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Applicability of SEDIMOT II Model in Flood and Sediment Yield Estimation

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ABSTRACT

The application of various models with different structures and applications for the assessment of hydrologic events such as floods and soil erosion is of much interest to both experts and decision-makers owing to a potential saving of time and money. The most recent version (1982) of the SEdimentology by DIstributed MOdel Treatment approach (henceforth SEDIMOT II) as a tool for flood and sediment estimation was selected to be evaluated for its applicability to the experimental Amameh watershed in Iran. The main watershed, with an area of 3712 ha, was divided into 12 sub-areas and required inputs were extracted for each of them. Afterwards, 12 storm events with a coincident hyetograph, hydrograph and sediment data were selected to run the model. A high degree of agreement of 92% was found between the computed peak discharge and the observed data whereas the applicability of the model in sediment yield estimation was found to be poor.

Keywords: Amameh, Computer model, Distributed model, Flood estimation, Iran, Sediment yield, SEDIMOT.

INTRODUCTION

Intolerable pressure on the different available resources has been caused as a result of an ever increasing demand for food and energy resulting from population growth. The feedback of this irregularity appears in the form of unwilling events such as flood, drought, landslides, famine and so on. A fast and a comparatively accurate evaluation of the aforesaid phenomena may therefore be helpful for their prediction, forecasting and, ultimately, management. The aforementioned computer model can be used as a suitable tool for a rapid and precise assessment of effective parameters.

Since no substantial part of the universe is so simple that it can be grasped and controlled without abstraction (Singh, 1988), some level of error is expected during the modeling process. In general, the models should ideally be both simple and accurate. In practice, however, a trade off between simplicity and theoretical accuracy is necessary. On the other hand, the application of computer models, particularly to a complicated process such as hydrological and erosion study, is advised to facilitate managerial processes.

It is possible to model the response of the entire runoff-erosion-transport process for a watershed using either a lumped or distributed parameter approach. In spite of lumped parameter models which evaluate the response of the entire watershed as a single hydrologic unit, the distributed models are applied for studying the spatial and the temporal variation of phenomena and therefore can be used for a better management of watersheds (Williams and Arnold, 1993). HYMO (ARS, 1973), ANSWERS (Beasley,

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1977), SWAT (Arnold *et al.*, 1996), WEPP (Ascough *et al.*, 1997) and SWRRB (Arnold and Williams, 1998) are some of the commonly used distributed models developed in the field of hydrology. A simple distributed parameter simulation model called SEDIMOT I (Wilson *et al.*, 1981) was developed by University of Kentucky in which the SCS method and the Williams' technique (1975) had been used for hydrograph and sediment graph development, respectively. Another simple model called WASHMO (Warner *et al.* 1982) was developed which it was similar to SEDIMOT I but the sediment routing was not taken into account and the unit hydrograph approach was applied to develop the hydrograph. These two models (SEDIMOT I and WASHMO) were then combined together to contain the advantages of both and the result was named SEDIMOT II. The distributed nature of the model SEDIMOT II, its simplicity, its not requiring special or rarely available input data and its having no special constraints for application made it an appropriate model for the present study leading to the estimation of flood peak and sediment yield resulting from each storm.

MATERIALS AND METHODS

The storm-wise model SEDIMOT II consists of four components, namely rainfall, runoff, sediment and sediment control (Sadeghi, 1993). The first three components are briefly explained in the following directing to estimate the flood and sediment yield in the study area.

Rainfall Component

The input parameters for this option are storm duration, total depth, an array of accumulated rainfall depth, an array of time values corresponding to the rainfall depth and the peak 30 minute intensity that can be extracted from the rainfall charts. The SCS's type I and type II curves were suggested as default options of the model for representing the storm pattern. For the study area, where rainfall pattern does not follow the SCS's pattern, the storm pattern is set by representing a new rainfall distribution pattern.

Runoff Component

Runoff hydrographs from different subareas are predicted in SEDIMOT II and then combined with each other to form a composite hydrograph. In SEDIMOT II, the watershed is divided into a sequence of structures, branches and junctions. Rainfall extraction through vegetation interception, depression storage and infiltration are estimated using the SCS curve number method (US Soil Conservation Service, 1969). The antecedent moisture condition is evaluated on the basis of the summation of available daily precipitation and growth and un-growth situation of vegetation cover. The overland flow component of the SEDIMOT II is predicted using a unit hydrograph. According to the governed condition, the user selects the unit hydrograph shape as input information by choosing one of the defaulted codes corresponding to disturbed, agricultural and forested land uses. The fractioned values can also be chosen for intermediate conditions. The channel flow is routed to structures and between them by Muskingum's routing procedure (Chow *et al.*, 1988). The value of the storage coefficient (k) is assumed to be equal to the total travel time in the reach. The value of the weighting factor (x) is estimated by knowing the average velocity of the flow (V_m) in ms^{-1} determined by applying SCS Upland Curves and using the following equation (Wilson *et al.*, 1981 and Subramanya, 2000):

$$x= (0.5V_m) / (1.7+V_m) \qquad (1$$

The required parameters for the runoff component therefore consist of the number of structures, branches and junctions, Muskingum's storage and weighing factors, the number and area of watersheds above each structure, the curve number, the time of con-

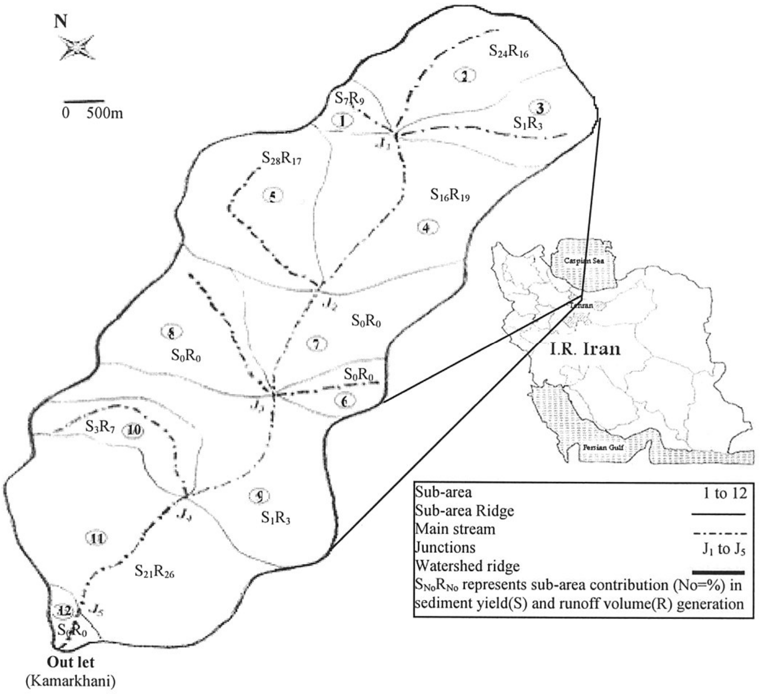

Figure 1. Sub-divided study units in Amameh watershed.

centration, the unit hydrograph type and Muskingum's parameters for each sub-watershed.

Sediment Component

Specific gravity, coefficient for distribution, submerged bulk specific gravity, number of particle size distribution, particle size data of the sediment sampled from the main river bed as well as MUSLE parameters (Williams, and Berndt, 1977) comprise the input data for running the sediment sector of the model. The total sediment yield and sediment graph in storm basis serve as the main outputs of the model.

Study Area

The Amameh experimental watershed located on the skirt of the Alborz mountain range and 40 km far from Tehran, the capital of Iran, was chosen for the study. It has been equipped with hydrological and meteorological instruments for 30 years. The watershed is extended between 35°51′00″ to 35°75′00″ N latitudes and 51°32′30″ to 51°38′30″ E longitudes and covers an area of 3712 ha from 1800 to 3868 m with an average of 2620 m above mean sea level. A schematic view of the watershed is shown in Figure 1. The area is mostly covered by mountainous rangelands with an average precipitation of 848.4 mm of which almost 73 percent falls during winter and spring. The average long-term discharge at Kamakhani station located at the outlet is 0.575 m^3/s (WRRC, Iran, 1996). The maximum and the minimum observed discharges are 21.2 and 0.01 m^3/s, respectively. The months of April and September are the wettest and the driest months during the year, respectively.

As it is seen in Figure 1, the main watershed was divided into 12 sub-watersheds according to the drainage density pattern and

Table 1. Specifications of selected storms

No.	Storm	Depth (mm)	Duration (h)	Intensity (mm/h)	AMC[a]	Volume of runoff (m^3)	Peak discharge (m^3/s)	Sediment yield (Tonnes)
1	1 May 70	24.6	6.5	17	I	85559	2.00	N. A.
2	13 Apr. 71	25.9	7	11.2	II	197375	9.70	67.83
3	2 Aug. 72	9.8	2	7.11	I	0	0..90	0.61
4	17 July 74	13.3	2	10.92	II	52743	3.70	2.97
5	1 Oct. 74	14.1	3	10.92	I	0	0.98	N. A.
6	1 May 75	27.6	5	9.14	I	93215	6.90	N. A.
7	16 Apr. 80	26.8	4	16.51	I	90683	6.80	N. A.
8	1 May 83	25	12.5	7.11	I	86285	3.44	N. A.
9	4 May 84	13.6	2.5	7.84	II	54551	1.51	0.62
10	13 May 89	12.5	3	7.11	I	0	0.58	16.14
11	1 May 92	34.5	8.5	8.89	I	82842	6.98	N. A.
12	2 June 92	13.3	7	6.86	II	28573	3.20	N. A.

[a] AMC= Antecedent moisture condition, N. A. = Not available

land use. Then 12 individual storms mostly having coincident hyetograph, hydrograph and sediment data were selected. All necessary input data and parameters required for running the model were determined and extracted using information collected and summarized in Tables 1 and 2.

RESULTS AND DISCUSSION

The designated outputs of the model were found by entering the determined input data and parameters resulting from the analysis of information collected for both the flood and sediment components. The results belonging to flood and sediment estimations were presented in the form of a hydrograph and sediment graph, respectively. The estimated hydrographs were compared with ones observed in view points of general shape and the peak values, since these two components of the hydrographs are very important in water resource management pro-

Table 2. Input parameters of sub-areas in the Amameh watershed.

Sub-area	Area (ha)	CN (AMCII)	TC (h)	TT (h)	k (h)	x	UH	K	LS	CP
1	223.4	89.0	0.188	0.000	0.000	0.000	1.5	0.22	15.08	0.20
2	344.8	89.5	0.209	0.000	0.000	0.000	1.5	0.22	16.79	0.23
3	56.8	89.5	0.083	0.000	0.000	0.000	1.5	0.22	20.99	0.23
4	534.6	88.0	0.291	0.222	0.222	0.433	1.5	0.26	22.69	0.07
5	414.5	89.0	0.288	0.000	0.000	0.000	1.5	0.25	23.09	0.14
6	81.3	49.0	0.305	0.000	0.000	0.000	2.0	0.18	13.54	0.10
7	194.7	58.0	1.363	0.234	0.234	0.411	2.5	0.15	16.41	0.08
8	343.5	58.0	1.009	0.000	0.000	0.000	2.0	0.28	8.44	0.08
9	547.5	80.0	0.895	0.486	0.486	0.378	1.5	0.15	8.41	0.07
10	192.5	88.0	0.487	0.000	0.000	0.000	1.5	0.23	16.53	0.16
11	740.0	88.0	0.415	0.355	0.355	0.388	1.5	0.12	28.76	0.07
12	38.7	74.5	0.085	0.072	0.072	0.437	2.5	0.14	10.20	0.12

Notations: TC= Time of concentration (SCS upland method), TT= Travel time,
k= Storage coefficient, x= Weighing factor, UN= Type of unit hydrograph, K= Erodibility factor,
L=Slope length factor, S= Slope steepness factor and CP= Management factor

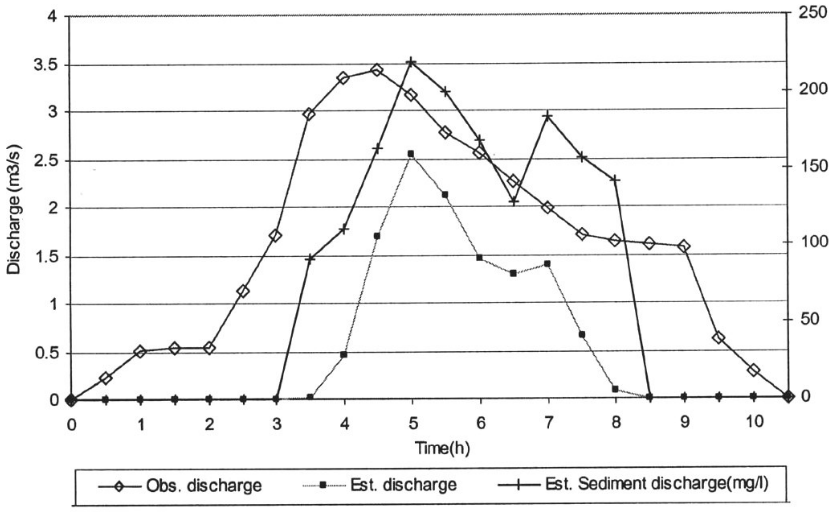

Figure 2. The estimated and observed hydrograph and estimated sediment graph for storm May 1, 1983.

jects. The values of total predicted sediment yield were also considered for comparison with those of observed ones, since the measured sediment flux versus time (i.e. observed sediment graph) were not available for the study area. The storm-wise estimated and the observed peak discharges as well as sediment yield are given in Table 3. An example of the estimated and the observed hydrographs as well as the estimated sediment graph belonging to the storm of May 1, 1983 has also been demonstrated in Figure 2.

As is seen in Table 3, the calculated discharge under dry antecedent moisture conditions (AMC I) across all of the study subareas and the entire watershed was zero when the storm duration was less than or equal to the time of concentration. The relationship between observed and estimated discharges is shown in Figure 3. The results of the regression analysis between estimated (E_Q) and observed (O_Q) peak discharges in m^3s^{-1} have been shown in the following linear equation with a correlation coefficient of 92.19% and a relative estimation error of 12.1%.

$$E_Q = -1.03 + 1.40\, O_Q \quad (2$$

Other important components of estimated hydrographs such as time to peak, base time and concentration time as introduced by ASCE (1993) were almost the same as the actual hydrographs. Application of a pair t-test also verified the equality of the average values of two set data. The sensitivity analysis (Tiscareno *et al.*, 1993) of the model also depicted that the CN and the time of concentration are the important parameters to which the model is very sensitive. The importance of the CN values on controlling the runoff of the watershed could simply be recognized in cases of estimated discharges for AMC I and AMC III that were respectively less and more than observed ones. The CN

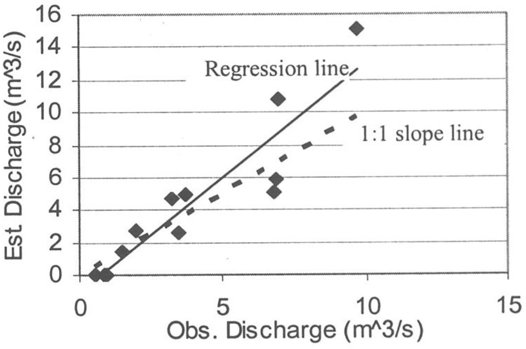

Figure 3. The relationship between observed and the estimated runoff peak

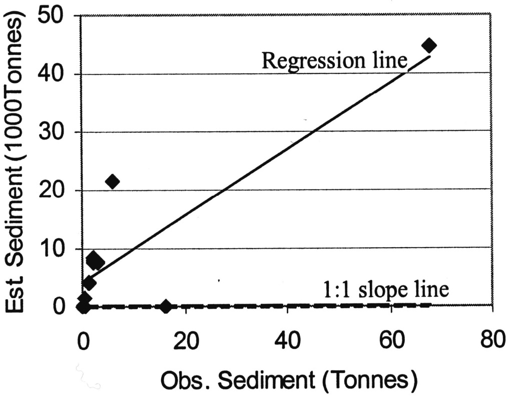

Figure 4. The relationship between observed and the estimated sediment yield

parameter was then calibrated based on the summation of the previous five days, precipitation. The error of estimation was thus significantly reduced in the calibrated cases.

As is also seen in Table 3, no reasonable correlation could be identified between estimated and observed sediment yield. Comparison between these two set data verified the inapplicability of SEDIMOT II for estimating sediment yield in the study area while the regression analysis showed a high degree of agreement between estimated and observed sediment yield to the tune of 86%. The relationship between observed and estimated sediment yield is also shown in Figure 4. The following equation could be ultimately established between estimated (E_S) and observed sediment yield (O_S) with very high level of estimation error. Application of a pair t-test also verified the inequality of the average values of the two set data.

$$E_S = 570.25\ O_S + 4111.8 \qquad (3$$

The thumb estimation of mean annual sediment yield using the estimated values and with respect to the numbers of storm usually occur per year is almost equal to 13.03 tones per hectare which is nearly equal to that reported for the Latian dam watershed adjacent to the study area. This inability might be due to the unreliable and the inconsistent sediment data, unavailability of suspended sediment samples during peak floods and the application of an uncalibrated sediment model i.e. MUSLE for the study area. Scrutinizing Figure 2 belonging a sample storm shows that peak values in the estimated sediment graph and hydrograph in the Amameh watershed occur simultaneously. The percentiles of partial contributions of each sub-area in generation of the total sediment yield and the volume of runoff during selected storms have been also mapped in Figure 1. It is seen from Figure 1 that the sub-areas 2, 4, 5 and 11 contribute the maximum in different ways whereas the sub-areas 6, 7, 8 and 12 with an almost zero percent contribution have the least share in generation of sediment yield and runoff volume, respectively. It is therefore very important to allocate different invests accordingly.

CONCLUSION

The results of the application of the stormwise SEDIMOT II model to the Amameh watershed in Iran revealed very applicable approaches which are useful for watershed management projects. The model was statistically accurate in flood hydrograph simula-

Table 3. The observed and the computed discharge and sediment yield using SEDIMOT II.

Storms		1	2	3	4	5	6	7	8	9	10	11	12
Peak Discharge (m^3s^{-1})	Obs.	2.00	9.70	0.90	3.70	0.98	6.90	6.80	3.44	1.51	0.58	6.98	3.20
	Est.	2.67	15.03	0.00	4.95	0.00	5.82	5.12	2.54	1.47	0.00	10.74	4.73
Sediment yield (Tonnes)	Obs.	1.14	67.83	0.61	2.97	0.00	2.33	2.14	1.11	0.62	16.14	5.85	2.07
	Est.	4223.41	44470.02	0.00	7619.39	0.00	8651.25	7955.95	4125.82	1528.71	0.00	21727.37	7667.50

Obs.= Observed, Est.= Estimated

tion whereas it performed weakly in storm-wise sediment yield estimation compared with the observed data. In spite of the acceptable accuracy of the model in flood estimation, the proper application of and providing the appropriate and accurate data to the model is a must which has to be thoroughly considered. Since no particular limitation has been mentioned by the developers to confine the application of the model, it can be used for any type of watersheds where necessary data and information are available. The calibration of the model SEDIMOT II with the help of reliable and consistent sediment data in the form of sediment graphs for its better evaluation is strongly recommended.

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ارزیابی کاربرد مدل SEDOMOT II در تخمین سیلاب و تولید رسوب

س. ح .ر. صادقی و م. مهدوی

چکیده

استفاده از مدلهای مختلف با ساختارها و کاربردهای گوناگون برای ارزیابی وقایع هیدرولوژیکی مثل سیلاب و فرسایش خاک به واسطه صرفه‌جویی در زمان و سرمایه بسیار مورد توجه کارشناسان و تصمیم‌گیران قرار گرفته است. طی این تحقیق، آخرین نسخه (۱۹۸۲) رسوب‌شناسی به وسیله دیدگاه استفاده از مدلهای توزیعی که به اختصار SEDIMOT II نامیده شده و به عنوان ابزاری برای تخمین سیلاب و رسوب بکار می‌رود، برای ارزیابی در حوزه آبخیز امامه در ایران انتخاب گردید. آبخیز اصلی با مساحت ۳۷۱۲ هکتار به ۱۲ زیرحوزه تقسیم شده و کلیه اطلاعات ورودی برای هر یک از آنها بدست آورده شد. سپس، ۱۲ رگبار با باران‌نگار، آب‌نگار و داده‌های رسوب همزمان برای اجرای مدل انتخاب شدند. نتایج بدست آمده از کاربرد مدل نشان داد که میزان توافق مقادیر دبی اوج تخمینی مدل با مقادیر مشاهده‌ای بسیار بالا و در حدود ۹۲٪ بوده حال آنکه عملکرد مدل در تخمین مقدار رسوب ضعیف ارزیابی گردید.