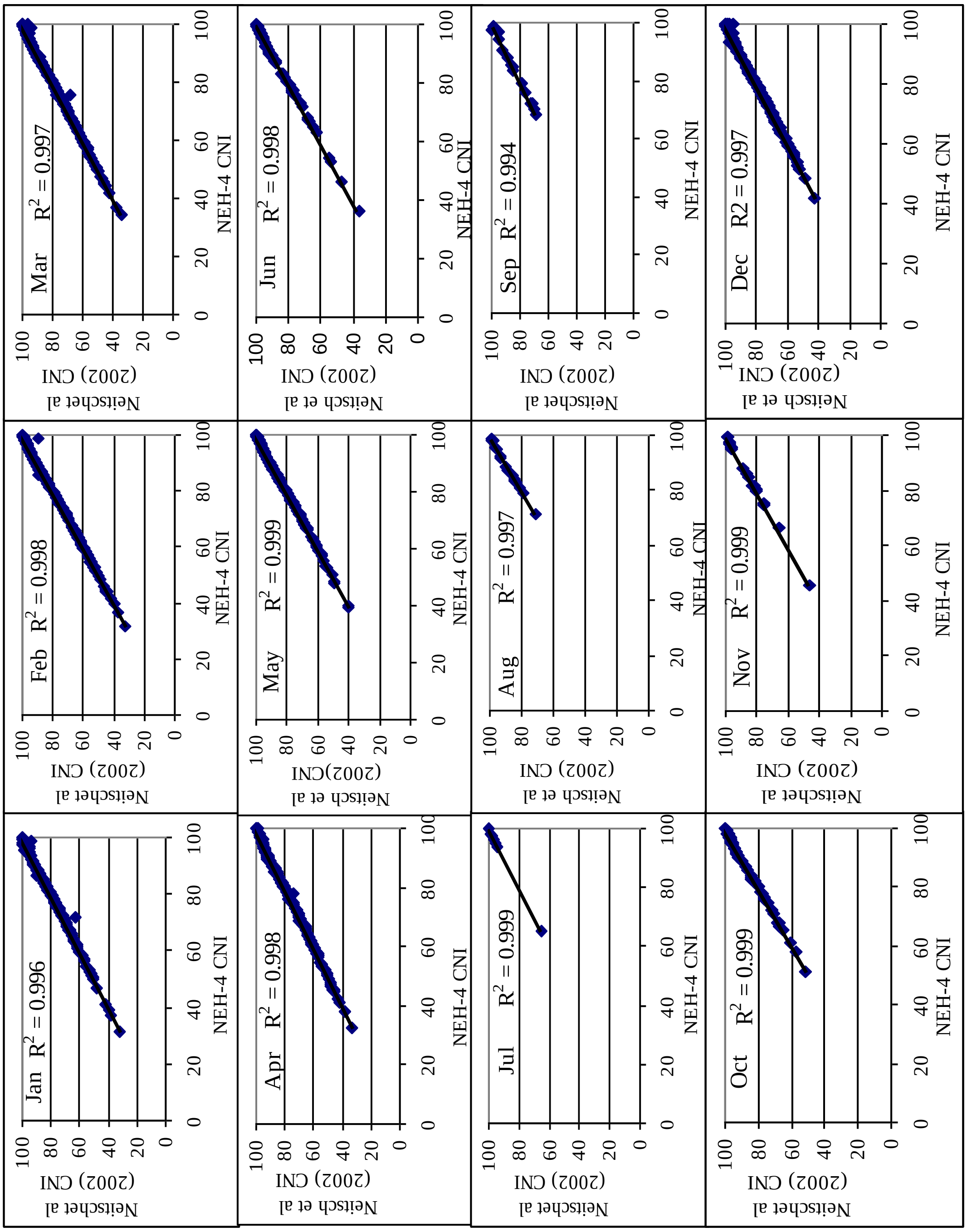

Figure 2 The performance of the best model (Neitsch *et al.*, in CNI condition 2002)

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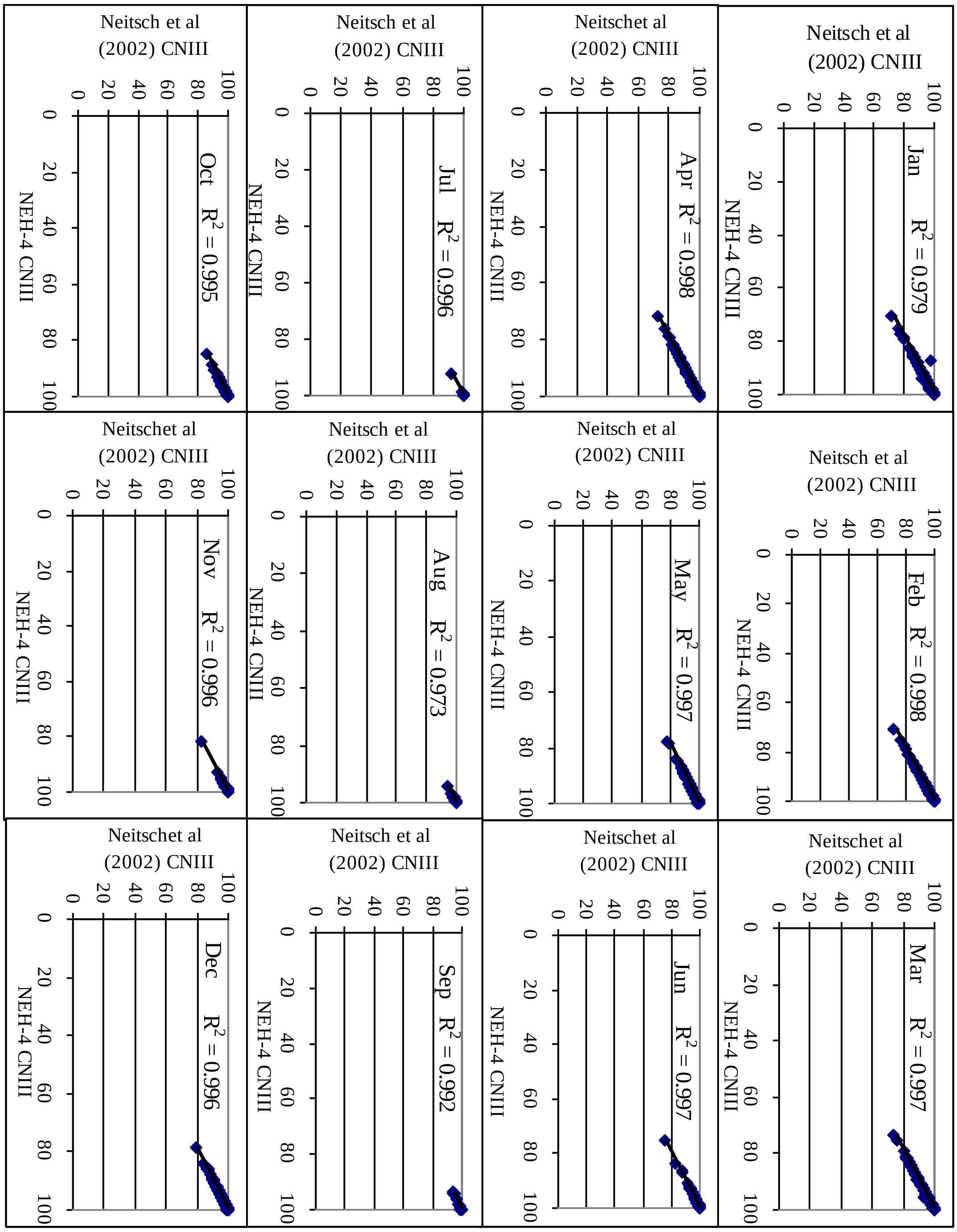

Figure 3 The performance of the best model (Neitsch *et al.*, in CNIII condition 2002)

5 CONCLUSION

This work tried to evaluate some methods which are related to runoff computation. One of the best models is SCS-CN which presented by Natural Resources Conservation Services (NRCS). It is a standard approach for runoff estimation in a watershed due to the simplicity and high speed of computing and applicability for agriculture and urban watershed. Some scientists have presented some methods such as Sobhani, Hawkins, Chow, Neitsch and Mishra. Therefore, in this article these methods were compared with each other and the results showed that Neitsch model was the best and Mishra was the poorest model in CNI and CNIII. Since the SCS-CN is used for estimation of storm runoff and it cannot be used for snow and base flow estimation, application of modified CN methods in other Watersheds are also advised. At the end, we recommended these matters should be investigated by using some techniques such as GIS and RS and in other watersheds with longer duration. In addition, land-use change should be considered, especially for its impact in the flood season. The role of land-use change should be appropriately considered due to its impact on water resources and ecosystem health in the watershed.

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کارائی مدل‌های مختلف تخمین شماره منحنی
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چکیده از میان مدل‌های موجود برای تخمین رواناب در مدیریت حوزه آبخیز، روش شماره منحنی سرویس حفاظت خاک همراه با تغییرات آن به‌طور گسترده‌ای برای سیستم‌های آبخیز غیر تجهیز شده به‌دلیل برآورد سریع‌تر و دقیقی از رواناب سطحی، در بین مدل‌های دیگر می‌باشد. این دیدگاه به‌طور وسیعی توسط هیدرولوژیست‌ها، متخصصان منابع آب، جنگل‌داران و مهندسین مورد قبول قرار گرفته است. بنابراین، مطالعه حاضر به‌منظور برآورد شماره منحنی با استفاده از مقادیر شماره منحنی از طریق روش‌های مختلف از جمله SCS، Sobhani (۱۹۷۵)، Hawkins و همکاران (۱۹۸۵)، Chow و همکاران (۱۹۸۸)، Neitsch و همکاران (۲۰۰۲) و Mishra و همکاران (۲۰۰۸) در حوزه آبخیز بار در ایران انجام شد. نتایج نشان داد که فرمول Neitsch دارای بهترین نتایج در تبدیل شماره منحنی برای شرایط با رطوبت پیشین کم (CNI) و شماره منحنی برای شرایط با رطوبت پیشین زیاد (CNIII) بر اساس حداقل خطای نسبی بوده است. در حالی که ضعیف‌ترین عملکرد مربوط به فرمول و روش Mishra و همکاران (۲۰۰۸) بوده است. وجود چنین نتایجی می‌تواند به‌علت شکل خاص در روش Neitsch و همکاران (۲۰۰۲) به‌دلیل حالت نمایی و هم‌چنین شرایط آب و هوایی حوزه آبخیز بار در طول یک سال باشد.

کلمات کلیدی: تخمین سیلاب، رطوبت پیشین خاک، شمال شرقی ایران، مدل‌سازی بارش-رواناب

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