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ORIGINAL RESEARCH PAPER

Kinematic runoff and erosion model efficiency assessment for hydrological simulation of semi-arid watersheds

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ABSTRACT: Hydrologic modeling of semi-arid watersheds is imperative for the development of appropriate water and soil conservation plans. In the current study, the efficiency of Kinematic Runoff and Erosion model-version 2 (K2) model was used to evaluate water discharge and sediment load simulation of Bar watershed, located in the north-eastern part of Iran. The K2 model relies on the kinematic wave approach to route surface flow. The drainage network and planes are discretized to represent the watershed. In order to evaluate the model, 3 and 2 reported rainfall incidents in various dates were selected for K2 calibration and validation, respectively. The multiplier approach was employed for model calibration. The results of sensitivity investigation revealed that the soil parameters Ks-CH, n and G had the highest impact on flow discharge. Through the calibration process, the Nash-Sutcliff Efficiency and the coefficient of determination as fitting metrics for water discharge simulation (based on event #2, dated 16 March 1992) were estimated to be 0.78 and 0.88, respectively. According to the aggregated measure, the highest K2 efficiency was obtained during the calibration process based on event #2. Other storm events were resulted in a good simulation, as well. During the validation process, K2 simulation (based on event #4, dated 07 March 1991) led to the Nash-Sutcliffe Efficiency and R^2 of 0.77 and 0.71, respectively. The K2 calibration for sediment load simulation was performed through the alterations of the Pave and Rainsplash parameters. The bias percentages between simulated and observed total sediment loads based on events #2 and #4 were 5% and 16%, respectively. Conclusively, the K2 model showed an acceptable robustness in the hydrological simulation of Bar watershed as a representative semi-arid watershed in northeast of Iran.

KEYWORDS: *Calibration; Hydrologic simulation; Kinematic runoff and erosion model (Kineros2); Runoff yield; Sediment load; Sensitivity analysis; Validation.*

INTRODUCTION

Realizing the hydrology process in arid and semi-arid areas is necessary for the identification of these environments and their vulnerability to environmental change (Faures *et al.,* 1995). Therefore, the optimal usage of water assets in proper management of watersheds is raised. Simulation of hydrological phenomena in watersheds could be an optimal solution for their proper management, especially in drought and climate change conditions (Neitsch *et al.,* 2011). Recently, utilization of hydrological models has turn into an important means for discovering the occurrence of natural courses in the catchments (Sorooshian and Gupta, 1995). Soil erosion in the watershed and sediment load of the rivers is one of the main issues in management of water resources in Iran and has negative consequences for utilizing water facilities and dams. The amount of runoff, erosion and sediment transportation changes depending on the hydrological, soil and vegetation condition. Thus, simulation of the referred processes requires

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sufficient information about how these factors change spatially. A fundamental tool for studying runoff and soil erosion and as a result to improve soil and water conservation plans, especially in catchments, is modeling of hydrological processes according to the geographic information system (Memarian *et al.,* 2012). Different hydrological models have been employed in arid and semi-arid areas, including Identification of unit Hydrograph and Component flows from Rainfall Evaporation and Stream flow data (IHACRES), Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) and Hydrologiska Byrans Vattenavdelning (HBV). Various physical-mathematical models have also been considered for estimating the sediment produced by erosion within the watershed, such as Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) (Beasley *et al.,* 1980), Chemicals Runoff and Erosion from Agricultural Management systems (CREAM) (Knisel and Foster, 1981), Erosion Productivity Impact Calculator (EPIC) (Sharpley and Williams, 1989), Simulator for Water Resources in Rural Basin (SWRRB) (Williams *et al.,* 1985), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1994) and Kinematic Runoff and Erosion 2 (KINEROS 2 or K2) (Woolhiser *et al.,* 1990). In the present study, K2 was used for hydrological simulation of Bar watershed. Several studies are available on K2 application and its efficiency analysis. For instances, Smith *et al.* (1999) examined the ability of the K2 model to forecast flow and sediment load by selected storms in the CATSOP watershed, Netherland. Kalin and Hantush (2003) assessed the efficiency of the K2 and Gridded Surface/Subsurface Hydrologic Analysis (GSSHA) model (Downer and Ogden, 2004) in simulating sediment and water movement. Based on the results, the K2 model was more efficient than the GSSHA for sediment routing due to its better formulation in the algorithm structure. De Lima Paiva *et al.* (2005) studied the impact of vegetation on the erosion potential using the K2 model in a semi-arid watershed in Brazil. The simulation outcomes indicated that the coefficient of initial soil saturation and splash coefficient were the most effective factors throughout the calibration course. Yatheendradas *et al.* (2008) showed that canal and surface roughness parameters, saturated hydraulic conductivity, rain intensity and initial content of moisture were the most important variables in K2 calibration. Cabral *et al.* (2013) assessed the influence of urban development on the sediment yield of Jakaryska watershed in northeastern Brazil using the K2 model. The outcomes indicated that the K2 model was a promising tool for sediment load simulation. Schaffner *et al.* (2010) showed that the saturated hydraulic conductivity on plane and the channel length are the most important parameters affecting flow speed and time to reach the peak discharge. The findings of a study conducted by Memarian *et al*. (2013) revealed that the observed records were in agreement with the simulated records for simulating runoff and sediment yield in a developed watershed in Malaysia. Nguyen *et al*. (2015) reported a method that integrated the two models KINEROS2 and HEC-River Analysis System (HEC-RAS) to have precise prediction of flash floods in northern Vietnam. The outcomes indicated good relationships between river geometry and flow velocity and between water level and streamflow power. Bar watershed is considered as one of the most important and flood prone areas in Khorasan Razavi province, Iran, which requires a comprehensive simulation of hydrological processes to propose flood and soil erosion controlling plans. This watershed is one of the main ecotourism centers in the region and also it has a particular importance in terms of flood control, so that any changes in the watershed condition could have a straight effect on the residential areas. The aim of the current study is to evaluate the efficiency of K2 model in the runoff and sediment load simulation of Bar watershed. The K2 sensitivity analysis was also analyzed in the current study. This study has been carried out in Bar watershed in Neyshabour in Khorasan province, Iran, in 2016.

MATERIALS AND METHODS

Study area

Bar watershed in Khorasan Razavi province, Iran, with an area of 11,388 ha is located between latitude of 36° 27′ 38″ to 36° 36′ 32″ N and longitude of 58° 40′ 46″ to 58° 49′ 31″ E (Fig. 1). The average altitude of Bar watershed is 2,226 m above sea level. Its average slope and concentration time is 32.66% and 6 hours, respectively. The main waterway in Bar watershed has a length of 11.28 km and finally reaches to Neyshabour plain. The climate of the study area is categorized within the semi-arid class, with a normal temperature and yearly rainfall of 4.7 °C and 330.4 mm, respectively. Its average discharge is around 0.7 m^3/s and the average annual runoff coefficient is 35%.

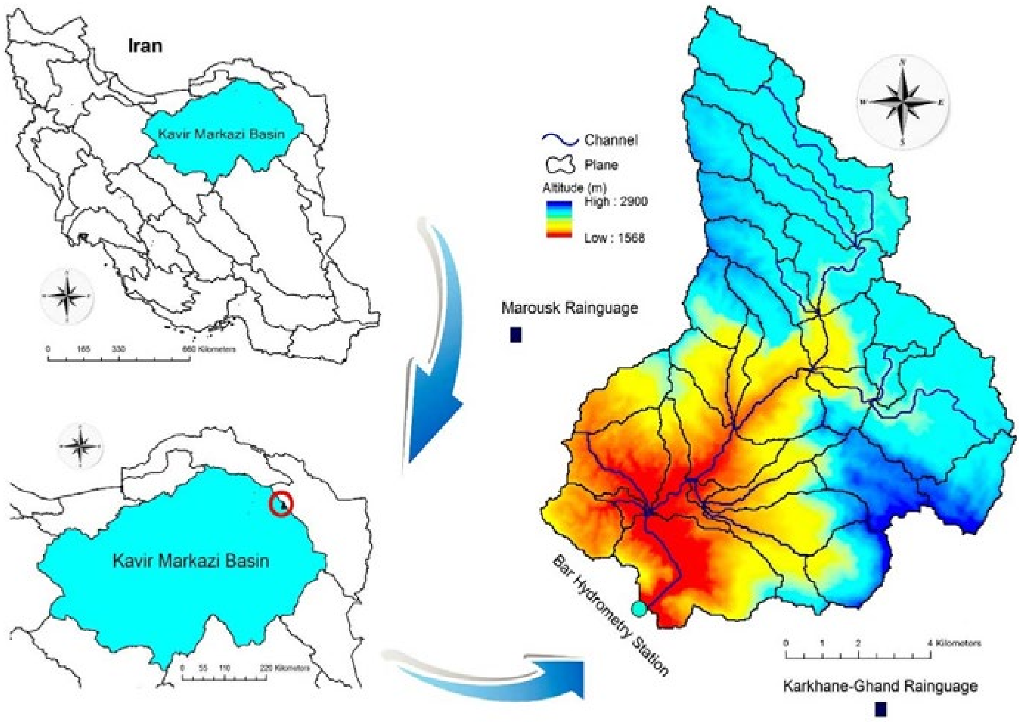

Fig. 1: Geographic location of study area

Data set

Following data and information were collected to model the hydrological conditions in Bar watershed:

1- Digital elevation model (DEM) with a pixel size of 30 m, achieved via Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) global DEM (Fig. 1).

2- Land use and cover map with the raster structure (Fig. 2), obtained through the visual interpretation of Landsat imageries and field observations.

3- Food and Agriculture Organization (FAO) soil database (Nachtergaele *et al.,* 2008) and available soil series map to describe the soil features vital for the usage in K2.

4- The rainfall data, recorded at the Marousk Rainfall Station, where was more correlated and synchronized with the flood occurrences in the watershed. Three rainfall events with various intensities and time lengths during 1991 and 1992 were chosen for calibration. Two other events in 1991 and 1994 were chosen to check the validity of the model (Table1).

5- Water flow data and suspended sediment loads, recorded at Bar hydrometric station.

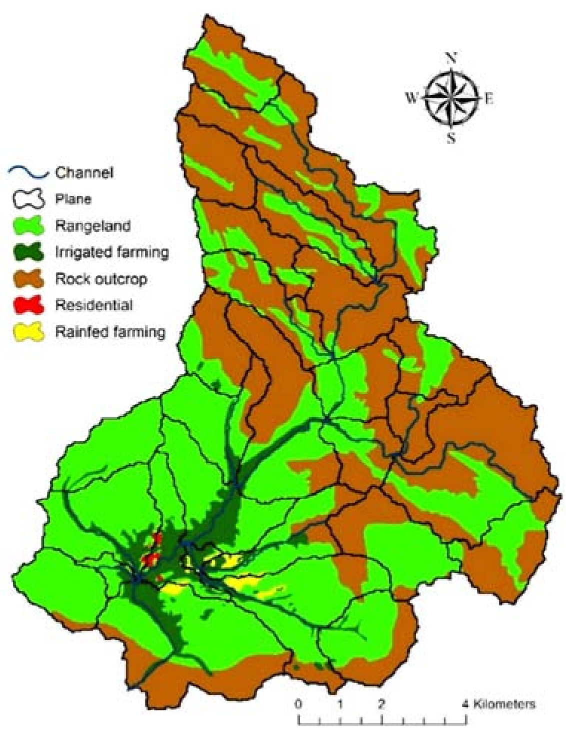

Fig. 2: Land use map of Bar watershed

Table 1: Characteristics of chosen rainfall events

Application	Event #	Date	Duration (h)	Depth (mm)	Volume (m^3)	I30-Max (mm/h)
Calibration	1	11 May 1991	465	18.4	2095392	5.9
	2	16 March 1992	675	9.6	1093248	2.5
	3	31 March 1992	300	13.9	1582932	4.6
Validation	4	07 March 1991	540	11.30	1286844	2.8
	5	04 December 1994	765	9	1024920	2.59

I30_Max: Maximum 30 min. intensity

The hydrological data, i.e. flow discharge and sediment load for Bar watershed, were obtained from Khorasan Razavi Regional Water Authority (KRRWA).

Kineros

Kineros, as a physical model, examines the amount of runoff and erosion and simulates routing of surface runoff at the catchment scale. In this model, the movement of water is evaluated using kinematic wave estimate of Saint-Venant equations and the resulted runoff is estimated based on the Horton equation. In line with this equation, there is an occurrence of runoff whenever the infiltration speed is lower than the rainfall intensity. Infiltration equations employed in Kineros are according to the Smith and Parlange (1978) infiltration model (Memarian *et al.*, 2013). In Kineros model, watershed is separated into several sub-catchments, each of which is simulated based on similar surface flow planes and channels. In each sub-watershed, surface flow planes are in the form of rectangle and regular surfaces with similar input parameters. The parameters of model may be changed from one plane/channel to another, but the specifications in each element are assumed to be similar. These specifications mainly include hydraulic attributes of soil, rainfall properties, topography, geometric shape of earth and land use and land cover characteristics. In this model, surface flow plane is created based on the general slope of the earth through selecting maximum and minimum altitudes of the area. The channels with specific slope and assumed trapezoidal shape are speared towards the basin outlet (Memarian *et al.*, 2013). In the conceptual model of overland flow, small scale changes of infiltration and micro topography are parameterized and considered in the simulation.

Kineros2 (K2) is updated version of Kineros model (Woolhiser *et al.*, 1990) implemented under a graphical user interface, i.e. Automated Geospatial Watershed Assessment (AGWA) in ArcGIS environment. Modeling in urban region is based on runoff estimation of pervious and impervious sections. In K2 model, the dynamic infiltration is associated with rainfall and runoff. The conceptual model is able to incorporate two layers in soil profile and redistributes soil moisture through storm hiatus (Semmens *et al.*, 2008). In K2, the surface flow is considered as a one-dimensional flow, as Eq. 1.

$$\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial x}=q(x,t) \quad (1)$$

Where, Q is discharge per unit width, h is depth of surface runoff and q is difference between rainfall and infiltration intensity (Smith *et al.*, 1999; Semmens *et al.*, 2008; Memarian *et al.*, 2012).

Using kinematic wave approximation, Q (Eq. 1) is replaced with Eq. 2 and the resulting differential equation (Eq. 3) is solved by the finite difference method. In Eq. 2, the coefficients m and α depend on the amount of slope (s), roughness (n) and surface flow regime on the planes (Semmens *et al.*, 2008; Memarian *et al.*, 2012):

$$Q=\alpha h^{m} \quad (2)$$

$$\frac{\partial A}{\partial t}+\alpha m h^{m-1}\frac{\partial h}{\partial x}=q(x,t) \quad (3)$$

Given the boundary conditions in upstream and downstream of planes, Eq. 3 will be solved. In K2, flow equation (Eq. 4) in channels is estimated by the equation of Saint-Venant:

$$\frac{\partial A}{\partial x}+\frac{\partial Q}{\partial x}=q_c(x,t) \quad (4)$$

Where, Q is water discharge in the channel, A is cross sectional area of the channel, and qc is lateral flow. Using kinematic wave approximation of Eq. 5 and substituting it in Eq. 4, differential Eq. 6 can be obtained and resolved through finite difference method giving the boundary conditions in upstream and downstream of channel (Smith *et al.,* 1999; Semmens *et al.,* 2008; Memarian *et al.,* 2012):

$$Q = \alpha \mathcal{R}^{m-1} \quad (5)$$

$$\frac{\partial A}{\partial t} + \alpha m \mathcal{R}^{m-1} \frac{\partial A}{\partial x} = q_c(x,t) \quad (6)$$

In Eq. 6, the values of m and α can be calculated using the Manning and Chezy equations in the channel.

$$\alpha = 1.49 \frac{S^{\frac{1}{2}}}{n} \qquad m = \frac{5}{3} \qquad m = \frac{3}{2} \quad (7)$$

$$CS^{\frac{1}{2}} = \alpha \quad (8)$$

Where, S is channel slope, n is Manning roughness coefficient and c is Chezy roughness coefficient.

Sediment transport in K2 is evaluated using sediment hydraulic equations and based on the mass balance concept.

$$\frac{\partial (AC_S)}{\partial t} + \frac{\partial (QC_S)}{\partial x} - e(x,t) = q_S(x,t) \quad (9)$$

Where, Cs is sediment concentration [L^3/L^3], Q is water discharge rate [L^3/T], A is cross sectional area of flow [L^2], e is rate of erosion of the soil bed [L^2/T], and q_s is rate of lateral sediment inflow for channels [$L^3/T/L$] (Semmens *et al.,* 2008; Smith *et al.,* 1999).

In the current study, local minimum technique was used to separate the base flow (McCuen, 1989). 48 planes with the average area of 2.32 km^2 and 19 channels with the average length of 2.9 km were discretized using the AGWA interface.

K2 calibration parameters

The most important parameters of the K2 used for flow and sediment load simulation are represented in Table 2. The initial rates of these variables were obtained from the K2 guidebook (Woolhiser *et al.,* 1990) and literature review (Meyer *et al.,* 1997; Wagener and Franks, 2005; Al-Qurashi *et al.,* 2008; Vatseva *et al.,* 2008; Guber *et al.,* 2009; Guber *et al.,* 2011; Kennedy *et al.,* 2012; Memarian *et al.,* 2012; Koster, 2013; Kasmaei *et al.,* 2015).

Model evaluation

The statistical metrics employed in the current study are Model Bias (MB), Modified Correlation Coefficient (r_{mod}), and Nash-Sutcliffe Efficiency (NSE). These measures were computed using the Microsoft Excel spreadsheet 2013. Proficiency of the model in flow simulation can be evaluated by MB, while r_{mod} denotes the dissimilarities in hydrograph size and shape (McCuen and Snyder, 1975; Safari *et al.,* 2012; Memarian *et al.,* 2013). Furthermore, the ability of the model for emulating the hydrograph can be scanned using the NSE (Nash and Sutcliffe, 1970; Safari *et al.,* 2012; Memarian *et al.,* 2013). Eqs. 10, 11 and 12 define the mentioned measures.

$$MB = \left[\frac{\sum_{i=1}^{n}(Q_{s_i} - Q_{o_i})}{\sum_{i=1}^{n} Q_{o_i}}\right] \quad (10)$$

$$r_{mod} = \left[\frac{min\{\sigma_o, \sigma_s\}}{max\{\sigma_o, \sigma_s\}} * r\right] \quad (11)$$

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_{s_i} - Q_{o_i})^2}{\sum_{i=1}^{n}(Q_{o_i} - \bar{Q}_o)^2}\right] \quad (12)$$

Table 1: Characteristics of chosen rainfall events

No.	Symbol	Parameter	Initial values	Optimized values	Multiplier range used in the current study	
					Lower	Upper
1	Ks_P	Saturated hydraulic conductivity (mm/h) planes	0.001-19.2	0.0001-4.5	0.2	2
2	Ks_CH	Saturated hydraulic conductivity (mm/h) channels	210	63	0.2	2
3	n_P	Manning's roughness coefficient_planes	0.038-0.15	0.02-0.075	0.5	5
4	n_CH	Manning's roughness coefficient_channels	0.035	0.028	0.5	5
5	CV_P	Coefficient of variations of Ks_planes	1.39-1.4	0.56	0	2
6	G_P	Mean capillary drive (mm) planes	120.67-197.4	36.2-59.2	0.3	3
7	G_CH	Mean capillary drive (mm) channels	101	31	0.3	3
8	In_P	Interception depth (mm)	0-2	0-1	0.1	2
9	C_P	Percent of surface covered by intercepting cover	0.1-0.68	0.05-0.35	0.5	2
10	Pave	Fraction of surface covered by erosion pavement	0-0.86	0-1.3	0	3
11	Splash	Rainsplash coefficient	119.29-120.64	220	0.1	3

Table 3: Model efficiency classes (Safari *et al.*, 2012)

Goodness of fit	Aggregated measure (AM)
Excellent	>0.85
Very good	0.70-0.85
Good	0.55-0.70
Poor	0.40-0.55
Very poor	<0.4

Where, Q_{s_i} and Q_{o_i} are predicted and real water discharges at time pace i respectively, $\bar{Q}_O$ is the mean of measured flow in the simulation period, σ_o and σ_s describe the standard deviations of measured and predicted discharges respectively, r is correlation coefficient between measured and predicted data, and n is number of observations in the prediction interval. The perfect rate for Model Bias is 0 and for other assessors is 1. NSE is a normalized statistic, extending between -∞ and 1, which defines the relative amount of the residual variance in comparison with the observed data variance. NSE values between 0.75 and 0.36 reflect satisfactory simulation while values ≥ 0.75 are considered excellent (Geza *et al.*, 2009; Musau *et al.*, 2015). To evaluate the size, shape and volume of simulated hydrographs, Aggregated Measure (AM) can be computed as Eq. 13.

$$AM = \frac{r_{mod} + NSE + (1 - |MB|)}{3} \tag{13}$$

The AM value of 1 reveals a complete fit. Table 3 shows classes of goodness of fit based on AM value.

K2 calibration for sediment load simulation

The studied watershed suffers from the lack of measured sediment loads for the selected storm events at the hydrometric station. Only the total volume of

Table 4: Coefficient of variations (CV) in peak discharge in accordance with the alterations in K2 parameters

Event #	CV (%)									Mean
	Ks_P	Ks_CH	IN_P	C_P	n_CH	n_P	G_P	G_CH	CV_P	
1	0.00	125.23	4.16	3.49	107.97	64/61	4.36	73.76	0.05	38.36
2	2.68	207.92	42.56	42.08	89.73	112.74	189.09	146.25	30.05	86.31
3	0.00	129.80	0.94	0.79	93.31	20.75	4.32	61.27	0.01	31.12
Mean	0.89	154.32	15.88	15.45	96.98	66.03	68.92	93.76	10.04	51.93

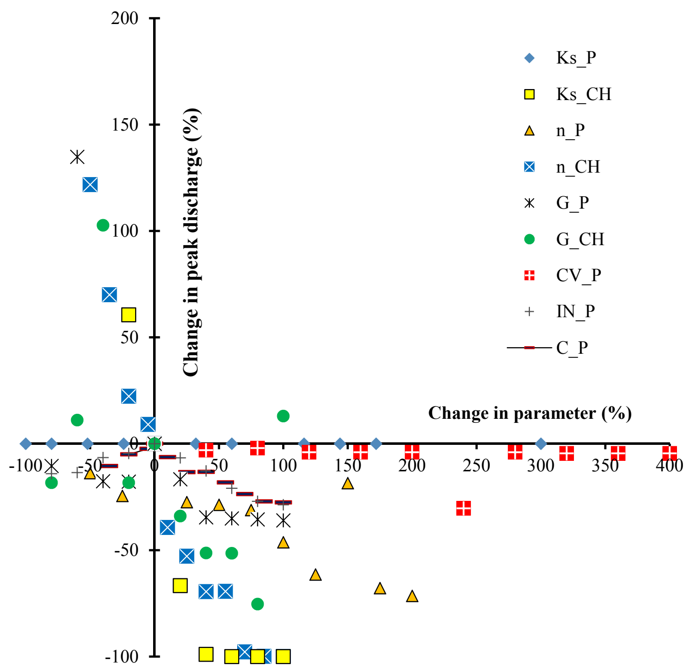

Fig. 3: Changes in peak discharge with the changes of chosen parameters

suspended sediment load was available for the storm events #2 and #3. Therefore, first the K2 optimum parameters, obtained during the K2 calibration for water discharge simulation, were fed into the model without any changes in sediment calibration parameters, i.e. Pave and Rainsplash coefficients. Next the predicted sediment loads were contrasted with the observed data at the hydrometric station. To calculate the total simulated sediment load for each event, the area under sedigraph was obtained via the trapezoidal shapes computation approach. Then the total simulated sediment load was compared with the observed values and the K2 efficiency for sediment load simulation was evaluated.

RESULTS AND DISCUSSION

Sensitivity analysis

The sensitivity investigation of the K2 variables, effective on flow simulation, was carried out through the multiplier approach. The variations of the 9 parameters entered into the sensitivity analysis are presented in Table 4. The outcomes implied that by changing the model parameters during the sensitivity analysis, the maximum (154.32) and minimum (0.89) percentages of change in simulated peak water discharge can be achieved. The K2 sensitivity analysis indicated that the model was very sensitive to the variations of KS, n and G variables (Fig. 3). Slope of the changes resulted from variations in Ks_CH, G_CH, and n_CH within a range of 0-100% increases sharply. On the other hand, changes in Ks_CH, n_CH and G_CH parameters respectively cause 154.3%, 98.96% and 93.76% alterations in peak discharge. The results are confirmed by prior studies conducted by Al-Qurashi *et al.,* (2008), Yatheendradas *et al.,* (2008), Schaffner *et al.,* (2010) and Memarian *et al.,* (2012). Considering the geological situation of the study area, Bar watershed contains two types of geological formations. At the upstream, there are calcareous deposits and thick layer of dolomite limestone, which are resistant to soil erosion and cover the largest part of the watershed. At the downstream, there are light gray marls with intercalated lime. Therefore, the geological diversity of Bar watershed is low and results in a lower sensitivity (about 0.89) of the K2 to variations of Ks_P. The average K2 sensitivities to changes of CV_P, C_P, IN_P, G_P and n_P parameters were 10.04%, 15.45%, 15.88%, 65.92% and 66.03%, respectively. According to Table 4, the average coefficient of variations in the peak discharge for event #2 (86.31%) was more than that of variations in the peak discharge for other storm events.

Table 5. Fitting measures for runoff simulation during calibration process

Fitting metrics	Event		
	1	2	3
MB	-0.45	-0.29	-0.44
rmod	0.87	0.80	0.82
NS	0.54	0.78	0.65
AM	0.66	0.77	0.68
Goodness of fit	Good	Very good	Good

Table 6. Fitting metrics during validation analysis for direct runoff simulation

Fitting metrics	Event #	
	4	5
MB	-0.46	-0.46
rmod	0.73	0.56
NS	0.46	0.57
AM	0.57	0.55
Goodness of fit	Good	Good

K2 Calibration analysis

The results of K2 calibration for runoff simulation showed the highest deviation from observed values (-0.45) and the highest modified correlation coefficient (r_{mod} = 0.87) between the observed and simulated records in the simulation based on event #1 (Table 5). The simulation based on event #2 showed the highest NSE (0.78) and AM (0.77) and also the lowest MB (-0.29). According to Table 3 and the AM fitting metric, the flow simulations based on events #2, #3 and #1 were classified within the fitting groups of very good, good and good, respectively (Table 5).

The simulated versus observed hydrographs for selected storm events are depicted in Figs. 4a, 4b, and 4c. According to event #2 in March 16, 1992, the imitated hydrograph was more agreed with the observed data, as compared to other events (Fig. 4). However, runoff simulation based on event #1 showed more robustness for peak discharge estimation, in comparison with other simulations. Some deflections from the observed data are also detected in the rising and recession limbs of the hydrographs (Fig. 4). In other words, the model had an underestimation problem in all simulations, especially in direct runoff simulations based on events #1 and #3. This could be

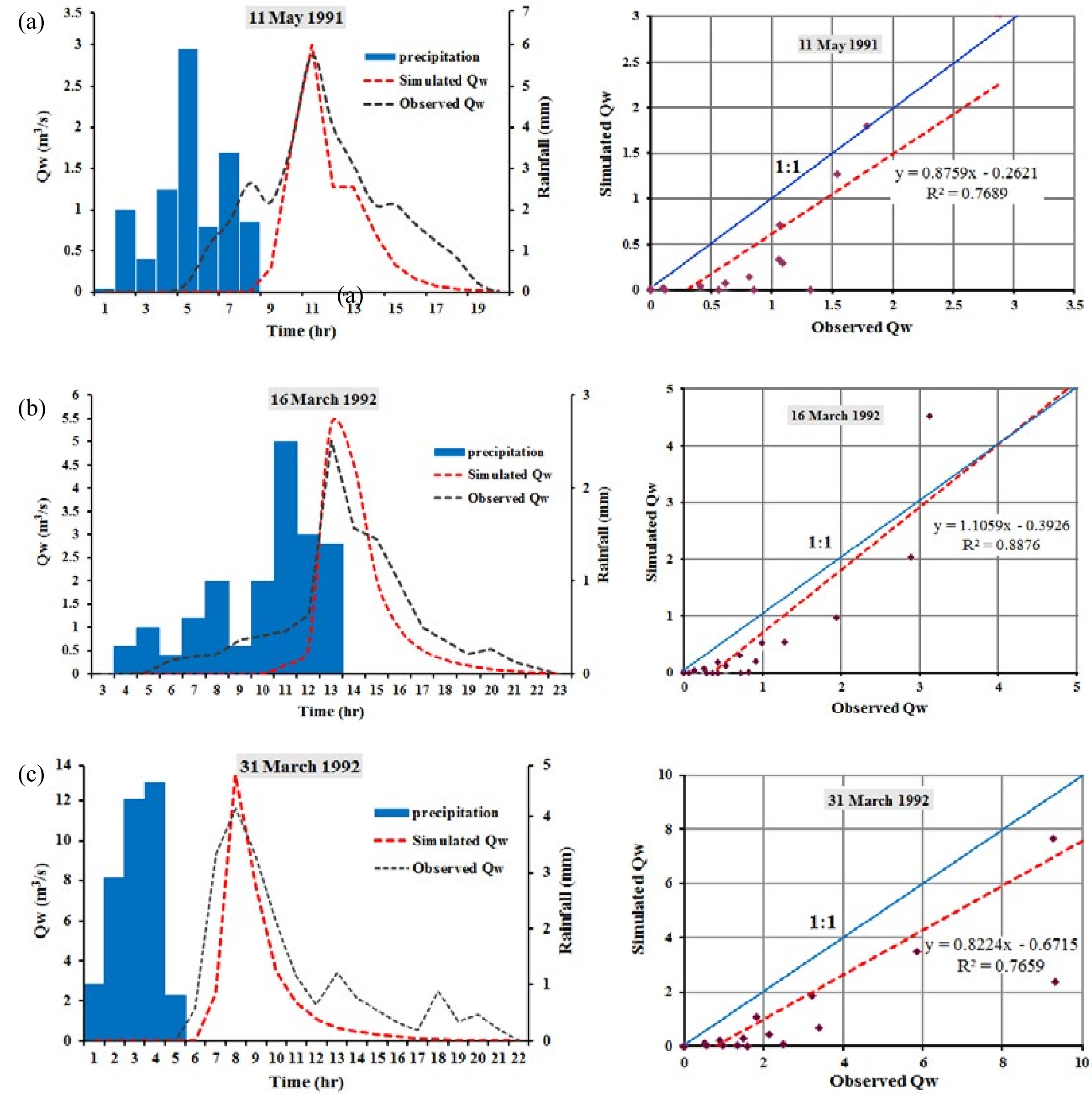

Fig. 4: Simulated vs. observed hydrographs during calibration process based on: a) storm event #1; b) storm event #2 and c) storm event #3

attributed to errors in the observed flow and rainfall measurements, use of only one rain gauge, application of an isolated rainfall event in the entire watershed (Memarian *et al.,* 2012), and rough scale of the utilized soil map. The highest coefficient of determination was observed in the flow simulation based on storm event #2 ($R^2 = 0.88$). It reveals that the measured records are well agreed with the simulated records (Fig. 4b).

K2 validation analysis

The K2 validation study was done according to storm events #4 and #5. Results indicated that the K2 was talented to estimate the direct runoff with good precision (Table 6). Deviation of the model from the observed values for both storm events was the same (MB = -0.46), and the highest r_{mod} (0.73) and AM (0.57) were obtained in the flow simulation based on

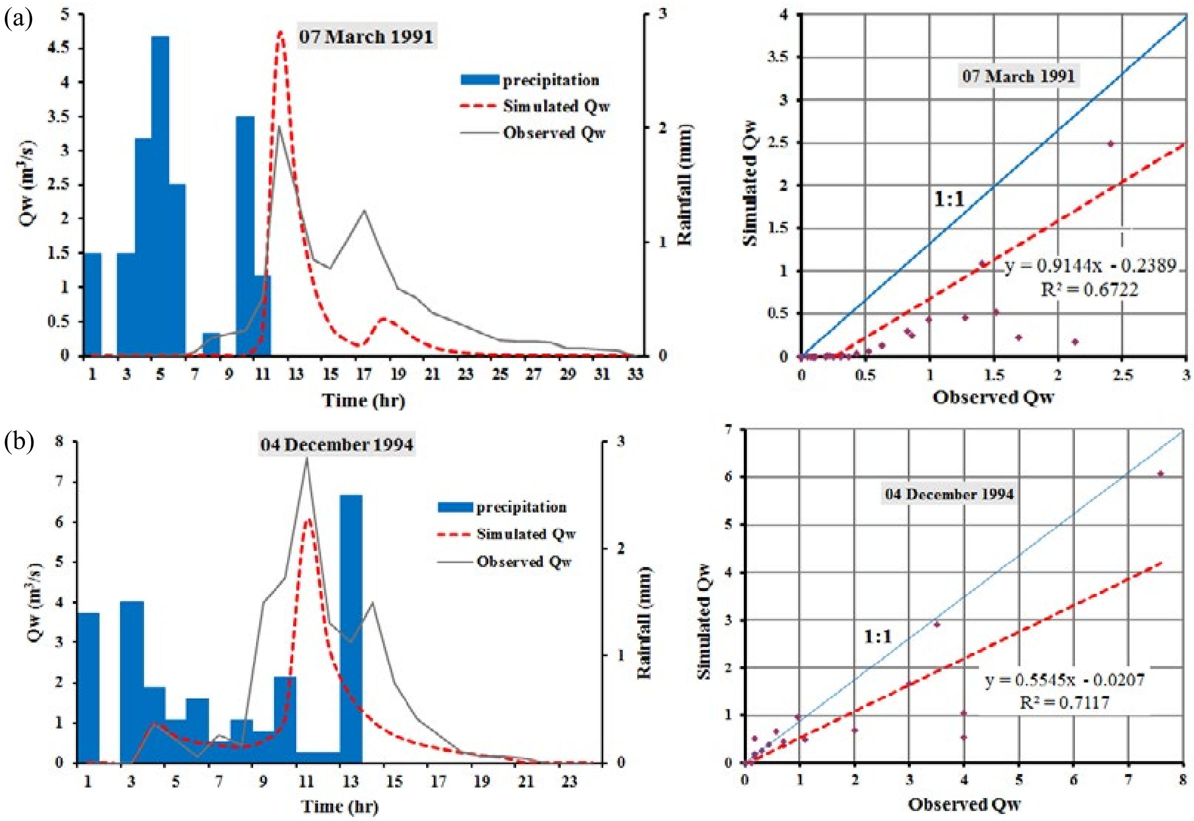

Fig. 5: Simulated vs. observed hydrographs during validation process based on: a) storm event #4 and b) storm event #5

storm event #4. However, the highest NSE (0.57) was obtained during the flow simulation based on event # 5.

Fig. 5 shows the simulated versus observed hydrographs based on storm events #4 and #5 during the validation process. Hydrographs demonstrate a relatively good capability of the model in simulation of water discharges, though the K2 shows a degree of underestimation in both simulations. This can be overwhelmed by establishing the new representative rain gauges within the watershed and developing the regional hydraulic geometry equations that are used in the watershed discretization stage.

One of the main challenges in hydrological modeling of arid and semi-arid watersheds is the high spatial unevenness of rainfall (Wheater and Brown, 1989). Furthermore, rainfall amount and its temporal distribution depend on seasonal weather (Yatheendradas *et al.,* 2008). Lack of rain gauges in arid and semi-arid areas is one of the limitations that cause errors and uncertainties in estimations of hydrological models (Michaud and Sorooshian, 1994). The results show that this issue is clearly understandable in the study area. Another factor that contributes to the difficulty in hydrological modeling of arid and semi-arid regions is the high spatio-temporal variations in canopy interception and infiltration losses, which also cause significant changes in runoff rates (Huges, 1995). Other issues that induce complexity of modeling in these areas are lack of information about initial moisture conditions (Grayson *et al.,* 1992), seasonal and annual variations in vegetation condition (Huges, 1995), losses in channels and complication of channel morphology (Costelloe *et al.,* 2006). Nevertheless, the rainfall-runoff distributed models, applied based on different mechanisms to arid and semi-arid watersheds, reported a level of success in simulation and proved benefits of using distributed models (Costelloe *et al.,* 2006; El-Hames and Richards, 1998). The K2 is

Table 7: The K2 simulation for sediment load according to the selected storm events

Event	Duration (min)	Properties of the selected storm events			Observed sediment load (t/day)	Simulated sediment load (t/day)	Difference (%)
		Rainfall		I60-max (mm/hr)			
		Volume (m^3)	Depth (mm)				
2	675	1093248	9.6	2.5	3145.236	3303.266	5
3	300	1582933	13.9	4.6	1372.095	1596.802	16

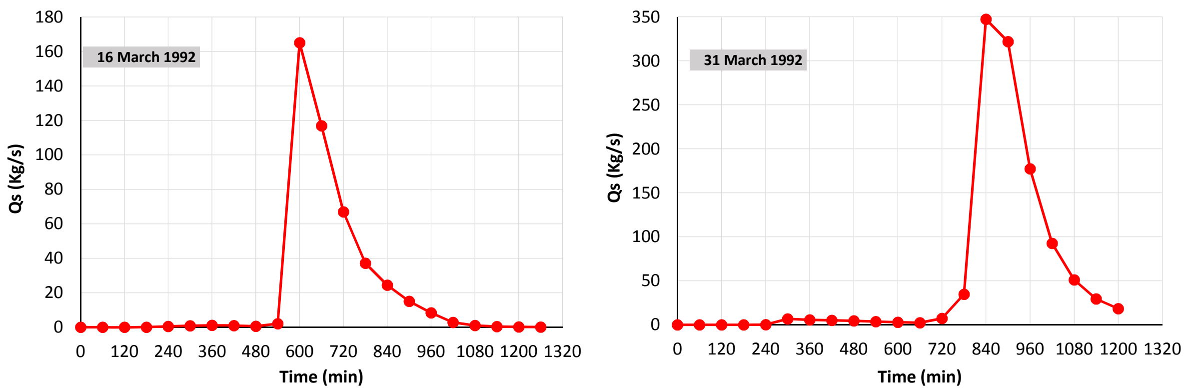

Fig. 7: Simulated sedigraphs, based on the selected storm events

also a physically distributed model and has a good capability for flood simulation in semi-arid regions that have accurate rainfall inputs (Yatheendradas *et al.,* 2008). De Lima Paiva *et al.,* (2005) also showed that the K2 could be used as a promising model for runoff yield and sediment load simulation in semi-arid region of the north-eastern Brazil with data scarcity. Sidman *et al.,* (2016) used the K2 model to compare several spatial and temporal rainfall representations of post-fire rainfall-runoff events in order to determine the effect of differing representations on modelled peak flow and determine at-risk locations within a watershed. Results showed that rainfall representation greatly affected modelled peak flow, but did not significantly alter the model's predictions for high-risk locations. This has important implications for post-fire assessments before a flood-inducing rainfall event, or for post-storm assessments in areas with low-gauge density or lack of radar data due to mountain beam blockage. The applicability of K2 in hydrologic simulation of arid and semi-arid watersheds has been also confirmed by several studies (Schaffner *et al.*, 2010; Kennedy *et al.*, 2012; Dody *et al.*, 2017).

Sediment load simulation

By changing the coefficients of Pave and Rainsplash parameters, the best simulated total sediment loads were obtained with the 5% and 16% of bias, as compared to the observed sediment loads for storm events #2 and #3, respectively (Table 7). Fig. 6 illustrates the simulated sedigraphs based on the selected storm events. The best multipliers for the Pave and Rainsplash parameters based on calibration event #2 were obtained as 2 and 2, respectively. Based on storm event #3, these multipliers were 1 and 1.7, respectively. The obtained results indicated the efficiency K2 in simulating the erosion/sediment process in Bar watershed, as confirmed by other studies (Smith *et al.,* 1999; Kalin and Hantush, 2003; De Lima Paiva *et al.,* 2005; Cabral *et al.,* 2013; Memarian *et al.,* 2013). However, more detailed examination of the model's robustness for sediment load simulation requires more detailed information on the sediment load in short time steps. Additionally, this study demonstrated that for a good erosion simulation, the first need is to have an accurate flow simulation (Smith *et al.,* 1999).

CONCLUSION

The KINEROS2 (K2), as an event-based physical model, was used in a semi-arid watershed in Iran to simulate runoff and sediment yield. Its robustness was evaluated through the calibration and validation processes. Three storm events in various intensities and durations were essential for K2 calibration. K2 validation was accomplished using two additional rainfall events. Sensitivity analysis indicated that the saturated hydraulic conductivity in channels (Ks), Manning's roughness (n), and mean capillary drive (G) parameters had the highest impact on runoff simulation. During the calibration process, there were good fittings for direct runoff simulation according to the Aggregated Measure (AM). Based on the validation findings, K2 was credible for runoff modelling. According to the results, the used K2 showed a degree of underestimation in direct runoff simulation, which could be attributed to errors in the observed flow and rainfall measurements, use of only one rain gauge, application of an isolated rainfall event in the entire watershed, and rough scale of the utilized soil map. K2 calibration for sediment load simulation was performed via alteration of the Pave and Rainsplash parameters. Results showed 5% and 16% differences between the simulated and observed total sediment loads based on events #2 and #4, respectively. Flow discharge in arid and semi-arid watersheds shows quick react to precipitation events. Most events are often spatially variable and inadequate precipitation data in most watersheds impose limitations on accurate runoff and sediment yield simulation. However with all these limitations, K2 showed a satisfactory vigor in hydrological simulation of Bar watershed as a typical semi-arid watershed in northeast of Iran.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

AGWA	Automated geospatial watershed assessment
AM	Aggregated measure
AN-SWERS	Areal nonpoint source watershed environment response simulation
ASTER	Advanced space borne thermal emission and reflection radiometer
C	Percent of surface covered by intercepting cover
CH	Channel
C_P	Percent of surface covered by intercepting cover in planes
CREAM	Chemicals runoff and erosion from agricultural management systems
CV	Coefficient of variations
CV_P	Coefficient of variations of Ks_planes
DEM	Digital Elevation Model
EPIC	Erosion productivity impact calculator
FAO	Food and Agriculture Organization
G	Mean capillary drive
G_CH	Mean capillary drive in channels
G_P	Mean capillary drive in planes
GSSHA	Gridded Surface/Subsurface Hydrologic Analysis
HBV	Hydrologiska Bryans Vattenavdelning
hr	Hour
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
IHACRES	Identification of unit Hydrograph and Component flows from Rainfall Evaporation and Stream flow data
I30-Max	Maximum 30 minute intensity of rainfall
In	Interception depth
In_P	Interception depth in planes
K2	KINEROS2
Kg/s	Kilograms per second
KINEROS2	Kinematic runoff and erosion, version 2
KRRWA	Khorasan Razavi Regional Water Authority
Ks	Saturated hydraulic conductivity
Ks_CH	Saturated hydraulic conductivity in channels
Ks_P	Saturated hydraulic conductivity in planes
MB	Model Bias
m^3	Cubic meter
m^3/s	Cubic meters per second
min	Minute
mm	Millimeter

mm/h	Millimeter per hour
n	Manning's roughness coefficient
n_CH	Manning's roughness coefficient in channels
n_P	Manning's roughness coefficient in planes
NSE	Nash sutcliffe efficiency
P	Plane
Pave	Fraction of surface covered by erosion pavement
Qw	Water discharge
r_{mod}	Modified correlation coefficient
S	Slope
Splash	Rainsplash coefficient
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for water resources in rural basin
t/day	Tones per day

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