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Adaptation of RUSLE in the Eastern Part of the Mediterranean Region

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ABSTRACT / Empirically based models are used worldwide to estimate soil erosion. The Revised Universal Soil Loss Equation (RUSLE) is one such model that has been intensively tested and validated under conditions in the United States. RUSLE estimates average soil loss as a function of five main factors: rainfall erosivity (R), soil erodibility (K), crop management (C), support practice (P), and topographic (LS) factors. This study investigated the application of RUSLE to Mediterranean conditions. The validation and calibration of RUSLE in the study area utilized field plots' soil erosion measurements. The results found the RUSLE soil loss estimation to be three times the actual soil loss (7.8 and 2.6 Mg/ha, for RUSLE and actual measured soil loss, respectively). The difference between the RUSLE factors and the measured factors were responsible for the differences between the soil loss estimation by RUSLE and the measured soil loss. Specifically, the RUSLE K-factor showed three times the magnitude of the measured K-factor, the RUSLE C-factor underestimated the measured C-factor, and the RUSLE P-factor overestimated the measured P-factor by three times. Adjusting the RUSLE factors according to the measured ones increased the model's predictability, whereas the adjusted-RUSLE soil loss estimation underestimated the measured soil loss by 14%. The adjustment of RUSLE, according to the prevailing conditions of the study area, increased the model efficiency three times (0.26 and 0.86 before and after adjustment of the mode,l respectively). For more accurate and reliable validation of the RUSLE under the Mediterranean conditions, it is advisable to conduct long-term soil loss experimentation and measurements.

Soil erosion is an important cause of soil fertility decline and the consequent reduction in land productivity. The loss of fertile topsoil, which contains plant nutrients, is the main driving force behind reductions in soil fertility status (Hussein 1998; Pimentel 2000).

The eastern part of the Mediterranean region is well known for its semiarid conditions, with interseasonal and intraseasonal climatic variability. Occasional extreme rainfall events are not unusual, and they result in a high risk of runoff and vulnerability to soil erosion (Martinez-Casasnovas and others 2002; Haddad 1998). In this area, the average annual surface runoff is estimated at 14 mm per year (72 million cubic meters [MCM], per year) and comprises 3.5% of the mean annual rainfall (Haddad 1998). Hortonian overland flow, especially on bare sloped areas, is a major contributor to runoff and soil erosion. Sediment concentration during such short, intense thunderstorms is estimated at 0.2–9.4 g/L, with an erosion rate of 0.15–421 g/m^2/h (Cerda 1998a). The wide range of the erosion rates reflects the spatial variations in soil and the degree and type of the vegetative cover, which is aggravated by continuous deterioration of the currently used land conservation measures (Cerda 1998a, 1998b). Past research has emphasized the importance of extreme rain events on soil erosion, especially where various land uses and soil conservation measures are employed (Poesen and Hooke 1997; Cerda 1994).

In the eastern part of the Mediterranean (Israel and the Palestinian Autonomous Areas), gradual land degradation is currently taking place. This is the result of rapid socio-economic changes, an increase in population growth and its associated demands, in addition to the abandonment of adopted land conservation measures and the misuse of land. This necessitates the

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need for evaluation of the extent and severity of such problems under the prevailing conditions. Hence, erosion risk assessment is an important tool for both the evaluation and the formation of future soil and water conservation plans, which will decelerate such processes.

Under Mediterranean conditions, the development of local models for erosion risk assessment is limited. Additionally, large investments are required to construct monitoring systems, which are important for creating new models for the area and for validating other existing models, such as the Revised Universal Soil Loss Equation (RUSLE). RUSLE is a predictive tool used for assessing land degradation by soil erosion on hill slopes and fields (Morgan 1986; Renard and others 1996). It has been intensively tested and validated under conditions in the United States, but has not been well tested under other conditions, specifically in the eastern Mediterranean. Available knowledge in this area is largely based on the direct application of such models, although validation and adjustment are necessary in order to suit these models to the local conditions.

A few studies have applied the validation and application of RUSLE in the Mediterranean region using experimental field plot data. Arhonditsis (2002) studied the applicability of mathematical modeling, including RUSLE, to assess runoff and soil erosion in the Mediterranean. The study used three replicates of 10-m^2 plot size to quantify sediment losses from different ecosystems of the study area. In this study, the estimation of the crop factor (C), soil erodibility (K), and the erosion control practice factor (P) was based on 3 years of experimental data (Arhonditsis and others 2002). Hussein (1998) adjusted the RUSLE K-factor using soil loss measurements from natural runoff plots in Iraq.

The objective of this study was to concentrate on the assessment of RUSLE applicability and predictability under different terrestrial ecosystems (conservation terraces with and without canopy cover, no conservation practice with and without canopy cover). The assessment will deal mainly with the annual rate of erosion. The study will also investigate the conceptual framework of the RUSLE, concentrating on its requirements and defects, for better suitability and applicability of the model to local conditions of the study area.

Materials and Methods

Study Area and Climate

The study area represents a typical terrestrial Mediterranean ecosystem, characterized mainly by shallow soil, a moderate-to-steep slope, water deficiency, and limited arable lands. This shortage has been compensated for by the construction of an extensive system of terraces to minimize soil erosion and which benefits agricultural objectives.

The study was conducted 6 km southeast of the Ramallah District in the Palestinian Autonomous Area (Figure 1). The area resides on a 900-m elevation. It is characterized by well-marked summer and winter seasons, with 580 mm mean annual rainfall (Figure 1), of which more than 90% occurs from October to April during the winter (Ministry of Transport 1998), with no rainfall during the summer. The mean monthly temperature is 17.1°C, with July, August, and September being the hottest months of the summer (Ministry of Transport 1998). A high mean annual potential evapotranspiration of 861 mm prevails in the area (Land Research Center 1999). According to US Department of Agriculture (USDA) classification, the soil temperature and moisture regimes are Thermic and Xeric, respectively (Soil Survey Staff 1998; Dan and others 1976). The geological formation consists mainly of limestone, marl, and dolomite dated to the Turonian age (Abed 1999). According to the USDA classification, the soil in the experimental location is classified as Lithic Xerorthent (Land Research Center 1999), with silty loam of the surface (0–15 cm) and silty clay loam of the subsurface. The soil depth varies according to the location: less than 40 cm in the hilly and sloped areas and up to 100 cm in areas of low inclination. Organic matter ranges from 2% to 4%.

Soil Analysis, Soil Moisture, Rainfall, Runoff: Erosion Plots Measurements

Two adjacent locations were selected for the purposes of the experiment: The first featured an old soil conservation technique of stonewalled terrace; the second had no conservation measures. The experiment was conducted during the winter seasons of 2000 and 2001.

The field plots experiment had four treatments replicated three times. The treatments were the following: stonewalled terrace plots with and without wheat canopy cover, and nonterraced plots with and without wheat cover. Due to size limitations, especially in terraced areas, erosion and runoff plots were limited to 15 m in length, and 2 m in width, with a main slope of 3% along the length of the plot. Slope steepness was measured using the Abney level, whereas the slope length was measured by measuring tape.

For the determination of the RUSLE soil erodibility factor (K), soil organic matter content was analyzed using the Walkley–Black method (Nelson and Som-

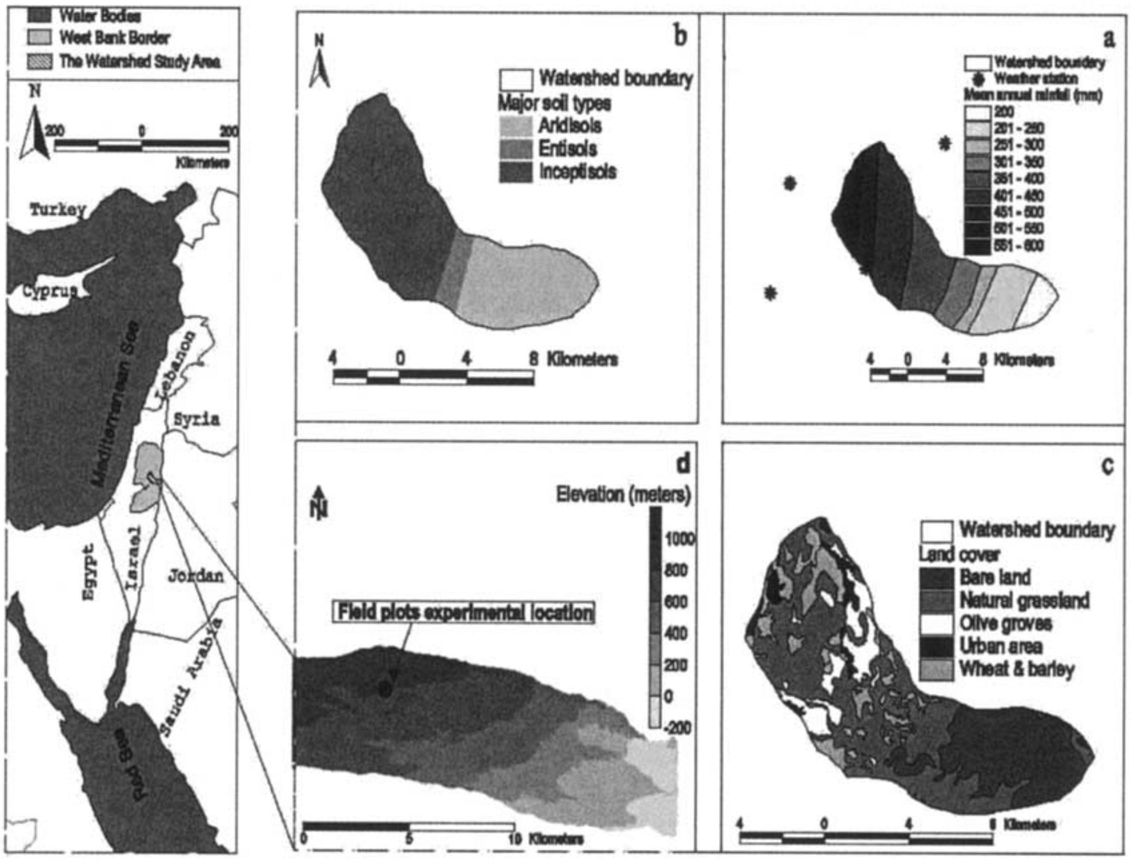

Figure 1. Location map of the study area showing isohyets with the rainfall stations (a), soil types (b), existing land cover in the area (c), and three-dimensional elevation model (d).

mers 1982), whereas soil particle size distribution was determined using the pipette method (Bouwer 1986). Two replicates for organic matter and particle size were applied to each plot from the top layer (0–10 cm), with the average being used for different calculations and validations of the RUSLE. In addition, soil structure (type and grade) was described for the first top layer in each plot. Validation of the RUSLE model will be based on the field plots' soil loss experimental results for different treatments.

All plots were kept free of weeds by hand hoeing and animal plowing as required and performed according to prevailing local practices. Cultivated plots were planted with wheat using similar practices (planting date, sowing rate, seed varieties, etc.) used by local farmers.

For runoff and erosion plots, earth levees surrounded each plot on all sides except for the end of the slope. Around each experimental location, a drain was dug to prevent runoff from adjacent areas outside the experimental sites. A plate was fixed at the end of each plot to block the runoff with the eroded material and direct it to 0.2-m^3 tanks through conveyor pipes. After each rainstorm event, the amount of runoff was measured after allowing the sediments to settle. The runoff in each tank was then mixed thoroughly and four subsamples were taken to determine the weight of soil loss after oven drying at 105°C. The total seasonal average of the four subsamples for each plot was used to conduct the necessary calculation and validation of the RUSLE model. Rainfall was measured at the experimental site using a 0.2-mm tipping-bucket pluviometer connected to a data logger recorder. The pluviometer measured rainfall at 30-min intervals. Rainfall data were also obtained from three rain measurement stations close to the experimental site (Figure 1).

For the crop management factor (C), soil moisture was measured during the winter season using the gypsum block soil moisture tester model KS-D1 (DELMHORST Instrument Co.) with two replicates for each plot. The measurements' range was 0.1–15 bar. The depth of installation was 7.5 cm for the surface layer. Soil moisture readings were taken immediately at the end of each rainfall event. During both seasons, plant density and height were also measured on a half-month basis with three replicates for each cultivated plot. The average was used for different calculations and validation of the RUSLE C-factor.

Measurements of splash erosion were undertaken during 2001 only and using splash funnels following the method of Gorchichko (Gorchichko 1977). The funnels protruded 2 mm above ground level to eliminate the entry of overland flow (Morgan 1986). Two splash funnels were used in each plot. At the end of each rain event, the contents of each funnel were mixed thoroughly and dried at 105°C. The total seasonal average of the two funnels was used to conduct the necessary calculations. Splash erosion was calculated as kilograms per hectare in order to enable the calculation of the RUSLE m-subfactor. The assumption was that the area contributing to splash erosion is equivalent to the area of the funnel, which conforms with the field-calculated area that contributed to the splash funnel (0.033 m^2).

RUSLE

The RUSLE is an empirically based model that has been developed under agroclimatic conditions specific to the United States for both natural and simulated runoff plots. RUSLE's simplicity, its black-box characters, and its statistical relationships between input and output variables makes it easily adaptable to other environments (Morgan 1986; Soil and Water Conservation Society 1994). RUSLE uses large experimental databases to calculate different factors of the model (Wischmeier and Smith 1978). These databases have been developed for a unit plot 22 m (72.6 ft) long, 1.8 m (6 ft) wide, with a 9% slope, and a continuously clean-tilled fallow condition with tillage performed in an upslope–downslope direction (Renard and others 1996; Wischmeier and Smith 1978).

The general equation of RUSLE is

$$A = R \times K \times LS \times XCP \qquad (1)$$

where A is the average soil loss (Mg/ha) per year.

Rainfall Erosivity Factor

The R-factor is calculated on annual average basis. The calculation of the R-factor is based on rainfall measurements at 30-min intervals, both on a yearly and 5-year average basis. The R-factor is calculated using (Foster and others 2002)

$$R_i = 0.01 \times E_i \times I_i^{30} \qquad (2)$$

where R_i is the storm erosivity factor (MJ mm/ha/h), I_i^{30} is the maximum 30-min intensity of the ith storm (mm/h), and E_i is the total kinetic energy of the ith rainstorm (MJ/ha). E_i is calculated by the following equation (Wischmeier and Smith 1978; Renard and others 1996):

$$E_i = \sum_{j=1}^{n} (0.29[1 - 0.72\exp^{(-0.05Ij)}])r_j \qquad (3)$$

where I_j is the 30-min intensity of the jth interval into the ith storm. r_j is the total rain (mm) of the jth interval into the ith storm. When applying Equation 3 for the calculation of E_i, RUSLE excludes storms with rainfalls <12 mm except when 6 mm of this rain falls within 15 min. In this study, the authors considered this condition only when such storms did not result in erosion. Otherwise, it was included in the calculation of E_i. The annual rainfall erosivity factor (R_A) is then the sum of the individual storm erosivities.

If more than 1 year is included in the calculation of rainfall erosivity, Equation 4 should be used

$$R_A = \left(\sum_{i=1}^{j} R_i\right)/N \qquad (4)$$

where N is the number of years used in the calculation.

Soil Erodibility Factor (K)

The K-factor is the rate of soil erosion per unit erosivity of rainfall, measured on a unit plot having the aforementioned specifications (Wischmeier and Smith 1978; Renard and others 1996; Foster and others 2002). In this case, K represents the effect of the inherent soil properties on soil erosion, especially those related to the surface layer (Renard and others 1996; Mati and Veihe 2001). Originally, K was derived from soil loss measurements on unit plots of medium textured soil with poor aggregate stability (Wischmeier and Smith 1978). Hence, deviation of the RUSLE K-factor from the actual K-factor is expected, especially when considering its application to other types of soil with different properties than those used by RUSLE (smectite clay soil or soil having more than 70% of silt content) (Mati and Veihe 2001; Roose 1977).

The K-factor is best obtained from direct measurements on natural runoff plots, with large databases and over a long period of time. The RUSLE K-factor depends on soil and climatic databases developed for the United States; consequently, the adjustment of K according to different climatic conditions and soil properties is necessary. In addition, some researchers indicated the importance of K adjustment according to different antecedent soil moisture (Wang and others 2001), which will account for temporal variations in K during the season. Procedures for the calculation of the RUSLE K-factor are well known and documented in many studies (Foster and others 2002; Mati and Veihe 2001; Renard and others 1996; Renard and others 1991; Roose 1977).

Soil erosion data from the experimental plots will be used to calculate the average annual K-factor, which will help in calibrating the RUSLE for the study area.

The temporal K-factor was calculated using

$$K_i = A_i/(R_i \times LS \times C \times P) \qquad (5)$$

where K_i is the soil erodibility factor for the ith storm (Mg h/MJ/mm), A_i is the measured soil loss for the ith storm (Mg/ha), R_i is the rain erosivity factor for the ith storm (MJ mm/ha/h), LS is the slope length and steepness factor, C is the cover management factor for the fallow plots (equals 1), and P is the support practice factor (equals 1 for no support practice).

Slope Length and Steepness Factor

The Revised Universal Soil Loss Equation reflects the effects of topography on soil erosion by slope length (L) and steepness (S). The effect of steepness is more pronounced than that for slope length. The slope length (L) is the horizontal distance (not the distance parallel to the soil surface) from the point of origin of overland flow to the point where either deposition begins or runoff concentrates in defined channels (Wischmeier and Smith 1978). The L-factor is calculated using (Wischmeier and Smith 1978; Renard and others 1996)

$$L = (\lambda/22.1)^m \qquad (6)$$

where λ is the horizontal distance of the slope length (m), m is a slope-length exponent related to the ratio (β) of rill erosion caused by flow to interrill erosion caused by raindrop impact. m is calculated using (Wischmeier and Smith 1978; Renard and others 1996)

$$m = \beta/(1+\beta) \qquad (7)$$

For slopes less than 9%, the slope steepness (S) is calculated by RUSLE according to equation 8:

$$S = 10.8\sin\theta + 0.03 \qquad (8)$$

where θ is the slope angle in degrees.

Direct calculation of m will be undertaken utilizing direct measurements of splash and interrill erosion from the field experimental plots. This will provide a good alternative to the RUSLE m-subfactor, and consequently to the L-factor. Hence, it will give more precise calibration to local conditions of the study area.

Crop Management Factor

The C-factor is based on the concept of deviation of erosion from a standard, where the standard is an area under clean-tilled continuous fallow conditions (Wischmeier and Smith 1978; Renard and others 1996). Calculation of the C-factor depends on the soil loss ratio (SLR), which is an estimate of the ratio of soil loss under actual conditions to the loss under the reference unit plot conditions (Wischmeier 1975; Laflen and others 1985). In this study, noncultivated plots will be given a C-factor of unity. For the cultivated plots, the SLR value was calculated on a half-month basis. The reason behind using half-month periods is that all SLR subfactors (prior tillage effect, canopy and crop residue cover, and soil moisture) are assumed to remain constant over each period (Foster and others 2002; Renard and others 1996). In this case, the crop management is assumed to be constant, yielding 24 different SLRs. Each of the 24 SLRs' values is then weighted by the fraction of rainfall expressed as the rainfall erosivity for that specific period. The reason for weighing each SLR with its respective rain erosivity is that the authors assumed that all of the SLRs' subfactors were constant over that period. Hence, rainfall was the only changeable and influential factor in determining the soil loss for that period. The overall C is then calculated according to (Renard and others 1996; Foster and others 2002):

$$C = (\mathrm{SLR}_1 \times \mathrm{EI}_1 \times \mathrm{EI}_2 + \ldots + \mathrm{SLR}_n \times \mathrm{EI}_n) \qquad (9)$$

where SLR_i is the value of SLR for the time period i, EI_i is the percentage of the annual EI during the time period i, and n is the number of periods. SLR is calculated using the documented procedures of RUSLE (Foster and others 2002; Mati and Veihe 2001; Renard and others 1996).

The experimental data provides an option to calculate SLRs directly from the cultivated and noncultivated plots, on a half-month basis, weighing each SLR according to the corresponding rain erosivity fraction. This will provide a further adjustment tool of the RUSLE C-factor, which could increase its predictability under the conditions of the study area.

Support Practice Factor

The RUSLE P-factor represents the ratio of soil loss from a unit plot with specific support practices to one without support practices (Foster and others 2002; Renard and others 1996). The effect of P comes from the modification in the flow pattern and/or the direction of the surface runoff, as well as the reduction of the amount and rate of runoff (Renard and others 1996). The only support practice in the study area is the terrace. Terraces affect sheet and rill erosion on the terrace area by breaking the slope into shorter length, thus affecting the amount and the velocity of the flow. The RUSLE computation of the P-factor depends on the spacing between terraces. The value of the P-factor is provided by the RUSLE guideline through various tables and formulas (Wischmeier and Smith 1978; Renard and others 1996; Foster and others 2002).

For this study, plots without terraces were assigned a unit P-factor, whereas the P-factor for the terraced plots was calculated according to RUSLE procedures. In addition, the P-factor was calculated as the ratio between erosion on terraced plots to nonterraced plots, providing more options to adjust RUSLE factors in accordance to the study area conditions.

Results and Discussion

Rainfall Erosivity Factor

Table 1 shows the annual R-factor as well as the 5-year average. The two annual values represent the two extremes of rainfall erosivity: dry and wet. Studies on rainfall erosivity factor in related areas of the Mediterranean (specifically in Catalonia in Spain) showed similar R-factors, ranging from 800 to 1100 MJ mm/ha/h (Martinez-Casasnovas and others 2002). Other studies in the northern part of Iraq showed an erosivity twice as high as the results of this study [the range was 600–2000 MJ mm/ha/h (Hussein 1998)]. This difference in erosivity is attributed mainly to differences in spatio-temporal characteristics of rainfall in both study areas, especially those related to seasonal variability in rainfall intensity, duration, amount, and the specific location of the rain measurement stations (Renschler and others 1999). Renschler and others (1999) found a positive correlation between the long-term annual precipitation and the elevation of rainfall measuring stations in Spain. They also pointed out the importance of the seasonal variability of rainfall amounts and the associated rainfall erosivities in assessing the seasonal risk of erosion. The effect of spatio-temporal variability of rainfall in erosion risk assessment studies using RUSLE was emphasized by other researchers (Wang and others 2002).

Figure 2 shows the rainfall erosivity distribution on a half-month basis. In general, most of the erosive rain occurs during a short period (i.e., January and February), which is applicable on a yearly as well as a 5-year average basis. In this regard, it is important to highlight the limited applicability of both the annual and the 5-year average rainfall data in predicting erosion. Implications of the uniqueness of the study area, the time, and the availability of long rainfall data records add to the difficulties of extrapolating results indicated in this research to other locations within the same area, in addition to further limitations when applying to other neighboring countries of the Mediterranean (Renschler and others 1999; Wang and others 2002).

About 70% of the annual rain erosivity occurs during the first 40 days beginning January 1 (Figure 3), with the remainder occurring during March and December. In general, January is the most erosive month of the year, with about 55% of the annual rain erosivity (Figure 3). During this period, the plant canopy height is only 5 cm, which provides poor protection against raindrop impact. The combination of high erosivity and poor vegetative cover at this time causes a detrimental effect: increasing soil aggregate slacking and disintegration, with a final increase in runoff and erosion (Barthes and Roose 2002).

Table 1. Maximum 30-min intensity I^{30}, yearly and 5-years average rainfall erosivity

	I^{30} (mm/h)	R (MJ mm/ha/h)
2000 season	10.5	351
2001 season	29.5	1006
5-Year average	15.4	760

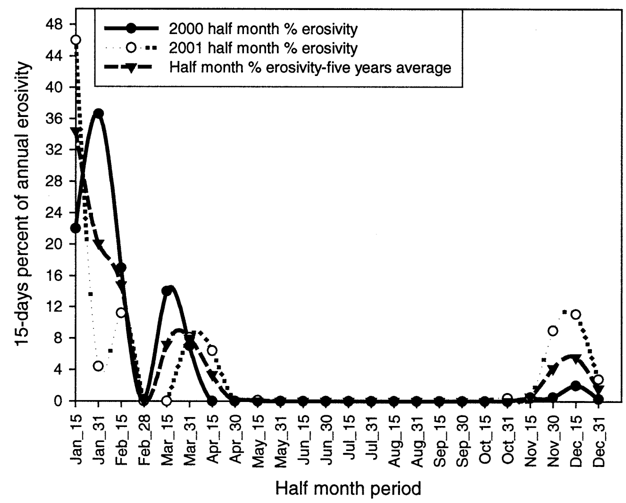

Figure 2. Rainfall erosivity distribution for the 2000 and 2001 seasons and the 5-year average distribution.

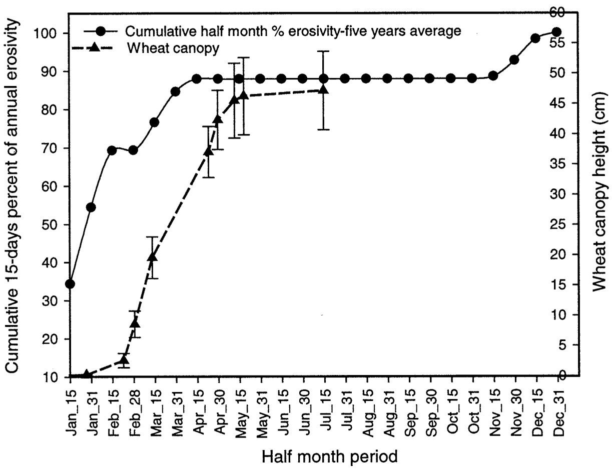

Figure 3. Cumulative half-month rainfall erosivity, based on 5-year average distribution, and wheat canopy height during the same periods. Bar represent the standard deviation.

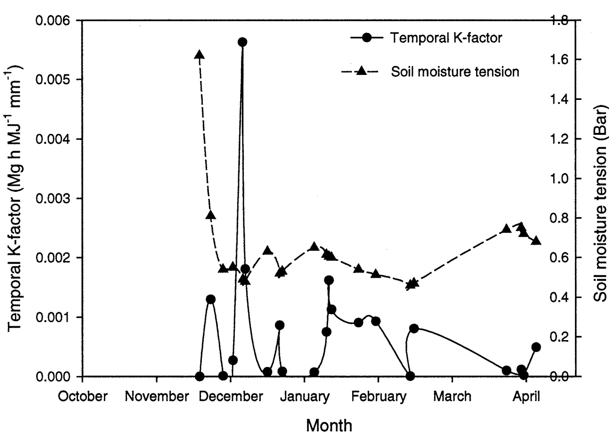

Figure 4. Storms' K-factors at different soil moisture tension during the winter season.

Soil Erodibility Factor

As previously mentioned, the RUSLE K-factor is based on a combination of soil and climatic parameters developed under specific conditions in the United States. These parameters might not be suitable to conditions outside of this particular context. Additionally, the RUSLE K-factor assumes a constant value during different periods of the season. Antecedent soil moisture, spatial and temporal soil, and rainfall variability results in a dynamic K-factor in terms of time and space are not accounted for in the RUSLE K-factor, particularly when applied to climatic conditions that differ from those in the United States (Renard and others 1996; Wang and others 2001). Hence, adjustment of the K-factor is necessary for the purpose of this project.

The field measurement of soil moisture tension (SMT) and the temporal K-factor (Figure 4) emphasized this and necessitated the adjustment of the K-factor at different times. Figure 4 shows an inverse relationship between the K-factor and the SMT (K is highest at lower SMT and vice versa). The highest K-factor occurred in December and January (Figure 4). The spatial change of the K-factor according to different soil types is not possible to verify because of the small difference in the two locations of the experiment with respect to silt, sand, and organic matter content.

Available measurements, from natural runoff plots in the study area, indicate that the RUSLE K-factor overestimates the measured K-factor of the area by 1.1–3.5 times the magnitude (Table 2), basically due to the reasons mentioned earlier.

Results from other studies in the Mediterranean region showed RUSLE K-factors that are similar to the findings of this study (Arhonditsis and others 2002; Hussein 1998). Research from the northern part of the Middle East, specifically Iraq, showed a RUSLE K-factor value nearly 10 times that of the measured K-factor (Hussein 1998), which is consistent with the findings of this study. Previous researchers have applied methods of calculating the RUSLE K-factor, which match the method employed in this study. These studies did not account for variations in K according to soil and climate variability.

To account for temporal variability in the K-factor, a regression analysis between the ratios of the cumulative measured K-factor to the RUSLE K-factor and the soil moisture tension was performed. The regression showed a highly significant correlation ($P < 1\%$) between both factors (Figure 5). The equation represented a tool for estimating the real K-factor at any time during the winter season, provided that soil moisture tension at that time was known.

Using the regression equation of Figure 5, the overall measured K-factor at the end of the season could be estimated by measuring the soil moisture tension at that time, in addition to knowledge of the RUSLE K-factor value derived from the normal RUSLE calculation. However, one constraint of this equation is the small soil moisture tension range (0.25–0.75 bar). Beyond this range, the equation cannot predict the magnitude of the K-factor.

Slope Length and Steepness Factor

The RUSLE LS-factor was derived originally from experimental data on slopes not exceeding 18° and a length of 91.4 m (300 ft). Beyond these ranges, the relationship of the LS-factor cannot be judged for accuracy because the calculation of the LS-factor will

Table 2. Calculated and measured annual soil erodibility factor (*K*) for the different experimental plots in the two locations

	Treatment					
	Terraced plots			Nonterraced plots		
Plot no.	Organic matter[a] (%)	RUSLE-calculated *K* (Mg h/MJ/mm)	Measured *K*[a] (Mg h/MJ/mm)	Organic matter[a] (%)	RUSLE-calculated *K* (Mg h/MJ/mm)	Measured *K*[a] (Mg h/MJ/mm)
1	2.4	0.045	0.020	2.2	0.052	0.045
2	2.8	0.052	0.021	2.3	0.045	0.029
3	3.7	0.035	0.010	2.3	0.049	0.026
4	2.6	0.055	0.024	2.4	0.048	0.024
5	3.1	0.043	0.022	2.2	0.050	0.035
6	3.5	0.037	0.019	2.4	0.051	0.027

[a]Values are the mean of two replicates.

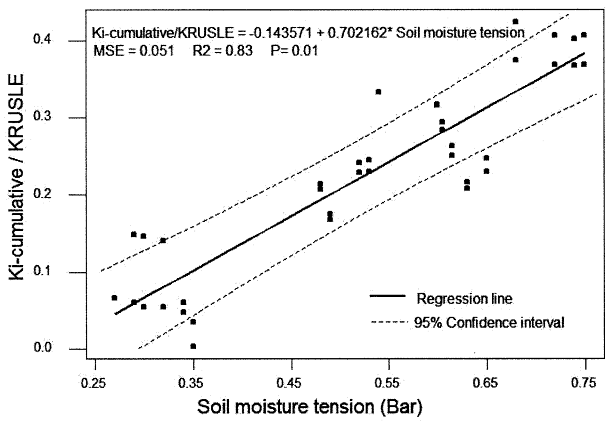

Figure 5. Linear regression relation between ratios of cumulative measured K-factor to RUSLE K-factor with the soil moisture tension.

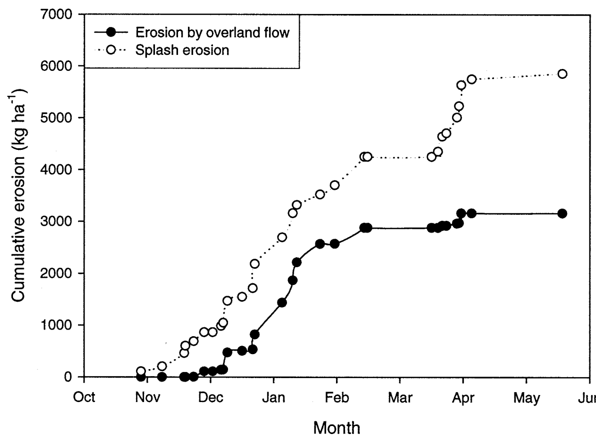

Figure 6. Cumulative measured erosion by overland flow and by raindrop impacts (splash erosion) during the 2001 season.

Table 3. Slope length and steepness factor with their associated subfactors derived from different RUSLE equations.

Parameter	
β	0.51
m	0.34
λ	14.99
LS-factor	0.36

Note: Values are the mean of six replicates.

deviate from the original range of the experimental data (Wischmeier and Smith 1978). Table 3 shows the LS-factor with the associated subfactors used in different equations for the RUSLE calculation of the LS-factor.

Calculation of the m-subfactor, from direct measurements of interrill erosion and splash erosion (Figure 6), showed β and m-subfactors closely related to those calculated by RUSLE, where the measured β and *m* are 0.54 and 0.35, respectively. Hence, RUSLE provides a good approximation for the ratio between erosion by overland flow and splash erosion. Consequently, the RUSLE-calculated LS-factor is a good approximation of the measured LS-factor in the study area.

Crop Management Factor

The C-factor reflects the effects of any surface cover resulting from any management practices as well as human-related activities on soil erosion (Renard and others 1991).

The actual measurement of the C-factor indicates a higher C value than the RUSLE-calculated C-factor (Table 4). The measured *C* value is 1.5 times the RUSLE C-factor. This could be due to the deviation of the SLR's subfactors calculated by RUSLE from the actual conditions of the study area, which, in turn, gave a lower estimation of RUSLE soil loss than the direct

Table 4. Average RUSLE-calculated and field-measured crop management factor (C) for the different experimental plots during 2000 and 2001 winter season

Treatment	Terraced	Nonterraced
2000 season	0.36	0.44
2001 season	0.30	0.33
Average calculated C^a	0.33	0.39
Average field-measured C^a	0.44	0.59

[a] Values are average of six replicates.

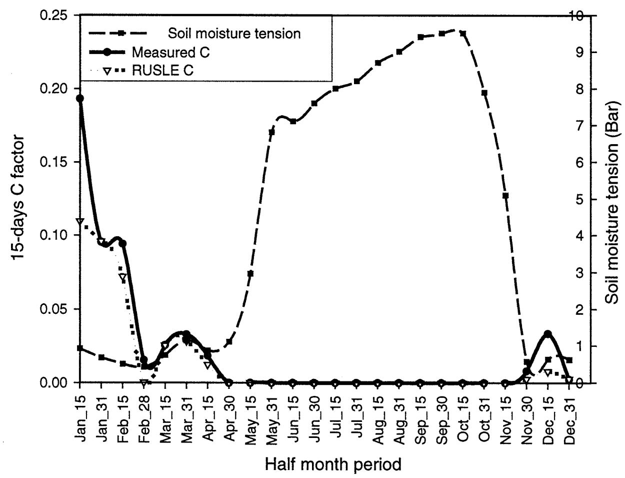

Figure 7. Actual soil moisture replenishment-depletion pattern for the study area, with measured and RUSLE C-factor based on 15-day interval.

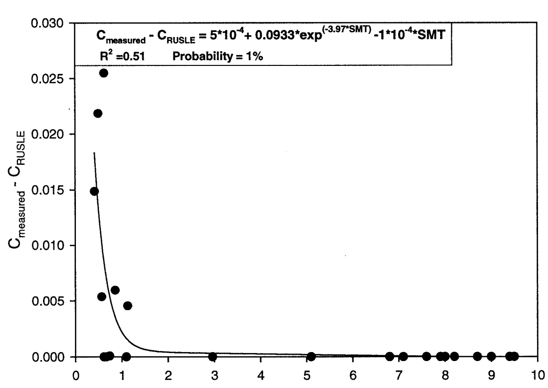

Figure 8. Exponential regression relationship for the difference between measured C-factor and RUSLE C-factor with the soil moisture tension.

measurements of soil loss in the study area. For example, RUSLE approximates the soil moisture subfactor (SM) according to a fixed soil moisture replenishment–depletion pattern, whereas this pattern is different in the study area (Figure 7). RUSLE assumes a linear ascending C-factor during the rainy season, regardless of the nature of the rain (i.e., intensity, amount, etc.) and the variation in soil moisture over the season due to the variations in the climatic parameters (i.e., temperature and humidity). However, under the actual condition of the study area, variations during the season might produce variations in the C-factor, causing the RUSLE to underestimate the existing soil loss in the study area.

The differences between the RUSLE and the measured C-factor occur mainly when soil moisture tension is below 1 bar, whereas differences are negligible above that range of SMT (Figure 7). In addition, these differences occurred from January to March. The differences were negligible during the rest of the season (Figure 7).

Antecedent soil moisture has a substantial influence on both the management factor and the soil erodibility through its effect on soil hydraulic properties (Renard and others 1996; Marceau and Hay 1999; Foster and others 2002). Consequently, it is essential to adjust the relationship among the measured C-factor, the RUSLE C-factor, and the SMT for the effect of soil moisture variations at different times during the season, particularly during periods of high moisture content with associated weak topsoil aggregate stability.

Exponential regression, *vis-à-vis* the difference between the measured C-factor and the RUSLE C-factor with SMT, reveals a significant relationship between these parameters ($P < 0.01$), with R^2 of 0.51 (Figure 8). The limitations of this equation and the need for more long-term experimentation to obtain more reliable calibration must be emphasized. It is particularly important to consider that SMT is a site-specific parameter and cannot extend beyond the area for which it has been developed and should be applied with caution by anyone intending to test in other areas of the Mediterranean using this system. Nevertheless, this relationship is useful for the adjustment of the RUSLE C-factor to suit the actual conditions of the study area.

Figure 8 also emphasizes the fact that the main differences between both C-factors occur only under nearly saturated conditions (SMT < 1 bar).

Rearranging the equation in Figure 8 yields the following equation:

$$C_{\text{estimated}} = C_{\text{RUSLE}} + (5 \times 10^{-4} + 0.0933 \exp^{(-3.97\text{SMT})} - 1 \times 10^{-4}\text{SMT}) \tag{10}$$

Table 5. RUSLE-calculated P-factor and actual measured P-factor for the experimental field plots

Plot No.	RUSLE P-factor	Measured P-factor
1	0.55	0.13
2	0.55	0.28
3	0.55	0.21
4	0.55	0.10
5	0.55	0.27
6	0.55	0.24

Note: Values for measured *P* are the mean of two replicates.

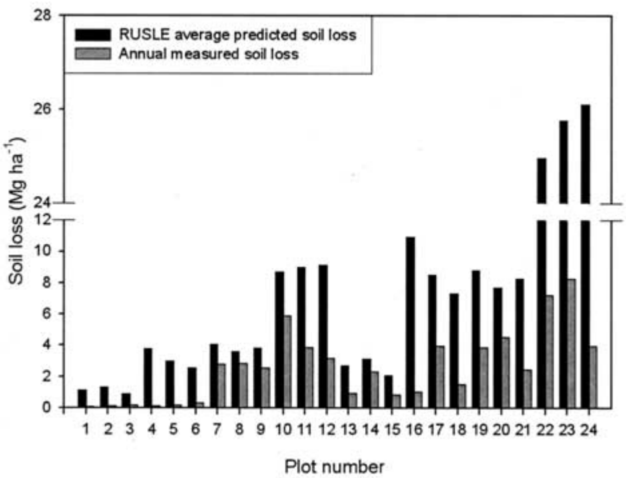

Figure 9. Measured and RUSLE-predicted annual average soil loss, for different experimental plots during 2000 (plots 1–12) and 2001 winter season (plots 13–24). Terraced plots are 1–6 and 13–18; the rest are for nonterraced plots.

Conservation Practice Factor

The conservation practice factor is related to certain soil conservation measures, which reduce the effects of slopes on soil erosion (Mati and Veihe 2001). The RUSLE-computed P-factor for terraces is based on the spacing between terraces. The result shows that the RUSLE P-factor overestimates the actual P-factor (Table 5) by 2.8 times (RUSLE *P* is 0.55, average measured *P* is 0.20). Adjustment of the RUSLE P-factor is necessary, therefore, in order to increase its accuracy to predict the actual effect of terraces on the study area. The adjustment can be made using the following simple equation:

$$P_{\text{estimated}} = 0.36\ P_{\text{RUSLE}} \tag{11}$$

Testing and Calibration of RUSLE

The process of testing a model aims to define uncertainties related to the prediction of the model, whereas calibration of the model aims to choose the best set of parameters, in order to increase its accuracy and predictability of the actual conditions, and, finally, to achieve a good fit between predicted and measured values (Grayson and Bloschl 2001).

The RUSLE testing indicates an overestimation of the soil loss (Figure 9). The average predicted RUSLE soil loss is 7.8 Mg/ha, whereas the average measured soil loss is 2.6 Mg/ha. The ratio between the total measured soil losses to the RUSLE prediction is 0.33. Hence, RUSLE overestimated the actual soil loss by three times.

The Nash efficiency coefficient (R_s^2) is a measure of the model efficiency, which avoids the influence of different scales of output values on model performance and efficiency (Nash and Shutcliff 1970; Refsgaard 1997; Christiaens and Feyen 2001). It is a measure of the deviation of predicted values from the measured ones. R_s^2 is calculated according

$$R_s^2 = 1 - \left[\sum (Q_{\text{predicted}} - Q_{\text{measured}})^2 \Big/ \sum (Q_{\text{predicted}} - Q_{\text{measured-mean}})^2\right] \tag{12}$$

The calculation of R_s^2 indicates low efficiency of the RUSLE model ($R_s^2 = 0.26$) under the investigated conditions.

To optimize RUSLE parameters in order to reduce the gap between predicted and measured values, the RUSLE equation was modified according to the calibration, which was applied previously to different RUSLE factors. The final modified RUSLE equation will be as follows:

$$A = R_{\text{5-years average}} \times [(K_{\text{RUSLE}}(-0.144 + 0.702\text{SMT})] \times LS \times C_{\text{estimated}} \times (0.36P_{\text{RUSLE}}) \tag{13}$$

and

$$C_{\text{estimated}} = C_{\text{RUSLE}} + (5 \times 10^{-4} + 0.0933\exp^{(-3.97\text{SMT})} - 1 \times 10^{-4}\text{SMT}) \tag{14}$$

For the calculation of the adjusted K-factor and C-factor, the SMT was assumed to be 0.5 bar at all times. This is a valid assumption because the average soil moisture tension during the entire rainy season did not exceed the 0.5 bar (Figure 7).

The result of the RUSLE calibration process, using the adjusted RUSLE factors, shows almost similar values of RUSLE-predicted soil losses and measured soil losses (Figure 10), where the average adjusted RUSLE value is close to the measured one (2.30 and 2.63 Mg/ha, respectively). The ratio between the total measured

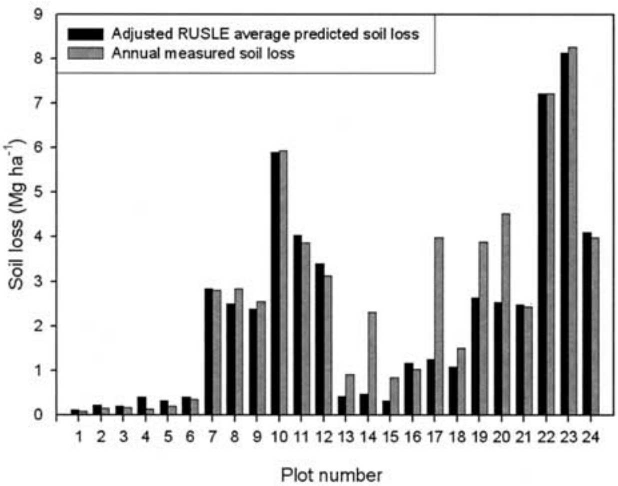

Figure 10. Measured and adjusted RUSLE average annual soil loss, for different experimental plots during 2000 (plots 1–12) and 2001 winter season (plots 13–24). Terraced plots are 1–6 and 13–18; the rest are for nonterraced plots.

soil losses to the adjusted RUSLE value is 1.14, although the adjusted RUSLE underestimated the actual soil loss by about 14%.

The calculation of R_s^2 indicates good efficiency of the adjusted RUSLE model ($R_s^2 = 0.86$) with the new adjusted factors according to the study area conditions. In this regard, it is worth mentioning the limited time period of the soil loss data (2 years), in addition to the scarcity of long-term rainfall data for precise calibration and validation of RUSLE to the local conditions of the study area, which adds some limitations and precautions to the long-run applicability of the adjusted model.

It has been mentioned that RUSLE was originally developed in accordance with conditions in the United States. RUSLE has been calibrated by a set of long-term soil loss and rainfall data measurements (20 years and more) and over large areas of the United States with different soils, rainfall, as well as physico-chemical characteristics. This made RUSLE a powerful and reliable modeling tool to predict the average soil loss for certain areas in the United States, taking into account the existing spatial and temporal variability in that area and approaching the average soil loss with minimum deviation from the actual one (Renard and others 1991, 1996; Wang and others 2002). Meanwhile, the application of RUSLE to this study resulted in many limitations and defects: the small size of the experimental area, the short-term soil loss measurement, and the lack of long-term and inclusive rainfall data records for the country. All of these factors contributed to the large deviation of the RUSLE-predicted average soil loss from the actual measured one (Renschler and others 1999; Wang and others 2001, 2002). Hence, it is advisable to deal with the results of this study with caution, especially when the calibrated RUSLE needs to be extended to other regions of the Mediterranean.

Conclusions

Different soil management practices are important tools that can be used to reduce erosion and runoff, especially under the semiarid Mediterranean conditions of the study area. The calculation of different RUSLE and measured factors in the 2 years during which experimentations were performed were so done in order to test and validate RUSLE for future use by land-use planners and conservationists.

It should now be clear that for a more precise and reliable application of RUSLE in the study area, long-term soil erosion and rainfall records are necessary in order to minimize the spatio-temporal variability effects to an acceptable level. However, the study revealed the following conclusions:

1. Under the local conditions of the study area, RUSLE overestimated the annual soil loss up to three times the measured soil loss.
2. The adjustment of RUSLE factors (K, C, and P) according to the local conditions of the study area is necessary in order that the RUSLE prediction of soil loss be more reliable and accurate.
3. Although the adjusted RUSLE underestimated the measured soil loss value by 14%, it gave very close approximation of the measured one (2.30 Mg/ha and 2.63 Mg/ha for predicted and measured, respectively).
4. Under the current experimental setup and considering the effect of the variation in time and space on soil erosion modeling by RUSLE, the authors urge the careful use of the calibrated RUSLE both in the study area as well as other areas of the Mediterranean.
5. For more reliable calibration of RUSLE in the Mediterranean conditions of the study area, researchers are recommended to conduct more long-term soil loss experimentation and rainfall measurements, so that more precise and reliable RUSLE factors can be derived.
6. Although it should be used with caution, the calibrated RUSLE equation developed during this study might prove to be a good tool for land-use

planners and future management practices in the area. It also constitutes a base for future research of soil erosion in the study area as well as other areas with similar conditions.

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