Environmental Resources Research
Vol. 2, No. 2, 2014

GUASNR

Efficiency Assessment of Rangeland Hydrology and Erosion Model (RHEM) for water erosion quantification (Case Study: Sangane Watershed-Iran)

M. Felegari[1*], A. Talebi[1], M.T. Dastorani[1], A.S. Rangavar[2]

[1] Group of Watershed & Range Management, Department of Natural Resources and Desert Studies, Yazd University, Yazd, Iran

[2] Research Center for Agriculture and Natural Resources, Khorasan Razavi, Iran

Received: September 2013   Accepted: December 2013

Abstract

Computer simulation models are becoming increasingly popular for predicting soil loss through quantification of the processes of detachment, transport and deposition of eroded soils. To assess the effects of different management practices on soil erosion and to select the best management practices, application of models (especially process-oriented models) and their validation is considered a positive step. In this research, the Rangeland Hydrology and Erosion Model (RHEM) was evaluated using soil erosion measuring plots and the recorded rain in Sangane Research Station, Khorasan Razavi Province of Iran. The model was run and the predicted runoff and sediment yield values were compared with measured runoff and sediment yield values. Then sensitivity analysis and calibration were done on sensitive parameters and model was run with calibrated parameters. In the calibration period the, the model efficiency (E_{NS}) values and the coefficient of determination (r^2) were 0.92 and 0.95 for sediment, and 0.60 and 0.70 for runoff, respectively. In validation period, the (E_{NS}) values and (r^2) values in 99% Confidence level were 0.70 and 0.84 for sediment and 0.11 and 0.65 for runoff, respectively. Our research indicated that the results of model were acceptable in 99% confidence level for sediment and could be used with reasonable confidence for soil loss quantification in the Sangane watershed and the other rangeland watershed with similar condition.

Keywords: Hillslope Erosion, Rangeland Hydrology, Runoff, RHEM, Sensitivity analysis, Sangane.

---

[*] Corresponding author; m.flegari@gmail.com

1. Introduction

Many countries in the world have been threatened by land degradation which has occurred as a result of soil erosion and sedimentation of the water bodies. This has led to loss of soil productivity, water quality degradation and less capacity to prevent natural disasters such as floods (Novotny and Olem, 1994). Soil erosion in Iran causes irreparable damages to watershed ecosystems and the economy every year. In the past century and especially in recent decades, Iran watersheds have been changed in management and coverage. Outcome of destructive forces of past and present problems have been caused to increase erosion and production sediment of surface watersheds dramatically. The amount of erosion and sediment in Iran, presented slightly different figures, but based on available documents, it can be calculated that the amount of sediment in last 40 years has reached from 500 million tons of soil per year (Nakhjavani., 1976) to 2 billion ton per year (Arabkhedri., 2005) and even according to some statistics, about 3.5 billion tone per years have been reported. Unfortunately there is no patterns and accurate model to estimate damages of erosion, to predict and control erosion well defined.

According to the arising problems in relation to erosion and preventing further damages and restoring damaged resources, we need to estimate and measure sediment loss. Indirect measurement with contribution models are another ways to estimate erosion and sediment that have recently presented. In this regard, simulation models are important tools for analysis of hillslopes normal process and watersheds (Santhi *et al.*, 2006; He *et al.*, 2003; Lu *et al.*, 2005; Miller *et al.*, 2007).

In this case the importance of erosion on hillslope surface as the starting point of erosion, is an important place in the watersheds. The processes that are responsible of detachment, transport and deposition on hillslope surface are very complicated, Therefore for predicting this processes, a natural recourses management model is necessary and required (Cogle *et al.*, 2003). Process of soil erosion modeling on the hillslopes was carried out by Elison et al (1940) and then was presented to form of equations by Meyer and Wischmeier (1969). Later the different erosion models developed on surface hillslope and analytical solutions for surfaces, was presented by Singh (1992). Finally the WEPP model was used index rill and inter rill in soil erosion that simulated Erosion processes in hillslope surface and described role of soil, plant, plant debris and rain. WEPP model is a model with high performance to estimate erosion, but factors such as the complexity of the model, and also requirement of a large input data, especially in many of watersheds, In Iran there is no proper data then it limit the users to use that. However WEPP is limited in application to rangelands because many of model concepts and erosion equations were developed from experiments on croplands (Nearing *et al.*, 2011).

RHEM (Rangeland Hydrology and Erosion Model) is a mathematical and physical based model to describe erosion and sediment generate processes on hillslope in southwest USA rangelands (Nearing *et al.*, 2011). This model has been developed in USA and it is based on mathematical relationships among a large data set of sediment yield, runoff, hillslope characteristics and a relative soil erodibility value (acceptable at http://dss.tucson.ars.ag. gov/rhem, 2009). RHEM can simulate hydrology and erosion from climate data and hillslope characteristics. RHEM represents modified and improved (for rangeland application) version of the WEPP model code specific for rangeland application and based on fundamentals of infiltration, hydrology, plant science, hydraulics, and erosion mechanics (Speath *et al.*, 2006). This mode, also represents erosion processes under disturbed and undisturbed rangeland conditions; it adopts a new splash erosion and thin sheet-flow transport equation developed from rangeland data, and it links the model hydrologic and erosion by providing a new system of parameter estimates equations based on 204 plots in 49 rangeland site distributed across 15 western U.S states (Nearing *et al.*, 2011). RHEM models splash erosion and thin sheet-flow transport as the dominant set of processes on undisturbed rangeland sites. For representing erosion on sites with significant disturbances, the model has the capacity to combine splash and sheet erosion with concentrated flow erosion based on the degree of the system disturbance. RHEM parameterizes hydraulic and erodibility coefficients for different plant groups based on vegetation cover and soil properties. To capture the heterogeneity of rangeland topography, plant types and surface conditions, RHEM uses a larger representative area to measure, model, and parameterize rainfall splash and sheet erosion (Nearing *et al.*, 2011). Model inputs are climate, soil, steep slope, canopy and grand cover. During recent years, some researchers have used the RHEM model in the US for instance:

Wei et al (2007) published a paper on a Comprehensive sensitivity analysis framework for model evaluation and improvement using a case study of the rangeland hydrology and erosion model which demonstrated rain is the most sensitive input parameter. Wei et al (2008) also studied a dual Monte-Carlo approach to estimate model uncertainty and its application to the rangeland hydrology and erosion model and the results indicated that model uncertainty increased with increased storm size and increased instance levels. Weltz et al (2008) assessed the benefits of grazing land conservation practices and conclude that, using this approach, it is possible to quantify the impact of conservation practices that directly impact vegetation and the corresponding impact on surface hydrologic process and soil erosion rates of the site. Pierson et al (2009) studied the Hydrologic effects of fire in sagebrush plant communities: Implications for rangeland hydrology and erosion modeling, this research has demonstrated fire reductions in ground cover increases raindrop detachment rates and the connectivity of overland flow sources and facilitate rill formation where overland flow velocity and sediment detachment and transport increase. Nearing et al (2011) applied RHEM model to estimate erosion and runoff based on 204 plots in 49 rangeland site distributed across 15 western U.S states. Experiments were conducted to generate independent data for model evaluation and the coefficients of determination (r2) of runoff and erosion predictions were 0.87 and 0.50 respectively, which indicated the ability of RHEM to provide reasonable runoff and soil loss prediction capabilities for rangeland management and research needs.

To provide conservationists, rangeland management and other land users with the tools they need to evaluate the impact of various management strategies on soil loss and sediment yield, and plan for the optimal use of the land. The present study aims to assess the applicability and efficiency of the RHEM to predict sediment yield by using soil erosion measuring plots and record observed rain in Sangane research station, Khorasan Razavi province, Iran.

2. Material and methods

The method of this model is based on the solution of the coupled kinematic wave equations for overland flow and the sediment continuity equation and using following relationship:

The infiltration equations in RHEM are taken directly from the WEPP model. Infiltration is computed using the Green-Ampt Mein-Larson model (Mein and Larson, 1973) for unsteady intermittent rainfall as modified by Chu (1978).

$$K_e t = F_i - \psi\theta_d \ln\left(1 + \frac{F_i}{\psi\theta_d}\right) \tag{1}$$

where Ke is infiltration rate (m s-1), t is time after time to ponding (s), ψ is average capillary potential (m) and θ_d is soil moisture deficit (mm-1), which is calculated as the difference between porosity and initial soil water content.

Equation [2], the kinematic wave equation, is used to route the rainfall excess on a sloping surface:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = v \tag{2}$$

Where h is depth of flow (m), q is discharge per unit width of the plane (m3.m-1.s-1), and x is distance from the top of the plane (m). Runoff discharge, q (m), is calculated using a depth-discharge relationship:

$$q = \alpha h^{1.5} \tag{3}$$

Where α is the depth-discharge coefficient that is related to Darcy-Weisbach hydraulic friction factors.

RHEM calculates sediment load in the runoff along the hillslope as the total net detachment and deposition from rainfall splash, overland sheet flow, and concentrated flow, using a steady state sediment continuity equation (Nearing *et al.*, 1989):

$$\frac{dG}{dX} = D_{ss} + D_c \tag{4}$$

Where G (kg m-1 s-1) is sediment load in the flow and Dss and Dc are splash and sheet erosion and concentrated flow erosion, respectively, as is discussed below. The numerical solution of Equation [4] was used in the WEPP model (Nearing *et al.*, 1989), with source terms (Dss and Dc) based on rangeland derived parameters. RHEM adopts the new splash and sheet erosion equation developed from rangeland erosion data (Wei *et al.*, 2009):

$$D_{ss} = k_{ss} . I^{1.052} . q^{0.592} \tag{5}$$

Where Dss (kg m-2 s-1) is the rate of splash and sheet erosion for the area, Kss is sheet erodibility coefficient; I (m s-1) is rainfall intensity; and q (m s-1) is the splash is runoff rate. Also for Ke and Kss coefficients there are different equations for different vegetation types (refer to Nearing *et al.*, 2011).

Concentrated flow erosion in RHEM is represented using an excess shear stress equation of the form (Foster, 1982b):

$$D_c = K_c (t - t_c)\left(1 - \frac{G}{T_c}\right) \tag{6}$$

Where Dc (kg m-2 s-1) is the rate of concentrated flow erosion for the area, Kc (s m-1) is the concentrated flow erodibility coefficient, τc (Pa) is the shear stress of the concentrated flow on the soil surface, τ (Pa) is the critical shear stress for the soil (the level of flow shear that must be exceeded before concentrated flow detachment is initiated), G (kg m-1s-1) is the sediment load in the flow, and Tc (kg m-1 s-1) is the sediment transport capacity of the flow.

Study area

This study was conducted in the Sangane watershed in the northeast Khorasan Razavi (60o15'E, 36o41' E) encompassing some 50 ha. The mean elevation of the study area is 700m above the mean sea level. The general features and the location of the study watershed, has been shown in fig.1. According to the collected data, the meteorological station the general climate of the watershed is semiarid. The area receives less than 180 mm annual precipitation. The mean annual temperature has been reported to be 15o C. From geology viewpoint, the study area has been covered by shill with thin siltstone layer. Shallow soil texture is loamy sand and soil dept is from 5cm to 120cm in different parts of this area. The dominate vegetation Type is Artemisia sieberi about 60 to 70 percent northern hillslopes but in some parts Poa bulbosa and Salsola spp is dominat, and vegetation in southern hillslopes is about 20 percent (Rangavar 2004).

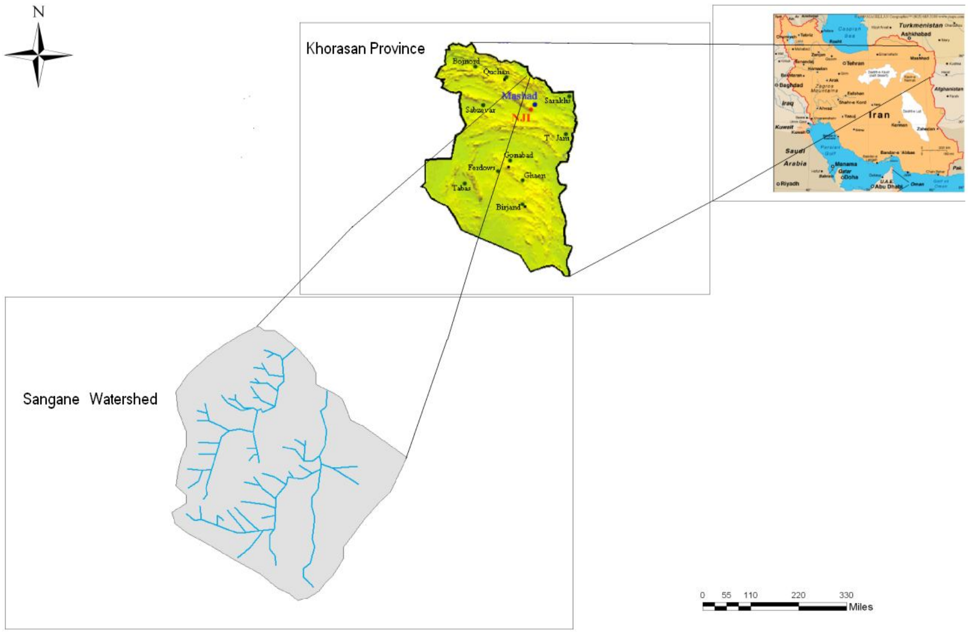

Figure 1. Location of the study site in Iran

Establishment of plots

After study and survey the geological, soil science, vegetation and slop maps, suitable area for experimental plot was determined and 92 standard erosion plots with 5, 10, 15, 20 and 25m length by 2m width were established in 1996. The experimental plots to measure sediment and runoff in different condition of vegetation, slop and soil depth were established, and sediment and runoff were measured from 1996 to 2011 after every rainfall event. For recording each rainfall event (intensity, duration and amount) two rain gauges have been established (Rangavar 2004). The details of the study plots have been shown in Figure 2.

The sediment concentration was also determined through sampling from the collected runoff at the outlet of each plot. The volume of 1L was taken for lab analysis from the total runoff after mixing up the entire runoff. Sediment concentration was determined using a drying and weighting method (Inbar & Lierena, 2000). The runoff and sediment measurements were taken during 8 natural storm events that occurred during the study period. To run the model 19 plots by 5m 10m 20m length were selected and the model was run by all the input values like: slope length, steepness, canopy cover and ground cover (Table 1), then the predicted runoff and sediment yield values were compared with measured runoff and sediment yield values. The corresponding result from one hillslopes has been summarised in Table 2.

Table 1. Experimental plot used for model evaluation

Hillslope Number	Plot Number	Length (m)	Slope%	Soil Texture	Dominant plant Form
E1	8	5	30	Sandy Loam	Shrub
E2	10	10	23	Sandy Loam	Sod Grass
	11	5	23		
E3	16	5	67	Sandy Loam	Sod Grass
	17	10	67		
E4	24	5	30	Sandy Loam	Shrub
	25	10	30		
E5	26	5	55	Sandy Loam	Forbs
	27	10	65		
	28	20	65		
E6	30	5	36	Sandy Loam	Annual Grass
	31	10	60		
	32	20	60		
E7	33	5	40	Sandy Loam	Shrub
	34	10	40		
	36	20	40		
E8	69	5	60	Sandy Loam	Sod Grass
	70	10	60		
	72	20	60		

Figure 2. Experimental plots with a runoff and sediment collection system on deep soil (left) and shallow soil (right).

Table 2. Storms properties, observed and predicted sediment for the study area on one of the slopes

	Storm properties			Observed sediment (t/ha)			Measured sediment (t/ha)		
	Date	Depth (mm)	Intensity (mm/h)	5 m	10 m	20 m	5 m	10 m	20 m
1	1997/4/18	7.7	10.6	0.0064	0.0037	0.0025	0.0061	0.0073	0.0131
2	1997/5/25	7.2	28	0.104	0.0808	0.0378	0.0083	0.0098	0.0138
3	1997/6/17	8.4	9	0.142	0.0931	0.0896	0.0152	0.0191	0.0316
4	1998/2/27	14.6	5.2	0.0036	0.0151	0.0028	0.0142	0.0176	0.0351
5	2007/3/17	12.4	6.8	0.0059	0.0053	0	0.0125	0.0125	0.0178
6	2007/4/6	6.2	24.8	0.0536	0.195	0.0113	0.0137	0.0187	0.0291
7	2007/12/8	6.6	9.6	0.0235	0.0085	0.0021	0.0023	0.0022	0.0026
8	2009/4/20	9	13.6	0.594	0.0713	0.0939	0.0088	0.0096	0.0175

To calibrate any model, sensitivity analyses were performed by changing the value of a parameter within an acceptable range and observing the runoff and sediment yield output. Sensitivity analysis evaluates the relative magnitudes of changes in the model response as a function of relative changes in the values of model input parameters. The parameter that produced the maximum sensitivity was adjusted first, followed by the other parameters. The input parameters that showed negligible variation were not calibrated and were taken as model default values. Thus, the calibration process focused mainly on input parameters that control runoff and sediment production. Once the model was calibrated, it was run with the calibrated parameters, and the runoff and sediment yield values predicted for the validation period.

The simulated values by different runs were evaluated by visual inspection of plots of the range of observed and simulated values. The root mean square error (RMSE), Mean Bias Error (MBE), Mean Absolute Error (MAE) and the model efficiency values (ENS) were computed as criteria for goodness-of-fit.

3. Results

The results of run the model with experimental plots by different characteristics and different storms showed that model is estimated higher than the observed values except 5m plots. The ratio between average of predicted sediment values and observed values in plots by 5m, 10m and 20m longs was 0.124, 0.387 and 0.425 times larger respectively, it can be due to relation between sediment with plot long that is reducer and it is often nonlinear because of sediment large handling from slop long (Dendy and Bolton) and (Parker and Storcamp). For runoff the ratio between estimation values and observed values were 4.6, 6.4 and 10.5 respectively. This indicated that with increasing length plots estimates model were higher than observed values. Therefore, sensitivity analyses were performed on two hillslopes with completely different plots by 5m, 10m, 15m and 20m lengths. Table 3 shows characteristics of these two hillslopes.

Table 3. Characteristics of two hillslopes

Hillslopes	Steepness	Soil Texture	Canopy Cover %	Rock Cover %	Litter %
1	40	Loam	85	5	4
2	60	Sandy Loam	14	5	1

The sensitivity analysis result for soil erosion showed that in slopes with less than 60% steepness, vegetation canopy cover was found to be the most sensitive parameter and precipitation as the second and slop steepness was third sensitive parameter. But in slopes with more than 60% steepness and with lengths more than 10m, results were different and precipitation was sensitive parameter and slop length was the second parameter and slope steepness as the third sensitive parameter was found. The sensitivity analysis results for runoff showed that canopy cover and then slop steepness were the most sensitive parameters. The results of this analysis have been shown in Figure 3 and 4.

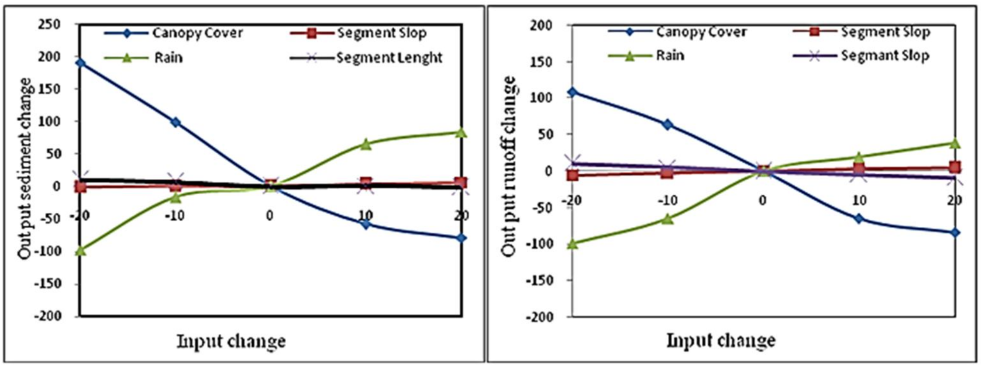

Figure 3. Sensitivity analysis of RHEM for sediment (Left) yield and runoff (Right) in slopes with less than 60% steepness

Calibration and validation

In the present study, the model was calibrated with measured data at the plots. The calibrated RHEM model was then used to simulate runoff and sediment yield; the measured runoff and sediment yield values were compared with simulated values to evaluate the model validation performance. The calibration and validation results for soil erosion and runoff have been shown in Figure 5 and 6.

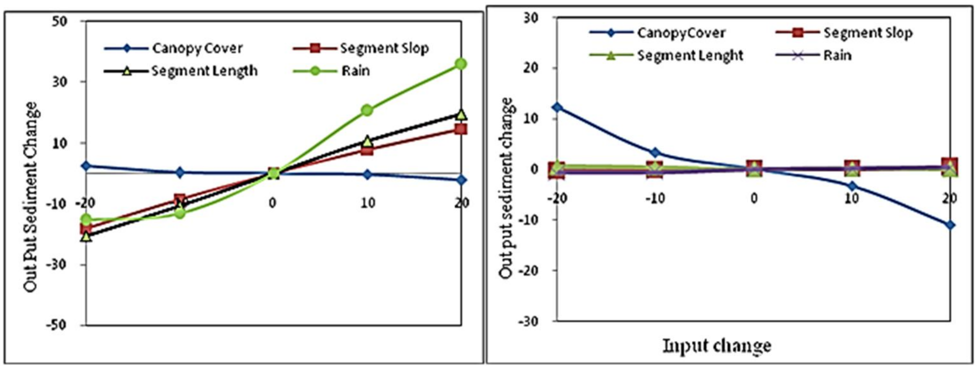

Figure 4. Sensitivity analysis of RHEM for sediment (Left) yield and runoff (Right) in slopes with more than 60% steepness

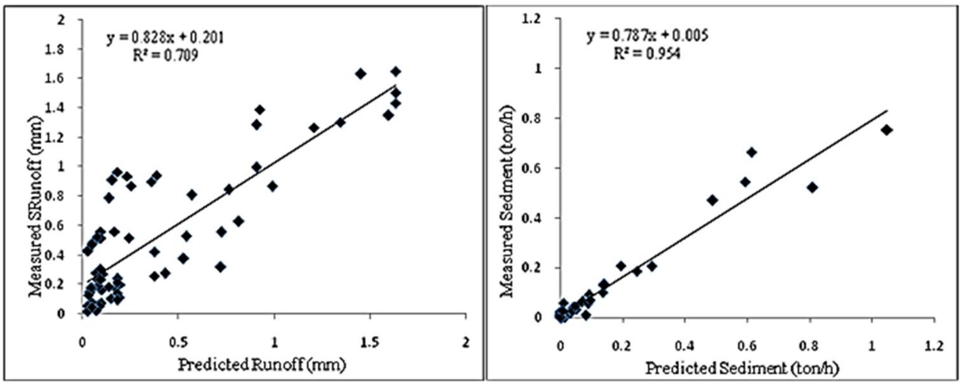

Figure 5. Comparison of measured and simulated sediment (Left) and runoff (Right) in calibration phase.

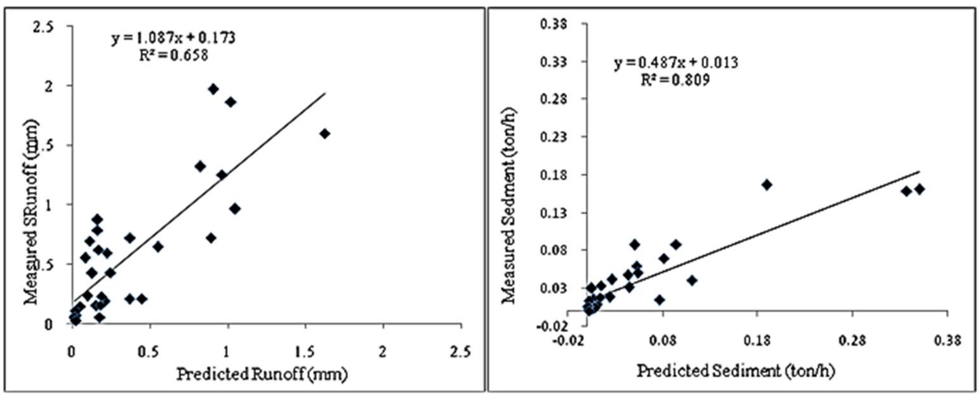

Figure 6. Comparison of measured and simulated sediment (Left) and runoff (Right) in validation phase.

The high coefficients of determination (0.95 and 0.84) indicate a positive relationship between the measured and simulated sediment yields (Figure 5). Reasonably high ENS values for the calibration and validation periods (0.92 and 0.70) showed that the model performed satisfactorily in estimation of sediment yield (Table 4).

Table 4. Statistical analysis of observed and simulated sediment

	Mean Sediment (t)		RMSE	r2	ENS	MBE	MAE
	Predicted	Observed					
Calibration	0.060	0.070	0.0012	0.95	0.70	-0.0096	0.018
Validation	0.039	0.050	0.0011	0.83	0.92	-0.012	0.022

The values of coefficients of determination in calibration (0.70 and 0.65) indicate a positive relationship between the measured and simulated runoff (Figure 6). Furthermore, the performance for runoff in the validation period (0.60) was slightly degraded compared to the calibration period (0.11), but it was a little acceptable (Table 5).

Table 5. Statistical analysis of observed and simulated runoff

	Mean Runoff (mm)		RMSE	r2	ENS	MBE	MAE
	Predicted	Observed					
Calibration	0.52	0.38	0.043	0.70	0.60	0.14	0.21
Validation	0.57	0.37	0.073	0.65	0.11	0.21	0.26

According to this result and by comparing correlation coefficients (r2) and performance coefficients (ENS) with studies carried out by Nearing (2011) can be concluded that model have acceptable result to estimate sediment and runoff.

4. Conclusion

The Rangeland Hydrology and Erosion Model (RHEM) was used to simulate runoff and sediment yield in the northeast part of Iran. According to Weltz et al (2008) and Pierson et al (2009) researches vegetation canopy cover was found to be the most sensitive parameter in prevent soil erosion and in validation period, the (ENS) values and (r2) values in 99% Confidence level were 0.70 and 0.84 for sediment and 0.11 and 0.65 for runoff, respectively. Our research indicated that the results of model were acceptable in 99% confidence level for sediment and this results compared to Nearing (2011) were a little different, as the result showed that this model is more efficient in estimating sediment than runoff in our study area. The evaluation of RHEM has shown that while the model is already a valuable accessible tool, application of the model to areas rather than in the USA and other land treatments required calibration with observed data as has been carried out in this study. Nevertheless Further work with different datasets and further validation of model in other rangelands are required.

References

Arabkhedri, M. 2001. Educational workshop of method of increasing accuracy estimate suspensed sediment in the rivers. Conference Management Soil Erosion lands and Stable improvement. p: 54

Arabkhedri, M. 2005. Survey sediment suspense discharge in Iran watersheds. Iranian Water Resources Research. 4:48-58

Chang, M. 2006. Forest hydrology, an introduction to water and forest. Second Edition, Iowa State University. 474p.

Chu, S.T. 1978. Infiltration during an unsteady rain. Water Resources Research. 14(3):461-466.

Cogle, A.L., Lane, L.J., and Basher, L. 2003. Testing the hillslope Erosion model for Application in India, New Zealand and Australia. Environmental Modeling and Software. 18: 825-830.

Dendy, F.E., Bolton, G.C. 1976, Sediment Yield Runoff Drainage Area Relationship in the United States. Journal of Soil and Water Conservation. 31: 264-266.

Fernandez, C., Wu, J.Q., McCool, D.K., and Stookle, C.O. 2003. Estimating Water Erosion and Sediment Yield with GIS, RUSLE and SEDD. Journal of Soil Water Conservation. 58:128-136.

Gubin, F., Shulin C., and Donald, K.M. 2005 Modeling the Impacts of No-Till Parctice on Soil Erosion and Sediment Yield with RUSLE, SEDD, and ArcView GIS. Journal of Soil and Tillage Research. 85: 1-2, 36-49.

He, C. 2003. Integration of geographic information system and simulation model for watershed management. Environmental modeling and Software. 18: 809-813.

Inbar, M., and Lierena, C.A. 2000. Erosion processes in high mount ain agricultural terraces in Peru. Mountain Research and Development. 1 (1): 72–79.

Lu, H., Moran C.J., and Posser, I.P. 2005. Modeling sediment delivery into over The Murray Darling Basin. Environmental Modeling and Software. 21: 1297-1308

Mein, R.G., and Larson, C.L. 1973. Modeling infiltration during a steady rain. Water Resources Res. 9(2): 384-394.

Meyer, L.D., and Wischmeier, W.H. 1969. Mathematical simulation of the process of soil erosion by water. Transaction of American Society of Agricultural Engineers.12: 754-755.

Miller, S.N., Semmens, D.J., Goodrich, D.C., Hernandez, M., Miller, R.C., Kepner, W.G., and Guertin, D.P. 2007. The automated geospatial watershed assessment tool. Environmental Modeling and Software. 22: 365-377.

Nakhjavani, F. 1976. Soil conservation brochure. Tehran University. 50p.

Nearing, M.A., Foster, G.R., Lane, L.J., and Finkner, S.C. 1989. A process-based soil erosion model for USDA Water Erosion Prediction Project technology. Transaction of American Society of Agricultural Engineers. 32(5): 1587-1593.

Nearing, M.A., Wei, H., Stone, J.J., Pierson, F.B., Speath, K.E., Weltz, M.A., Flanagan, D.C., and Hernandez, M. 2011. A Rangeland Hydrology and Erosion Model. P:2132-52.

Novotny, V., and Olem, H. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York. P: 46.

Parker, R.S., and Osterkamp, W.R. 1995. Identifying Trends in Sediment Discharge from Alteration in Upstream Land Use, In Effects of Scale on Interpretation and Management of Sediment and Water Quality, In: Boulder Symposium, Osterkamp. 226: 207-213.

Pierson, Jr, Moffet, C.A., and Robichaud, P.R. 2009. Concentrated flow experiments on burned and unburned sagebrush communities: Applications for the Rangeland Hydrology and Erosion Model. 62nd Annual Meeting, Society of Range Management. Albuquerque, New Mexico. P: 8-12.

Rangavar, A.S. 2004. Final report project, research in important elements in soil erosion in Khorasan rangelands, Research Center for Agriculture and Natural Resources of Razavi Khorasan. 92 P.

Santhi, C., Srinivasan, R., Arnold, J.G., and Williams, J.R. 2006. A modeling approach to evaluate the impact of water quality management palns implemented in a watershed in Texas. Environmental Modeling and Software. 21: 1141-1157.

Singh, V.P. 1992. Elementary Hydrology. Prentic-Hall. 973 p. Englewood Cliffs New Jersey, 973 pp.

Spaeth, K.E., Pierson, F.B., and Moffet, C.A. 2006. Rangeland hydrology and erosion model (RHEM) for ESD development. In: Proceedings of the3rd National Conference on Grazing Lands, December. P: 13-16.

Wei, H., Nearing, M.A., Stone, J.J., Guertin, D.P., Spaeth, K.E., Pierson, F.B., Nichols, M. H., and Moffett, C.A. 2009. A new splash and sheet erosion equation for rangelands. Soil Science Society American Journal. 73(4):1386-1392.

Wei, H., Nearing, M.A., Stone, J.J., and Breshears, D.D. 2008. A Dual Monte Carlo Approach to Estimate Model Uncertainty and Its Application to the Rangeland Hydrology and Erosion Model. 51(2): 515-520.

Wei, H., Nearing, M.A., and Stone, J.J. 2007. A Comprehensive Sensitivity Analysis Framework for Model Evaluation and Improvement using a Case Study of The Rangeland Hydrology and Erosion Model. 50(3): 945−953.

Weltz, M.A., Jolley, L., Nearing, M., Stone, J., Goodrich, D., Spaeth, K., Kiniry, J., Arnold, J., Bubenheim, D., Hernandez, M., and Wei, H. 2008. Assessing the benefits of grazing land conservation practices. Journal of Soil and Water Conservation. 63(6):214-217