

Article

Estimating Human Impacts on Soil Erosion Considering Different Hillslope Inclinations and Land Uses in the Coastal Region of Syria

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Abstract: Soils in the coastal region of Syria (CRoS) are one of the most fragile components of natural ecosystems. However, they are adversely affected by water erosion processes after extreme land cover modifications such as wildfires or intensive agricultural activities. The main goal of this research was to clarify the dynamic interaction between erosion processes and different ecosystem components (inclination, land cover/land use, and rainy storms) along with the vulnerable territory of the CRoS. Experiments were carried out in five different locations using a total of 15 erosion plots. Soil loss and runoff were quantified in each experimental plot, considering different inclinations and land uses (agricultural land (AG), burnt forest (BF), forest/control plot (F)). Observed runoff and soil loss varied greatly according to both inclination and land cover after 750 mm of rainfall (26 events). In the cultivated areas, the average soil water erosion ranged between 0.14 ± 0.07 and 0.74 ± 0.33 kg/m²; in the BF plots, mean soil erosion ranged between 0.03 ± 0.01 and 0.24 ± 0.10 kg/m². The lowest

amount of erosion was recorded in the F plots where the erosion ranged between 0.1 ± 0.001 and 0.07 ± 0.03 kg/m². Interestingly, the General Linear Model revealed that all factors (i.e., inclination, rainfall and land use) had a significant ($p < 0.001$) effect on the soil loss. We concluded that human activities greatly influenced soil erosion rates, being higher in the AG lands, followed by BF and F. Therefore, the current study could be very useful to policymakers and planners for proposing immediate conservation or restoration plans in a less studied area which has been shown to be vulnerable to soil erosion processes.

Keywords: soil management; land cover changes; Syria; soil erosion; hillslopes

1. Introduction

Soils are vital components of environmental systems and supply livelihoods, services and goods for humans and natural ecosystems [1,2]. Soils are formed by numerous factors such as parent material, topography, climate, water, organisms, and time; however, it is well-known that this process is slow and endangered by land degradation due to certain human activities [3–5]. Intensification of anthropogenic effects has become a key factor that causes negative structural shifts in the soil matrix and health; thus, there has been an acceleration of the erosional cycle from prehistoric times [6] to today [7]. Current soil erosion rates, caused by water or wind, are high and can be considered one of the most serious ecological threats to land sustainability globally [8], given that more than 75 billion tons per year of soil are lost due to soil erosion [9]. The problem associated with soil erosion by water is the result of spatial integration of physical and human factors, which vary significantly across scales (from pedon to watershed), and make any estimation difficult [10–12]. Soil erosion irretrievably reduces the quality of the physico-chemical and biological properties, soil fertility and land productivity, which considerably affect cultivated areas [13,14]. Therefore, nature-based solutions to achieve land degradation neutrality can be a key to conserving ecosystem services [15,16]. However, for any ecological restoration, stakeholders and land managers must be fully motivated and convinced, and this is still a current challenge [17,18].

Soil erosion is progressively limiting the availability of resources, threatening biodiversity, and affecting food production, and is accelerated by specific drivers such as climate change, land use/land cover changes, overgrazing, inappropriate farming procedures, or armed conflicts [19–23]. Consequently, soil erosion is defined as a physical and anthropological challenge [24]. During the 1980s, statistics indicated that about two billion hectares of agricultural land had completely deteriorated since 1000 AD, and currently, the FAO estimates ~75 billion tons of agricultural soil loss, causing an annual cost of USD 400 billion [25]. Consequently, an increasing interest in soil stability and conservation is progressively evolving to deal with this worldwide environmental problem in the context of the landscape changes which have occurred in the current century [9,26,27].

Soil erosion is the outcome of the dynamic interaction between different ecosystem components, e.g., land use, inclination, rainfall intensity, and soil properties [28]. The mechanism of soil erosion by water includes splashing and detachment of soil particles due to the kinetic energy of raindrops, then the transportation of these particles by surface runoff [29]. However, due to its tremendous impact, recent research has been directed more towards erosion control techniques in many parts of the world, for example in Austria [30], Spain [31], China [32], Hungary [33], Germany [34], and France [35], among others.

The components of the Mediterranean environment are considered one of the most fragile around the world, especially as regards soils, which are exposed to severe degradation processes [36,37]. In several cases, rainfall and runoff have induced soil erosion, which is a well-known degradation challenge in terms of ecological mismanagement [8,38]. Rugged and dissected terrains, steep slopes, high rainfall intensities, shallow and skeletal soil thicknesses, receding and sparse vegetation, and

chronic and severe drought stress in summer are among the most important physical factors which drive soil erosion [39,40]. Several authors have reported that the annual rates of soil erosion have reached dangerous levels, exceeding the allowable soil loss tolerance limits (2 to 12 Mg ha⁻¹ year⁻¹) for agricultural and economic sustainability in the Mediterranean environment [41–45]; nevertheless, these numbers can vary depending on the main goal of the research and the specific area [46]. For example, Kouli et al. [47] determined that more than 1 Mg ha⁻¹ year⁻¹ may be irreversible within a time dimension ranging from 50 to 100 years.

Syria is among the eastern Mediterranean countries which are seriously exposed to the problem of water-related soil erosion, especially in the coastal region of the country (CRoS). This area represents an appropriate terrestrial, structural, climatic, hydrological, and intense anthropological case of the acceleration of soil erosion by water [23,48]. In the CRoS, soil erosion by water is the first threat to agricultural activity, which is the pivot of economic life for 34.8% of the population [49]. Meanwhile, CRoS is considered the first agricultural stability zone in Syria, receiving more than 600 mm of rainfall and being used for rainfed agriculture, with a total agricultural land area of 2.7 million ha [50]. Accordingly, the issue of soil erosion in CRoS has been assessed by many local scholars at the administrative area or catchment area level, using different models such as the Revised Universal Soil Loss Equation (RUSLE) [51,52], the Water Erosion Prediction Project (WEPP) model [48,53], and the Coordination of Information on the Environment (CORINE) model [54]. On the other hand, a limited number of studies have dealt with soil erosion after wildfires. Al-Ali and Kheder [55] stressed the importance of monitoring soil erosion after wildfires, where the soil erosion from burnt forests reached 7.22 Mg ha⁻¹ year⁻¹.

In the CRoS, as well as in the Mediterranean region in general, different anthropogenic activities (i.e., rapid changes in land use driven by intense population pressure or agricultural expansion) and climate change have rapidly exacerbated soil water erosion. However, information about soil erosion on the field-scale in the near-eastern Mediterranean remains limited compared to that in the western and northern Mediterranean. Some representative examples can be found in the territories of border countries, highlighting the importance of assessing land degradation processes from different points of view, e.g., [55–58]. Within this perspective, the main aim of this research was to bridge the gap in the common literature on soil water erosion in the coastal territories of Syria by measuring soil water erosion and runoff under three different land uses (agricultural land (AG), burnt forest (BF), forest/control plot (F)). Our hypotheses were the following: (i) agricultural areas are the main areas at risk of soil loss; (ii) burnt forests are endangered by the increased runoff and severe soil loss; (iii) the effect of inclination on erosion rates has a saturation curve, i.e., above a threshold inclination, the rate of erosion does not increase relevantly; and (iv) slopes and land cover have a significant interactive effect, thus, these two factors determine erosion hazard together.

2. Materials and Methods

2.1. Study Area

The study area is located in the western part of Syria (35°49′ to 36°31′ E; 34°49′ to 36°05′ N) within an area of 5274 km² (Figure 1). The elevation of the region ranges from 0 to 1700 m a.s.l. The Syrian coast area consists of three basic geomorphological units: the plain (0–100 m), the plateau (100–400) and the mountains (400–1700) [59]. The study area is characterized by narrow plains near the coast, followed by dissected mountains. The degree of inclination generally ranges from 0° to more than 60°. The coastal strip was affected by recent tectonics, which caused a fluctuation in the sea level from the Early Pleistocene to the recent “upper” Holocene. This is reflected in the diversity of rock formations such as sandstones, sands and conglomerates, which were laid down as sedimentary deposits with limestone and marls. Interestingly, these rocks were penetrated by basaltic rocks in the southern part of the coastline [60].

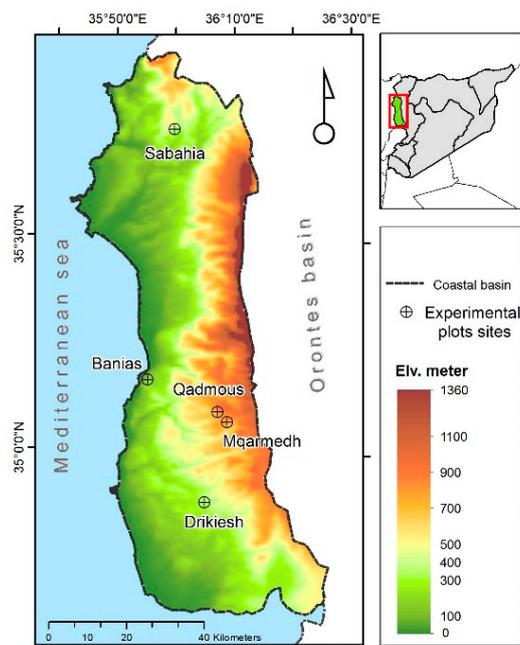


Figure 1. The coastal region of Syria and locations of the experimental plots.

According to the Köppen climate classification, the study area falls into two categories (Csa and Csb) with the main group being C, which follows the Mediterranean climate. The rainy winter season is mostly concentrated between November and March [61]. In general, the average rainfall ranges from 765 mm (near the coast) to 1250 mm (in the high mountains) [61]. The mean annual temperature in the plain areas is about 19.3 °C and in the mountains, it is about 14.8 °C [61]. The common soil orders are Inceptisols, Entisols, and Mollisols [62]. The study area includes the governorates of Tartous and Lattakia, with a population of approximately three million [61]. Syria is divided into five agricultural stability zones, according to distributed rainfall and the suitability for rainfed agriculture. The study area is located in the first agricultural stability zone, where rainfall exceeds 600 mm [63].

Traditional agriculture is the most essential economic axis for rural inhabitants, and most fields are cultivated with wheat, and olive and citrus orchards. Between 2010 and 2018, more than 800 wildfires were recorded in the coastal region of Syria. Wildfires usually occur between June and late August (summer season), and are typically induced by human activities. In this research, the experimental burnt sites were selected based on fire time and intensity.

2.2. Experimental Design

Based on a field survey conducted in the study area, five different locations (SY1, SY2, SY3, SY4, SY5) with different hillslope inclinations (38%, 45%, 15%, 29%, 10%) were chosen as representative sites for measuring soil erosion (Table 1). Three different land uses were selected at each location: (i) agricultural land (AG), where traditional cultivation, sowing, and harvesting occurs, with the absence of any mechanization; the common crops in AG lands are wheat (SY1, SY2), olives (SY3, SY4), and citrus orchards (SY5); (ii) burnt forest (BF), where soil cover varies from 30% to 55% with local natural vegetation; and (iii) forest land (F), which is characterized by mixed forest, and is used as a control plot without recently extensive human disturbance. The soil cover for all treatments was sampled without any disturbance.

Table 1. Experimental characteristics of the five locations studied.

Location	Code	X	Y	Slope (%)	Rainfall (mm)
Drikiesh	SY1	36°07'	34°53'	38%	965
Qadmous	SY2	36°09'	35°05'	45%	936
Banias	SY3	35°56'	35°10'	15%	914
Mqarmedh	SY4	36°10'	35°04'	29%	890
Sabahia	SY5	36°00'	35°45'	10%	765

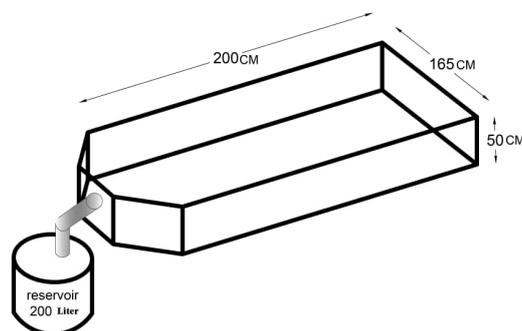
Experimental plots of 2×1.6 m were installed with metal barriers of 0.5 m height (0.15 m into the soil) to collect runoff and soil loss. This method was previously adopted in Syria by [64], and applied by [61,65] and [61,66]. Nonetheless, the plots designed were similar to [61,67], but of a smaller size.

The amount of rainfall (mm) was measured on-site by placing a metal rainfall gauge at each location. Meanwhile, runoff (L/m^2) was recorded at each plot after each rainy event by recording the volume in each sediment collector. Soil loss (kg/m^2) was also determined by mixing the collected soil detachment and a representative sample of 5 L each. Finally, the samples were transported to the laboratory. In the laboratory, each sample was placed in a small container and dried in an oven ($105^\circ C$) for 24 h.

In addition, soil samples were collected at the beginning of the monitoring period from the topsoil (0–0.15 m) in each plot, and soil texture and soil erodibility factors were determined (Table 2). The design and performance of the chosen experimental plot with the sampling strategy were tested following [39] (Figure 2). Data were collected from October 2012 to December 2013 (i.e., the vegetation period). A total of 26 rainy storms were observed during the monitoring period.

Table 2. Soil texture and K value in the studied locations (SY1-SY5) for three land uses (agricultural land (AG), burnt forest (BF), and forest land (F)).

Code	Agricultural Land (AG)				Burnt Forest (BF)				Forest Land (F)			
	Sand	Silt	Clay	K	Sand	Silt	Clay	K	Sand	Silt	Clay	K
SY1	31.5	27.0	41.5	0.154	30.5	32.5	37.0	0.128	32.5	35.5	32.0	0.074
SY2	23.0	35.0	42.0	0.236	23.0	35.0	42.0	0.215	24.0	36.0	40.0	0.161
SY3	27.0	31.0	42.0	0.172	25.0	33.0	42.0	0.155	29.0	33.0	38.0	0.124
SY4	22.0	30.5	47.5	0.186	21.0	32.0	47.0	0.173	23.0	31.0	46.0	0.119
SY5	20.5	39.5	40.0	0.257	27.5	42.0	30.5	0.224	17.5	51.0	31.5	0.151

**Figure 2.** Sketch design for the experimental plot.

2.3. Data Analysis

Average, maximum, minimum, and median values were determined. Soil erosion and runoff data were depicted in boxplots, together with the linear regression among them in each land cover class. Normal distribution was checked by the Shapiro–Wilk test (S-W); as this failed, the non-parametric Kruskal–Wallis test (K-W) [68] was applied as an alternative to the one-way ANOVA. The K–W test

aimed to detect the difference between the medians of the treatments with the following hypothesis: H_0 was that the medians of the studied groups were from the same distribution, while H_1 represented the idea that the medians of the studied groups were different. As the K–W test did not show which plot is statistically different from any other, the pairwise comparison among slopes was performed with the Mann–Whitney test with Bonferroni correction. Pairwise analyses in the same hillslope but for different land uses (i.e., AG-F; AG-BF, BF-F) were neglected as we focused on the differences caused by inclination and did not analyze the obvious differences among land use types. Finally, to assess the relationships between the studied variables, a correspondence analysis was carried out. We applied a General Linear Model (GLM) to reveal the importance of rainfall, inclination and land use types. The inclination type was included as ordinal data and land use as a categorical dummy variable. We determined the model parameters, and the effect sizes expressed as partial η^2p , which expressed the contribution of each variable and the interaction of the factors as a standardized measure [69]. The effect can be very small ($\eta^2p < 0.01$), small ($0.01 > \eta^2p > 0.06$), medium ($0.06 > \eta^2p > 0.14$), and large ($\eta^2p > 0.14$). Differences among inclination degrees were analyzed with the t-test and ANOVA using the 1999 Monte-Carlo permutation. Statistical analyses were conducted with SPSS (v24; IBM, Chicago, IL, USA), the EViews software package (v10; [70] New York, NY, USA), and R 3.6.3 [71] with the gamlj package [72].

3. Results

3.1. Soil Water Erosion and Runoff

Observed runoff and soil erosion varied according to both inclination and land use, as can be observed in Appendix A (Figure A1). The total rainfall in the study area exceeded 750 mm, divided into 26 events. The average soil loss ranged between 0.74 ± 0.33 and 0.14 ± 0.07 kg/m², while runoff ranged between 42.14 ± 15.27 and 12.77 ± 5.84 L/m² in the AG (Table 3). Meanwhile, in the BF plots, mean soil loss ranged between 0.24 ± 0.10 and 0.03 ± 0.01 kg/m², and runoff from 22.95 ± 9.33 to 3.77 ± 1.62 L/m². The lowest amounts of soil loss and runoff were recorded in the F lands, where the ranges were between 0.07 ± 0.03 and 0.1 ± 0.001 kg/m², and 11.98 ± 4.73 and 1.78 ± 0.78 L/m², respectively.

Table 3. Univariate statistics of observed soil loss and runoff in the studied locations (SY1–SY5) under three land uses (AG: agricultural land, BF: burnt forest, F: forest).

System	Code	Soil Loss (kg/m ²)							Runoff (L/m ²)						
		Min.	Max.	Range	Median	Mean	SD	φ	Min.	Max.	Range	Median	Mean	SD	φ
AG	SY1	0.07	1.34	1.27	0.71	0.74	0.33	0.07	15.20	72.50	57.30	39.75	42.14	15.27	3.05
	SY2	0.23	1.17	0.94	0.66	0.69	0.29	0.06	13.00	72.50	59.50	41.75	41.42	16.88	3.38
	SY3	0.09	0.47	0.38	0.22	0.24	0.11	0.02	6.50	33.00	26.50	17.10	18.66	8.19	1.64
	SY4	0.01	0.94	0.93	0.45	0.50	0.25	0.05	5.20	50.00	44.80	25.25	28.07	12.61	2.52
	SY5	0.04	0.29	0.25	0.11	0.14	0.07	0.01	3.90	22.50	18.60	10.75	12.77	5.48	1.10
BF	SY1	0.08	0.43	0.35	0.20	0.22	0.09	0.02	7.50	37.00	29.50	18.75	20.35	7.80	1.56
	SY2	0.08	0.45	0.37	0.22	0.24	0.10	0.02	7.90	41.50	33.60	22.50	22.95	9.33	1.87
	SY3	0.04	0.22	0.18	0.10	0.11	0.05	0.01	1.80	12.00	10.20	5.10	6.06	2.92	0.58
	SY4	0.06	0.37	0.31	0.17	0.20	0.09	0.02	4.10	22.00	17.90	11.50	12.58	5.36	1.07
	SY5	0.01	0.05	0.04	0.02	0.03	0.01	0.00	1.10	7.20	6.10	3.25	3.72	1.62	0.32
F	SY1	0.02	0.10	0.08	0.05	0.05	0.02	0.001	4.10	21.50	17.40	11.20	11.98	4.73	0.95
	SY2	0.02	0.13	0.11	0.06	0.07	0.03	0.01	3.10	20.00	16.90	10.95	11.03	4.85	0.97
	SY3	0.01	0.05	0.04	0.02	0.02	0.01	0.001	1.10	6.90	5.80	3.40	3.79	1.79	0.36
	SY4	0.01	0.07	0.06	0.04	0.04	0.02	0.001	2.00	12.50	10.50	6.13	6.54	3.21	0.64
	SY5	0.00	0.02	0.02	0.01	0.01	0.00	0.001	0.50	3.50	3.00	1.50	1.78	0.78	0.16

Min: Minimum; Max: Maximum; SD (n): Standard deviation (n); φ : Standard error of the mean.

The highest soil loss was 1.34 ± 0.33 kg/m², registered in the AG lands with 38% inclination, and the lowest was in the gentlest slope (10%), reaching 0.29 ± 0.07 kg/m² (Figure 3a; Table 3). Soil

loss was the highest in both BF and F with a hillslope inclination of 45%, reaching 0.45 ± 0.10 and $0.13 \pm 0.03 \text{ kg/m}^2$, respectively (Figure 3b,c; Table 3).

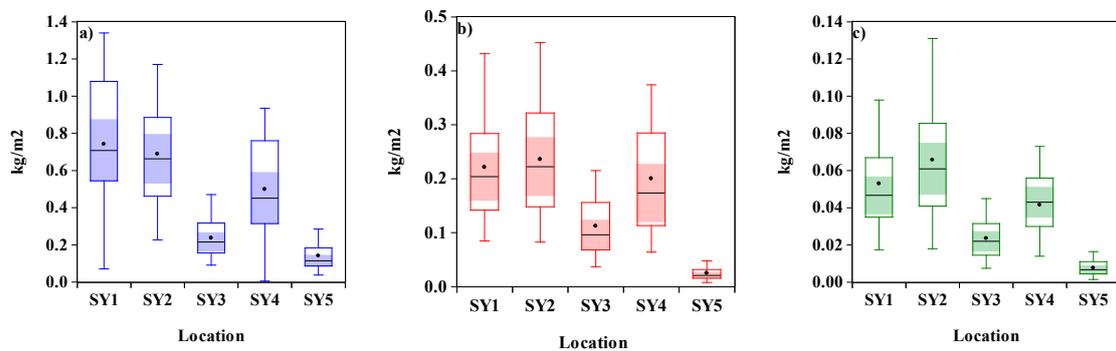


Figure 3. Box plots of soil erosion in each ecosystem (with respect to slope): (a) agricultural land; (b) burnt forest, and (c) forest (median (—); mean (●); median 95% confidence (shaded)).

Similarly, a maximum runoff was recorded in the AG lands with 72.5 L/m^2 in the steepest slopes (Figure 4a). In BF, the highest runoff was 41.51 L/m^2 with 45% inclination; meanwhile, the lowest was observed with the gentlest slopes, reaching 1.1 L/m^2 (Figure 4b). In F lands, the highest runoff was 21.50 L/m^2 (SY1) and the lowest was 3.50 L/m^2 (SY5) (Figure 4c).

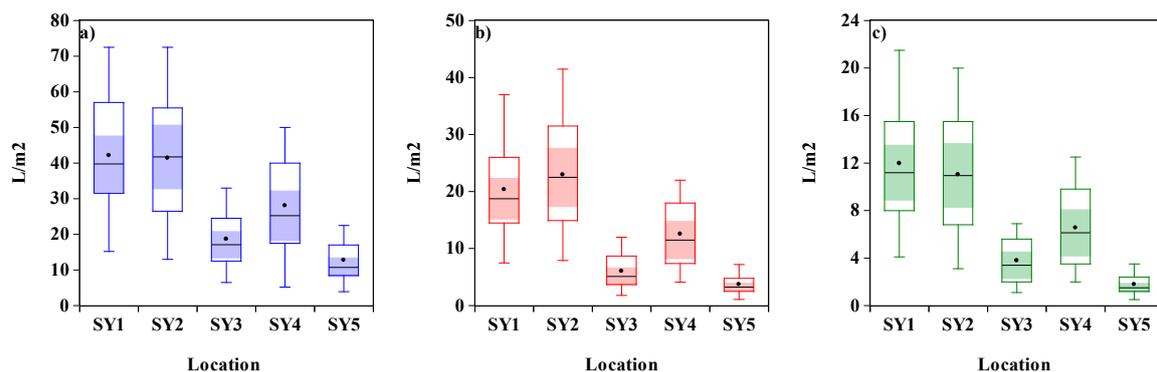


Figure 4. Box plots of runoff in each ecosystem (with respect to slope): (a) agricultural land; (b) burnt forest, and (c) forest (median (—); mean (●); median 95% confidence (shaded)).

In each studied land-use type, regression analysis detected a high correlation between the generation of runoff and the activation of soil loss: R^2 values were 0.91, 0.87, and 0.89 ($p < 0.05$) in AG, BF, and F, respectively (Figure 5).

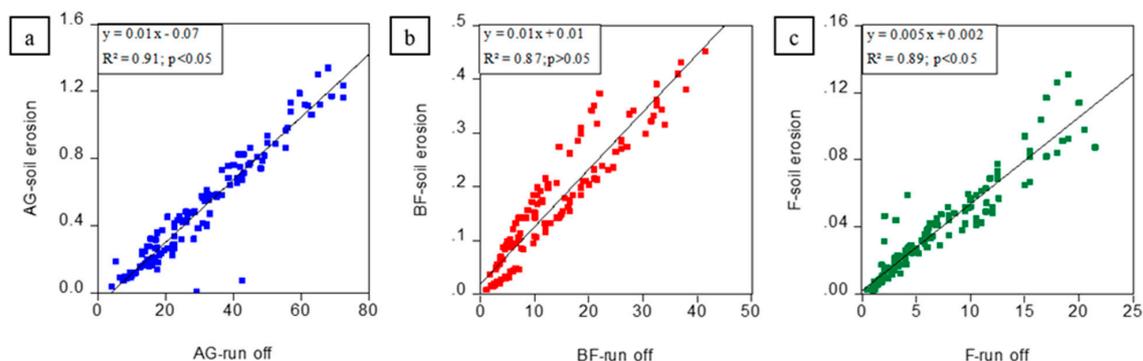


Figure 5. Correlation between soil loss (kg/m^2) and runoff (L/m^2) (regardless slope): (a) agricultural land, (b) burnt forest, and (c) forest.

3.2. Impact of Inclination on Soil Water Erosion

The Kruskal–Wallis test (K–W) showed that at least one of the studied plots was significantly ($p < 0.05$) different from other treatments in each slope inclination (SY1, SY2, SY3, SY4, SY5), and land use (AG, BF, F) (Table 4).

Table 4. Kruskal–Wallis analysis in each ecosystem for both soil water erosion and runoff ($p < 0.05$).

Kruskal–Wallis	Soil Loss		Runoff	
	H (chi ²)	p	H (chi ²)	p
SY1	63.41	0.00	48.99	0.00
SY2	62.47	0.00	45.69	0.00
SY3	59.44	0.00	43.81	0.00
SY4	55.52	0.00	40.89	0.00
SY5	65.83	0.00	59.14	0.00
Agricultural land	76.35	0.00	67.33	0.00
Burnt forest	78.57	0.00	92.08	0.00
Forest	83.09	0.00	86.17	0.00

The significance level is 0.05.

The pairwise comparison among the inclinations showed that there was a significant difference ($p < 0.05$) among them in the agricultural lands, both in the case of soil loss and runoff under different inclinations (Table 5). Differences were also significant ($p < 0.05$) between 15% (SY3) and 45% (SY2), and between 15% (SY3) and 38% (SY1). However, non-significant differences were noticed among the following plots: 10% vs 15%; 29% vs 45%; 29% vs 38%; and 45% vs 38% (Table 5). Just as with the AG, the F plots showed similar values with one exception: in the 29% vs the 38% plots, where the difference was significant regarding the runoff. In BF plots, significant differences were recorded in soil loss data among the following pairs: 10% vs 29%; 10% vs 38%; and 10% vs 45%; meanwhile, the pairwise analysis of runoff data showed identical results in the F plots.

Table 5. Pairwise comparisons between slopes for soil loss and runoff for three land uses (AG: agricultural land, BF: burnt forest, F: forest).

System	Inclination	Soil Loss					Runoff				
		Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig. ^a	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig. ^a
AG	10–15%	18.64	10.45	1.78	0.07	0.75	18.96	10.45	1.82	0.07	0.70
	10–29%	52.89	10.45	5.06	0.00	0.00	42.44	10.45	4.06	0.00	0.00
	10–45%	70.35	10.45	6.73	0.00	0.00	66.96	10.45	6.41	0.00	0.00
	10–38%	72.65	10.45	6.95	0.00	0.00	70.00	10.45	6.70	0.00	0.00
	15–29%	−34.25	10.45	−3.28	0.00	0.01	−23.48	10.45	−2.25	0.03	0.25
	15–45%	51.71	10.45	4.95	0.00	0.00	48.00	10.45	4.60	0.00	0.00
	15–38%	54.02	10.45	5.17	0.00	0.00	51.04	10.45	4.89	0.00	0.00
	29–45%	17.46	10.45	1.67	0.10	0.95	24.52	10.45	2.35	0.02	0.19
	29–38%	19.77	10.45	1.89	0.06	0.59	27.56	10.45	2.64	0.01	0.08
	45–38%	2.31	10.45	0.22	0.83	1.00	3.04	10.45	0.29	0.77	1.00
BF	10–15%	38.98	10.45	3.73	0.00	0.00	16.96	10.45	1.62	0.10	1.00
	10–29%	67.44	10.45	6.46	0.00	0.00	50.56	10.45	4.84	0.00	0.00
	10–38%	74.71	10.45	7.15	0.00	0.00	75.73	10.45	7.25	0.00	0.00
	10–45%	77.71	10.45	7.44	0.00	0.00	80.21	10.45	7.68	0.00	0.00
	15–29%	−28.46	10.45	−2.72	0.01	0.06	−33.60	10.45	−3.22	0.00	0.01
	15–38%	35.73	10.45	3.42	0.00	0.01	58.77	10.45	5.63	0.00	0.00
	15–45%	38.73	10.45	3.71	0.00	0.00	63.25	10.45	6.05	0.00	0.00
	29–38%	7.27	10.45	0.70	0.49	1.00	25.17	10.45	2.41	0.02	0.16
	29–45%	10.27	10.45	0.98	0.33	1.00	29.65	10.45	2.84	0.01	0.05
	38–45%	−3.00	10.45	−0.29	0.77	1.00	−4.48	10.45	−0.43	0.67	1.00
F	10–15%	32.85	10.45	3.14	0.00	0.02	26.48	10.45	2.54	0.01	0.11
	10–29%	61.79	10.45	5.91	0.00	0.00	50.35	10.45	4.82	0.00	0.00
	10–38%	73.65	10.45	7.05	0.00	0.00	76.64	10.45	7.34	0.00	0.00
	10–45%	82.29	10.45	7.88	0.00	0.00	82.02	10.45	7.85	0.00	0.00
	15–29%	−28.94	10.45	−2.77	0.01	0.06	−23.87	10.45	−2.29	0.02	0.22
	15–38%	40.81	10.45	3.91	0.00	0.00	50.15	10.45	4.80	0.00	0.00
	15–45%	49.44	10.45	4.73	0.00	0.00	55.54	10.45	5.32	0.00	0.00
	29–38%	11.87	10.45	1.14	0.26	1.00	26.29	10.45	2.52	0.01	0.12
	29–45%	20.50	10.45	1.96	0.05	0.50	31.67	10.45	3.03	0.00	0.02
	38–45%	−8.64	10.45	−0.83	0.41	1.00	5.39	10.45	0.52	0.61	1.00

Each row tests the null hypothesis that Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05. ^a Significance values have been adjusted by the Bonferroni correction for multiple tests. The bold numbers and bold color express the significance ($p < 0.05$).

The correspondence analysis revealed that erosion and runoff in the F plots can be discriminated and highly differentiated from both AG and BF, as it was located in a position further from the origin ($x = 0, y = 0$), whilst AG and BF were less distinct (Figure 6a). Similarly, erosion on 45% hillslope inclination, followed by 38%, was differentiated from other hillslope inclinations, while the 10%, followed by 45%, and 38% were differentiated from other slope inclinations in terms of runoff (Figure 6b).

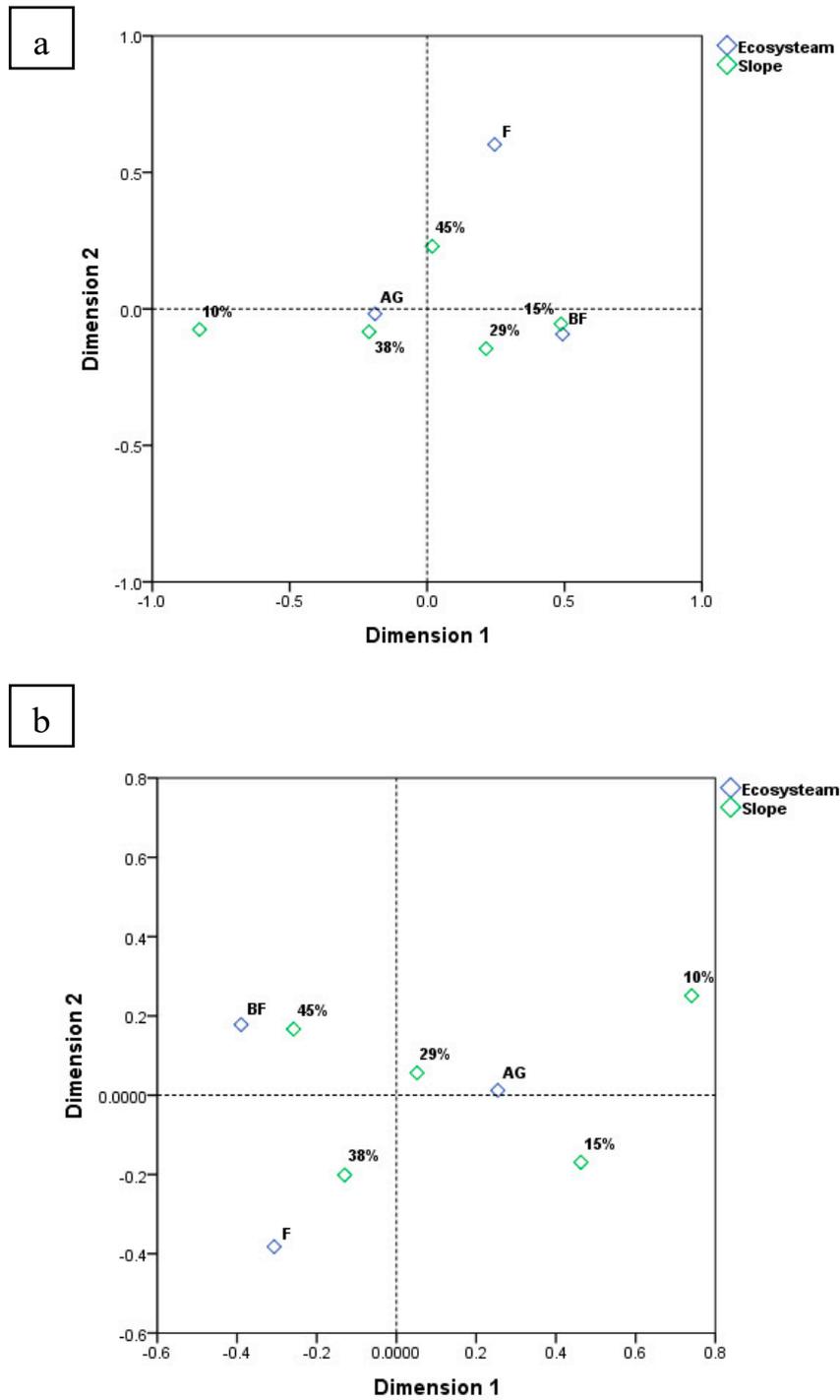


Figure 6. Correspondence analysis per plot: (a) soil loss and (b) runoff.

3.3. Multivariate Analysis of Factors and Covariates

The GLM revealed that all the factors involved (inclination and land use) and the covariate (rainfall) had a significant ($p < 0.001$) effect on the soil loss, and the explained variance was 85.1% (based on the adjusted $R^2 = 0.851$). Furthermore, the statistical interaction also obtained a significant ($p < 0.001$) effect (Table 6). Regarding the relevance of the predictors, land use registered the largest effect, while the effect of rainfall was 40% smaller, and the inclination effect was about half. The effect of the interaction of inclination and rainfall was similar to the rainfall effect.

Table 6. Summary of the General Linear Model (GLM) performed with soil erosion as the target variable (SS: sum of squares, df: the degree of freedom, F: F-statistic, p: significance, η^2p : effect size; $p < 0.001$ is highlighted in bold).

GLM	SS	df	F	p	η^2p
Model	24.33	15	142.8	<0.001	0.851
Inclination	2.30	4	50.7	<0.001	0.352
Land use	12.38	2	544.7	<0.001	0.744
Rainfall	3.69	1	324.5	<0.001	0.465
Inclination \times Land use	3.41	8	37.5	<0.001	0.445
Residuals	4.25	374			
Total	28.58	389			

Generally, the soil loss rate of the AG lands was the greatest in all hillslopes, while the control areas (F) had the lowest rate. The erosion can be regarded as linear in these areas; locally estimated scatterplot smoothing (LOESS) curves were almost linear in all possible combinations (Figure 7). Visual evaluation of the data showed that inclination degrees can be divided into two different groups based on the soil loss: (i) inclination of 10 and 15%, and (ii) 29, 38 and 45%. In the case of group (i), the erosion rate was below 0.5 kg/m^2 , although the difference between the AG lands was significant (mean difference: 0.096; $p_{M-C} < 0.0005$). Larger differences were caused by the heaviest rainfalls in the study area with 15% inclination. Erosion rates within group (ii) were similar regarding all the three land cover types, and the soil loss in the 45% inclination area was not significantly different ($p > 0.05$) from the 38% or 29% inclination degree areas according to the ANOVA test ($F = 2.059$, $df = 2$, $p = 0.129$).

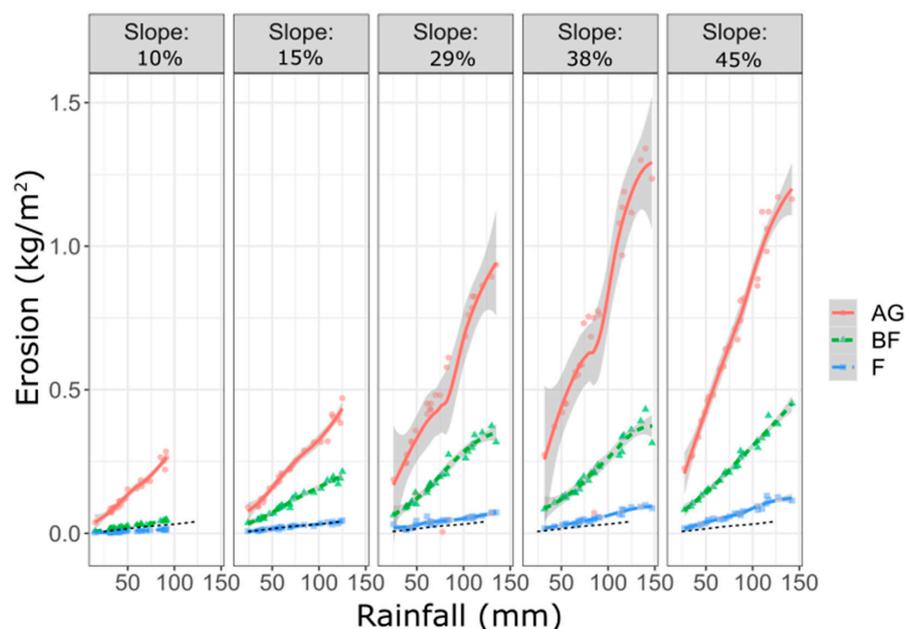


Figure 7. Relation between erosion rates and rainfall by slope and land cover type (agricultural land: AG; burnt forest: BF, and forest: F).

4. Discussion

Soil erosion by water is considered one of the most important agricultural sustainability challenges in the CRoS as a result of the following factors: heavy rainfall, severe inclinations, high erodibility, massive gushes of runoff, land-use changes, and non-sustainable agricultural practices [48]. Therefore, the assessment of water erosion derived from field analysis provides a detailed method of approaching the relationship between erosion, runoff and soil properties.

4.1. Criteria to Assess Current Erosion

4.1.1. The Role of Physical Features in Erosion

The climate of the study area is characterized by a high-intensity precipitation pattern with the intense kinetic energy of raindrops that hit the hillslopes with different land uses. Land use played an influential role in determining the quantities of eroded material and discharged runoff, which varied according to other physical features such as topography and soil properties [73]. Recently, forest lands in the CRoS were badly affected by severe wildfires, which increase the susceptibility to soil loss in the study area. In this regard, the importance of soil management was clear. In our research, soil loss and runoff were the highest in the AG and BF plots compared to the F plots. Within the study area, the cultivated land (AG plots) and burnt plots remained bare and exposed directly to raindrops, which could explain the high amount of soil erosion and runoff in comparison to the F plots, as other recent investigations in cultivated or abandoned fields have demonstrated [14,74], or in areas after recent wildfires [75].

4.1.2. The Role of Slope Steepness in Erosion

Of the five locations used for measuring soil loss and runoff, three of them were chosen with an inclination higher than 25%, i.e., SY1, SY2, SY4. Our statistical analysis revealed that from 29%, the critical limit was to be found above this value, similarly to a saturation curve, in that a greater slope gradient did not cause a relevant increase in the erosion rate (Figure 8). These results agree with other soil erosion and runoff reports presented by [76–79]. In the light of the high-intensity rainstorms in the study area, inclination was also a driving factor in the occurrence of high-velocity runoff events which enhance soil detachment. Additionally, this inclination could motivate both ponding depth and depression storage [80–82]. Under the same land use, inclination degree could accelerate the erosion remarkably, as can be revealed from Table 3 and Figure 7. Land use had a relevant effect on the soil erosion rate, with the highest values observed in the AG plots, and the lowest ones in the F plots. In Syria, only a few studies have reported on soil erosion at the plot scale. Barneveld et al. [83] claimed that soil erosion in the NW part of Syria rarely exceeded 5 kg/m² in cultivated olive lands with average slopes of 25%. However, this difference in measuring soil erosion could be explained by the physiographic difference between each research location, especially the steepness of the slope, the form and development of terrain, precipitation intensity, soil characteristics, and agricultural practices. Notably, our results are higher than the erosion observed in Mediterranean mountains by [84] (147.3 g m⁻²) and lower than results reported by [83] (5 kg/m²).

4.1.3. Role of Human Activities in Erosion

If the physical factors are compared to human activities, the latter is the main driver of erosion through poor and unsustainable soil management and tampering with soil structure, and altering its physical, chemical and biological properties, especially its organic matter content [85]. However, these consequences should be considered as serious in fragile and vulnerable soils as in the Mediterranean environment. Intensive tillage and bare soils play a key role in accelerating soil erosion [86,87] by enhancing the separation of macro-aggregates, which negatively affects the soil aggregates' stability [88–92]. Soils in forest plots are protected by more vegetation and we hypothesize that soil aggregates are stronger and are not affected by the negative impacts of the kinetic energy of raindrops.

Some authors have observed that the collapse of soil aggregates can minimize soil porosity by blocking pores by fine particles (silt, clay) and can magnify soil sealing and crusting, and, subsequently, soil erosion can be enhanced [93]. As a consequence, some authors have even reported that the soil erodibility factor (K) is higher in AG plots for this reason, which indirectly indicates the susceptibility of AG plots to soil erosion [94]. In this regard, organic matter (OM) is expected to be higher in the F plots, which significantly enhances aggregate stability against rainy storms, while aggregates in AG and BF plots would be more vulnerable [95–97]. Our results are consistent with [98], who indicated that inappropriate agricultural practices in shallow topsoil can increase the susceptibility of runoff and erosion. This is extensive in various agricultural activities in the Mediterranean belt [99,100]. The relevance of OM content in mitigating erosion has been proved by several authors, i.e., soils with <2% OM are highly susceptible to erosion and runoff [101,102]. In addition, [36,103–105] highlighted the vital role of agricultural activities and the Mediterranean climate in accelerating soil erosion in semi-arid regions, while other studies stressed the importance of ground soil cover for preventing erosion and runoff [99,106–109]. As extensive fieldwork in the CRoS has revealed, in the AG plots there is an absence of most of the agricultural practices that conserve soil, especially crop rotation, maintaining tillage, contour and strip farming, grass water channels, and diversion structures.

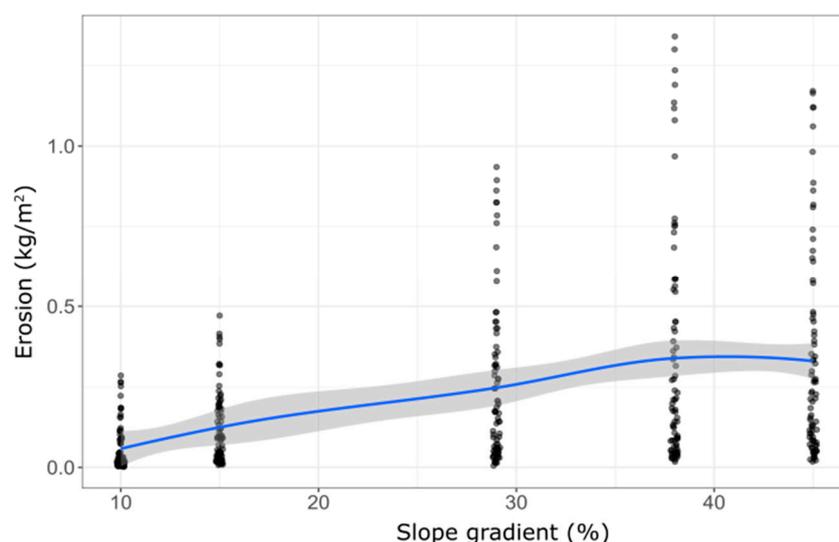


Figure 8. Slope gradient and erosion rate (—LOESS fit line with 95% confidence intervals).

4.2. Dimensions of the Current Evaluation

The CroS constitutes the first agricultural stability zone and the agricultural and economic backbone of the local population, and therefore the protection of its natural resources, especially soils from erosion, is a priority in the framework of agricultural sustainability. Thus, the implementation of some conservation practices (CP) or even the establishment of a national action plan for soil conservation to repair local ecosystems is a high priority. Some authors have recommended CP including soil mulching [110,111], tillage reduction [112,113], buffer strips and minimum cultivation [114] or a correct planification of soil terraces [115]. Nonetheless, field analysis of soil erosion is at the forefront of the measures that will develop strategies for preserving farmland, especially during the ongoing war that has negatively affected the agricultural and food system in the country. In the context of soil erosion, cultivated hillslopes in the CRoS are subject to intensive use pressure which includes poor maintenance technologies, and overuse of fertilizers. Consequently, soil aggregates are more dynamic once there are other agents of erosion, especially high-intensity raindrops. In this regard, the orographic precipitation model imposes high rainfall intensities, and consequently massive runoff which accelerates soil erosion. Unfortunately, in this research, the intensity and duration of rainfall could not be measured. However, further studies should address those elements instead of using the total rainfall amount per event. In

addition, further research should be carried out to address appropriate measures for land conservation, especially with hillslopes of over 29% inclination.

5. Conclusions

In this research, soil loss and runoff were measured in five different locations (hillslopes) with three different land uses (AG, BF, F) in the coastal region of Syria. The main findings of this research are:

1. Observed soil loss and runoff were higher in the AG lands, followed by BF and F.
2. In the CRoS, land use has the greatest effect on soil erosion, followed by rainfall amount and hillslope inclination.
3. Concerning the inclination degree, SY1 (38%) and SY2 (45%) showed the greatest soil erosion and runoff amounts per event, followed by SY4 (29%), SY3 (15%), and SY5 (10%).
4. Regardless of the land use type, our results show an absence of statistical differences ($p < 0.05$) between 10 and 15% inclination, and between 38 and 45%.
5. Soil loss was $0.14 \pm 0.07 \text{ kg/m}^2$ in the AG plots, while it did not exceed $0.1 \pm 0.001 \text{ kg/m}^2$ in the F plots. Meanwhile, the highest runoff was recorded in the AG plots, which ranged between 3.77 ± 1.62 and $22.95 \pm 9.33 \text{ L/m}^2$
6. In the CRoS, the pairwise comparison among the hillslopes revealed that 29% inclination can be the maximum tolerable threshold to apply urgent soil erosion control measures.

Few studies have dealt with soil erosion in Syria, and to our knowledge none of these have measured erosion per rainfall event at different hillslope positions comparing human disturbances under three different land uses. The outcome of this research could play an important role in setting up the first conservation plan in Syria. Moreover, the output of this research will contribute to bridging the gap in the common literature on soil water erosion in the near-eastern Mediterranean, and could be used for the improvement of erosion equations or soil protection policies not only in Syria, but all over the Mediterranean belt.

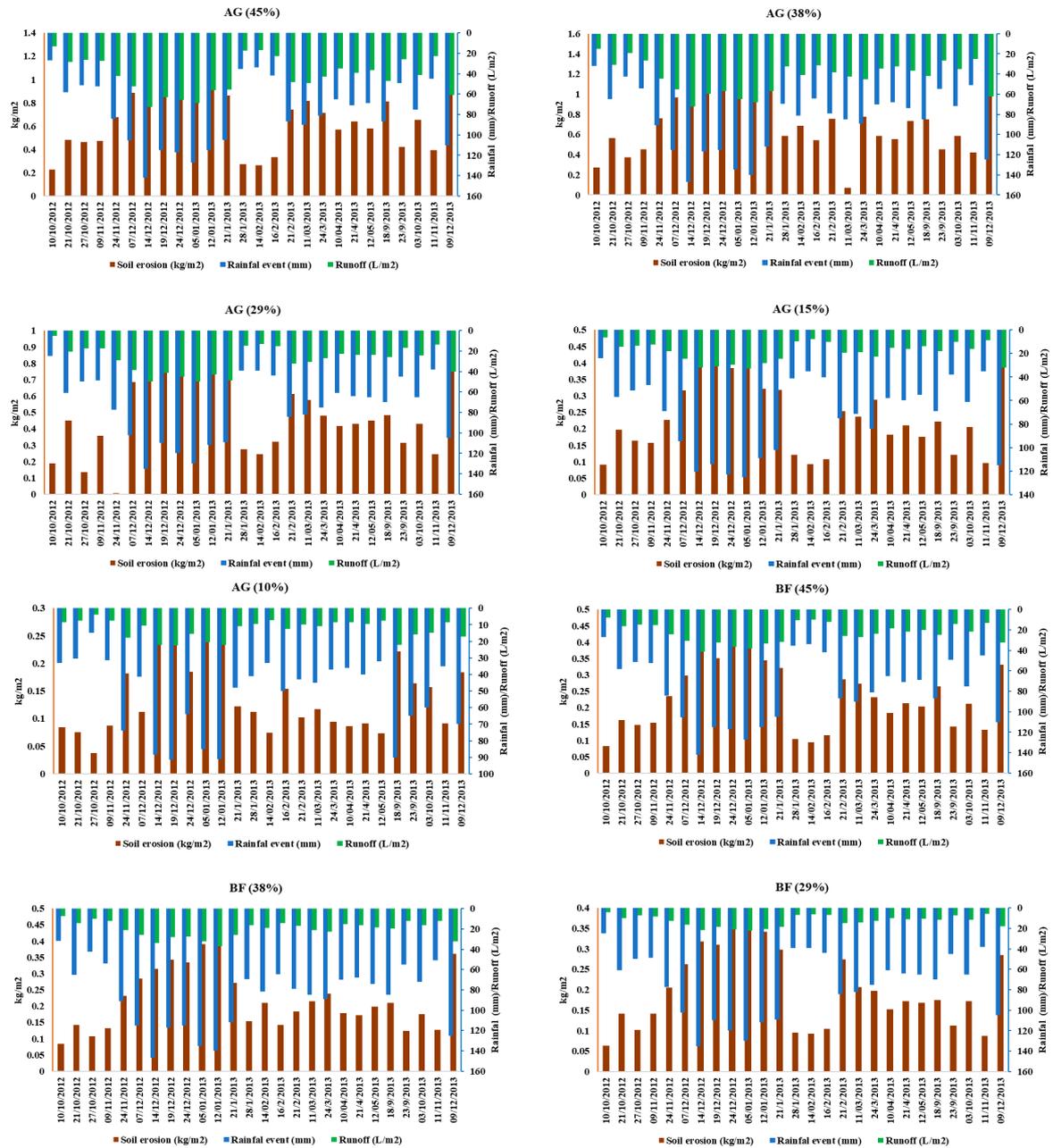
Author Contributions: Conceptualization, S.M., I.K. and J.I.; Data curation and collection, I.K. and J.I.; Resources, I.J.H.; Supervision, S.S. and J.R.-C.; Visualization, K.A., Q.B.P., N.T.T.L., D.T.A., A.M. and I.J.H.; Writing—original draft, S.M., and H.G.A.; Writing—review and editing, All authors. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A



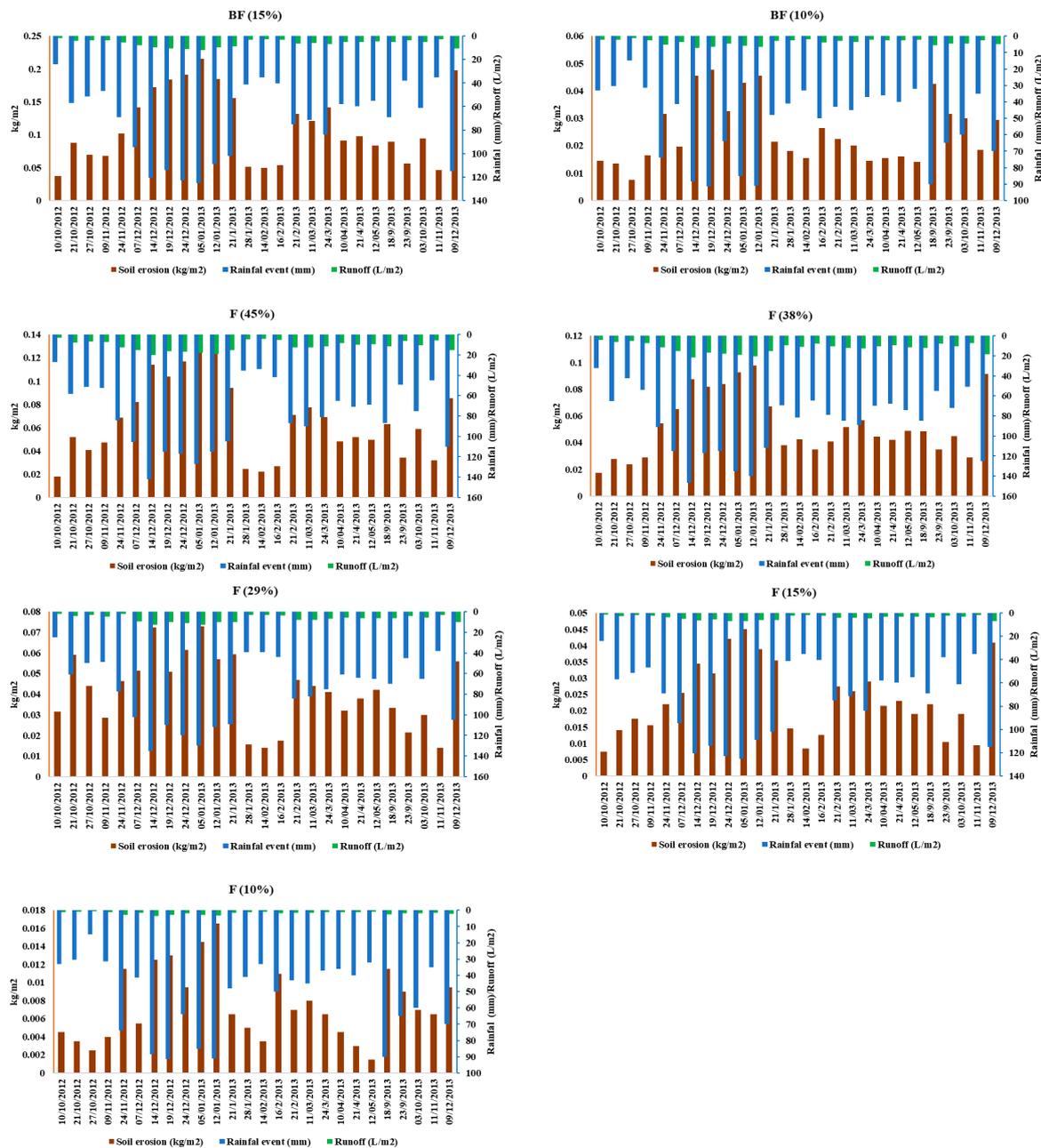


Figure A1. Dynamic interaction between erosion, runoff, and rainfall in each land use.

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