Iran Agricultural Research 21:157-172(2002)

PREDICTION OF SEDIMENT DELIVERY RATIO IN A SMALL AGRICULTURAL WATERSHED

S. AMIN, A. GAROSI AND A. SHIRVANI[1]

Department of Irrigation, College of Agriculture, Shiraz University, Shiraz, I.R. Iran.

(Received: December 6, 1998)

ABSTRACT

Due to sediment deposition, overall sediment yield is usually less than soil loss from the soil surfaces of a watershed. The ratio of sediment yield at a watershed outlet to gross erosion within it is usually referred to as the sediment delivery ratio (SDR). Since the relationship between detachment and transport of the soil particles is not linear for each storm, simulation of SDR was performed on an individual storm basis using the *ANSWERS* model modified for prediction of the SDR in a small agricultural watershed (3.62 ha) located in south of Iran with an average slope of 2.6% and fallow conditions. Data from independent rainfall events during 1994 to 1997 were analysed. Stepwise regression analysis showed that SDR was correlated with antecedent soil moisture content (ASM), maximum suspended solids concentration of runoff (C_{max}), and mean rainfall intensity (I_{mean}), (p= 0.001). Because it was expected that the total runoff volume would also make a significant contribution to soil erosion and SDR, the effect of the runoff volume of each storm was also tested. Further stepwise regression analysis showed not only a higher coefficient of determination (R^2= 0.90) but also a higher significant level introducing other variables, i.e. runoff volume ($\alpha \geq 0.53$). In the case of introducing runoff volume as a new variable in the regression equation the model was an artificial one. However, the relationship between SDR and the watershed hydrological properties best represents the situation of soil erosion in our study area. For other watersheds of different sizes, soils, and slope characteristics, more

1. Professor, former Graduate Student and Research Assistant, respectively.

research is necessary to investigate the relationship between SDR, watershed characteristics and climatological conditions. The overall average SDR for the watershed under study was 54.70%, which can be recommended for estimation of soil erosion and sedimentation from the watersheds.

Key words: Agricultural watersheds, *ANSWERS* model, Iran, Sediment delivery ratio, Shiraz, Soil erosion.

تحقیقات کشاورزی ایران

۲۱: ۱۵۷-۱۷۲ (۱۳۸۱)

پیش‌بینی نسبت رسوب‌دهی در یک حوضه آبخیز کوچک کشاورزی

سیف الله امین، عباس گروسی و امین شیروانی

به ترتیب استاد و دانشجوی پیشین کارشناسی ارشد بخش آبیاری دانشکده کشاورزی و مربی پژوهش مرکز اقلیم شناسی دانشگاه شیراز، شیراز، جمهوری اسلامی ایران.

چکیده

به علت ته نشینی مواد رسوبی، به طور معمول رسوب حاصل از یک حوضه آبخیز، کمتر از فرسایش سطح خاک‌های آن حوضه است. نسبت رسوب خارج شده از خروجی یک حوضه آبخیز به فرسایش کل داخل آن نسبت رسوب دهی (SDR) نامیده می‌شود. از آنجا که رابطه بین کنده شدن و انتقال ذرات خاک برای واقعه های بارندگی خطی نیست، شبیه سازی نسبت رسوب‌دهی در مورد بارندگی‌های مستقل با استفاده از مدل *ANSWERS* در مورد یک حوضه آبخیز کوچک کشاورزی (با وسعت ۳/۶۲ هکتار و میانگین شیب ۲/۶٪) تحت شرایط آیش واقع در جنوب ایران انجام شد. داده‌های سیلاب و رسوب مربوط به بارش‌های مستقل برای سال‌های ۱۹۹۷-۱۹۹۴ (۱۳۷۶-۱۳۷۳) تجزیه و تحلیل شدند. تحلیل رگرسیون گام به گام نشان داد که مقدار SDR با رطوبت اولیه خاک،

بیشترین غلظت ذرات معلق روان‌آب، و متوسط شدت بارندگی وابسته است ($P = ۰/۰۰۱$). از آن جایی که انتظار می‌رود کل حجم رواناب حاصل از یک بارندگی مستقل، سهم قابل توجهی در فرسایش خاک و SDR داشته باشد، اثر این عامل در هر واقعه بارندگی نیز بررسی شد. تحلیل مراحل بعدی رگرسیون گام به گام ضریب همبستگی بالاتری نشان داد ($R^2 = ۰/۹۰$)، اما سطح معنی دار بالاتری نیز برای ورود حجم روان آب به معادله به دست آمد ($\alpha \geq ۰/۵۳$) به طوری که، ورود حجم روان‌آب به عنوان یک متغیر جدید در معادله، مدل رگرسیونی را به طرف یک مدل مصنوعی سوق می‌دهد. به هرحال رابطه بین نسبت رسوب‌دهی و ویژگی‌های هیدرولوژی حوضه مورد مطالعه نشان‌دهنده وضعیت فرسایش خاک در منطقه است. برای سایر آبخیزها با اندازه، نوع خاک و ویژگی‌های شیب مختلف تحقیقات بیشتری لازم است تا رابطه بین SDR و عوامل مرتبط با هیدرولوژی حوضه‌های آبخیز در شرایط اقلیمی متفاوت به‌دست آید. با توجه به شرایط این حوضه آبخیز، میانگین SDR برابر با ٥٤/٧٪ به‌دست آمد، که می‌توان این ضریب را برای برآورد مقادیر فرسایش و رسوب حوضه‌های آبخیز به کار برد.

INTRODUCTION

Sediment yield from a watershed has been shown to be usually a fraction of the total eroded soil materials. Wade and Heady (29) reported that the sediment transported from 105 agricultural production areas in USA ranged from 0.1 to 37.8% of the gross soil erosion. The sediment yield from a watershed in some cases may be 25% (3) or 30% of eroded materials (15). The delivery of sediment as reported by Brierley and Fryirs (8) could be around 70% of the eroded soil as in Wolumla Creek catchment of Australia. Golubev (14) showed that 10 % of the total eroded soil from the Oka Basin in European USSR was transported into the large rivers. Since the sediment yield of a watershed is always less than the total soil eroded (9, 11, 22) the concept of sediment delivery ratio, SDR, as a percentage of the gross erosion could be applied in the USLE to determine the net soil erosion from a watershed (17, 28, 30, 31).

The value of SDR for a watershed depends on different factors such as the nature and distribution of the deposition points, slope characteristics, drainage distribution patterns, crop coverage, land management, and soil textures (3, 18, 20, 25, 30). Renfro (24) concluded that the SDR is influenced by sediment source, magnitude and proximity of sediment materials, deposition areas, and watershed characteristics. The SDR of a light soil is lower than that of a heavy textured soil (24, 25). This could be due to the selective properties of the erosion process.

Piest *et al.* (23) found no relationship between sediment yield and soil erosion for 55 rainfall events over 6 years. For several Mississippi watersheds, the SDR values were not correlated with any physical parameters of the watershed (27). However, the SDR varied widely, and ranged from 1% to 54.4%. This parameter was explained to be a function of the season, antecedent soil moisture, intensive cultivation, biotic activity, and freeze-thaw (19). Sheridan *et al.* (25) conducted their research on the monthly, seasonal, and annual variations in SDR. They showed that SDR was not constant for single rainfall events but was a function of crop coverage, land use management, rainfall intensity, and distribution.

Williams (32) and Williams and Berndt (33) studied 5 watersheds for 8 years and concluded that the SDR was a function of sequential segments of the main channel of the watershed. Ebisemiju (10) studied the relationship between SDR and degree of the slope, slope length, soil erodibility factor and soil infiltration of the watershed on a soil with and without crop coverage. He concluded that, slope length and soil erodibility are the two most important factors in estimation of SDR when crop coverage exists, and the slope steepness and average soil infiltration are the major factors involved when the watershed is without crop coverage.

Although several equations are available to calculate SDR, none of them is universally applicable. These equations lump the watershed characteristics, resulting in an average value for SDR. Since detachment and transport relationships are not linear (12), an individual storm approach should be considered to simulate runoff, sediment yield, and SDR during a rainfall event. Among the individual storm-based models that exist, we chose the *ANSWERS* model (6) which uses the characteristics of the individual storms and runoff factors, to estimate SDR.

The objectives of this study were to:

1. Develop a sediment delivery ratio (SDR) concept and incorporate it into *ANSWERS* model.
2. Evaluate the accuracy of the modified model for simulation of data and comparing with observed field data of a small agricultural watershed for different individual rainfall events.
3. Develop a regression equation to demonstrate the effects of hydrological parameters of rainfall events and watershed responses on SDR.

MATERIALS AND METHODS

Experimental Watershed

The *ANSWERS* model (4, 5) was applied using data from a small agricultural watershed located in Badjgah Valley, 16 km north of Shiraz, Iran. This small agricultural watershed has an area of 3.62 ha and a time of concentration of 15 minutes. The watershed has an average slope of 2.6% with minimum slope of 0.2% and a maximum slope of around 4.8%. A topographic map of this watershed is shown in Fig. 1. This small agricultural watershed was used because it is representative of most watersheds of Fars province in south of Iran, and has substantial runoff and sediment data since 1988.

Precipitation occurs primarily during November through May with the greatest frequency occurring in February. The average annual rainfall in the valley is 400 mm and rainfall events fit the B distribution form (1, 2). The rainfall data were from the recording raingauge installed at the College of Agriculture weather station. The storm events used in this study are representative of those received in this region of Iran. The basic assumption in selection of the precipitations in our study was that the rainfall events were independent and identically distributed over the watershed. There is no general agreement as to separate different rainfall events. Thus, at least one hour lag time with no precipitation between two consecutive storm events was considered to identify them as two independent rainfalls (2).

The predominant soil types on the experimental site are Kuye-Asatid (loamy-skeletal over fragmental, carbonatic, mesic, Fluentic, Xerorthent) sandy loam in the upper portion of the watershed and Ramjerdi (fine, mixed, mesic, Fluentic, Xerochrept) clay loam in the lower portion. Information concerning soil texture, total porosity, soil type, and the area of each soil type in the watershed was collected from Solhi (26). Several studies have been conducted on this watershed since 1988. Our soil test and field observations showed that the structure of the soil and other physicochemical properties of the watershed soils did not change significantly. Therefore we believe the previous watershed soil physicochemical data could be used for simulation of runoff and sediment without major error in the model outputs. At the time of simulation, the watershed was under fallow conditions providing maximum runoff and soil erosion.

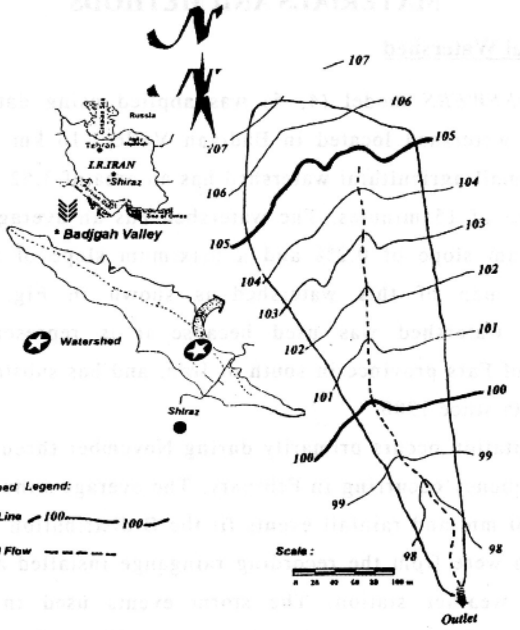

Fig. 1. Location of the experimental watershed in Bajgah valley in the north of Shiraz. Adapted from Amin *et al.* (2).

Soil samples were taken intermittently during the course of the study in order to update the antecedent soil moisture information (ASM) needed in the simulation. Representative plots of each soil type were completely saturated in order to measure the field capacity of the soils. This was determined by taking samples over two days. Infiltration capacity of the soil was determined by the double-ring infiltrometer method (16). The soil erodibility factor, K, was determined using particle size distribution of the soils of the watershed under study (34). Channel sizes and specifications were determined through direct observations and measurements using topographic map of the watershed. Other information such as depth of the control zone for infiltration of the soils was extracted from the *ANSWERS* user's manual (6).

A 15-cm and a 22-cm Parshall flume were installed in series at the outlet of the watershed to measure runoff flow rate from the site. As the flow was measured water grab samples were taken for laboratory measurement of the suspended solids.

Three single severe storms of different rainfall amounts and intensities in 1996 and 1997, which produced substantial runoff and sediment, were used to investigate the response of the watershed. The data also served to modify transport capacity of the overland flow (rainfall and overland flow detachment coefficient of the *ANSWERS* model) to provide a close agreement between observed and simulated values of sediment yield from the watershed. In addition to the data from these three rainfall events, the simulated hydrologic data of seven more severe storm events from 1994 and 1995 were used to develop a stepwise regression equation between SDR and hydrologic outputs. For accuracy of the simulation, a grid system of 10 m $\times$10 m was used in preparing the input data file for the watershed.

The *ANSWERS* model was used in this study for the following specific reasons:

1. *ANSWERS* is a deterministic model with different subroutines which can be modified for different purposes without changing its other parts.
2. The model can be transferred to other watersheds without calibration.
3. Numerous watersheds of various sizes and configurations have been simulated by *ANSWERS* and its hydrological and erosion/sedimentation parts are well tested and verified.
4. The model accounts for the spatial variability of slope, crop coverage and management in a rational and reasonably accurate way.
5. The model has been applied since 1988 in a small agricultural watershed and a substantial runoff and sediment data are available for research purposes.

ANSWERS Basic Erosion Model

Erosion is represented in a subroutine called SED in the *ANSWERS* as detachment by rainfall and overland flow and transport processes. Detachment and transport rates are compared and the lower rate equals predicted soil loss (6). Rainfall and overland flow detachments are calculated using the relationships described by Meyer and Wischmeier (21), respectively as:

$$DETR = CE_1 \times CDR \times SKDR \times A_i \times R^2 \quad [1]$$

and

$$DETF = CE_2 \times CDR \times SKDR \times A_i \times SL \times Q \quad [2]$$

where in equations 1 and 2:

CE_1 and CE_2 = rainfall and overland flow detachment coefficients, respectively.

DETR = rainfall detachment rate, kg min^{-1},

CDR = cropping and management factor, C from USLE chart (34),

SKDR = soil readability factor, K from USLE nomograph (34),

R = rainfall intensity during a time interval, mm min^{-1}

DETF = overland flow detachment rate, kg min^{-1},

SL = slope steepness, and

Q = overland flow rate per unit width of an element of the watershed network, $m^2\ min^{-1}$.

Sum of DETR and DETF is the available potential sediment, which could be transported by overland flow. Once the available detached sediment is calculated, the transport capacity is computed and compared with the available delivered sediment. Sediment transport capacity is the maximum limit by which characteristic flows, on a geometric plane, can carry detached sediments without depositing them. In the *ANSWERS* model it is expressed as a sediment mass per unit width per unit time and is modelled as follows:

$$TF = 161 \times SL \times Q^{0.5}, \quad \text{when } Q \le 0.046\ m^2\ min^{-1} \quad [3]$$

$$TF = 16320 \times SL \times Q^2, \quad \text{when } Q > 0.046\ m^2\ min^{-1} \quad [4]$$

Where:

TF = potential transport rate of sediment, $kg min^{-1} m^{-1}$

Development of these equations is given in details by Beasley (4) and Beasley and Huggins (6). *ANSWERS* simulates these entire processes for each element and each time increment (specified by user of the model) during the simulation of a storm event and after, while the hydrograph is receding.

The sensitivity of the *ANSWERS* model to the overland flow detachment coefficient and its modification along with rainfall detachment coefficients and the overland flow capacity coefficients has been reported by Beasley *et al.* (7). Based on a number of close examination of photographs and field survey information, the rainfall detachment coefficient, CE_1, was increased by a factor of 4. Later, the simulation results of *ANSWERS* showed that the accepted value of CE_1 was twice the original value. In 1982, the overland flow detachment rate coefficient CE_2 was increased by a factor of 50 due to rainfall simulator data (7). A re-examination of the flow detachment equation showed that this coefficient should be increased by a factor of 5 of the original version (7).

RESULTS AND DISCUSSION

The accumulated rainfall during the study period (Nov.1996 to May 1997) was 256.6 mm, and as compared to the 25-year average of 414 mm, it shows that this period was particularly dry. Table 1 contains all the rainfall events recorded from 1994 to 1997. During 1996 to 1997, most precipitation events were of low intensity, except three, which produced substantial runoff and sediment yield from the watershed.

To calculate the sediment delivery ratio by the *ANSWERS* model, the agreement between the simulated and observed runoff values was investigated (13). A correlation coefficient of more than 92% between predicted and observed values of the runoff data related to the three selected single rainfall events showed a very good prediction of runoff (13). In the second step, the predicted values of sediment yield in the rainfall events were compared to the observed values. These were not in close agreement. Therefore, *ANSWERS*'s sediment transport capacity coefficients for laminar and turbulent overland flow (Eqs. 3 and 4) were reduced by 20%, and the rainfall and overland flow detachment coefficients were increased 5-fold and decreased to 0.013 times its original value, respectively. Modifications of these coefficients corresponding to our watershed observed data showed that the correlation coefficient between observed and predicted values of the sediment yield had a range of 92 % to 96% for the selected rainfall events (p=0.001). The details of these modificatios are given in Garosi (13).

The *ANSWERS* model with the modified coefficients of transport capacity and detachment rates was applied to calculate the SDR. The results of the simulation are summarized in Table 1. The results of simulations showed that the SDR of the watershed under study changed from one rainfall event to the next.

The average value of SDR was 60.4 % for the rainfall events of 1994, 59.5 % for the rainfall events of 1995, and about 44.3% for the rainfall events of 1997. The overall average of SDR was 54.70% for the watershed under the study. As Table 1 shows the value of SDR was 31.7 % for the rainfall event of 17/1/97, 51.2 % for the rainfall event of 24/3/97, and about 50% for the rainfall event of 29/3/97. The amount of rainfall during the last storm was 19.25 mm, (about one-third of the storm of 24/3/97), but the rainfall intensity was higher and more runoff and sediment yield was produced. Thus, antecedent soil moisture had a very significant effect on SDR.

Table 1 contains the average and maximum rainfall intensities of the three major storms of 1997. The average rainfall event intensities were 2.05 mm hr^{-1}, 2.03 mm hr^{-1}, and 2.06 mm hr^{-1}, with maximum intensities of 6 mm hr^{-1}, 3.75 mm hr^{-1}, and 12 mm hr^{-1}, respectively. Therefore, the rainfall detachment was similar for the first and third storm, but the mean and maximum runoff rates were higher in the case of the third rainfall event. Antecedent soil moisture was 32% for the first storm and 72 % of saturation for the last storm. This explains why SDR was about 50% for the third rainfall event as compared to 31.70% for the first event.

The antecedent soil moisture for the second storm event was 65% of saturation. With 60.3 mm of rainfall, the runoff volume was 7 mm. The storm duration was almost 30 hr, which resulted in flow detachment rather than rainfall detachment. Therefore, the SDR value for this storm was 51.2%. Different factors that might have affected the value of SDR are presented in Table 1. These factors were tested in a stepwise regression for the ten most severe storms which occurred between 1994 and 1997. The results of the simulations are shown in Table 2. The results of the stepwise regression showed that the SDR was firstly related to ASM, the antecedent soil moisture of the watershed, secondly to the maximum sediment

Table 1. Rainfall events of 1994 to 1997 and the results of watershed responses.

Date: year, month, day	Rainfall amount (mm)	Durat. (hr)	Runoff (mm)	ASM (% sat.)	Rainfall rate I_{mean}	Rainfall rate I_{max}	Rate mean ($mm\ hr^{-1}$)	Runoff mm	Sed. con. Mean (mg l^{-1})	Sed. con. Max (mg l^{-1})	SDR %
1994/8/											
11	26.92	5.00	13.12	77	5.04	9.00	1.47	5.80	17189	31158	68
16	19.80	10.67	2.34	77	1.85	6.00	0.18	1.65	7220	29075	55
17	43.50	11.67	19.5[illegible]	77	3.83	9.00	1.22	5.70	14658	28587	69
1994/12/											
19	20.50	13.67	57	2.11	1.50	6.00	0.08	1.80	5135	32431	54
20	15.75	8.67	61	3.26	2.58	7.50	0.37	1.44	15917	31966	56
									mean SDR = 60.4		
1995/2/											
5	34.50	10.33	9.10	67	3.33	7.50	0.57	2.45	14240	32409	61
7	32.30	12.67	5.44	42	2.55	6.75	0.33	2.52	13988	33635	58
									mean SDR = 59.5		
1997/1/											
17	28.00	13.67	3.10	32	2.05	6.00	0.19	1.26	13736	39970	31.7
1997/3/											
24	60.30	29.67	7.00	65	2.03	3.75	0.21	0.62	11940	31460	51.2
29	19.25	9.33	5.71	72	2.06	12.00	0.36	5.11	8790	29940	50.0
									mean SDR = 44.3		
									Total average SDR = 54.7		

concentration (C_{max}) in the runoff flow and finally to the mean rainfall intensity, I_{mean} according to:

$$SDR = -16.35 + 0.56\ ASM + 0.0009\ C_{max} + 3.361\ I_{mean},\quad R^2 = 0.88 \qquad [5]$$

where

SDR = sediment delivery ratio, %,

ASM = antecedent soil moisture, %,

C_{max} = maximum suspended load, mg l^{-1}, and

I_{mean} = mean rainfall intensity, mm hr^{-1}

Table 2. The results of the stepwise regression between SDR and hydrological responses of the site under study.

Step	Regression Equation	Significance level entering new variable (%)	P-value	R^2
1	SDR =-0.69 + 0.85 ASM	5	0.70	0.57
2	SDR = -20.5 + 0.68ASM + 0.001 C_{max}	5	0.07	0.84
3	SDR= -16.35 + 0.56 ASM + 0.0009 C_{max} +3.361 I_{mean}	15	0.10	0.88

This equation is for fallow conditions and also single rainfall events. The relationships between SDR and ASM and SDR and ASM and C_{max} were significant at the 5% level while the relationship between SDR and ASM, C_{max}, and I_{mean} was significant at the 15% level.

It was expected that the runoff volume would also have a substantial effect on SDR. But further stepwise regression analysis showed that entering this factor in the SDR equation resulted in increasing the significance level to more than 54%. Therefore, runoff volume for our situation did not have much effect on SDR.

As the stepwise regression shows (Table 2) the maximum sediment concentration has appeared in the second and third steps increasing the R^2 but the coefficients of this variable in the second and third equation are 0.001 and 0.0009, respectively. Thus the effect of the maximum sediment concentration is not so high in the third equation. However, in the final step (Eq. 5), mean rainfall is introduced, which has caused the R^2 to increase to 0.88. This equation has also physical meaning based on the watershed situation. The average ASM of a watershed soil could be estimated or measured directly by soil sampling and properties of a rainfall event with a specified recurrance period could be also achieved. The maximum runoff sediment concentration from historical data of our watershed or from the nearby watershed could be estimated and finally the sediment delivery ratio of the watershed could be calculated.

Further stepwise regression analysis showed a higher coefficient of determination (R^2=0.90) but also a higher significance level introducing other variables, i. e. runoff volume ($\alpha \geq 0.53$). In the case of introducing runoff volume as a new variable in the regression equation the model was an artificial one.

SUMMARY AND CONCLUSIONS

In planning a variety of water conservation projects such as dams and sediment basins, the design of the specific structure can be optimized by reducing the gross erosion by SDR. In the previous works the SDR was studied on a long-term basis (monthly, seasonally, or annually) providing very little contribution to the understanding of smaller periods of time, i.e. during individual rainfall events. Therefore, the effects of the watershed and storm characteristics were lumped together. To conduct research on a rainfall event basis many factors that are related to soil erosion and transport of particles to produce sediment yield must become clearer. Using a single rainfall event basis oriented model such as *ANSWERS* will allow for a more precise understanding of the physical and climatological factors affecting soil erosion and sediment yield. After modification of the rainfall and flow detachment coefficients, the *ANSWERS* model was modified to find the SDR for rainfall events in the selected watershed. This study was conducted in a 3.62 ha watershed, under fallow conditions, to allow for maximum soil erosion. As Eq. 5 shows, the SDR will increase with high amount of ASM and high rates of soil detachment by rainfall in the watershed. Under high mean intensities of rainfall, the high rate of soil detachment in the watershed resulted and suspended solids will more likely stay in suspension and be transported to the outlet of the watershed. Therefore, in these cases, SDR will increase. As Eq. 5 indicates, the maximum sediment concentration does not have significant effect on SDR. However, this equation is specific to the watershed in this study. For other watersheds of different sizes and characteristics more detailed work is needed.

LITERATURE CITED

1. Amin, S., H. Momtahan and B.A. Engel. 1990. Application of the ANSWERS model for prediction of runoff and sediment from a small agricultural watershed of Iran. Iran. Agric. Res. 9:101-120.
2. Amin, S., A.R. Sepaskhah and B. Keshmiripour. 2000. Rainfall distribution patterns in climatological conditions of four stations in Fars province, Iran. Iran. J. Sci. Tech. 24:89-98.
3. ASCE. 1970. Task Committee on Preparation of Manual on Sedimentation. Sedimentation Engineering, Chapter IV: Sediment sources and sediment yields. J. Hydrol. Div., ASCE, 96:1283-1329.
4. Beasley, D.B. 1977. *ANSWERS:* A mathematical model for simulating the effect of land use and management on water quality. Ph.D. Thesis Purdue Univ. W. Laf. IN, U.S.A. 157 p.
5. Beasley, D.B., L.F. Huggins and E.J. Monke. 1980. *ANSWERS:* a model for watershed planning. Trans. ASAE 23:938-944.
6. Beasley, D.B. and L.F. Huggins. 1982. *ANSWERS* User's Manual. Dept. Agric. Eng., Purdue Univ., W. Laf., IN, U.S.A. 55 p.
7. Beasley, D.B., L.F. Huggins and J.R. Burney. 1984. *ANSWERS*: List of Programs (Ver. 4.840801). Dept. Agric. Eng., Purdue Univ., W. Laf., IN, U.S.A.
8. Brierley, G.J. and K. Fryirs. 1998. A fluvial sediment budget for upper Wolumla Creek, south coast, New South Wales, Australia. Aust. Geographer 29:107-124.
9. Di Silvio, G. and A. Marion. 1997. About delivery ratio: How does it change in time and space? Energy and Water: Sustainable Development Proceedings, Cong. Int. Assoc. Hydraulic Res., Vol. D., ASCE, NY, U.S.A. 90-95.
10. Ebisemiju, F.S. 1990. Sediment delivery ratio prediction equations for short catchment slopes in a humid tropical environment. J. Hydrol. 114:191-208.
11. Ferro, V. 1997. Further remarks on a distributed approach to sediment delivery. Hydrol. Sci. J. 42:633-647.
12. Foster, G.R., L.J. Lane, J.D. Nowlin, J.M. Laflen and R.A. Young. 1980. A model to estimate sediment yield from field-sized areas: Development of model. In: W.G. Knisel (ed.), CREAMS: A Field-scaled Model for

Chemicals, Runoff, and Erosion from Agricultural Management Systems. Conservation Res. Rep. No. 26, USDA-SEA. Washington, DC. U.S.A. 36-64.

13. Garosi, A. 1997. Modification of the *ANSWERS* model for prediction of sediment delivery ratio (SDR) in a small agricultural watershed. M.Sc. Thesis. Dept. of Irrigation, Shiraz Univ., Shiraz, Iran (In Farsi). 144 p.
14. Golubev, G.N. 1982. Soil erosion and agriculture in world: An assessment and hydrological implications. Int. Assoc. Hydrol. Sci., Pub. 137:261-268.
15. Hadley, R.F. and L.M. Shown. 1976. Relation of erosion to sediment yield. In: Proc. 3rd. Inter-Agency Sediment. Conf. U.S. Resour. Coun., Washington, DC., U.S.A. 1-132-1-139.
16. Hansen, V.E., O.W. Israelsen and G.E. Stringham. 1980. Irrigation Principles and Practices. 5th ed., John Wiley and Sons. New York, U.S.A. 77-85.
17. Khanbilvardi, R. M. and A. S. Rogowski. 1984. Quantitative evaluation of sediment delivery ratios. Water Res. Bul. 20:865-874.
18. Kothyari, U.C. 1996. Temporal variation of sediment yield. J. of Hyd. Eng. 1:169-176.
19. Kreznor, W.R., K.R. Olson, D.L. Johnson and R.L. Jones. 1990. Quantification of postsettlement deposition in northwestern Illinois sediment basin. Soil Sci. Soc. Amer. J. 54:1393-1401.
20. Mou, J. and O. Meng. 1981. Sediment delivery ratio as used in the computation of the watershed sediment yield. J. Hydrol. 20:27-38.
21. Meyer, L.D. and W.H. Wischmeier. 1969. Mathematical simulation of the processes of soil erosion by water. Trans. ASAE 12:754-758.
22. Ongley, E.D. 1987. Scale effects in fluvial sediment- associated chemical data. Hydrological Processes 1:171-179.
23. Piest, R.S., L.A. Kramer and H. G. Heinemann. 1975. Sediment movement from loessial watershed. Proc. Sediment Yield Workshop. USDA Sediment Lab. Oxford, MS, Nov. 28-30, ARS-S-40. 130-141.
24. Renfro, G.W. 1975. Use of erosion equations and sediment delivery ratios for predicting sediment yield. Proc. Sediment Yield Workshop. USDA Sediment Laboratory, Oxford, MS, U.S.A. Nov. 28-30, ARS-S-40. 33-45.
25. Sheridan, J.M., C.V. Booram and L.E. Asmussen. 1982. Sediment delivery ratios for a small coastal plain agricultural watershed. Trans. ASAE 25:610-615, 622.

26. Solhi, M. 1987. Soil genesis, morphology, physiochemical properties and classification of Badjgah region soils (Fars province) Iran. M.Sc. Thesis. Dept. Soil Sci., Shiraz Univ., Shiraz, Iran (In Farsi). 140 p.

27. Sprayberry, J.A., R. Woodburn and J.R. McHenry. 1960. Sediment delivery ratio studies in Mississippi. I. A preliminary Report, Agron. J. 52:434-436.

28. Summer, W., E. Klaghofer and K. Hintersteiner. 1996. Trends in soil erosion and sediment yield in the Alpine basin of the Austrian Danube. Internl. Asso. of Hydrological Sci., Wallingford, England. 236:473-479.

29. Wade, J.C. and E.O. Heady. 1978. Measurement of sediment control impacts on agriculture. Water Resour. Res. 14:1-8.

30. Walling, D.E. 1983. The sediment delivery problem. J. Hydrol. 65:209-237.

31. White, S. 1996. Erosion, sediement delivery and sediment yield patterns in the Philippines. Int. Asso. Hydrol. Sci., Wallingford, England. 236:233-240.

32. Williams, J.R. 1975. Sediment routing for agricultural watersheds. Water Res. Bul. 11:965-974.

33. Williams, J.R. and H.D. Berndt. 1972. Sediment yield computed with universal equation. J. Hydraul. Div., Proc. ASCE, 98(HY2):2087-2098.

34. Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses. Agricultural Handbook No. 537, USDA, Science and Education Administration. 58 p.