Water and Environmental Sustainability (WES)
ISSN: 2710-3404
DOI: 10.52293/WES.3.4.113
Homepage: https://www.journalwes.com/

ORIGINAL RESEARCH PAPER

Development of a Distributed Fuzzy Curve Number for Simulating Monthly Sediment Load

T. Tahmasbi*[1], K. Abdollahi[2] and M. Pajoohesh[2]

1. Graduated student from the department of Natural Engineering, Shahrekord University, Shahrekord City, Iran

2. Department of Natural Engineering, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord City, Iran

ARTICLEINFO

Keywords:
Monthly simulated
Sediment yield
Soil Conservation Sediment
Rating Curve
Open-source software
Beheshtabad Basin

Corresponding Author:
tahmasbi.tayebe@gmail.com

Article History:
Received: 18 May, 2023
Revised: 19 Nov, 2023
Accepted: 25 Dec, 2023

ABSTRACT

Curve number is a dimensionless empirical method for predicting direct runoff. Since river discharge and sediment load are highly connected thus the relationship between runoff and bed load could be used to evaluate the continuous sediment load. This study proposes a new curve number that characterizes this parameter based on redefined lookup tables and a fuzzy approach for calculating sediment load. The developed distributed monthly Fuzzy Curve Number Sediment Simulation (CNS2) in Python was applied to predict runoff and sediment load using the rating curve concept. The model uses the fuzzy curve number and some factors such as the number of rainy days, the management of RUSLE-3D, slope, teta coefficient, and soil texture for simulating sediment load at a monthly time scale. The results of model sensitivity analysis indicated that rainfall, base-flow and runoff were the most critical factors affecting sediment load in the study area of interest. The Nash-Sutcliff index evaluated the effectiveness of the simulated runoff; the calculated metric value was 0.6 and 0.53 during two calibration and validation periods, respectively. The Nash-Sutcliff index for simulated sediment load was 0.54 and 0.43 during the calibration and validation periods, respectively. The distributed structure of the developed model provides the possibility for improving estimating spatial variability of sediment yield over the basins; therefore, it can capture the heterogeneity in affecting factors for sediment production.

Introduction

Sediment transport and deposition are major contributing factors to surface water's quantitative and qualitative issues.The consequences of such sediments stayed on behind the built dams. Simulation of the amount of suspended sediment downstream gives the unusable volume of barriers.Sediment and water quality interactions such as fish and invertebrate habitats, malfunctioning hydroelectric power plants, mining and river restoration, and canal navigability are also significant (Walling,1977 &Williams,1989).The CN method methodology is a standard model used in various climatic conditions. Combining this approach with fuzzy logic (LotfiZadeh, 1965)provides a more flexible and reprehensive relationship between the sediment load and discharge.In the 1970s, the American Agricultural Research Institute formed a team of researchers to develop models for simulating non-degradable sediment sources across the United States.The development of several models, such as SWAT (Soil and Water Assessment Tool) (Neitsch*et al.,* 2002), was a sort of effort in this direction.

Recently, the application of fuzzy logic for estimating the sediment load(Kisi *et al.,* 2006).They explained that the undefined inference method calculates complex systems and reliably estimates sediment load.Developed a new model system for suspended sediment using an evolutionary fuzzy logic approach (Kisi, 2016).Similar applications like (Mitra *et al.,* 1999;Changying, & Junzheng, 2000;Chang, & Ayyub, 2001;Goktepe *et al.,*2005;Lee & Lee, 2006;Akyurck, & Okalp, 2006;Shakouri, 2007;Ferraro, 2009) were reported. Such applications gradually became common, especially in the compatibility of soil erosion models with fuzzy logic.In the 1960s and 1970s, further development of rainfall-runoff calculation and early simulation models occurred (Sorooshian, 1983).Since then, many researchers have used probabilistic, empirical, distributional-spatial, conceptual, and integrated models in hydrological studies, such as Stanford Watershed Model (SWM) by the American Stanford Watershed Model (Nash & Sutcliffe, 1979).

Hydrologic engineering center hydrologic modeling system (HEC-HMS), HEC-river analysis system (RAS), or HEC-GEO (geospatial)-the US Army Hydrological Engineering Center presented RAS model was established in 1973-2001; ILLUDAS model, PLOAD model, etc. (Alizadeh, 2012).Since 1990, various GIS capabilities have been taken into consideration by many hydrologists for hydrological modeling.There are many models for simulating hydrological processes with practical application.They contain soil parameters, water basin physiographic features, drainage networks, land use, vegetation, and geological structure.

Nowadays, raster maps of digital elevation models are easily accessible for most regions.Studies show that topography affects the number of curves that justify the promotion of distributed models. presented a two-CN system (Soulis & Valiantzas, 2012). Made a composite curve Number using an improved SCS-CN method with remotely sensed variables in Guangzhon (Fan *et al.,* 2013). Also applied an experimental verification of the effect of slope and land use on SCS runoff Curve Number that could lead to improved runoff results (Mishra *et al.,* 2014).The impact of slope adjustment on curve numbers by using global digital elevation data (Akbari *et al.,* 2016).They expressed a new look is needed into Sharply-Willimas and Huang method as their results showed that in areas where the slope increases, the curve number also increased. This study also proposed using a fuzzy teta soil coefficient to eliminate the contradiction between soil hydrological groups among derived CNs.

Developed the spatially distributed WetSpa model to predict the transfer of water and energy between soils, plants, and the atmosphere in the aquifer (Wang *et al.,* 1997).Formulated a distributed version of the Wetspass (water and energy transfer between soil, plants and atmosphere under a quasi-Steady state)model in the Black Volta Basin in West Africa (Abdollahi*et al.,* 2017) The developed model uses remote sensing data to analyze the form of water balance in spatial and temporal steps and evaluates the runoff coefficient in different classes.

Graduate high-level programming has expanded its application in environmental engineering. Hence, the Python programming language started to grow compared to other languages. One reason for such attention was because of its simple and powerful syntax. Whit advances in software engineering gradually users found access to a combination of GIS tools, Statistics, Mathematics, etc., making it a valuable language for the hydrologist (Tomer, 2011).

Soil Conservation Service (SCS) runoff curve number model. This software is widely entering for watershed modeling(Runkui *et al.,* 2014).Recently, it has undergone many changes. For example, explored the impact of monthly curve numbers on daily runoff estimation for the Ozat catchment in India (Gundalia and Dholakia, 2014).Estimated direct runoff using the Thornthwaite water balance approach (Ferguson, 1996).Their simulation results showed that the monthly balance analysis is instrumental when data availability is an issue, so it makes more sense to go for the monthly time scale. Mentioned increasing the detail of distributed runoff modeling using fuzzy logic in curve numbers may end up with more spatial information (Runkui *et al.,* 2014).Along with the trend in better understanding of spatial variability of runoff and sediment load, this study aims to formulate a fuzzy methodology to access the changes of distribution and spatial runoff and sediment at a monthly scale in the Iron-Python programming language.

Methods and materials

Methods

The modified CNS2 model is a raster-based (Ascii) fuzzy curve number coded in Iron-Python2.7(an open-source implementation of Python for Microsoft. NET Framework v4.5, www.ironpython.net) programming language and H2PL (Hydrology and Hydraulic Programming Library) (Abdollahi, 2015) as open-source software.This monthly model as a distributed model simulates each cell's runoff and sediment values by applying a fuzzy curve number.Meanwhile, several factors such as the number of rainy days, the management of RUSLE-3D, Slope, teta coefficient, and soil texture are required to compute the CN value of each pixel.Evaluation of sediment measurement curve method, the amount of monthly sediment is obtained for each cell.Several static Grid maps, including a digital elevation model, soil texture, land use, flow length, and slope maps, are required for this purpose. Those maps do not alter over time, while the model also involves several dynamic maps whose cell values change over time. These monthly-varying maps are rainfall, rainy days, potential evapotranspiration, leaf area index, and temperature maps. The model uses the inputs mentioned above to partition the precipitation into interception, runoff, evapotranspiration, recharge, and sediment as the model outputs. Figure 1 shows the flowchart of the newly developed model (CNS2).

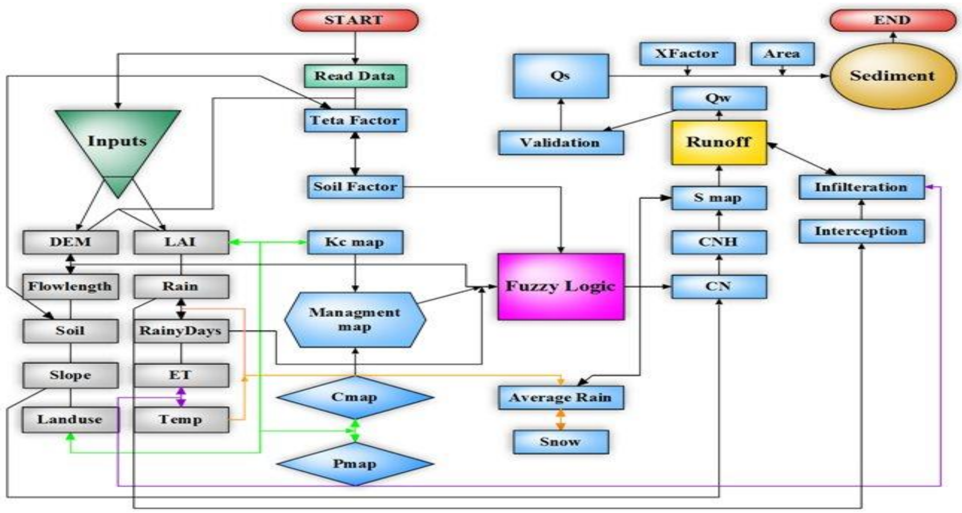

Figure 1: Flowchart for monthly spatially distributed Fuzzy Curve Number Sediment Simulation model

The fuzzy definition for the model variables, including curve number, rainy days, management coefficient, runoff, snow, topography (slope percentage), and sediment load and their range, were calculated.Membership work affects each class's expert judgment of qualitative values (Table 1).

Table1: The range of independent variables and qualitative values

Code	Very very low	Very low	Rather very low	Rather low	Low	Median	Rather high	High	Rather very high	Very high	Very very high
Rainy Days					0-5	5-10	13<				
teta	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.71	0.71-0.72	0.72-0.73	0.73-0.85
Management	1-0.99	0.9-0.99	0.8-0.9	0.7-0.8	0.7-0.6	0.6-0.5	0.5-0.4	0.4-0.3	0.3-0.2	0.2-0.1	0.1-0
CN	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	95-100

Fuzzy rules are then applied under the conditional if and then to the three reciprocal changes that affect the dependent factors (i.e., sediment). Regarding the effect of independent variables on the amount of dependent variable or sediment, In the form of a table of numbers, the rules of the curve entered 361 times.

Table2: Functions for the calculation of interception

Function	Notation
$I_m = P_m I_R \quad (1)$	I_m:Interception(mm/month), P_m:Rain (mm/month), I_R:Interception ratio, (Abdollahi*et al.,* 2017)
$I_R = \frac{I_m}{P_m} = 1 - exp\left(\frac{-I_D nr}{P_m}\right) \ (2)$	I_D:Daily interception (Abdollahi, 2015; De Groen, 2002; De Groen and Savenije, 2006)Where I_D, or the Daily interception, depends on the type of land use (Sutanto *et al.,* 2012) nr:Rainydays(days/month) (De Groen and Savenije, 2006)
$I_D = ka \times LAI\left(1 - \frac{ka \times LAI}{1 + \frac{P_m[1-exp(-0.463LAI)]}{ka \times LAI}}\right) \ (3)$	LAI: Leaf area index ka:Interception parameter

Curve Number

The curve number calculating to fuzzy logic methodology; first, the if and then fuzzy rules are determined. Then, based on their numerical value,a corresponding label is assigned to each curve number. The resulted de-fuzzy curve number was then equivalent to CNII. Haung's equation 5 (Mishra *et al.,* 2003) examines the effect of slope on the curve number. In this regard, the CNM is equal to CNII, and the value of α investigating from equation 4:

$$\alpha = \frac{Slope}{100} \quad (4)$$

$$CN_H = CN_M \times \frac{322.79 + 15.63\alpha}{\alpha + 323.52} \quad (5)$$

Table3: Functions for the calculation of runoff

Function	Notation
$R = \frac{(\bar{P} - 0.2S)^2}{(\bar{P} + 0.8S)} \quad (6)$	R: Runoff (mm/month) (SCS,1985; Cronshey,1986) $\bar{P}$:Average pricipitation(mm/month) S:Soil moisture
$\bar{P} = \frac{P_m}{D} \quad (7)$	P_m:Rainfal(mm/month) D: Rainydays(days/month)
$S = ((\frac{25400}{CNH}) - 254)/S_{reduction} \ (8)$	CNH:Curve Number Huang $S_{reduction}$:Calibration parameter for reduce soil moisture
$Q_w = \frac{R}{1000} \times W_i \times A + \frac{R_n}{1000} \times W_i \times A_n \quad (9)$	Q_w:Water discharge(m^3/month) A:Pixel size(m) Wi:Flow effect
$W_i = W_L\left(exp\left(\frac{-L}{Lmax}\right)\right) \quad (10)$	W_L:Parameter L: Flow length
$Q_{(sr)} = x\sum_{cell=1}^{N} Q_{sr_{(t-1)}} + (1-x)\sum_{Cell=1}^{N} W_i \times R \times \frac{A}{T_p} \ (11)$	Q_{sr}:Surface runoff discharge(m^3/month) A: Area (km^2) t:Time(month) x:Delay factor T_P:Time Pick discharge

Evapotranspiration is another factor that affects runoff production. Since there is no direct measurement of evapotranspiration at the watershed scale, it saves time and requires limited extensive testing. Experimental methods for calculating evapotranspiration are related to the climatic conditions of an area. In different regions of the world with diverse climates, it is necessary to identify the appropriate regional relations. Due to water stress in this study area, the Turc method using in the model. A simple way (Turc*et al.,* 1955) requires annual precipitation P and annual potential evapotranspiration PET (seeTable4).

Table 4: Functions for the calculation of actual evapotranpiration

Function	Notation
$AET = \frac{P}{\left(1+\left(\frac{P}{K_v ET_p}\right)^{K_{ET}}\right)^{\frac{1}{K_{ET}}}}$ (12)	P:Rain(mm/month) K_v:Leaf area index effect (Gerosa *et al.,*2012) K_{ET}:Calibrasion parameter ETp:Potentialevapotranpiration (Pistocchi *et al.,* 2008)
$K_v = 1 - \frac{0.4}{EXP^{LAI}}$(13)	For Vegetation
If K_v=1 than LAI=0 (14)	For Bare Soil

The product of C and P contain to calculate the factors of land management and cover management. Where C includes the cultivation of linear lines, according to the land use map of the RUSLE-3D model, forest land cover without pollution, and P is defined as land use. Soil protection map and tables are required (same as the RUSLE-3D model).Then C is calculated through the relationships of 14 and 15 (Wischmeier & Smith, 1978)

$$C = K_C \times \bar{C} \quad (14)$$

where C is the annual management factor for changes in monthly management, K_C is the management changes during the month used to calculate it from Equation 15 (Kang *et al.,* 2014), and$\bar{C}$ is the annual management changes that depend on land use:

$$K_C = (0.27 \times LAI) + 0.27 \quad (15)$$

The model considers the total precipitation as input; then, it uses the relation 16 to separate the snow from the rainfall(Loukas*et al.,* 2005)The snowpack is the net of the snow cover and snowmelt, defined by liquid snow water equivalent (SWE) (Knight *et al.,* 2001).In the next step, the melting point amount recording by the degree-day method (Knight *et al.,* 2001; Mohseni & Stefan, 1998). The infiltration issimulated as the remainder of the precipitation (mm/month) as presented in Eq 18 (Batelaan & De Smedt, 2001).For calculating the base flow and the amount of stored (mm/month) used in Eq 19 (Abdollahi*et al.,* 2017; Arnold *et al.,* 2000):

Table5: Functions for the calculation of snowmelt and infilteration

Function	Notation
$CW = {}^{1}/(1.61 * (1.35^{T}) + 1)$ (16)	CW:snow T:temperature(˚C/month)
$Melt = C_{Snow} \times (T - T_0)$if $Melt = Snow$if	Melt>Snowstore+Snow (17) Melt<Snowstore+Snow
$Infilteration = Precipitation - Total\ Interception - AET - (R \times RainyDays)$(18)	
$Q_{b_{(t)}} = \beta Q_{b_{(t-1)}} + 0.001 N_m (1-\beta) \emptyset R_m$ (19)	$Q_{b_{(t-1)}}$:Base flow(m^3/month) β:Storage parameter (0-1) N_m:Number of days per month $\emptyset$:Infilteration contribution parameter(m^2/day)
$\emptyset = \frac{1.15A}{k}$ (20)	A: Cell area (m^2) k: recission index (day)

Sediment

The sediment rating curve (SRC) assessed the sediment discharge corresponding to the measured flow discharge (FAO. 1994):

$$Q_s = aQ_w^b \quad (21)$$

where a and b are the coefficients that provide the best relationship between discharge and the sediment load.

Materials

Study area

The developed model was applied to simulate runoff components and sediment load in the Beheshtabad Basin, comprising 3848.4 km^2 in the northeast of the Chaharmahal-Bakhtiari province, one of the western provinces of Iran (Figure 2).

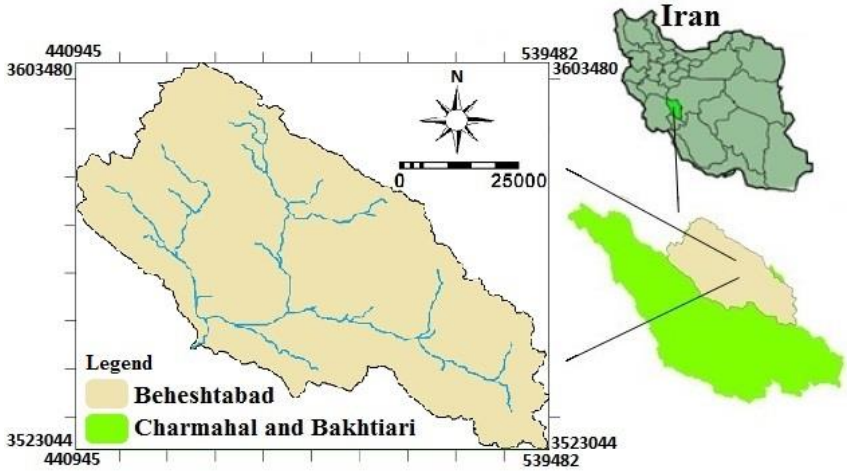

Figure 2: Location of Beheshtabad Basin

The study area with an average elevation of 2422 m above sea level, and the mean slope is around 21.7%.The local Basin has between 50° and 51° 26′ E longitude and 30° 49′ 30" - 32° 33′ 30" N latitude.The average minimum and maximum temperatures are 2.32 and 20.43 degrees, and the average sum of freezing days is 121 days.Annual precipitation is divided into Borujen 322.5 mm, Shalamzar 389.70 mm, and Farsan 496.80 mm.This study area is a highland mountain (see Figure 2).

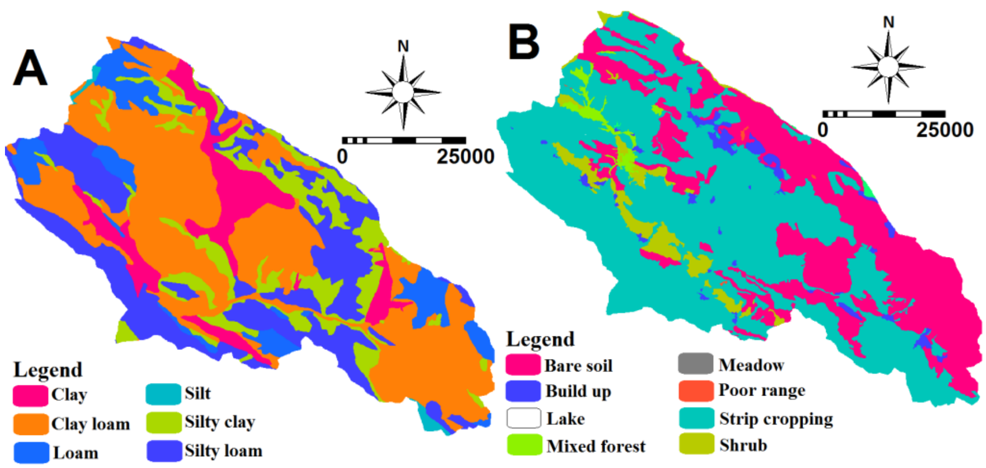

Figure 3: ASoil texture map; B land-cover map of Beheshtabad Basin

Input maps with a cell size of 100 meters of the rainfall, rainy days, potential evapotranspiration, temperature, and general maps, including soil texture (see Figure 3,A) and land use (see Figure 3,B) of Beheshtabad Basin, were prepared in ILWIS3.3 open software environment.The statistical period for simulating times was 14 years (2002 to 2015).A simple Kriging interpolation methodperformancefor the preparation of rainy days maps and precipitation map the Thissen interpolation method.

Preparation of maps evaporation and transpiration maps and temperature used the altitude method. The monthly satellite images of Landsat 8 (2002-2015) designed the study area's Leaf area index (LAI).We used meteorological data from theseseven stations: Avargan, Beheshtabad, Borujen, Gandoman, Saman, Shahr-e-Kord, and Suleman.We were considering the observational data list of stations in Beheshtabad used.Table 6 provides the basin's topographical, meteorological, and discharge characteristics.

Table 6: Main statistical parameters of the Beheshtabad Basin (SD:standard deviation)

Attribute	Unite	Mean	Median	MIN	MAX	SD
Elevation	M	2317.69	2270	1687	3600	233.89
Average Slope	%	17.19	11.143	0	192.021	17.89
Evaporation	mm/month	136.87	120.84	0	701.395	111.87
Rain	mm/month	36.91	23.91	0	189.9	40.74
Rainy Days	Day	4.163	4.205	0	14.17	3.418
Temperture	Oc	11.457	11.58	-20.98	25.11	10.411
Discharg	m^3/s	14.402	7.209	0.847	119.443	19.344

Results and discussion

The calculated runoff fromthe developed model is monthly.The number obtained from the average curve in the Beheshtakad basin was 71.8.Figure 4 shows the highest value for the curve number in the poor pasture, bare soil, and agriculture.

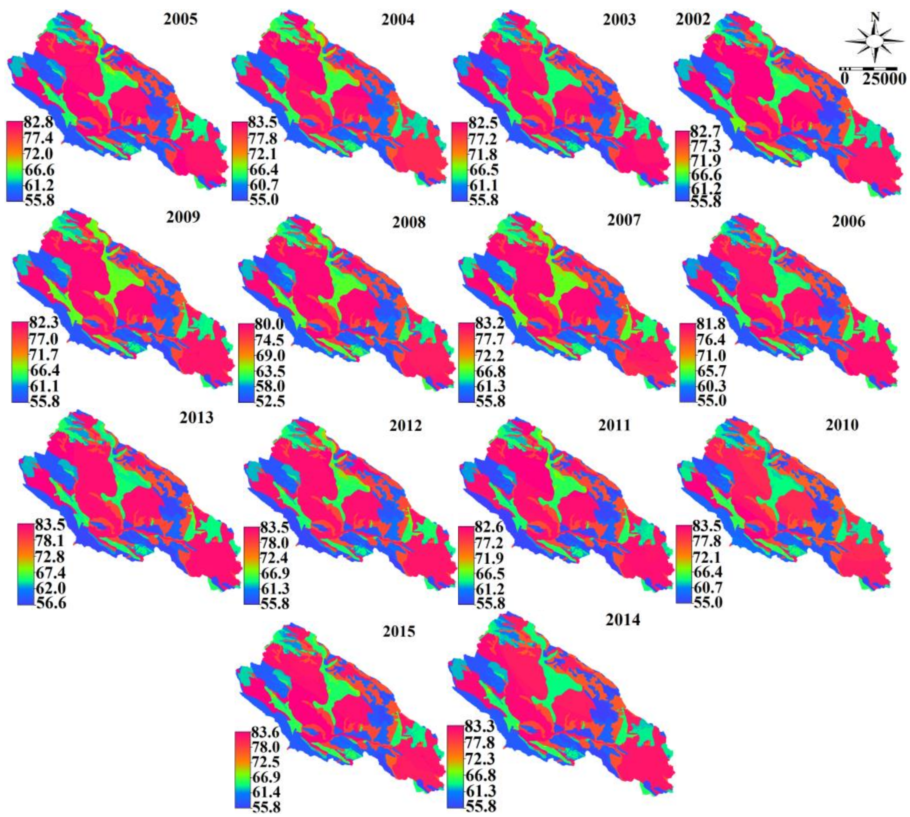

Figure4: MonthlyCurveNumber (CNII or CN_M) for 2002-2015

One of the influential factors in the runoff of the topographic factor as the Beheshtabad Watershed is a mountainous basin.As a slope adjustment factor, the effect of this factor is usable for the curve number.The average CN for the Beheshtabad basin was 72.3.The range of slope variations in the Beheshtabad basin varies between the range of 0 to 192 percent.After applying the slope effect on the CN (Having's a method), the de-fuzzified curve number is used to obtain the protection factor.According to Figure 5, the value of the curve number increased after using the slope effect by the Haung way.And according to the mountainous study area is growing with slope, and the amounts of curve number and runoff increase.This increase is primarily in regions with poor range and bare soil.The results are consistent with (Akbari *et al.,* 2016; Mishra *et al.,* 2003).

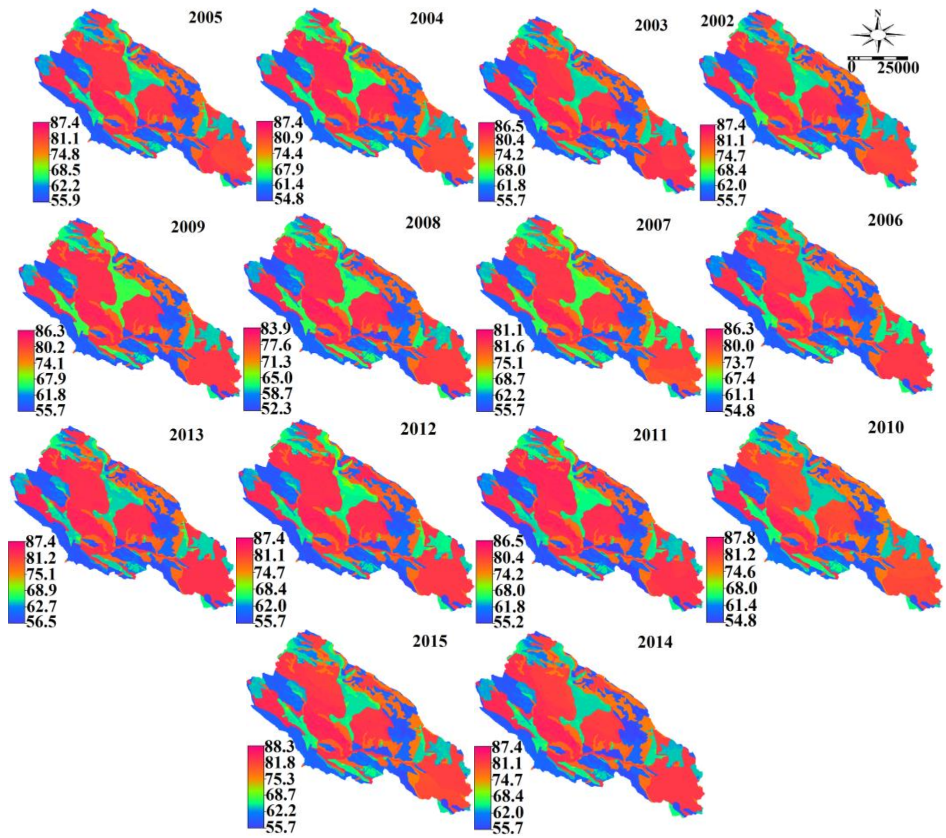

Figure5: Slope-adjusted CurveNumber by Huang method(CNH) for 2002-2015

Model evaluation results show that simulated and observed discharges have acceptable values. Increase in the precipitation, the number of shots increases directly; however, there are some differences in the simulation of peak flow that could be due to various sources such as snowmelt simulation or the function of karst in this basin (Figure6).We have used both Nash-Sutcliff and R^2 indices to evaluate the model. The runoff NSE in the calibration period was 0.6, and in the validation period, it was 0.53.Also, the value of runoff R^2 in the calibration period was 0.63, and for the validation period, it was 0.56.

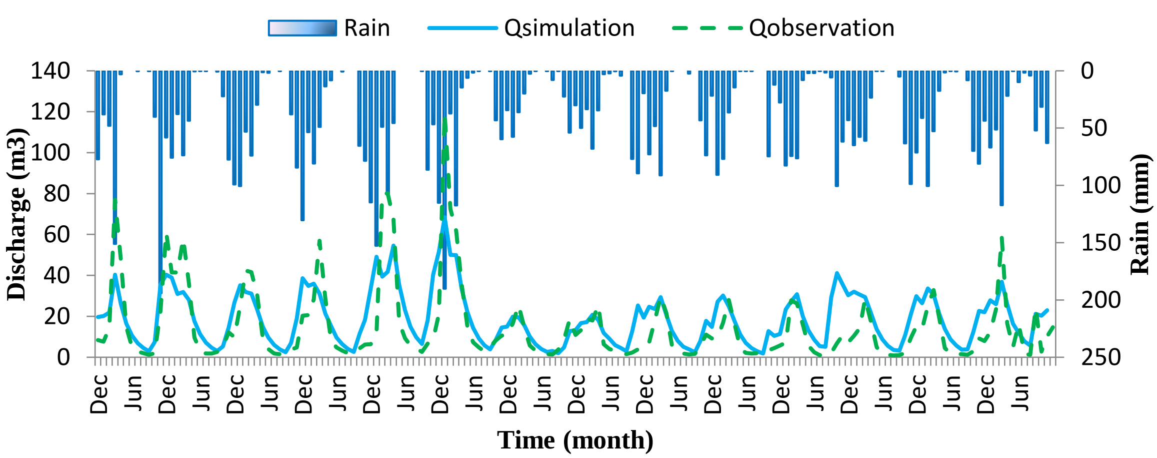

Figure6: Monthly simulated discharge versus observed for 2002-2015

Under the developed concept depending on the land use/land cover type, the total amount of monthly interception was considered a fraction of rainfall. As a result, changes in land use can alter the leaf area index (LAI), which influences interception and evapotranspiration in the form ofa water balance equation. Because Beheshtabad Basin essentially belongs to the land use with poor range and bare soil classes, such regions simulated many pixels with high runoff and sediment load.

However, the management change in this method is limited to the leaf area index and C factor. As a result, the management agent does not show many changes over a year.

Sediment simulation is achieved by volume runoff through the sediment rating curve method.The average sediment load for the Beheshtabad Basin is 6.5 to 7 ton/h per year.The efficiency of the sediment simulation model was 0.54 and 0.43 in the calibration and validation period, respectively(see Figure 7).These results indicate that the model has been able to simulate the sediment in this Basin.

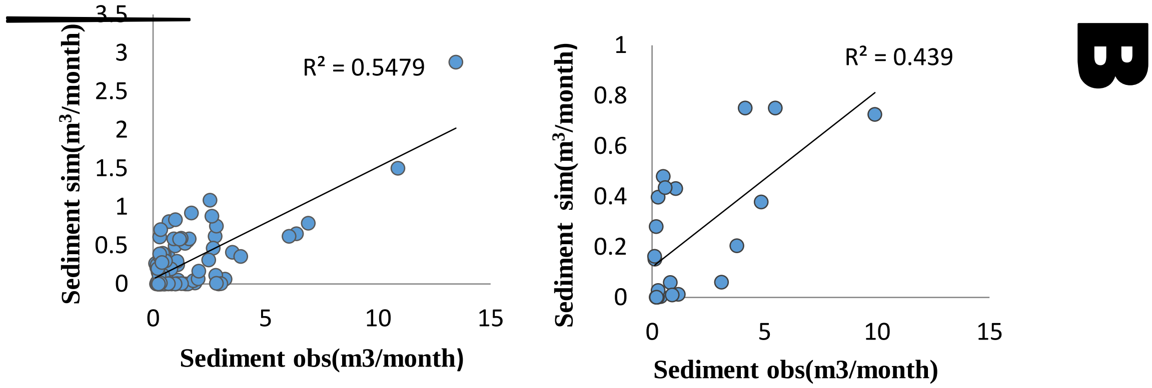

Figure7: Evolution of model efficiency in sediment simulation of calibration (A) and validation (B)

The highest amount of runoff is related to the hot months of the year. The number of rainy days in months increases the amount of runoff, which directly responds. The answer is somewhat different in the dry months of June, July, August, and September. The relationship between rainy days and runoff shows a non-linear effect (Figure 8).

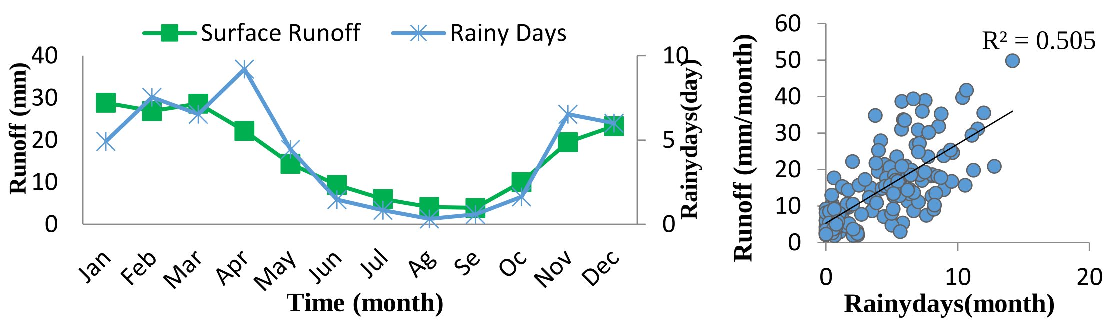

Figure 8: Comparison of rainy days and runoff for 2002–2015

The estimated sediment load in one region depends on the teta coefficient soil, land use (management), and the number of rainy days in the area. Amplification in the management coefficient reduces soil infiltration and therefore increases the amount of runoff and sediment. On the other hand, the high number of rainy days leads to an increase in runoff and sediment generation (Figure 9).

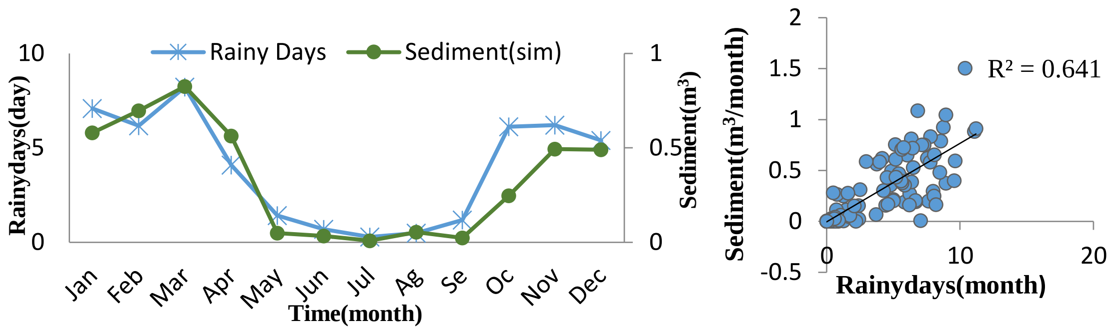

Figure 9: Comparison of rainy days and sediment for 2002–2014

Sensitivity and calibration

The developed procedure considers that the curve number value for each cell is a function of soil hydrological characteristics, land use, soil moisture and number of rainy days, and the land's slope. The results of the sensitivity analysis of the model for runoff simulation showed Seduction coefficient (reduction of soil moisture), Landa (runoff coefficient) parameters had the highest sensitivity, and the Wl parameter (water volume coefficient) showed the minor sensitivity (Figure 10).The sensitivity analysis for sediment load also showed that the rating curve power parameter (b) has the highest sensitivity (Figure 11).

The formula of the grading curve model for sediment estimation has concluded that the most critical factors in the runoff significantly affect the simulated sediment load.

The subject shows that there is an internal problem with sediment estimation.

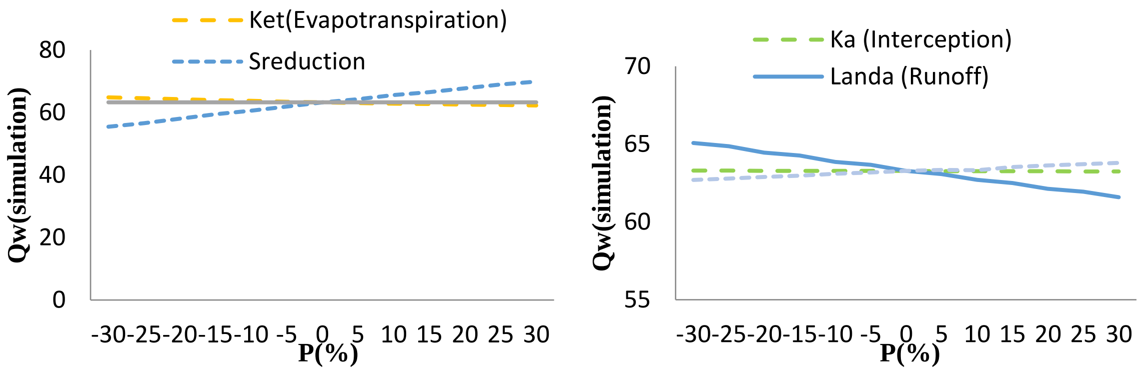

Figure 10: Sensitivity of different water discharge (m^3/month)

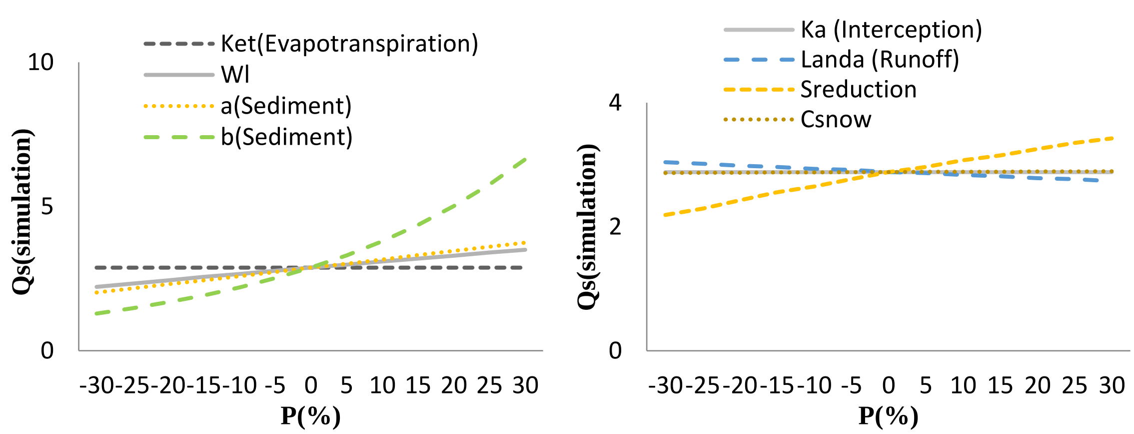

Figure 11: Sensitivity of different sediment discharge (m^3/month)

Conclusion

CNS2 model in general improves the sediment simulations. Some other conclusions are listed as below:

- A sediment simulation model with a fuzzy curve estimates quantitative data using qualitative changes (low, medium, and high).In other words, this method can simultaneously provide both numerical and qualitative information.
- CNS2 applies the effect of the slope effects on the monthly curve number by mean of the Haung method as a factor that can affect the production runoff and improve the results.
- A monthly model simulates the fuzzy curve, surface runoff, evaporation and transpiration, infiltration, and sedimentation
- Using the model in the Beheshtabad basin in the modified model shows satisfactory surface results and the hydrograph planned.

We noted that the differences were slightly higher during the cold months, which then turned to a lower range when the year's warm months showed up.

In the subsurface, this adaptation does not require a surface unless the snow agent performs a uniform and homogeneous process in its change with the temperature indication. As the amount of snow melt increases, its amount decreases and improves the hydrograph.In addition, we noted that the developed model shows that base-flow storage significantly contributed to the results for total flow.

For this reason, one of the most critical factors in the sediment load is precipitation, obtained as the factor of snow and rain, which makes the calculation formula more accurate. As rainfall increases, the number of runoff increases. The rainfall trend increases from December to March, and the simulation runoff tends to increase. Runoff production is low during the dry season, especially from April to August. Starting the rainfall in August month, the runoff production process is also increasing. Therefore, the results indicate a direct relationship (linear relationship) between precipitation and runoff in these conditions, which can reflect the severe sensitivity of the response function of the studied basin to the rainfall inputs. It also may be linked to the effect of the small reservoir in the catchment area.We are applying such conditions to meteorological and hydrological droughts. It is involved in conveying or withdrawing water from surface sources.

The infiltration factor was a crucial factor in calculating base flow.The scope of the study includes other influential factors, so it concluded that the main factor is the production of sediment load. These may account for a large share of precipitation.According to the lookup tables belonging to the original curve number provided by the American SCS method, most of the soil of the Beheshtabad basin falls in the D group(low permeability).Under these conditions, surface cover is essential for controlling the simulated runoff and sediment values. Instead of using the soil hydrological groups (HSG),CNS2 uses another factor called teta of earth.Then this teta map calculated the curve number. The estimated type of soil and the amount of runoff and sediment is relatively where the ground belongs to clay and clay loam.According to the Nash-Sutcliff coefficient for both calibration and validation periods, the results are acceptable - using Haung's method to apply the gradient effect.

The number of curves after the slope's impact is increasing—land's pivotal role in producing runoff, especially in this mountainous region. On steep slopes, the curve number values and the amount of runoff and sediment increase. As the slope decreases, the amount of the curve number, runoff, and sediment also decreases.SCS method influences soil hydrological groups (HSG), soil amount, and land use without considering the effects. But applying slope effects on the curve number is a factor that can affect the runoff production and may improve the results.This study showed that the fuzzy method could reduce the error value and provide a better estimate of sediment load. Also, this method is relatively simple compared to other empirical methods, and without any limitation, other factors may involve in calculating the sediment. Hence, this research is consistent with the results ,that concluded a method based on relatively easy and accurate variables that adds new factors to the original structure (Tran & Duckstein, 2001).Applied a sort of fuzzy logic to predict the month of soil erosion in a large watershed (Mitra*et al.,* 1999).They motioned that the method is low-cost and helpful in developing countries where digital data are unavailable. With the CNS2 model, the base of the CN estimation is on a fuzzy inference method. One of its disadvantages is that the domain space of variables and rules between independent and dependent variables is limited.In the CNS2 model, the curve number found from standard tables, rainy days, teta coefficient, and regulations related to the dependent variable (sediment) from the fuzzy inference method. Given the sediment phenomenon's complexity, using an undefined inference system method may be helpful in ranking and reducing the role of factors creating uncertainty. Also, applying this method as a distributed model can provide a better spatial representation of sediment load over the study area.

Conflict of interest

The author declares that there was no conflict of interest.

References

Abdollahi K. Bashir I. Verbeiren B. Harouna M. R. Griensven A. V. Huysmans M. Batelaan O. 2017. A distributed monthly water balance model: formulationand application on Black Volta Basin. Ph.D. Vrije Universiteit Brussel, Belgium.

Abdollahi, K. 2015. Basin scale water balance modeling for variable hydrological regimes and temporal scales. Ph.D. Vrije Universiteit Brussel. Belgium.

Alizadeh, A. 2012. Principles of applied hydrology. Imam Reza university press. P. 45-46 (In Persian).

Akyurck, Z. Okalp, K. 2006. A fuzzy-based tool for spatial reasoning A case study on soil erosion hazard prediction. 7th International Spatial Accuracy Assessment in Natural Resources and Environ. Sci., p.235-245.

Akbari, A. Azizan, A. S. and Ngien, S. K. 2016. Effect of slope Adjustment on curve number using global digital elevation data: new look into Sharply-Willimas and Huang method. Second International Conference on Science, Engineering & Environment. Osaka City. Japan. Nov.21-23. ISBN: 978-4-9905958-7-6 C3051.

Arnold, J. G. Muttiah, R. S. Srinivasan, R. Allen, PM. 2000. Regionalestimation of base-flow and groundwater recharge in the Upper Mississippi river basin. J Hydrol 227(1): 21–40.

Batelaan, O. De Smedt, F. 2001. WetSpass: a flexible, GIS based**,**distributed recharge methodology for regional ground water modeling. vol 269. IAHS Publication. P. 11–18.

Changying, J. Junzheng, P.2000. Fuzzy prediction of soil strength based on water content and composition. J. Terramechanics. 37 (2):57-63.

Chang, Y.H.O and Ayyub, B.M .2001. Fuzzy Regression Methods-A Comparative Assessment. Fuzzy Sets and Systems. 119(2): 187-203.

Cronshey R. 1986. Urban Hydrology for Small Watersheds. Technical release United States Department of Agriculture, Soil Conservation Service, Engineering Division 210-VT-TR-55,Second Ed, United States, 164.

De Groen, M.M. 2002. Modeling interception and transpiration atmonthly time steps introducing daily variability through Markovchains. Ph.D. Dissertation, IHE-Delft. Swets and Zeitlinger**,**Lisse, The Netherlands.

De Groen, MM. and Savenije, HH. 2006. A monthly interception equationbased on the statistical characteristics of daily rainfall. WaterResour Res, 42(12):W12417. doi:10.1029/2006WR005013.

Fan, F. L. Deng, Y. B. Hu, X. F. and Weng, Q. H. 2013. Estimating Composite Curve Number Using on Improved SCS-CN Method with Remotely Sensed Variables in Guangzhon, china. Remote Sensing. 5:1425-1438.

FAO. 1994. UNDP and UNEP, Land degradation in south Asia: 1ts severity, causes and effects upon the people, World Soil Resources. Report No, 78, FAO, Rome.

Ferraro, D. O. 2009. Fuzzy knowledge-based model for soil condition assessment in Argentinean cropping systems. Environmental Modelling & Software. 24(3):359-370.

Ferguson, B.K. 1996. Estimation of Direct Runoff in the Thornthwaite Water Balance.University of Georgia. 48 (3): 263-271.

Gerosa, G. A. Mereu, S. Finco, A. Marzuoli, R. 2012. Stomatal conductance modeling to estimate the evapotranspiration of natural and agricultural ecosystems. Evapotranspiration-Remote sensing and modeling. InTech. p.403-420.

Goktepe A. B. Altun, S. Sezer, A. 2005. Soil clustering by fuzzy c-means algorithm. Advances in Engineering Software, 36(9), pp. 691-698.

Gundalia, M. and Dholakia, M. 2014. Impact of Monthly Curve Number on Daily Runoff Estimation for Ozat Catchment in India. Open Journal of Modern Hydrology. 4: 144-155.

Kang, Sh. Hao, X. Ding, R. Tong,L. Li, F. Zhang Y. 2014. Variations of crop coefficient and its influencing factors in an arid advective cropland of northwest China. Hydrological processes, 29 (2): 239-249.

Kisi, O. Karahan, M. E. and Sen, Z. 2006. River Suspended Sediment Modeling Using a Fuzzy Logic Approach. Hydrological Processes.20: 4351-4362.

Kisi, O. 2016. A new approach for modeling suspended sediment: Evolutionary fuzzy approach. Hydrology and Earth System Sciences. p.1-41.

Knight, C.G. Chang,H. Staneva, M.P. and Kostov, D. 2001. A Simplified Basin Model For Simulating Runoff: The Struma River GIS. Professional Geogr. 53 (4):533–545.

Lee, G. S. LeeK. H. 2006. Application of fuzzy representation of geographic boundary to the soil loss model. Hydrology and Earth System Sciences. Discuss. 3: 115-133.

LotfiZadeh, A. 1965. Fuzzy sets and systems. In:Fax J, editor. System Theory. Brooklyn, NY:Polytechnic Press. p.29-39.

Loukas, A. Vasiliades, L. Domenikiotis, C. and Dalezios, N.R. 2005. Basin-Wide Actual Evapotranspiration Estimation Using NOOA/AVHRR Satellite Data. Phys. Chem. Earth. P.30.

Mitra, B. Scott,H. D. Dixon,J. C McKimmey,J. M. 1999. Applications of fuzzy logic to the prediction of soil erosion in a large watershed. Geoderma. 86:183-209.

Mishra, S.K. Chaudhary, A. Shrestha, R.K. Pandeym A. Lal, M. 2014. Experimental verification of the effect of Slope and Landuse on SCS Runoff Curve Number. Water Resour Manage. 28:3407-3416.

Mishra, S.K. Singh Vijay, P. Sansalone, J.J. Aravamuthan, V. 2003. A modified SCS-CN method:characterization and testing. Water Resources Management. 17 (1):37-68.

Mohseni, O. and Stefan, H. G.1998. A monthly streamflow model. Water Resources Research. 34(5): 1287-1298.

Nash J.E. and Sutcliffe J.V. 1979. River flow forecasting through conceptual model. Journal of Hydrology. 10:282-290.

Neitsch, S. L. Arnold, J. G. .Kiniry, J. R. Williams, J. R. .King, W. K. 2002. Soil and Water Assessment Tool: Theoretical Documentation. Blackland Research Center. Texas. Agricultural Experimental Station.

Pistocchi, A. Bouraoui, F. Bittelli, M. 2008. A simplified parameterization of the monthly topsoilwaterbudget. WaterResour Res;44:W12440. doi:10.1029/2007WR006603.

Runkui Li. Xiaoping Rui. A-Xing Zhu. Junzhi Liu. Lawrence E. Band. Xianfeng Song. 2014. Increasing detail of distributed runoff modeling using fuzzy logic in curve number, Envirom Earth Sci. p. 1-9.

Shakouri, H. Nadimi, G. R. Ghaderi, F. 2007. Fuzzy linear regression models with absolute errors and optimum uncertainty. IEEE Internat. Conf. Industrial Engineering and Engineering Manage. p. 917-921.

Sorooshian, S. and Gupta, V.j. 1983. Automatic calibration of conceptual Rainfall-Runoff Models: The question of Parameter observation and unquenss. Water Resurces Research. 19 (1):260-268.

Soulis, K.X. and Valiantzas, J.D. 2012. SCS-CN Parameter Determination Using Rainfall-Runoff Data in Heterogeneous Watersheds: The two-CN System Approach. Hydrology and Earth System Sciences, 16:1001-1015.

Soil Conservation Service, USDA. 1985. National Engineering Handbook, 210-VI. Part630, Chapter7, Hydrologic Soil-Cover Complex. Natural Resources Conservation Service, United States Department of Agriculture, Washington, DC.

Sutanto, SJ. Wenninger,J. Coenders-Gerrits, AMJ. Uhlenbrook, S. 2012. Partitioning of evaporation into transpiration, soil evaporation and interception: a comparison between isotope measurements and a HYDRUS-1D model", Hydrol Earth SystSc 16(8): 2605–2616. doi:10.5194/hess-16-2605-2012**.**

Tran, L. T. DucksteinL. 2001. Multiobjective fuzzy Regression with central tendency and possibilistic properties. Fuzzy Sets and Systems. Catena. 47: 305-322.

Tomer, S. K. 2011. Python in Hydrology. Green Tea Press. p.1-218. The book is translated into Persian by Mr. Moslem Heydari and is in print by Jihad Agriculture press of Shahrekord University, Iran.

Turc, L. bilan, Le. l'eau, de. sols, des. 1955. Relationships entre les precipitations, l'evaporationetl'ecoulement. INRA, Paris. p.252.

Walling,D. E. 1977. Limitations of the ratingcurve technique for estimating suspended sediment loads, with particular reference to British rivers, Erosion and Solute Matter Transport in Inland Waters. P. 34-38.

Williams, G. 1989. Sediment concentration versus water discharge during single hydrologic events in rivers, Journal of Hydrology 111. p. 89-106.

Wang, Z. Batelaan, O. and DeSmedt, F.1997. Adistributed model for water and energy transfer between soil, plants and atmosphere (Wetspa).Physics and chemistry of the earth. 21:189-193.

Wischmeier W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses: a guide to conservationplanning. Agriculture Handbook No. 537. US Department of Agriculture, Washington DC.