Int. J. Forest, Soil and Erosion, 2012 2 (4): 180-185
ISSN 2251-6387 [PRINT] 2251-824X [Online]

Research Paper

Assessment and simulation of biological soil conservation countermeasure (Case study: Northern Karoon River Watershed, Iran)

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Received: 2012-04-26 **Accepted: 2012-06-03**

Abstract: The objectives of the present study are twofold: 1) to evaluate the actual capability of EUROSEM, to simulate the biological method of the soil and water conservation, and 2) to assess the effectiveness of this technique to protect the soil and water in the mentioned study area. The study area is a part of Vanak catchment in the Northern Karoon River Watershed, Southwest of Iran. Runoff and sediment data were collected over a number of periodical rainfall events from the two catchments called biological and control catchments. Parameterization, calibration, and validation of the model were carried out based upon the input parameters. Experimental results confirmed the capability of the model to simulate biological soil and water conservation techniques. The simulation of biological soil and water conservation technique indicated that this protection approach caused significant differences in the total runoff generated, total soil loss, peak flow rates, and time to peak flow rates as compared to the same traits of the control. The result illustrated that this conservation technique reduced both output total runoff and total sediments by 40 to 81% and 45 to 69% respectively, yielding a sustainable ecosystem in the catchment.

Keywords: Biological measure, EUROSEM, Iran, Soil conservation

Introduction

Soil erosion is a major problem from both an agricultural and an environmental perspective as it may have destructive effects on the ecosystem either in its natural state or under human management (Pimental 2006). It leads not only to impoverished soil fertility but also to sediment deposits in waterways, conduits, and dams. Additionally it may give rise to destructive floods and pollutant transport.

The estimated soil erosion from watersheds in Iran is five times of the average global value (Ahmadi 1995). This rate should be compared with the value of 1 t ha^{-1} often considered to be the maximum permissible value if soil fertility is to be maintained and water pollution prevented (Grimm et al. 2002).

Conservation techniques are often classified into biological, mechanical, and soil management measures (Rickson 1994). These techniques are often used uniquely for a specific situation and cannot be exchanged with each other (Ghorbani 2000).

Most countries do not have an adequate system in place for assessing erosion risks, predicting erosion rates under existing conditions, or for formulating different strategies to address the problem. It is, therefore, necessary to identify and evaluate tools that can best be used for collecting data and information to be used for runoff and sediment management (Owens et al. 2004)

In the United States, some predictive erosion models as USLE, CREAMS, WEPP and ANSWERS have been used to evaluate the effectiveness of the soil conservation measures (Rickson 1994). However, these models are lumped models that only predict mean annual soil loss (e.g. USLE) or total storm soil loss (e.g. CREAMS and WEPP). These models do not normally account for temporal and spatial variations of input parameters such as rainfall changes, slope, and land use. Despite the undeniable attractions of these models, they should not be used in places other than in US (even in Europe), as they are empirically based on US data only (Rickson 1994).

European Soil Erosion Model (EUROSEM), a joint effort by many scientists, is a distributed single event and physically-based model. It is capable of evaluating the soil conservation measures, the soil management practices, and the way these practices influence runoff and the soil erosion rates (Rickson 1994).

There are a number of input variables and parameters in EUROSEM that are indirectly related to biological measures and its management. These include the canopy cover percentage (COV), maximum interception storage (DINTR), percentage of basal area of the vegetation (PBASE), average angle of the plant stems to the soil surface (PLANGLE), effective canopy height (PLANTH), and plant leaf shape factor (SHAPE). There are other input variables and parameters such as cohesivity of the soil root matrix (COH), across and along slope roughness (RAS and RFR), saturate hydraulic conductivity (FMIN), effective net capillary drive (G), Manning roughness coefficient (MANN), the soil porosity (POR), initial relative soil saturation (SMAX), and infiltration recession factor (RECS) which are indirectly related to biological conservation measures. It is possible to apply EUROSEM to any given storm in order to compare runoff and soil loss with and without these biological conservation measures.

The objectives of the present study are to evaluate the actual capability of EUROSEM, to simulate the biological method of soil and water conservation, and finally, to assess the effectiveness of this technique to protect soil and water in the study area.

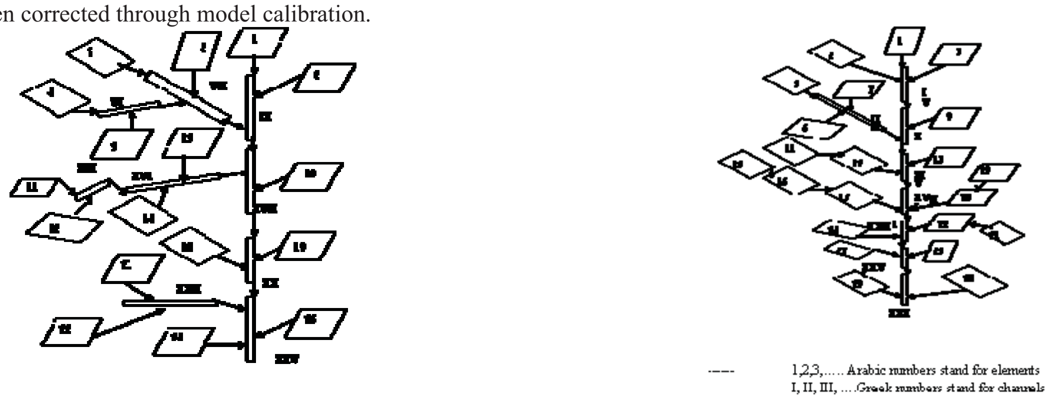
Martial and Methods

The experiments were carried out at Vanak catchment located in the Northern Karoon River watershed, Chahar Mahal and Bakhtiari Province, Iran. The latitude and longitude of the area are 51º, 2', 10" to 51º, 6', 11" East and 31º, 43', 10" to 31º, 48', 52" North, respectively. The average height is 2843 m above the sea level. The climate condition of region is semi arid and mean annual rainfall is 313 mm. Except in a few catchments where the grazing is controlled, the majority of the basin is used for pasture. So, due to this fact and the high mean steep slope, i.e. 32.6%, the rate of erosion is seriously high (nearly 5 times of the mean global average on erosion). The soil texture ranges from silt loam to sandy loam in different elements.

The study area is 35.5 km^2 and its main waterway stretches over 10 km. The length of equivalent square area is 10.74 km and its corresponding width is 3.31 km with a shape factor of 2.8. Two catchments of 2.5 and 1.1 ha in the region were selected as biological and control measure areas, respectively. The selected biological catchment has been already protected by shrub planting, grass seeding and grazing was forbidden for several years by Iran Natural Resources Organization (INRO). Control catchment was selected in a region which has already been left bare and unprotected by any biological technique for several years. Each catchment was selected in such a way that it represents the whole field area of the biological protective measure as well as its corresponding control plot.

Each catchment was divided into a number of homogeneous cascade elements that might be either planes, channels or both. For example, the biological and its corresponding control catchment were divided into 26 and 30 elements respectively (Figure 1). For model calibration purpose, observed field runoff and sediment data were collected every five minutes using a weir installed in the outlet. Two rainfall events in the year 2002 were used for this purpose (Habibian 2002).

Some of the input parameters of the model such as geometry, vegetation cover, and the soil characteristics of elements were directly measured in the field. Each measurement was replicated at three locations, upper, middle and lower end of each element. For example, the soil particle size distribution pattern and the soil textures were determined using both the pipette and sieve analysis methods. Particle density of soil and sediment were determined using the psychrometer method (Gee and Bauder, 1986). The saturated hydraulic conductivity values of undisturbed soil samples were measured using falling head permeameter in the lab. The soil water content was assumed to be at saturated condition to achieve a critical condition. The percentage of rock fragments was also determined in the laboratory using sieve analysis method. The soil erodibility factor, the soil cohesion and capillary drive parameters were taken from the table reported in the guide manual by Morgan et al. (1993) and then corrected through model calibration.



(A) **(B)**

Figure 1. Schematic representation of biological measure (A) and control (B) catchments and elements flow chart.

EUROSEM was used to simulate and analyze the data. The simulated and observed hydrographs and sedigraphs and their corresponding parameters such as total runoff generated, total soil loss, peak flow rates, peak sediments rates and time to peak flow rates were compared to the same traits of the control. Parameterization, calibration and validation of the model were also carried out using the collected data in the field.

Model calibration was carried out using half of the data available. For this purpose the variability of input parameters including hydraulic conductivity and capillary drive were performed with keeping other parameters set to be constant for hydrograph calibration. This was followed by basal area percentage, detachability and cohesivity for the soil erosion parameters

The input files (rainfall and catchment) were analyzed in an attempt to determine how physical characteristics (including soil, vegetation cover and geometric parameters) of biological conservation practice could be incorporated into the model. Then the indirect effects of these conservation measures had to be accounted for in the input files. The model outputs in terms of predicted runoff and sediment with and without conservation practices were compared and analyzed.

Data from 25 years of rainfall events recorded at a synoptic and climate station in the region were used for the model simulation. Events with any duration longer than the catchment concentration time, 20.4 min, were selected for the purposes of this study. Calibration of the model was accomplished using the year 2002 data.

Table 1. The values of input parameters of biological measure and corresponding control catchment used in the EUROSEM

Parameters	Symbols	Biological measure	Control
Number of elements	NELE	25	30
length	XL (m)	6.65-142.5	10.7-55.2
width	W (m)	0-73.5	0-41.9
Longitudinal slope	SIR (%)	9.3-84	3.1-88.7
Surface roughness along the slope	RFR (%)	0.01-6.7	0.001-1.90
Surface roughness across the slope	RAS (%)	0-4.9	0-3.70
Maximum soil moisture content (by volume)	THMAX	0.41-0.60	0.23-0.52
Capillary drive	G (mm)	480-812	480-812
Porosity	PRO (%)	43-63	24-54
Hydraulic conductivity	FMIN (mm h^{-1})	0.22-2.46	0.02-2.47
Mean particle size	D_{50} (μ)	1-4.2	3.8-5
Cohesivity	COH (kPas)	3-15	3-6.3
Plant coverage	COVER	0-0.71	0-0.08
Plant height	PlANTH (cm)	0-28.6	0-25
Plant basal area	PLANTBASE(m^2)	0-0.44	0-0.30

Certainty analysis was performed for further evaluation of model outputs. For statistical analysis, regression coefficient, mean square error, and T-test were used to analyze and compare simulated and observed output parameters of hydrographs and sedigraphs with those of the controls.

Results

Input data

For evaluation of the soil and water conservation techniques, it is essential to first parameterize, calibrate and validate input parameters. Parameterization means to collect, measure, calculate and revise input data. Table 1 shows the range of some of main input parameters of the biological measure and the corresponding control catchment used in the EUROSEM. Obviously, the magnitude of the different parameters varies from element to element, but to make it brief, only the main input parametric data are presented as the ranges of values in this table. For instance, the ranges of vegetation cover (COVER) for biological and its corresponding control catchments are 0-71% and 0-8%, respectively. The most dominant vegetation cover in the region was goat's-thorns which are needle leaf shrubs rarely ever more than 20 cm tall. Needle leaf plants are condensed and more effective in erosion control than tall wide leaf trees. As reported by Chapman in his study on the American needle leaf forests and by Masley on the Netherland rush forests, although tall plants reduce rain volume reaching the soil surface, the kinetic energy of raindrops occasionally increases and more erosion takes place [citation from Ghorbani 2000].

Erosion has a logarithmic relationship with longitudinal slope. Assuming the same slopes and conditions for two different longitudinal slopes, there will be more erosion on the longer slopes due to the greater quantity of rainfall received and the more opportunities existing for the soil particles to reach incipient motion. As shown in Table 1, the length of slopes (XL) in biological plots varies from 6.65 to 142.5 m, while the length of elements in the biological control plot varies from 10.7 to 55.2 m. So, the amount of erosion eroded from different elements is not the same.

With respect to resistance, the soil particle size (D_{50}) plays an important role on erosion. Particles in the range of 2 to 200 µ are the most susceptible sizes to erosion. The very large and very small-sized particles that are out of this range are resistance against erosion, due to their size and cohesivity (COH). The mean soil particle size in biological catchment and the relevant control fall within the limit of 1 to 5 µ. That is, the soil textures of these two catchments are highly susceptible to erosion.

As indicated in the Table 1, the values for the soil porosity (PRO) in biological catchment and its corresponding control vary from 24 to 63. High porosity soils exhibit high hydraulic conductivity values, high moisture holding capacities (THMAX) and consequently lower runoff and erosion. The existence of higher organic matter and humus in biological catchment, as compared to control, improves the soil physical properties such as the soil porosity and, thus, increases the soil infiltration and effective capillary drive (G). The values of (G) in biological catchment and its corresponding control fall within the limits of 480 to 812 mm. Obviously, this means that infiltration rate in biological catchment and its relevant control is generally high.

Model calibration and validation

In this study, the data from four experimental plots located in catchments were used for field model calibration purposes and the results were fitted to the whole study area. For calibration purposes, the rainfall event of March 27th 2002 was used. For the calibration of simulated hydrograph against the observed hydrograph, capillary drive (G) and hydraulic conductivity (FMIN) of each element were changed. This is due to high sensitivity of runoff hydrographs to the changes of these two parameters. The best agreement between observed and simulated data obtained when G values reduced to 42 mm and FMIN values increased to 35 mm/h, respectively. Satisfactory sedigraph calibration was accomplished by increasing the soil cohesivity (COH), Manning's roughness for both inter-rill (INRILMN) and rill area (RILMN). Table 2 shows the calibration results for the hydrograph and sedigraph of event March 27th, 2002. As given in this table, except for peak sediment rates in plots 3 and 4 located in biological catchment, the model has successfully predicted total runoff and sediment rates, peak runoff and sediment rates in each plot.

Table 2. The results of calibration of experimental plots for March 27th, 2002 rainfall event

Parameters	Total runoff (m^3 ha^{-1})		Total sediments (t ha^{-1})		Peak runoff (l min^{-1})		Peak sediments (g min^{-1})	
Plots	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	18.7	18.6	0.14	0.15	1.5	1.5	13	8.6
2	44	42.8	0.16	0.14	4	3.5	6.4	4.8

The calibrated March 27th, 2002 event was validated by the May 4th, 2002 event. The validation results of experimental plots are presented in the Table 3. The validation of the model using observed runoff and sediment data confirms the accuracy of the input physical parameters. As shown in this table, the model simulates all runoff hydrograph and sedigraph parameters, except for the time to start runoff. The calibrated and validated output results can, therefore, be generalized to other plots in the study area.

For further evaluation of the model, three input parameters that were not already used in calibration and validation processes were selected for this purpose. This involves minimum and maximum values of initial soil water content, i.e. THI, the soil surface roughness along the slope, i.e. RFR and the percentage of plant cover, i.e. COVER for biological techniques (refer to Table 4). Minimum and maximum values of the selected inputs were chosen whatever observed in the field. The values of predicted total runoff (T_r), peak flow rate (P_r), total sediment (T_s) and peak sediment rate (P_s) values for a recorded rainfall intensities, i.e. 10 to 20.2 mm h^{-1} were used. The results of evaluation are indicated in Table 4 for biological countermeasures and its control. As shown in this table, further evaluation of the model is confirmed by the predicted output total runoff, peak flow rate, total and peak sediments values that are in the ranges of (0.12-3.40) and (0.7-13.10) respectively for THI (0.38-.57), RFR (0.01-6.7) and COVER (0-0.71) input parameters values used in biological catchment. However, there is an exception for peak sediment value for RFR which is nearly out of the range of values simulated for 16 recorded events in the region. The output results for the control catchment are more or less alike that of biological catchment with few exception for minimum and maximum output values as shown by symbol (*) in the Table 4.

Table 3. The results of validation of experimental plots for the May 4th, 2002 rainfall event

Parameters	Total runoff (m^3 ha^{-1})		Total sediments (t ha^{-1})		Peak runoff (L min^{-1})		Peak sediments (gr min^{-1})	
Plots	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	25.2	24.1	0.078	0.076	2.1	2.5	6.4	5
2	131.5	125	0.26	0.23	9	8.4	9	8

Rainfall data

Out of the rainfall events annually recorded over 20 years; sixteen events with varying characteristics were selected for evaluation purposes. The 16 events were classified into four duration categories: 20, 30, 40, and 60 minute periods having rainfall depth 5-14.7 mm, temperature 10-18 C^o and running time, 18-58 min. The pairs of time accumulated rainfall depth for all events were determined. The March 27th and May 4th 2002 rainfalls events were used for calibration and validation purposes. The durations and amounts of these events are 45 and 60 minutes and 6.9 and 10.1 mm respectively.

Uncertainty analysis

Model calibration and validation reveal uncertainties surrounding model outputs. In other words, the simulation results cannot be recorded as absolute values. The reason for this uncertainty is the effectiveness of spatial and temporal variety and the measurement errors of input parameters. Therefore, it will be better if model outputs data are shown in ranges including minimum, maximum and mean values in the form of simple relative distribution of probability values (Quinton 1997; Folly et al. 1999).

Frequency histograms of main output parameters for biological countermeasure is shown in the Figure 2 at the level of 95 percent probability distribution. According to this figure, 65% of total runoff , 72% of peak runoff, 60% total sediment and 60% of peak sediment rate are in the range 0-1 mm, 2-10 mm hr^{-1}, 100-700 kg ha^{-1} and 30-50 kg min^{-1}, respectively.

Table 4. Comparison of observed output results for a variety of THI, RFR and COVER input parameters and rainfall intensities of 10.0 to 20.2 mm h^{-1} with the simulated results of 16 events for biological countermeasure

A- Biological catchment:				
Predicted	Q_r (mm)	Q_p (mm h^{-1})	Q_s (kg ha^{-1})	Q_{sp} (kg min^{-1})
For 16 events	0.12-3.40	0.7-13.10	166-1775	14.9-66.70
		Input parameter, THI = 0.38-.57 (0.486)		
For THI	0.14-3.40	1.1-13.10	171-1612	16.6-64.3
	Input parameter, RFR = 0.01-6.7 (1.98)			
For RFR	0.15-3.30	1.30-12.90	52.90-1705	14.8-119.0
	Input parameter, COVER = 0-0.71 (0.22)			
For Cover	0.16-3.0	1.60-9.50	190-1759	18.0-66.0
B- Control catchment:				
Predicted	Q_r (mm)	Q_p (mm h^{-1})	Q_s (kg ha^{-1})	Q_{sp} (kg min^{-1})
For 16 events	0.62-5.70	2.4-15.50	166-4001	31.9-227
		Input parameter, THI = 0.20-0.49 (0.345)		
For THI	0.8-4.6	2.5-13.8	163-4168*	34-234
		Input parameter, RFR = 0.001-1.87(0.94)		
For RFR	0.76-2.80	*1.6-12.8	185-1954	*26.1-68.1
		Input parameter, COVER = 0-0.08 (0.04)		
For Cover	*0.16-1.40	2.5-9.8	169-1790	50.0-267*

Notes: Q_r = total runoff, Q_p = peak flow rate, Q_s = total sediments, Q_{sp} = peak sediment rates, ( ) = value in the bracket refer to mean, * = values out of the ranges predicted by 16 events

In general, as indicated by the results from this study, the biological measures caused runoff to be reduced by 40% to 80% and the soil loss by 50% to 65% compared to those of the control. This significant difference is not limited to runoff and sediment, but it also includes other parameters such as time to start runoff, peak flow rate and time to reach the peak flow. A comparison of peak flow rates of both biological and corresponding catchment revealed that the biological measure reduced peak flow rate for some of the events by 2.6 mm/h and successfully created a sustainable ecosystem. There is also a reduction in time to peak flow rate by 3 to 9 minutes and runoff from biological catchment stopped 12 to 32 minutes earlier as compared to that of control. This conclusion was confirmed by studies performed by Folly, et al. (1999) on Catsoop watershed, The Netherlands, or by Quinton and Morgan (1998) in Oklahama, and by Khalil Moghadam (2001) on Bazoft watershed in Iran.

Discussion

EUROSEM has high capabilities in evaluating the soil and water conservation techniques (Rickson 1994). Some of the model static outputs for 16 events in the biological measures were compared with their corresponding control outputs in Table 5. As indicated in this table, biological technique has reduced runoff by 40 to 81.2% and decreased erosion by 45 to 68.6% with respect to control plots in all the events. This wide discrepancy is not limited to surface runoff and the soil erosion, but also involves the other hydrograph and sedigraph parameters. For instance, the time to start runoff from biological catchment delays by 9 to 19 minutes and time to peak flow by 2 to 8 minutes, all with respect to control catchment. Values of peak flow rates and peak sediments transportation rates in biological catchment also reduced by 1.7 to 2.4 mm h^{-1} and 17 to 160.3 kg min^{-1} respectively. This is due to the existence of short and condensed plants on the biological study area which were effective in reducing runoff and erosion.

Table 6 also shows the results of the T-test for the comparison of biological techniques with control. The values indicate a successful assessment of the biological method. This is because of the significant differences between all parameters of runoff hydrographs and sediment sedigraphs in the biological method and the corresponding control at a level of 99% probability.

For example, a comparison of hydrograph and sedigraph of the biological catchments and those of corresponding control catchment for the event No. 5 are also shown in the Figure 3. The area below the main hydrograph that is a representative of total runoff is smaller than that of control curve by 0.7 mm. In other words, there is 80% reduction in runoff discharged from the biological catchment as compared to that of control. The highly condensed vegetation cover in the biological catchment has reduced runoff and erosion in several ways. Plant canopies and stems catch rain drops (otherwise they may fall directly on the soil surface and destroy the soil structure) and reduce runoff from the soil surface. Plant roots fix the soil structure and increase the soil hydraulic conductivity.

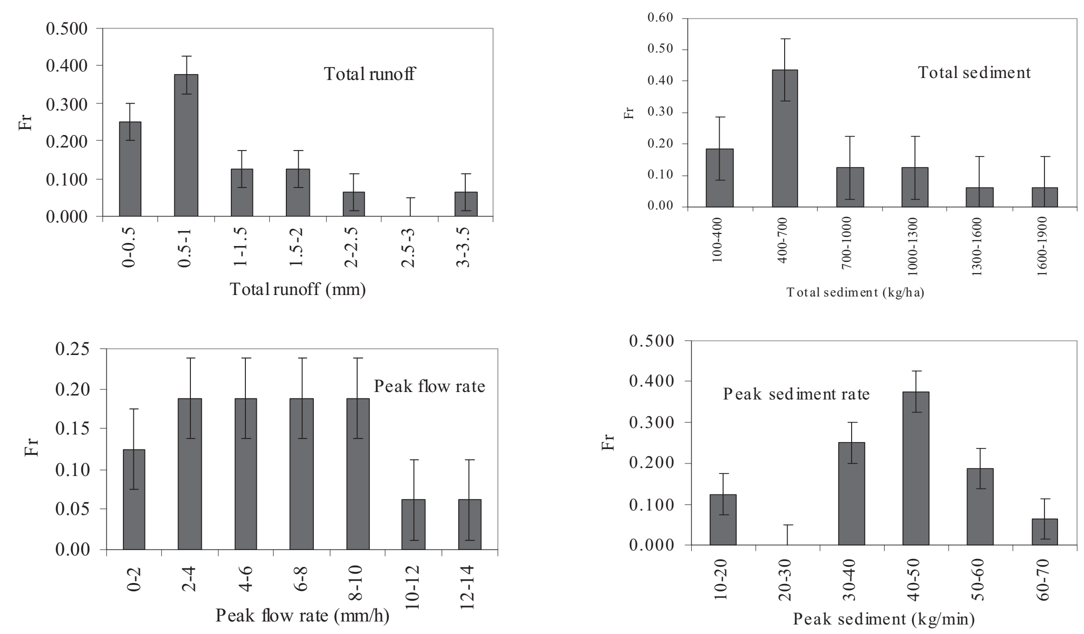


Figure 2. Frequency histograms of main predicted hydrograph and sedigraph parameters for 16 recorded rainfall events in the region for biological countermeasure

Table 5. Comparison of some of predicted output parameters of biological technique with control for selected rainfall events

Events	Catchment	R (mm h^{-1})	D (min)	Q_r (mm)	RR (%)	T_b (min)	Q_p(mm h^{-1})	T_p (min)	Q_s(kg ha^{-1})	SR (%)	Q_{sp} (kg min^{-1})
1	C	15	20	0.62		4	2.4	15	342		31.9
	B			0.12	80.6	11	0.7	18	166	51.5	14.9
2	C	17.1	20	0.90		3	4.2	15	975		100.0
	B			0.40	55.6	11	2.8	18	304	68.8	30.4
3	C	18.6	20	1.2		2	5.1	15	1047		103.7
	B			0.60	50.0	11	4.3	17	408	61.0	39.1
4	C	20.2	20	1.50		2	7.4	16	1180		157.0
	B			0.90	40.0	11	7.2	18	520	55.9	51.3
5	C	12.4	30	0.85		7	3.1	23	453		48.5
	B			0.16	81.2	26	1.1	28	249	45.0	19.8
6	C	13	30	1.20		3	4.9	23	1124		109.7
	B			0.45	62.5	16	2.3	27	401	64.3	34.4
7	C	15	30	1.6		2	6.2	21	1359		128
	B			0.70	56.3	16	5.1	26	525	61.4	41.1
8	C	16.1	30	1.90		3	7.4	20	1552		139
	B			0.99	47.9	14	6.6	25	648	58.2	47.7
9	C	11.8	40	1.50		6	5	29	1128		95.2
	B			0.50	66.7	22	2.9	33	495	56.1	33.0
10	C	13	40	2.10		5	6.6	28	1654		131.7
	B			0.98	53.3	21	5.8	32	678	59.0	42.0
11	C	14.1	40	2.70		4	8.3	27	2083		171
	B			1.40	48.1	21	8.0	32	901	56.7	49.8
12	C	157	40	3.30		3	10.4	26	2419		212
	B			1.80	45.5	19	9.7	32	1061	56.1	58.0
13	C	11.2	60	2.90		4	7.1	39	1963		125.5
	B			1.30	55.2	18	6.3	47	944	56.9	41.8
14	C	12.3	60	3.80		5	9.2	38	3025		191
	B			1.90	50.0	17	9.0	46	1226	59.5	49.1
15	C	13.7	60	4.90		3	12.5	37	3760		216
	B			2.80	42.9	16	11.5	46	1554	58.7	58.4
16	C	14.8	60	5.70		5	15.5	37	4001		227
	B			3.40	40.4	16	13.1	46	1775	55.6	66.7

C = control catchment, B = biological catchment, R = Rainfall intensity, D = Duration, Q_r= Total runoff, RR = Runoff Reduction, T_s =Time to runoff, P_f = Peak flow rate, T_p = Time to peak flow, Q_s = Sediment rate, SR = Sediment Reduction, Q_{sp} = Peak sediment rate

Consequently, these effects cause runoff and erosion to be reduced. Humus produced from the decomposition of leaves, roots and stems of plants causes the soil infiltration and water holding capacity of soil to increase, ultimately, reducing runoff volume. Vegetation cover also increases the shape factor and Manning's coefficient. Overall, these set of factors establish the ecosystem in the study area and prevent the occurrence of critical floods in the biological catchment.

Table 6. T-test for the comparison of biological measure with corresponding control

Parameters / Catchments	Total runoff	Total sediments	Peak runoff rate	Peak sediments rate	Time to start runoff	Time to stop runoff
B vs C[1]	7.9**	6.6**	4.8**	8.6**	3.3**	6.1**

Notes: B vs C[1] = biological approach vs control, ** significant at the level of 99%

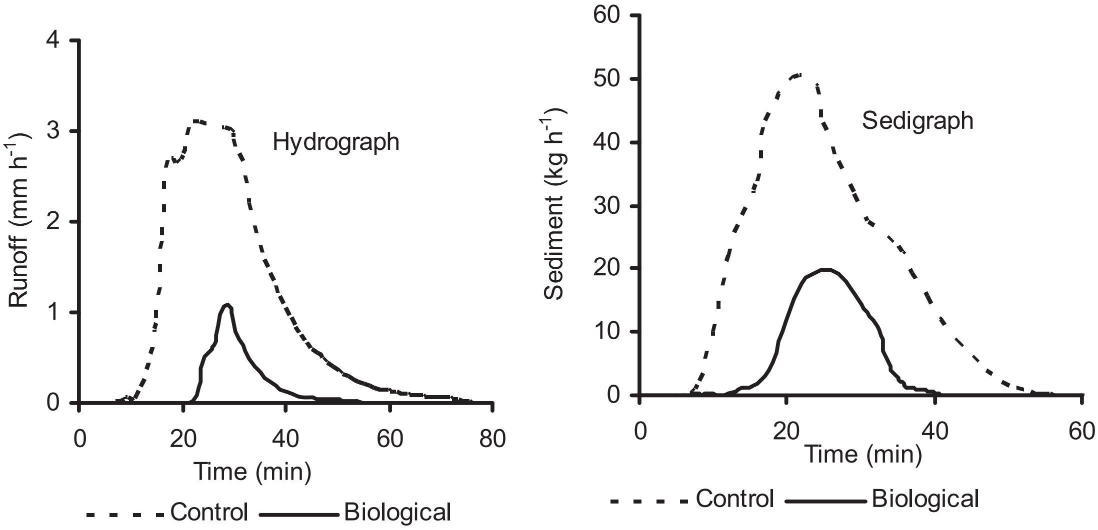


Figure 3. A comparison of runoff hydrograph and sedigraph of biological measure with the corresponding control for event No. 5

Conclusions

The conclusions drawn from this study are:

1- EUROSEM is capable of simulating the effect of the biological conservation measure in controlling runoff and erosion from real field conditions. Modeling of the soil and water conservation measure will be achieved by keeping rainfall input file constant but changing some of the relevant parameters in the catchment input file.

2- To simulate the biological method, EUROSEM was run by changing some of the input parameters such as percentage of vegetation cover, basal areas of plants, effective vegetation height and Manning's coefficient. The significant differences between runoff volume generated from biological and corresponding control catchments showed that the biological measures created a sustainable ecosystem in the study area. This was achieved by 40% to 81% reduction in runoff and 45% to 69% reduction in sediments transportation on biological catchments.

3- Further evaluation of the model outputs were carried out using three input parameters that were not already used in the calibration process. These are the values of initial soil water content, the soil surface roughness along the slope and the percentage of plant cover for biological countermeasure. Model evaluation showed that the predicted surface runoff outputs are in the domain of the values simulated for 16 recorded events in the region. However, some of the evaluation results did not match well with predicted sediment parameters outputs.

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