

The combined RUSLE/SDR approach integrated with GIS and geostatistics to estimate annual sediment flux rates in the semi-arid catchment, Turkey

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Abstract Quantitative evaluation of the spatial distribution of the erosion risk in any watershed or ecosystem is one of the most important tools for environmentalists, conservationists and engineers to plan natural resource management for the sustainable environment in a long term. This study was performed in the semi-arid catchment of the Saraykoy II Irrigation Dam, Cankiri, located in the transition zone between the Central Anatolia Steppe and the Black Sea Forests of Turkey. The total area of the catchment is 262.31 ha. The principal objectives were to quantify both potential and actual soil erosion risks by the Revised Universal Soil Loss Equation (RUSLE) and to estimate the amount of sediments to be delivered from the hillslope of the catchment to the reservoir of the dam using the sediment delivery ratio (SDR) in combination with the RUSLE model. All factor and sub-factor calculations required for solving the RUSLE model and SDR in the catchment were made spatially using DEM, GIS and

Geostatistics. As the main catchment was divided into twenty-five sub-catchments, the predicted actual soil loss (by the model) was $146,657.52 \text{ m}^3 \text{ year}^{-1}$ and the weighted average of SDR estimated by areal distribution (%) of the sub-watersheds was 0.344 for whole catchment, resulted in $50,450.19 \text{ m}^3 \text{ year}^{-1}$ sediment arriving to the reservoir. Since the Dam has a total storage capacity of $509 \times 10^3 \text{ m}^3$, the life expectancy of the Dam is estimated as 10.09 year. This estimation indicated that the dam has a relatively short economic life and there is a need for water-catchment management and soil conservation measures to reduce erosion.

Keywords Soil erosion risk · RUSLE · GIS · SDR

Introduction

The transition zone between the Central Anatolia Steppe and the Black Sea Forests in Turkey has fragile ecosystems including semi-arid lands, such as mountain passes, grasslands and forests together with croplands, and every ecosystem owns its unique features and resources. As it is in many arid, semi-arid and dry sub-humid areas, the demand for water resources rises in the region because of both population pressure increases and warmer temperatures and drier conditions that climate change brings about. As a result, many small dams have been recently constructed in the zone by the General Directorate of State Hydraulic Works (DSI), which is Turkey's state water agency, having the responsibility to develop and maintain all of water resources in the country, to balance this increasing water requirement. The Saraykoy II Irrigation Dam is only one of them, constructed at the lower altitude of the Saraykoy basin in 2006.

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Since demand for water resources rises in the region, a well organized and environmentally sound management of the available water resources is an urgent need. In fact, approximately 40 years ago, the Saraykoy I Irrigation Dam was constructed at the upper part of the Saraykoy basin. Its total catchment area was about 10.1 km², and unfortunately, since the dam lake was completely filled due to the siltation by soil erosion 6 years ago, it has no more been in use for irrigation purpose. Soil erosion is considered one of the most important forms of land degradation worldwide (Oldeman 1994; Angima et al. 2003; Onori et al. 2006), and for a similar fragile semi-arid ecosystem of Indagi Mountain Pass-Cankiri, Turkey, Ozcan et al. (2008) concluded that, rather than the topographical properties of the ecosystem, the degraded soil chemical and physical properties resulted from the land use conversion from either forest or grassland to the cropland and poor management by overgrazing in the grasslands had a greater influence on the magnitude of soil losses. Likewise, Evrendilek et al. (2004) and Celik (2005) reported parallel results for changes in soil organic carbon along adjacent Mediterranean forest, grassland, and cropland ecosystems in Turkey. Another research performed by Basaran et al. (2008) presented the effects of the land use changes on the soil properties that affect the ecosystem dynamics in the Indagi Mountain Pass-Cankiri, Turkey. Therefore, there are obvious needs for practicable and reasonable management strategies to deal with upland soil erosion and siltation problems in the reservoirs of the region.

The RUSLE technology could be successfully used to determine management strategies because it interactively takes the principal elements of the ecosystem (climate, soil, topography and land use/land cover) into account to properly plan resource conservation measures (Renard et al. 1997). Since RUSLE, by its very nature, has robust ecosystem factor estimators, the model has been recently combined with Geographic Information Systems (GIS) and Geostatistics successfully to expand its applicability to much larger scales than agricultural plots all over the world (Molnar and Julien 1998; Millward and Mersey 1999; Van der Kniff et al. 2000; Mati 2000; Mati and Veihe 2001; Ouyang and Bartholic 2001; Cerri et al. 2001; Jain et al. 2001; Bartsch et al. 2002; Lufafa et al. 2003; Grimm et al. 2003; Ma et al. 2003; Martin et al. 2003; Wang et al. 2003; Lu et al. 2004; Amore et al. 2004; Onori et al. 2006; Kouli et al. 2009; Beskow et al. 2009).

After being a useful tool for predicting soil losses and planning control practices in watersheds by the effective integration of the GIS-based procedures to estimate the factor values in a grid cell basis, either the RUSLE technology or its origin USLE has also been commonly used in Turkey since 2000 (Ekinci 2005; Irvem et al. 2007; Tagil

2007; Karabulut and Küçükönder 2008; Efe et al. 2008a, b; Yüksel et al. 2008; Karaburun 2009; Karaburun et al. 2009). GIS was integrated with the USLE model to predict soil erosion and the transport of nonpoint source pollution loads to the Gediz River, in the Aegean Sea coast of Turkey (Fistikoglu and Harmancioglu 2002). Erdogan et al. (2007) used the USLE/GIS technology to predict potential soil erosion in the semi-arid Kazan watershed located in the Central Anatolia, Turkey. Model parameters *R*, *K*, and *C* were, respectively, computed from the erosivity map (Dogan 2002), soil map and land use map of Turkey (GDPS 1986). In this study, spatial distribution of different erosion prone areas was identified in the watershed to take erosion control measures in the severely affected areas.

Not only GIS, but also spatial data analysis is successfully integrated with the RUSLE model for assessment of erosion risk (Goovaerts 1999; Wang et al. 2001, 2002a, b, 2003; Tran et al. 2002; Licznar and Nearing 2003; Parysow et al. 2003; Li et al. 2006). Akyurek and Okalp (2006) used fuzzy sets and fuzzy logic algebra in predicting the soil erosion hazard by the USLE model in the Kocadere Creek Watershed, Izmir, Turkey. The fuzzification of the landscape elements used in the model was performed using a Fuzzy Semantic Import modeling approach. By this attempt, it was concluded that the approach was very useful to explore relationships and incorporate uncertainty in spatial decision making although the model provided qualitative estimations. In another study performed in a semi-arid ecosystem of Turkey, the soil erodibility factor of USLE was determined by the nomograph (Wischmeier et al. 1971; Renard et al. 1997), and from those point data spatial patterns of USLE-K were evaluated by the geostatistics (Ozcan et al. 2008). Baskan et al. (2010) conducted a research to evaluate the use of the sequential Gaussian simulation (SGS) for mapping the soil erodibility factor of the USLE/RUSLE methodology in the Dalaman catchment, situated in the West Mediterranean region of Turkey. Saygin et al. (2011) performed a land degradation assessment by geospatially modeling different soil erodibility equations in a semi-arid catchment in Turkey.

As RUSLE estimates gross sheet and rill erosion, accounting neither for the sediment deposition nor for gully or channel erosion, there is a need to define the sediment delivery ratio (SDR) for determining the amount of sediment to be delivered to the stream system from the drainage area above (Renard et al. 1997). It could be possible to find numerous models to calculate SDR (Renfro 1975; Arnold et al. 1996; Kothyari and Jain 1997; Lu et al. 2006). Particularly, Williams and Berndt (1972) computed sediment yield by USLE. Indeed, they improved the model ability to estimate the sediment yield by using a runoff factor instead of the

rainfall factor. After their contribution, the modified equation (MUSLE) was used by many researchers (Banasik and Walling 1996; Kinnell and Risse 1998; Tripathi et al. 2001; Sadeghi et al. 2004; Sadeghi and Mizuyama 2007). Cambazoglu and Gogus (2004) approximated sediment yield by means of both MUSLE and USLE in the Western Black Sea region of Turkey. Restrepo et al. (2006) analyzed sediment load and morphometric, hydrologic, and climatic variables from 32 tributary catchments in the Magdalena River, Colombia and showed that no other catchment’s properties explained more variation than mean annual runoff did. On the other hand, de Vente et al. (2007) illustrated that the relation between basin area and area-specific sediment yield showed large regional variations. To predict annual sediment flux rates, Ricker et al. (2008) investigated two sub-watersheds of the Rappahannock River, Horsepen Run and Little Falls Run, Stafford County, Virginia using the Revised Universal Soil Loss Equation (RUSLE) and a SDR. Their estimates by RUSLE/SDR were close approximations to suspended sediment sample data in the latter case, but obviously were overestimated for the former case, and because of the overestimation, they suggested corrective factors be used with forested land cover plots. Beskow et al. (2009) performed a research to assess the applicability of the well-known USLE model along with remote sensing and GIS techniques for estimating soil loss in the Tapacurá river catchment, Brazil. They used the watershed area to calculate the SDR, which was in the order of 0.9.

In this study, a semi-arid catchment of Saraykoy II Irrigation Dam, Cankiri, Turkey was analyzed using the RUSLE and a SDR to estimate annual sediment flux rates. The combined RUSLE/SDR approach was integrated not only with GIS, but also with Geostatistics to calculate model estimators.

Materials and methods

Site description

The catchment area of Saraykoy II Irrigation Dam covers about 262.31 ha and is located in Cankiri, Turkey, approximately 110 km northeast of Ankara (Fig. 1). The study area has a terrestrial climate with minimum and maximum temperatures of -6.2 and 25.8 °C, respectively, and annual precipitation is about 500 mm. In the area, elevations vary from 960 to 1,460 m above the sea level and the slopes range from 12 to 36 %. Soils are generally moderately deep and with a texture of sandy clay loam. The calcareous and andesitic formations are dominant in the northern part of the area; whereas the serpentine

formation is present in the southwestern side of the area (Anonymous 1988).

To compensate irrigation water shortage emerged in the catchment after the complete siltation of the Saraykoy I Irrigation Dam with a total catchment area of 10.1 km² which has been out of use, the Saraykoy II Irrigation Dam was constructed at the lower altitude of Saraykoy catchment in 2006. Its maximum storage volume and lake area are 509 × 10³ m³ and 4.82 × 10⁻² km², respectively. Total collecting area of two dam catchments is approximately 12.8 km², and the Saraykoy II Irrigation Dam only receives sediments from the area of approximately 2.7 km² for the first dam collects from the rest of the catchment. The land use types broadly present in the area are grassland in the south and forest in the north (Fig. 1).

Procedure

The combined RUSLE/SDR methodology was used for this study to estimate sediment flux rates (t ha⁻¹ year⁻¹) into the reservoir of the Saraykoy II Irrigation Dam. A SDR value was added as a multiplier to the well-known RUSLE (Wischmeier and Smith 1978; Renard et al. 1997) (Eq. 1).

$$A = R \times K \times L \times S \times C \times P \times SDR \tag{1}$$

where *A* is the mean annual soil loss (t ha⁻¹ year⁻¹), *R* is the rainfall erosivity factor (MJ mm ha⁻¹ h⁻¹ year⁻¹), *K* is the soil erodibility factor (t ha h ha⁻¹ MJ⁻¹ mm⁻¹), *L* is the slope length factor, *S* is the slope steepness factor, *C* is the cover management factor, and *P* is the support practice factor.

Rainfall–runoff erosivity factor (RUSLE-R)

The rainfall–runoff erosivity factor of RUSLE (RUSLE-R), which is calculated as a product of the annual total energy of rainstorm (*E*, MJ ha⁻¹ year⁻¹) and the maximum 30-min intensity (*I*₃₀, mm h⁻¹) (*E* × *I*₃₀) (Wischmeier and Smith 1958; Foster et al. 1981; Renard et al. 1997), was directly taken from the study of Kaya (2008) and a scientific project report (Tubitak 2009), in which the *E* × *I*₃₀ values (MJ mm ha⁻¹ h⁻¹ year⁻¹) were calculated either by Eq. 2 or by Eq. 3 based on the conditions where *I* ≤ 76 and *I* ≥ 76 mm h⁻¹, respectively for 252 climate stations in the period of 1993–2007 all over Turkey.

$$E = 0.29 \left[1 - 0.72e^{(-0.05I)} \right] \tag{2}$$

$$E = 0.293 \tag{3}$$

By considering the effect of elevation on actual amount of precipitation (Toy and Foster 1998) (Eq. 4), the point data given in Table 1 were then associated with the digital elevation model (DEM) of the catchment of

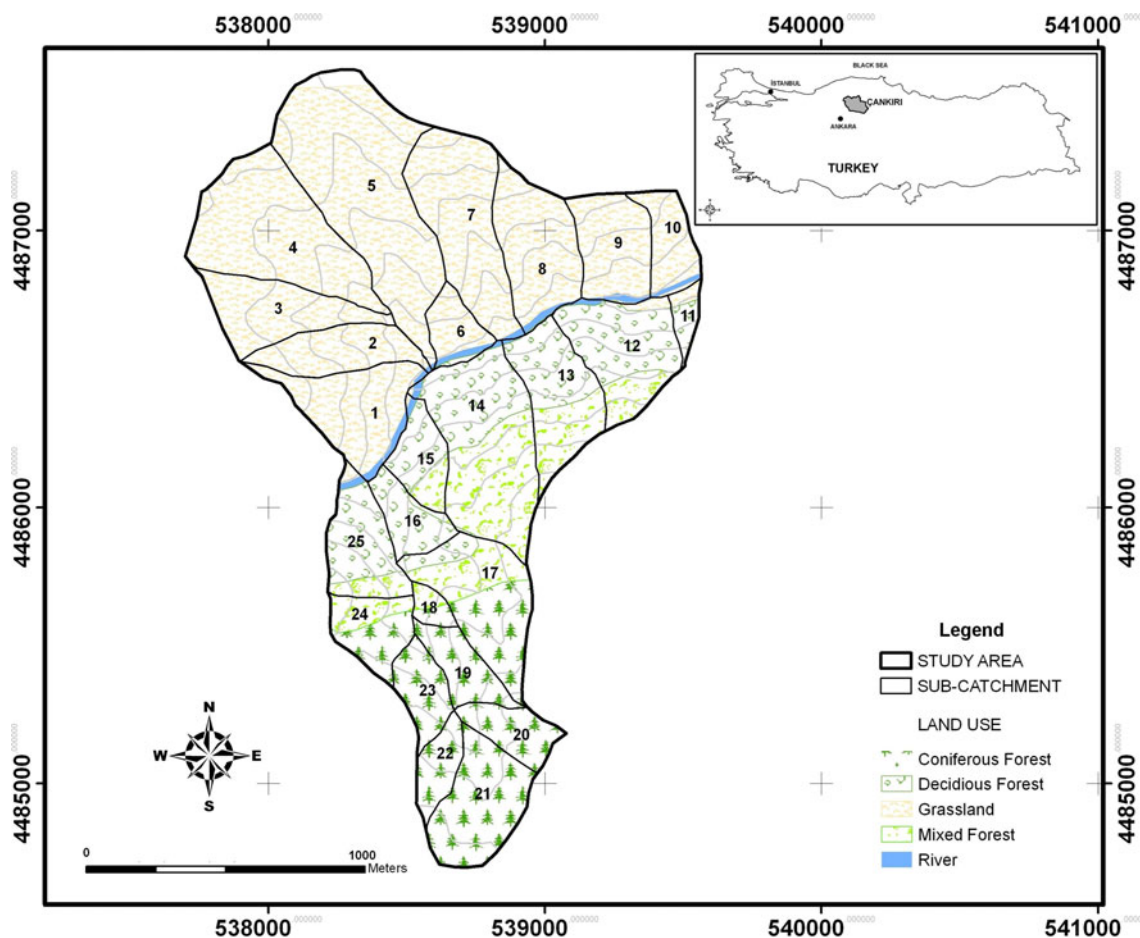


Fig. 1 The sub-catchments together with land use types in the catchment of Saraykoy II Irrigation Dam

the Saraykoy II Irrigation Dam to spatially create RUSLE-R surface:

$$R_{\text{new}} = R_{\text{base}} \left(\frac{P_{\text{new}}}{P_{\text{base}}} \right)^{1.75} \tag{4}$$

where R_{new} is the new value for RUSLE-R at the desired new location, R_{base} is the RUSLE-R value at the base location ($948 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}$) (Table 1), P_{new} is the calculated annual precipitation at new location, and P_{base} is the annual precipitation at the base location (Table 2). RUSLE-R values of unknown elevations were computed by using DEM in Arc view 9.2 and Eq. 4, with an assumption of a 50 mm increase in precipitation with each 300 m increment in the altitude.

Soil erodibility factor (RUSLE-K)

The soil erodibility factor of RUSLE (RUSLE-K) was assessed by Eq. 5 (Torri et al. 1997, 2002).

$$K = 0.0293(0.65 - D_G + 0.24D_G^2) \times \exp \left\{ -0.0021 \frac{\text{OM}}{C} - 0.00037 \left(\frac{\text{OM}}{C} \right)^2 - 4.02C + 1.72C^2 \right\} \tag{5}$$

where K is the soil erodibility factor ($\text{t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$), OM is the organic matter content (%), C is the clay fraction (%), and D_G is the decimal logarithm of the geometric mean of soil particle size (Eq. 6).

$$D_G = \sum f_i \log_{10} \left(\sqrt{d_i d_{i-1}} \right) \tag{6}$$

where f_i is the primary particle size fraction in percent with sizes within d_i and d_{i-1} defined by Shirazi and Boersma (1984).

The soil samples required to solve Eq. 6 were randomly taken as many as a very rough topography of the

Table 1 The RUSLE-R values (MJ mm ha⁻¹ h⁻¹ year⁻¹) and its annual distribution at the base location (Kaya 2008; Tubitak 2009)

Climate station: Cankırı (period of 1993–2007)

Months	1	2	3	4	5	6	7	8	9	10	11	12	Annual
<i>n</i> ^a	0	0	0	7	15	15	13	13	14	13	0	0	
ΣR ^b	0	0	0	1608	3101	1152	928	1173	2145	1555	0	0	11661
R_k ^c	0	0	0	230	207	77	71	90	153	120	0	0	948
% <i>R</i> ^d	0	0	0	24	22	8	8	10	16	13	0	0	100
% <i>R</i> ^e	0	0	0	24	46	54	62	71	87	100	100	100	
<i>R</i> ^f	0	0	0	409	283	170	140	123	450	311	0	0	450

- ^a Numbers of years
- ^b Total energy flux
- ^c Average energy flux
- ^d Average monthly percentage of energy flux
- ^e Cumulative average monthly percentage of energy flux
- ^f Maximum energy flux

Table 2 Monthly antecedent soil moisture subfactors (SM) of RUSLE-C calculated from precipitation and evapo-transpiration data (P–PE) of the catchment

Month	1	2	3	4	5	6	7	8	9	10	11	12
P ^a	44.2	28.9	34.3	53.5	58.1	40.7	22.3	18.9	17.2	33.6	31.2	45.8
PE ^b	0.00	1.6	18.2	49.8	88.1	121.7	152.1	136.5	87.2	47.4	13.6	2.0
P–PE	44.2	27.3	16.1	3.7	–30.0	–81.0	–129.8	–117.6	–70.00	–13.8	17.6	43.8
SM	1.00	0.90	0.84	0.77	0.57	0.28	0.00	0.07	0.34	0.67	0.85	1.00

- ^a Monthly average rainfall (1993–2007)
- ^b Monthly average evapo-transpiration (1993–2007)

catchment allowed, and it was very hard to collect soil samples with regular intervals at a grid base and their coordinates were determined by the Geographical Position System (GPS). A total of 311 soil samples were collected from two land uses, 158 samples from the grassland and 153 samples from the mixed forest, in May 2006 with irregular intervals from the mineral soil layer of 0–10 cm. Soil samples were analyzed for clay (C), silt (Si), and sand (S) contents and coarse sand (CS) by wet sieving through 0.100-mm screen openings (Soil Survey Staff 1996). The method of Nelson and Sommers (1982) was used to determine soil organic matter (SOM). Spatial correlation and spatial patterns of RUSLE-K were evaluated by the geostatistics and Arc view 9.2. Using the same soil data set as given in Table 3; Saygin et al. (2011) have recently compared the geostatistical performance of the commonly used different soil erodibility equations in the catchment of the Saraykoy II Irrigation Dam, and concluded that the values for mean absolute error (MAE) and mean square error (MSE) of Eq. 6 (Torri et al. 1997, 2002) were smaller than those of the

other erodibility equations developed by Wischmeier et al. (1971), Wischmeier and Smith (1978) and Römken et al. (1986). Therefore, Eq. 6 was preferred to describe the soil erodibility of the study area since its predictions by the kriging maps were much closer to the true values.

Experimental semivariogram for the separation distance (lag) *h* for the values of RUSLE-K was calculated by Eq. 7.

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \tag{7}$$

where $z(x_i)$ is the value of the calculated RUSLE-K from the measured soil properties at spatial location x_i and $N(h)$ is the number of RUSLE-K pairs with the separate distance (lag) h . The data were fitted to the exponential model for experimental semivariograms. In addition, the empirical semivariogram was directionally estimated at the angles of 0° (N–S), 45° (NE–SW), 90° (E–W), and 135° (SE–NW) to determine if the measured variables had any severe anisotropy. Since this indicated no severe anisotropy, Omni-directional semivariograms were

Table 3 Pixel-based weighted average values over every sub-catchment of the RUSLE factor layers

Sub-catchment		Area-weighted RUSLE predictor variables				Predicted soil losses (t ha ⁻¹ year ⁻¹)		SDR
No	Area (ha)	<i>R</i>	<i>K</i>	LS	<i>C</i>	<i>A</i> = RKLS	<i>A</i> = ARKLSC	
1	12.61	1,203.8	0.0340	19.52	0.095	798.938	75.899	0.350
2	8.42	1,210.6	0.0340	19.29	0.094	793.984	74.635	0.350
3	10.69	1,255.1	0.0326	16.21	0.095	663.253	63.009	0.366
4	22.12	1,267.7	0.0329	12.22	0.096	509.664	48.928	0.450
5	32.32	1,255.4	0.0334	13.74	0.088	576.123	50.699	0.484
6	4.55	1,142.1	0.0316	16.87	0.056	608.844	34.095	0.106
7	17.87	1,223.0	0.0341	18.85	0.065	786.126	51.098	0.506
8	13.26	1,170.7	0.0327	20.33	0.059	778.271	45.918	0.351
9	9.90	1,144.7	0.0324	18.62	0.068	690.584	46.960	0.193
10	5.85	1,121.8	0.0325	16.31	0.073	594.638	43.409	0.150
11	1.90	1,106.9	0.0299	21.90	0.034	724.809	24.644	0.106
12	13.41	1,153.7	0.0303	22.65	0.019	791.779	15.044	0.310
13	12.10	1,199.6	0.0295	22.91	0.016	810.744	12.972	0.356
14	22.25	1,126.4	0.0289	19.41	0.016	631.853	10.110	0.531
15	5.78	1,196.5	0.0301	22.53	0.017	811.41	13.794	0.150
16	5.20	1,227.9	0.0302	18.88	0.018	700.119	12.602	0.106
17	14.52	1,297.8	0.0284	15.75	0.015	580.506	8.708	0.350
18	1.75	1,268.8	0.0297	18.53	0.015	698.273	10.125	0.106
19	5.45	1,317.3	0.0282	17.86	0.015	663.461	9.687	0.139
20	5.08	1,385.4	0.0288	12.80	0.011	510.714	5.618	0.150
21	11.85	1,407.8	0.0294	15.06	0.011	623.323	6.607	0.350
22	4.07	1,385.4	0.0272	15.85	0.010	597.274	5.973	0.150
23	5.20	1,318.8	0.0280	17.64	0.011	651.382	7.426	0.150
24	6.72	1,290.4	0.0298	13.79	0.012	530.280	6.151	0.106
25	9.44	1,246.6	0.0298	20.49	0.019	761.176	14.767	0.150
	Σ262.31	1,232.2 ^a	0.0313 ^a	17.48 ^a	0.050 ^a	Σ16,887.526 ^b	Σ698.875 ^c	0.344a
								Σ240.41 ^d
								Σ50,450.19 ^e

^a Weighted average of *R*, *K*, LS, *C* and SDR factors estimated by areal distribution (%) of the sub-watersheds

^b Predicted potential soil loss obtained from sub-catchments (t ha⁻¹ year⁻¹)

^c predicted actual soil loss by the model (t ha⁻¹ year⁻¹)

^{d, e} Predicted sediment arriving in the reservoir by the units of t ha⁻¹ year⁻¹ and m³ year⁻¹, respectively

obtained using the best fitting model by the cross-validation method, and the data were modeled with isotropic functions to determine the spatially dependent variance within the research area (Saygin et al. 2011).

The RUSLE-K values at the observation points were used for predicting the values of unknown points using the ordinary kriging interpolation method by the generated model and parameters of the semivariogram. The software package GS+7 (Gamma Design Software) was used to perform geostatistical computation. A map of RUSLE-K was generated in the geostatistical tool of the Arc view 9.2 by means of the variogram models and parameters to obtain a high quality map.

Slope length (L) and steepness (S) factor (RUSLE-LS)

The slope length factor (*L*) and steepness factor (*S*), which are together described as the topographic factor in the RUSLE (RUSLE-LS) in a combined manner, was computed through an interaction between topography and flow accumulation (Moore and Bruch 1986a, b). By this way, the RUSLE-LS factor (Eq. 8) relied not only on steepness and length of slope but also on the flow expected to occur over land and later to concentrate on water courses of the catchment. A slope steepness layer was derived from DEM of the study area, and slope length was assumed to be fixed as 15 m for each pixel (Ogawa et al. 1997).

$$LS = \left(\frac{\chi\eta}{22.13}\right)^{0.4} \times \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \tag{8}$$

where χ is the flow accumulation and was derived from DEM using a GIS accumulation algorithm, which employs the watershed delineation tool of Arc view 9.2 (Lee 2004), η is the cell size, and θ is the slope steepness in degrees.

Cover management factor (RUSLE-C)

Cover management factor of the RUSLE (RUSLE-C) was computed based on the soil-loss ratios (SLR), introduced after Lafien et al. (1985) to the revised technology, as a product of five subfactors representing prior land use (PLU), surface cover (SC), crop canopy (CC), surface roughness (SR) and soil moisture (SM) by Eq. 9.

$$SLR = PLU \times CC \times SC \times SR \times SM \tag{9}$$

Since the catchment of the Saraykoy II Irrigation Dam is chiefly composed of the land uses of grassland and forest (Fig. 1), the annual soil-loss ratios were computed in this research other than the seasonal soil-loss ratios (Renard et al. 1997). The measured parameters in the field and the estimating equations together with their coefficients for the subfactors of PLU, CC, SC and SR are given by Eqs. 10–14.

$$PLU = C_f \times C_b \times \exp[(-c_{ur} \times B_{ur})] \tag{10}$$

where, B_{ur} is the mass density of live and dead roots found in the upper centimeter of the soil ($\text{kg ha}^{-1} \text{m}^{-1}$), C_f is a surface soil consolidation factor, C_b is the relative effectiveness of subsurface residue in consolidation, c_{uf} is the impact of soil consolidation on the effectiveness of incorporated residue, and c_{ur} and c_{us} are the calibration coefficients indicating the impacts of subsurface residues.

$$CC = 1 - F_c \times \exp(-0.1 \times H) \tag{11}$$

where F_c is the fraction of land surface covered by canopy (%) and H (m) is the distance that raindrops fall after striking the canopy.

$$SC = \exp\left[-b \times S_p \times \left(\frac{0.24}{R_u}\right)^{0.08}\right] \tag{12}$$

$$S_p = [1 - \exp(-\alpha \times B_s)] \times 100 \tag{13}$$

where S_p (%) is the percentage of land area covered by surface cover, which was further evaluated by the dry weight of residues on the surface (B_s , kg ha^{-1}) (Eq. 13), b is an empirical coefficient that indicates the effectiveness of surface cover in reducing soil erosion, R_u (cm) is the surface roughness at initial conditions and

just before tillage practices, and α is the ratio of the area covered by a piece of residue to the mass of that residue (ha kg^{-1}). Again, for there were no soil disturbances by tillage practices in the research area, a roughness value for rangeland conditions ($R_u = 1.00$ for mixed grass) was assumed for both Eqs. 13 and 14.

$$SR = \exp[-0.66(R_u - 0.24)] \tag{14}$$

Antecedent soil moisture sub-factor (SM) of RUSLE-C was monthly attained relying on a water balance determined by calculating the input, output, and storage from precipitation and evapotranspiration data (P–PE) (Table 2). A severe water conditions occurs on July in the area, therefore this value could be taken as a “field wilting point” to calculate a practical value for the lower bound of the SM value ($SM = 0$) ($P - PE = -129.8$ mm), indicating that no runoff and erosion are expected. As well, since the soil is sufficiently wet on January ($P-PE = 44.2$ mm), a “field capacity” might be assumed for this month with the value of $SM = 1$ as an upper bound. The other numerical values of P–PE between the bounds were interpolated for the SM values, and the annual average value for SM was calculated as 0.61.

Support practice factor (RUSLE-P)

Because there were no conservation practices designed to reduce the amount and rate of runoff and accordingly the amount of sediment reaching the reservoir, the support practice factor was assumed as 1 in the study area ($RUSLE-P = 1$). The soil loss was calculated for 25 sub-catchments, delineated in Fig. 1, by the factor layers obtained by both GIS and Geostatistics (ArcGIS 9.2 software), and then a sum was taken to predict the gross soil loss (A_t , $\text{t ha}^{-1} \text{year}^{-1}$) (Eq. 15) from the catchment of the Saraykoy II Irrigation Dam.

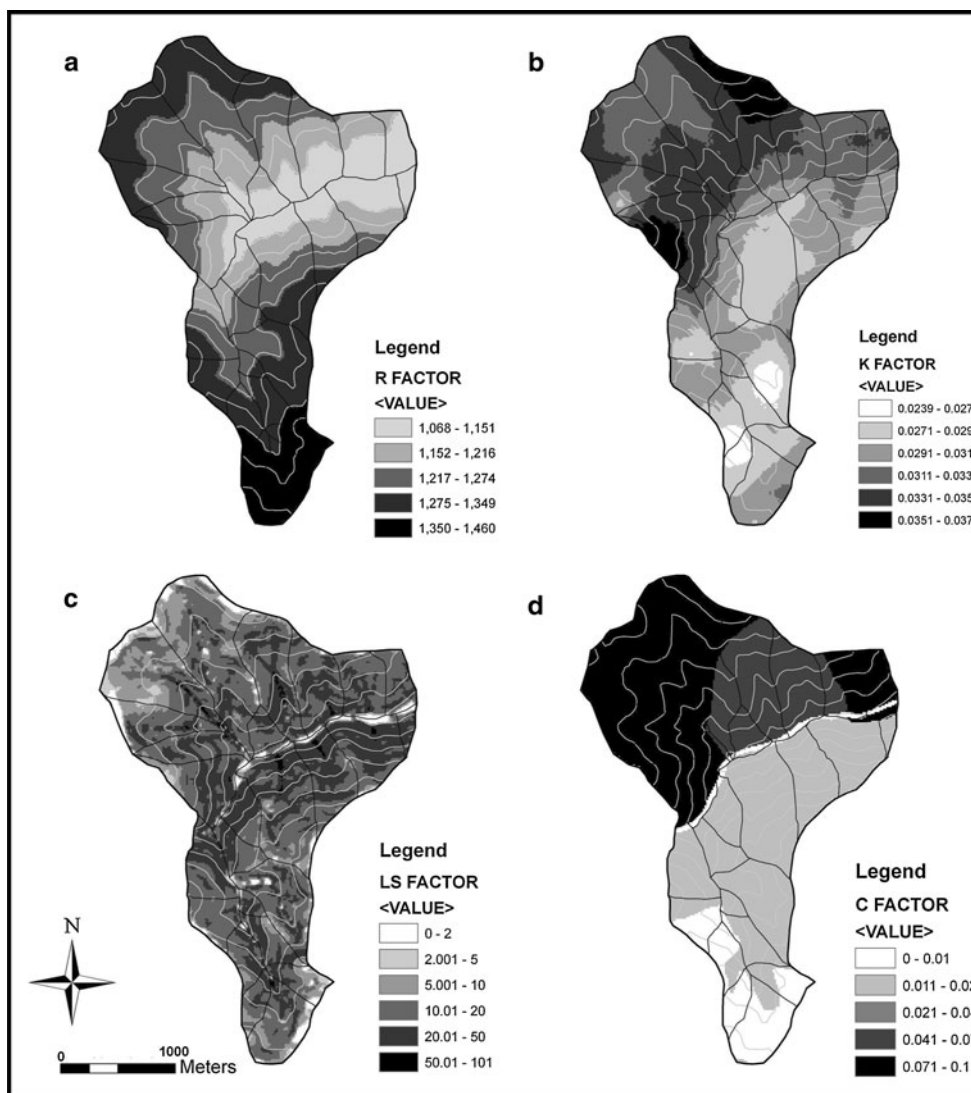
$$A_t = \sum_{i=1}^{25} A_i = A_1 + A_2 + A_3 + A_4 + \dots + A_{25} \tag{15}$$

where A_i is the estimated soil loss from i th sub-catchment. All GIS calculations were implemented on a pixel-by-pixel basis or a grid with 10×10 m cell in a uniform coordinate system.

Sediment delivery ratio (SDR)

A weighted SDR value for whole-of-catchment of the Saraykoy II Irrigation Dam area was calculated by Eqs. 16 and 17 (Ferro et al. 2001; Ferro and Minacapilli 1995, respectively).

Fig. 2 Spatial distributions of the rainfall erosivity factor (RUSLE-R) (a), the soil erodibility factor (RUSLE-K) (b), the slope-length factor (RUSLE-LS) (c), and the cover management factor (RUSLE-C) (d)



$$\begin{aligned}
 \text{SDR} &= \frac{1}{(\text{SA})_t} \sum_{i=1}^N (\text{SDR}_i \times \text{SA}_i) \\
 &= \frac{1}{(\text{SA})_t} \sum_{i=1}^N \left(\exp \left[-\beta_i \frac{l_{p,i}}{\sqrt{s_{p,i}}} \right] \times \text{SA}_i \right) \quad (16)
 \end{aligned}$$

where $(\text{SA})_t$ is the total surface area of the catchment (262.31 ha), N : numbers of the evaluated hydrological units ($i = 25$); $(\text{SA})_i$ is the surface area of the i th sub-catchment (ha); SDR_i is the defined SDR for each sub-catchment; $l_{p,i}$ and $s_{p,i}$ are length and slope of the hydraulic path found in each sub-catchment; β is the coefficient (m^{-1}) that is assumed constant for a given basin. Ferro et al. (2001) suggested to the Eq. 17 for calculating of the β coefficient.

$$\beta_i = 0.2802(\text{RUSLE-R})_i^{-0.6689} \quad (17)$$

where $(\text{RUSLE-R})_i$ and β_i are the rainfall erosivity factor and the SDR coefficient value estimated for i th sub-

catchment, respectively. Since an erosivity gradient occurred in RUSLE-R layer depending on the elevation distribution in each sub-catchment, an areal weighted average was computed for using in Eq. 17 by 18.

$$(\text{RUSLE-R})_i = \sum_{k=1}^n \frac{\text{SA}_k \times (\text{RUSLE-R})_k}{\text{SA}_i} \quad (18)$$

where SA_k and $(\text{RUSLE-R})_k$ are the surface area (ha) and the erosivity value ($\text{MJ mm ha}^{-1} \text{h}^{-1} \text{year}^{-1}$) of the k th gradient class, and n is the gradient class number occurred in i th sub-catchment. The same approach as that given by Eq. 18 were used to calculate $(\text{RUSLE-K})_i$, $(\text{RUSLE-LS})_i$ and $(\text{RUSLE-C})_i$ in the case that different factor classes existed in sub-catchment level.

Finally, the spatial distributions of the potential and actual erosion risks by the RUSLE methodology were obtained and the sediment yield for the Dam reservoir was calculated using Eq. 1.

Results and discussion

The factor layers of the RUSLE methodology were shown in Fig. 2 as outputs of both GIS and geostatistics, and their pixel-based weighted average values over every sub-catchment were given in Table 3. Within sub-catchments, the values were between 1,106.9 and 1,407.8 MJ mm ha⁻¹ h⁻¹ year⁻¹, 0.0272 and 0.0341 t ha h ha⁻¹ MJ⁻¹ mm⁻¹, 12.22 and 22.91 and 0.011 and 0.095 for RUSLE-R, -K, -LS, and -C, respectively.

The average annual RUSLE-R factor value varies from 1,068 to 1,460 MJ ha⁻¹ mm h⁻¹ year⁻¹ with a mean value of 1,232 ± 84.66 MJ ha⁻¹ mm h⁻¹ year⁻¹ in the catchment. South and southwest parts of the catchment had the greater rainfall erosivity values than those in the north and northwest parts. Figure 2a clearly shows an erosivity gradient, increasing from center of the catchment either to the northwest or to the south depending on the differences in the elevation. Not only spatial distribution, but also temporal distribution of RUSLE-R is very significant for the semi-arid regions of Central Anatolia, where highly uneven rainfall events happen (Bayramin et al. 2006, Ozcan et al. 2008). Therefore, the semi-arid catchment of the Saraykoy II Irrigation Dam is in the climatically sensible transition zone between the Central Anatolia Steppe and the Black Sea Forests in Turkey.

Figure 3 and Table 4 show the geostatistical model and parameters for isotropic semivariogram of RUSLE-K, respectively. An empirical semivariogram of the RUSLE-K factor was defined using exponential model. The nugget

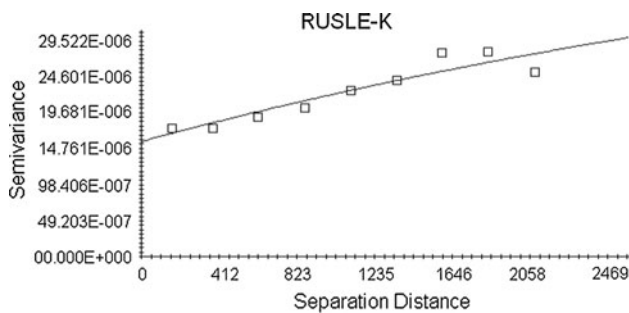


Fig. 3 Semivariogram of RUSLE-K (Saygin et al. 2011)

effect was 0.000016 and sill value was 0.000052. The maximum spatial correlation was found 5,097 m (Table 4).

The kriging map produced using the parameters of the geostatistics was depicted in Fig. 2b. The map indicated that the RUSLE-K factor varied between 0.023 and 0.037 t ha h ha⁻¹ MJ⁻¹ mm⁻¹ with a mean value of 0.031 ± 0.002 t ha h ha⁻¹ MJ⁻¹ mm⁻¹ in the catchment. The spatial pattern of RUSLE-K changed with the land use types. Especially, the higher values were in the northern part of the catchment, where the grassland was located; and the southern part where the deciduous, mixed and coniferous plantations were sited had the lower values of the USLE-K factor. Saygin et al. (2011) explained this situation with soil organic matter content. Soils developed under mixed forest had the higher organic matter content than those under the grassland. The studies indicated that the organic matter had some regulatory roles over numerous physical soil features like bulk density, hydraulic conductivity, aggregate stability, etc., greatly affecting soil susceptibility to erosion (Cerdeira 1996; Wu and Tiessen 2002; Basaran et al. 2008).

The dimensionless RUSLE-LS (Fig. 2c) was calculated using DEM of the watershed and considering the interactions between topography and flow accumulation (Eq. 8). The average annual RUSLE-LS factor value was in the range of 0 and 101 with a mean value of 17.48 ± 3.05. Indeed, the dominant classes had the values of 5 < RUSLE-LS ≤ 10, 10 < RUSLE-LS ≤ 20 and 20 < RUSLE-LS ≤ 50, and their spatial coverage in the catchment were 13.37, 46.68 and 32.71 %, respectively, totaling 92.76 %. The results suggested that the topography mostly favored higher erosion rates, and particularly 32.71 % of steeper and longer slopes was combined with the drainage pattern of the catchment such that the accumulated water amounts with higher velocities could occur, giving rise to greater erosion rates.

The value for the average annual RUSLE-C factor ranges from 0.01 to 0.1 with a mean value of 0.050 ± 0.033. The highest value (low soil protection) was in the northern part (grassland) while the southern part of the catchment (mixed forest) had the smallest value.

The different soil loss layers of the RUSLE methodology were shown in Fig. 4. In our study assessing the soil

Table 4 Parameters of the fitted variogram for the soil erodibility equations in the catchment area of Saraykoy II Irrigation Dam (Saygin et al. 2011)

Variable	Model	C ₀ ^a	C ₀ + C ^b	C ₀ /(C ₀ + C)	C ₁ ^c	a (m) ^d	R ²
RUSLE_K	Exponential	0.000016	0.000052	31	0.000036	5,097.00	0.867

^a Nugget variance

^b Sill variance

^c Structural variance

^d Range of influence in meters

Fig. 4 Erosion risk assessments for potential and actual soil losses by RUSLE (a, b, respectively) and the sediment delivery ratios at the sub-catchment level in the semi-arid catchment of the Saraykoy II Irrigation Dam

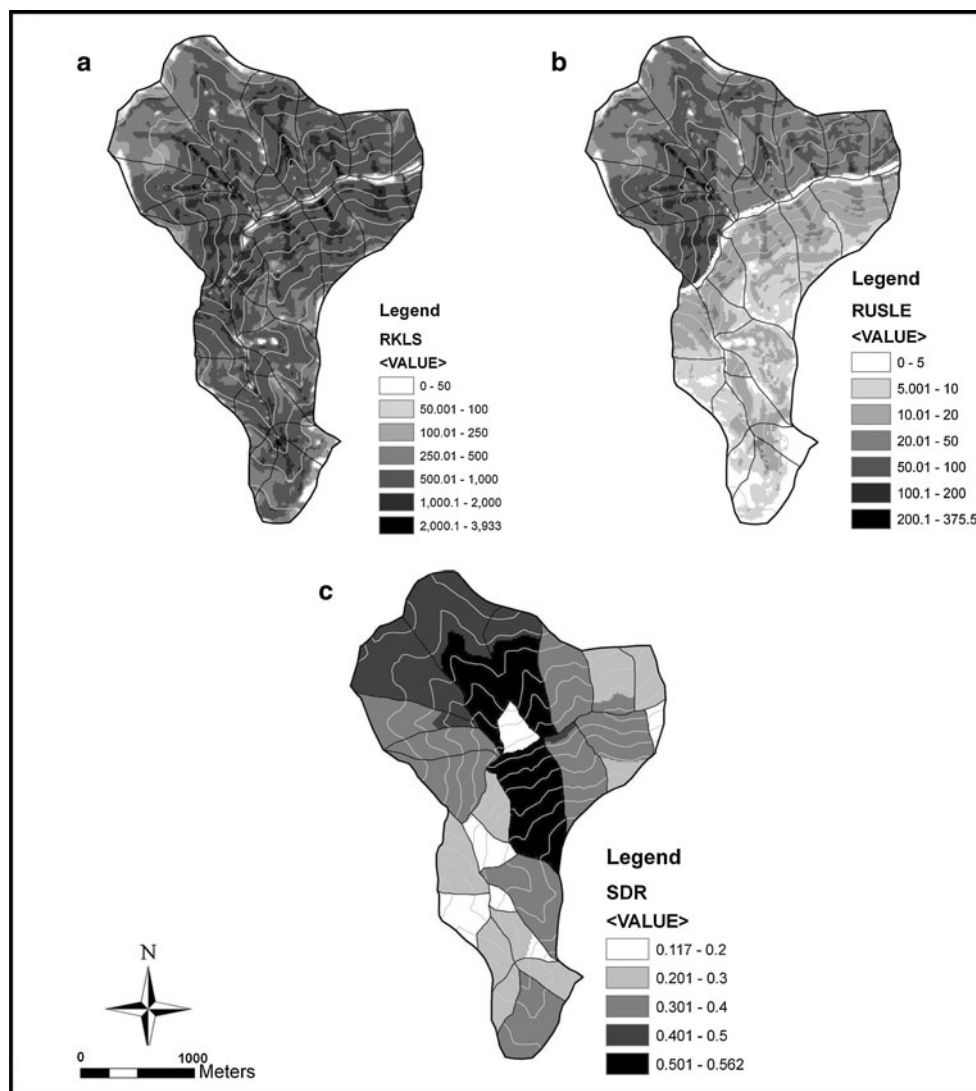


Table 5 The spatial distribution (%) of the annual actual soil losses ($\text{t ha}^{-1} \text{ year}^{-1}$) in terms of the land uses in the catchment the Saraykoy II Irrigation Dam

Soil loss ($\text{t ha}^{-1} \text{ year}^{-1}$)	Coniferous ^a	Deciduous ^a	Grassland ^a	Mixed ^a	River ^a	Spatial distribution (%) ^b
0–5	5.76	0.74	1.68	1.64	1.37	11.19
5–10	6.89	2.04	0.53	7.71		17.16
10–20	3.91	12.13	1.81	3.63		21.47
20–50	0.42	2.23	23.96	0.01		26.62
50–100		0.02	20.92			20.93
100–200			2.45			2.45
200–375			0.17			0.17
Total	16.98	17.16	51.51	12.99	1.37	100.00

^a Land uses defined in the catchment the Saraykoy II Irrigation Dam

^b Spatial distribution (%) of the land uses by the annual actual soil losses

erosion risk in the semi-arid catchment of the Saraykoy II Irrigation Dam, the first approximation was made for a potential soil loss map (Fig. 3a), which represented a

possible soil loss condition where $\text{RUSLE-C} = 1$. Therefore, at any time when the protective vegetation cover is entirely destroyed, the annual potential soil losses that

might occur in each sub-watershed are given in Table 3, being a sum of $16,887.5 \text{ t ha}^{-1} \text{ year}^{-1}$ for the catchment itself (Eq. 15). Although this stands for an extreme case of completely barren catchment, given its fragility, it is not unusual that progressive disturbance of the vegetation cover would cause the catchment to arrive at this stage of vulnerability in a short span of time.

A second estimation was performed for an actual soil loss map (Fig. 4b) with a calculated value of RUSLE-C for each sub-watershed. An annual total value for the catchment is estimated to be $698.875 \text{ t ha}^{-1} \text{ year}^{-1}$ (Table 3). Particularly, along with the greater RUSLE-R values, the fact that the relatively higher factor values of both RUSLE-K and RUSLE-C occur at northern and northwest sub-catchments (1–10) (Fig. 1) resulted in more soil losses than those located in central and southern sub-catchments (11–25). The former ones produced 77 % ($534.649 \text{ t ha}^{-1} \text{ year}^{-1}$), while the latter 15 sub-catchments yielded 23 % ($164.226 \text{ t ha}^{-1} \text{ year}^{-1}$) of the total soil loss in the catchment.

Besides, the spatial distribution of the annual actual soil losses in terms of the land uses over the whole catchment is shown in Table 5. The coverage percentages of the coniferous, deciduous and mixed forests are 16.98, 17.16 and 12.99 %, respectively. Given the actual soil loss classes for erosion risk mapping, very low ($\leq 5 \text{ t ha}^{-1} \text{ year}^{-1}$), low ($5\text{--}10 \text{ t ha}^{-1} \text{ year}^{-1}$), moderate ($10\text{--}20 \text{ t ha}^{-1} \text{ year}^{-1}$), high ($20\text{--}50 \text{ t ha}^{-1} \text{ year}^{-1}$) and very high ($>50 \text{ t ha}^{-1} \text{ year}^{-1}$), Table 5 shows that very few areas of the forest, particularly 71 % of the deciduous forest, totally constituting 17.16 % of the catchment area, had moderate erosion risk. On the other hand, the grassland with relatively higher RUSLE-C values (Fig. 2d) showed high and very high risks (23.96 and 23.54 %, respectively). These together amounted approximately to 92 % of the grassland, which is 51.51 % of the total area of the catchment.

A final prediction was made to find the sediment yield at the catchment outlet using the combined RUSLE/SDR approach. The calculated values of SDR for each sub-catchment by Eqs. 16 and 17 are given in Table 3 and mapped in Fig. 4c. The SDR values ranged between 0.106 and 0.506 based on the length and slope of the hydraulic path found in each sub-catchment. The northern part of the catchment having the sub-catchments with the much higher SDR values evidently contributed more sediment transport downward. The weighted SDR value for whole-of-catchment of the Saraykoy II Irrigation Dam area was 0.344, causing about $240.41 \text{ t ha}^{-1} \text{ year}^{-1}$ inflow of sediment into the reservoir. This value is equal to the amount of $63,061.95 \text{ t year}^{-1}$ when the whole catchment area is taken into consideration. To have sediment concentration in the unit of “ $\text{m}^3 \text{ year}^{-1}$ ”, $63,061.95 \text{ t year}^{-1}$ was divided by the average bulk density of sediments already deposited in the

reservoir (1.25 t m^{-3}). This resulted in $50,450.19 \text{ m}^3$ annual inflow of sediments into the reservoir. Finally, the life expectancy of the dam is estimated as 10.09 year using the total storage capacity of the constructed dam ($509 \times 10^3 \text{ m}^3$). As a result, there was a clear evidence that a small dam to be constructed in such an ecosystem without conservation measures of erosion and sediment controls would not be economically viable with a rather short life expectancy. This finding clearly indicated that there is a need for water-catchment management and soil conservation measures to reduce erosion. Of the factor values of the RUSLE methodology, the most decisive one affecting soil erosion in the catchment was RUSLE-LS, which accounted for the interaction between topography and overland flow accumulation and averagely increased the soil losses 17.48 times (Table 3). Therefore, constructing check dams are very important for controlling drainage and deposition patterns of the catchment to reduce the sediment-carrying capacity of the accumulated flows to the reservoir. In addition, the controlled grazing to have better plant cover might significantly mitigate the erosion risk in the grassland, which potentially produced greater soil losses.

Conclusion

The objective of this study was to estimate annual sediment flux rates in a semi-arid catchment of Saraykoy II Irrigation Dam, Cankırı, Turkey and to evaluate the dam's economic life from the viewpoint of sustainable use of water resources in the region. For this purpose, RUSLE/SDR approach integrated with GIS and geostatistics was applied. The results indicated that the dam would not be economically sustainable if soil and water conservation measures in the catchment are not taken. Especially, the results on grassland showed much higher potentiality for producing soil loss than the coniferous, deciduous and mixed forests did. Thus, to lengthen the lifespan of the dam, conservative practices are strongly suggested in this fragile semi-arid ecosystem. Specifically, controlled grazing systems would protect the natural vegetation cover in the grassland which more significantly contributed to the soil loss in the catchment. Additionally, reclaiming the gullies by structural measures (check dams) together with vegetative protection (grassed waterways) would help transporting concentrated flows at safe energies that could not deliver sediments into the reservoir. It is important to highlight that without taking these management practices by policy makers and land managers, the erosion rate would reach to a critical level in such semi-arid catchments that its economic impacts could affect the sustainability of local people with a strong dependence upon the land.

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References

- Akyurek Z, Okalp K (2006) A fuzzy-based tool for spatial reasoning: a case study on soil erosion hazard prediction. In: Caetano M, Painho M (eds) Proceedings of the 7th International Symposium on Spatial accuracy assessment in Natural Resources and Environmental Sciences, July 5–7, Lisbon, Portugal, pp 719–729
- Amore E, Modica C, Nearing MA, Santoro CV (2004) Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. *J Hydrol* 293:100–114
- Angima SD, Stott DE, O’Neill MK, Ong CK, Weesies GA (2003) Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agric Ecosyst Environ* 97:295–308
- Anonymous (1988) Çankırı-E16 paftası 1/100000 ölçekli açınsama nitelikli Türkiye jeoloji haritaları serisi. Maden Teknik Arama Genel Müdürlüğü. Ankara (in Turkish)
- Arnold JG, Williams JR, Srinivasan R, King KW (1996) SWAT—soil and water assessment tool. SWAT User’s Manual. Texas A&M University, Temple
- Banasik K, Walling DE (1996) Predicting sediment graphs for a small agricultural catchment. *Nord Hydrol* 27(4):275–294
- Bartsch KP, Van Miegroet H, Boettinger J, Dobrowolski JP (2002) Using empirical erosion models and GIS to determine erosion risk at Camp Williams. *J Soil Water Conserv* 57:29–37
- Basaran M, Erpul G, Tercan AE, Canga MR (2008) The effects of land use changes on some soil properties in Indağı Mountain Pass-Cankırı, Turkey. *Environ Monit Assess* 136:101–119
- Baskan O, Cebel H, Akgul S (2010) Conditional simulation of USLE/RUSLE soil erodibility factor by geostatistics in a Mediterranean Catchment, Turkey. *Environ Earth Sci* 60(6):1179–1187
- Bayramin I, Erpul G, Erdogan HE (2006) Use of CORINE methodology to assess soil erosion risk in the semi-arid area of Bepazari, Ankara. *Turk J Agric For* 30:81–100
- Beskow S, Mello CR, Norton LD, Curi N, Viola MR, Avanzi JC (2009) Soil erosion prediction in the Grande River Basin. Brazil using distributed modeling. *Catena* 79:49–59
- Cambazoglu MK, Gogus M (2004) Sediment yields of basins in the Western Black sea region of Turkey. *Turk J Eng Environ Sci* 28:355–367
- Celik I (2005) Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. *Soil Till Res* 83:270–277
- Cerda A (1996) Soil aggregate stability in three Mediterranean environments. *Soil Technol* 9:133–140
- Cerri CEP, Dematte JAM, Ballester MVR, Martinelli LA, Victoria RL, Roose E (2001) GIS erosion risk assessment of the Piracicaba River Basin, southeastern Brazil. *Gisci Remote Sens* 38:157–171
- De Vente J, Poesen J, Arabkhedri M, Verstraeten G (2007) The sediment delivery problem revisited. *Prog Phys Geogr* 31:155–178
- Dogan O (2002) Erosive potentials of rainfalls in Turkey and erosion index values of Universal Soil Loss Equation (publication no. 220, Report no. R-120). Ankara, Turkey: Publications of Ankara Research Institutes, General Directorate of Rural Service
- Efe R, Ekinci D, Cürebal İ (2008a) Erosion analysis of Fındıklı Creek watershed (NW of Turkey) using GIS based RUSLE (3D) method. *Fresen Environ Bull* 17(5):568–576
- Efe R, Ekinci D, Cürebal İ (2008b) Erosion analysis of Şahin Creek watershed (NW of Turkey) using GIS based RUSLE (3D) method. *J Appl Sci* 8(1):49–58
- Ekinci D (2005) Erosion analysis of Kozlu River basin with the GIS based a modified Rusle method. *IU Geogr Bull* 13:109–119
- Erdogan EH, Erpul G, Bayramin I (2007) Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. *Environ Monit Assess* 131:153–161
- Evrendilek F, Celik I, Kılıç S (2004) Changes in soil organic carbon and other physical soil properties along adjacent Mediterranean forest, grassland, and cropland ecosystems in Turkey. *J Arid Environ* 59:743–752
- Ferro V, Minacapilli M (1995) Sediment delivery processes at basin scale. *Hydrolog Sci J* 40(6):703–717
- Ferro V, Bagarello V, Di Stefano C, Giordano G, Porto P (2001) Monitoring and predicting sediment yield in a small Sicilian basin. *Trans ASAE* 44(3):585–595
- Fistikoglu O, Harmancioglu NB (2002) Integration of GIS and USLE in assessment of soil erosion. *Water Resour Manag* 16:447–467
- Foster GR, Jane LJ, Nowlin JD, Lafren JM, Young RA (1981) Estimating erosion and sediment yield on field size areas. *Trans ASAE* 24(5):1253–1262
- GDPS (General Directorate of Rural Service) (1986) 1/25000 Soil Map of Ankara, Turkey. Digital Soil Database: Soil and Water Resources National Information Centre, Turkey
- Goovaerts P (1999) Using elevation to aid the geostatistical mapping of rainfall erosivity. *Catena* 34:227–242
- Grimm M, Jones RJA, Rusco E, Montanarella L (2003) Soil erosion risk in Italy: a revised USLE approach. European Soil Bureau Research Report No. 11, EUR 20677 EN (2002). Office for official publications of the European Communities, Luxembourg
- Irvem A, Topaloglu F, Uygur V (2007) Estimating spatial distribution of soil loss over Seyhan River Basin in Turkey. *J Hydrol* 336:30–37
- Jain SK, Kumar S, Varghese J (2001) Estimation of soil erosion for a Himalayan watershed using GIS technique. *Water Resour Manag* 15:41–54
- Karabulut M, Küçükönder M (2008) Kahramanmaraş Ovası ve Çevresinde CBS Kullanılarak Erozyon Alanlarının Tespiti. *KSÜ Fen ve Mühendislik Dergisi* 11(2):14–22 (in Turkish)
- Karaburun A (2009) Estimating potential erosion risks in Corlu using the GIS-based RUSLE method. *Fresen Environ Bull* 18(9):1692–1700
- Karaburun A, Demirci A, Karakuyu M (2009) Erozyon Tahmininde Cbs Tabanlı Rusle Metodunun Kullanılması: Büyükçekmece Örneği. 3. Ulusal DEÜ CBS Sempozyumu. CBS ve Bilgi Teknolojileri Bildiriler Kitabı. İzmir, Türkiye (in Turkish), pp 43–49
- Kaya P (2008) Türkiye’ de Uzun Dönem Verileri Kullanılarak Ulusal Ölçekte RUSLE-R Faktörünün Belirlenmesi. Ankara Üniversitesi Fen Bilimleri Enstitüsü Basılmamış Yüksek Lisans Tezi (in Turkish)
- Kinnell PIA, Risse LM (1998) USLE-M: empirical modeling rainfall erosion through runoff and sediment concentration. *Soil Sci Soc Am J* 62:1667–1672
- Kothyari UC, Jain SK (1997) Sediment yield estimation using GIS. *Hydrolog Sci J* 42:833–843
- Kouli M, Soupios P, Vallianatos F (2009) Soil erosion prediction using the revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ Geol* 57:483–497
- Lafren JM, Foster GR, Onsiadt CA (1985) Simulation of individual-storm soil loss for modeling impact of erosion on crop productivity. In: Soil erosion and conservation. Proceedings of International Conference on soil erosion and conservation,

- Honolulu, HI. January 16–22, 1983. Soil Conservation Society of America, Ankeny I A, pp 285–295
- Lee S (2004) Soil erosion assessment and its verification using the Universal Soil Loss Equation and geographic information system: a case study at Boun. *Korea Environ Geol* 45:457–465
- Li AN, Wang AS, Liang SL (2006) Eco-environmental vulnerability evaluation in mountainous region using remote sensing and GIS: a case study in the upper reaches of Mingjiang River, China. *Ecol Model* 192:175–187
- Licznar P, Nearing MA (2003) Artificial neural networks of soil erosion and runoff prediction at the plot scale. *Catena* 51:89–114
- Lu DLG, Valladares GS, Batistella M (2004) Mapping soil erosion risk in Rondonia. Brazilian Amazonia: using RUSLE. Remote sensing and GIS. *Land Degrad Dev* 15:499–512
- Lu H, Moran CJ, Prosser IP (2006) Modelling sediment delivery ratio over the Murray darling Basin. *Environ Modell Softw* 21:1297–1308
- Lufafa A, Tenywa MM, Isabirye M, Majaliwa MJG, Woomeer PL (2003) Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based universal soil loss model. *Agric Syst* 76:883–894
- Ma JW, Xue Y, Ma CF, Wang ZG (2003) A data fusion approach for soil erosion monitoring in the Upper Yangtze River Basin of China based on Universal Soil Loss Equation (USLE) model. *Int J Remote Sens* 24:4777–4789
- Martin A, Gunter J, Regens J (2003) Estimating erosion in a riverine watershed, Bayou Liberty—Tchefuncta River in Louisiana. *Environ Sci Pollut R* 10(4):245–250
- Mati BM (2000) Assessment of erosion hazard with USLE and GIS—a case study of the upper Ewaso Ngiro Basin of Kenya. *Int J Appl Earth Observ Geoinform* 2:78–86
- Mati BM, Veihe A (2001) Application of the USLE in a savannah environment: comparative experiences from east and West Africa. *Singap J Trop Geo* 22:138–155
- Millward AA, Mersey JE (1999) Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. *Catena* 38:109–129
- Molnar DK, Julien PY (1998) Estimation of upland erosion using GIS. *Comput Geosci* 24(2):183–192
- Moore ID, Burch GJ (1986a) Modeling erosion and deposition. Topographic effects. *Trans Asae* 29:1624–1630
- Moore ID, Burch GJ (1986b) Physical basis of the length–slope factor in the Universal soil loss equation. *Soil Sci Soc Am J* 50:1294–1298
- Nelson DW, Sommers LE (1982) Total Carbon, organic carbon, and organic matter. In: Page AL (ed). *Methods of soil analysis*. Part 2. 2nd edn. American Society of Agronomy, Madison. pp 539–579
- Ogawa S, Saito G, Mino N, Uchida S, Khan NM, Shafiq M (1997) Estimation of soil erosion using USLE and Landsat TM in Pakistan (ACRS 1–5). Retrieved from GIS development.net
- Oldeman LR (1994) The global extent of soil degradation. In: Greenland DJ, Szabolcs I (eds) *Soil resilience and sustainable land use*. CAB International, Wallingford
- Onori F, De Bonis P, Grauso S (2006) Soil erosion prediction at the basin scale using the Revised Universal Soil Loss Equation (RUSLE) in a catchment of Sicily (southern Italy). *Environ Geol* 50:1129–1140
- Ouyang D, Bartholic J (2001) Web-based GIS application for soil erosion prediction. In: *Proceedings of an International Symposium—Soil Erosion Research for the 21st Century*, Honolulu, HI, pp 260–263
- Ozcan AU, Erpul G, Basaran M, Erdogan HE (2008) Use of USLE/GIS technology integrated with geostatistics to assess soil erosion risk in different land uses of Indagi Mountain Pass–Çankiri. *Turkey Environ Geol* 53:1731–1741
- Parysow P, Wang G, Gertner GZ, Anderson AB (2003) Spatial uncertainty analysis for mapping soil erodibility based on joint sequential simulation. *Catena* 53:65–78
- Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) *Predicting soil erosion by water—a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. United States Department of Agriculture. Agricultural Research Service (USDA-ARS) Handbook No. 703. United States Government Printing Office. Washington, DC
- Renfro WG (1975) Use of erosion equation and sediment delivery ratios for predicting sediment yield. In: *Present and prospective technology for predicting sediment yields and sources*. US Department of Agricultural Publications. ARS-S-40, pp 33–45
- Restrepo JD, Kjerfve B, Hermelin M, Restrepo JC (2006) Factors controlling sediment yield in a major South American drainage basin: the Magdalena River. *Colomb J Hydrol* 316:213–232
- Ricker MC, Odhiambo BK, Church JM (2008) Spatial analysis of soil erosion and sediment fluxes: a paired watershed study of two Rappahannock river tributaries. Stafford County. Virginia. *Environ Manag* 41:766–778
- Römken MJM, Prasad SN, Poesen JWA (1986) Soil erodibility and properties. In: *Proceedings of 13th Congress. International soil science society*. Hamburg, Germany, vol 5, pp 492–504
- Sadeghi SHR, Mizuyama T (2007) Applicability of the modified Universal Soil Loss Equation for prediction of sediment yield in Khanmirza watershed. *Iran Hydrol Sci J* 52(5):1068–1075
- Sadeghi SHR, Singh JK, Das G (2004) Efficiency of annual soil erosion models for storm-wise sediment prediction: a case study. *Int Agric Eng J* 13:1–14
- Saygin DS, Basaran B, Ozcan AU, Dolarslan M, Timur OB, Yilman FE, Erpul G (2011) Land degradation assessment by geospatially modeling different soil erodibility equations in a semi-arid catchment. *Environ Monit Assess* 180:201–215
- Shirazi MA, Boersma L (1984) A unifying quantitative analysis of soil texture. *Soil Sci Soc Am J* 48:142–147
- Soil Survey Staff (1996) *Soil survey laboratory methods manual*. Soil Survey Investigations Reports. No: 42, version 3.0. USDA-NRCS. Lincoln, NE
- Tagil S (2007) Monitor land degradation phenomena through landscape metrics and NDVI: Gordes, Kavacik, Ilicak, Kumcay and Marmara Lake Basins (Turkey). *J Appl Sci* 7:1827–1842
- Torri D, Poesen J, Borselli L (1997) Predictability and uncertainty of the soil erodibility factor using a global dataset. *Catena* 31:1–22
- Torri D, Poesen J, Borselli L (2002) Corrigendum to “Predictability and uncertainty of the soil erodibility factor using a global dataset” [Catena 31(1997): 1–22] and to “Erratum to Predictability and uncertainty of the soil erodibility factor using a global dataset. [Catena 32(1998):307–308]”. *Catena* 46:309–310
- Toy TJ, Foster GR (1998). In: Galetovic JR (ed) *Guidelines for the revised universal soil loss equation (RUSLE) version 1.06 on mined lands, construction sites and reclaimed lands*. The Office of Technology Transfer Western Regional Coordinating Center Office of Surface Mining, Denver
- Tran LT, Ridgley MA, Nearing MA, Duckstei L, Sutherland R (2002) Using fuzzy logic-based modeling to improve the performance of the revised Universal soil loss equation. In: Stott DE, Mohtar RH, Steinhardt GC (eds) *Sustaining the global farm-selected papers from the 10th International Soil Conservation Organization Meeting*. May 24–29, 1999. West Lafayette, IN. Published by the International Soil Conservation Organization, pp 919–923
- Tripathi MP, Panda RK, Pradhan S, Das RK (2001) Estimation of sediment yield from a small watershed using MUSLE and GIS. *J Inst Eng* 82(1):40–45
- TUBITAK (2009) Determination of rainfall energy and intensity for water erosion studies using long-term meteorological data at

- national scale in Turkey, The Scientific and Technical Research Council of Turkey (project number: CAYDAG-107Y155)
- Van der Kniff JM, Jones RJA, Montanarella L (2000) Soil erosion risk assessment in Europe, EUR 19044 EN. Luxembourg: Office for Official Publications of the European Communities
- Wang G, Gertner G, Liu X, Anderson A (2001) Uncertainty assessment of soil erodibility factor for revised universal soil loss equation. *Catena* 46:1–14
- Wang G, Gertner G, Singh V, Shinkareva S, Parysow P, Anderson A (2002a) Spatial and temporal prediction and uncertainty of soil loss using the revised universal soil loss equation: a case study of the rainfall–runoff erosivity R factor. *Ecol Model* 153:143–155
- Wang G, Wentz S, Gertner GZ, Anderson A (2002b) Improvement in mapping vegetation cover factor for the Universal Soil Loss Equation by geostatistical methods with Landsat Thematic Mapper images. *Int J Remote Sens* 23:3649–3667
- Wang G, Gertner G, Fang S, Anderson AB (2003) Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. *Photogramm Eng Remote Sens* 69:889–898
- Williams JR, Berndt HD (1972) Sediment yield computed with Universal equation. *J Hydraul Div Proc Am Soc Civil Eng* 98(HY12):2087–2098
- Wischmeier WH, Smith DD (1958) Rainfall energy and its relationship to soil loss. *Trans Am Geophys Union* 39(2):285–291
- Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses. A Guide to conservation planning. United States Department of Agriculture. Agricultural Research Service (USDA-ARS) Handbook, no 537. United States Government Printing Office, Washington, DC
- Wischmeier WH, Johnson CB, Cross BV (1971) A soil erodibility nomograph for farmland and construction sites. *J Soil Water Conserv* 26:189–193
- Wu R, Tiessen H (2002) Effect of land use on soil degradation in Alpine grassland soil, China. *Soil Sci Soc Am J* 66:1648–1655
- Yüksel A, Akay AE, Gundogan R, Reis M, Cetiner M (2008) Application of GeoWEPP for determining sediment yield and runoff in the Orcan Creek Watershed in Kahramanmaraş, Turkey. *Sensors* 8:1222–1236