Environmental Earth Sciences (2024) 83:258
https://doi.org/10.1007/s12665-024-11572-8

ORIGINAL ARTICLE

Effects of sediment-storage dams on suspended sediment transport in the Sera Lake Watershed, northeast Turkey

Betul Mete[1] · **Adem Bayram**[1]

Received: 1 March 2023 / Accepted: 24 March 2024 / Published online: 16 April 2024
© The Author(s) 2024

Abstract

In this study, the effects of cascade sediment-storage dams (SSDs) on the suspended sediment (SS) transport in the Sera Lake Watershed (northeast Turkey) were investigated. Ten SS monitoring stations from upstream (S01) to downstream (S10) were selected for the study considering the locations of the SSDs and Sera Lake. In a gauging station, where S05 was selected, the water stage monitoring studies were also conducted, and daily discharges and SS loads were computed. The Spearman correlation coefficient between SS and discharges data was computed as 0.592. The deterioration of the naturalness of the watershed with external interventions was effective on this value. While the Sera Lake trapped 33% of the SS transport, this value varied between –25.8 and 44% for SSDs. Although the SSDs have been proportionately succeed in trapping the SS, they have been insufficient in preventing sedimentation and problems caused by sediment transport in the watershed. In addition, the annual average soil erosion amount was determined by the revised universal soil loss equation (RUSLE) method in the watershed. According to the RUSLE method, the annual average soil loss of the watershed is 1.65 tons/ha. The SDR value of the watershed was calculated as 0.104. Integrating different environmental management tools to achieve a balanced and sustainable decision, a strategic environmental management plan should be constituted.

Keywords Discharge · RUSLE method · Sediment transport · Soil erosion · Watershed management

Introduction

Soil erosion is a natural geologic phenomenon that leads to environmental degradation, reduced agricultural yields, and negative impacts on water quality. Every year, 75 billion tons of soil are eroded from arable lands worldwide (Pimentel et al. 1995; Borrelli et al. 2017). In Turkey, this value has been reported as 500 million tons (Irvem et al. 2007). Water erosion is one of the most common types of erosion, and it accounts for about 55% of the eroded land (Bridges and Oldeman 1999). The susceptibility of a soil to water erosion is closely related by the erosive potential of rainfall, topography of the watershed, vegetative cover, and soil erodibility. The revised universal soil loss equation (RUSLE) is widely used method that estimates rates of soil erosion caused by rainfall and associated overland flow. Martin et al. (2003) integrated the universal soil loss equation (USLE) method with geographic information system (GIS) to estimate sheet erosion of the Tchefuncte River, Louisiana, USA. They stated that the GIS/USLE modeling approach offers an efficient and affordable method for estimating sheet erosion within watersheds. Zhou et al. (2008) investigated effect of vegetation cover on soil erosion by the RUSLE method in the Upper Min River Basin, Southwest China. Chen et al. (2011a, b) used the RUSLE, GIS, and remote sensing methods to map the soil erosion risk in the Miyun Watershed, North China. Ozsahin (2014) determined the erosion risk zones and average annual soil loss amount using the GIS based RUSLE method in Tekirdağ Province, Turkey. Tanyas et al. (2015) used the RUSLE method to determine the average annual eroded material in the drainage basin of Kartalkaya Dam, Southeastern Turkey. They developed an alternative approach to determine the cover-management factor using the GIS and remote sensing methods. Darama et al. (2021) computed sediment erosion resulting from rainfall events using the RUSLE method in the Harran Plain, Turkey. They determined that 20% of sediment erosion was caused by rainfall events in the plain. Demir et al. (2022) estimated annual soil loss using the RUSLE method in the Çapakçur

✉ Adem Bayram
abayram@ktu.edu.tr

[1] Department of Civil Engineering, Faculty of Engineering, Karadeniz Technical University, Trabzon, Turkey

watershed, Bingöl, Turkey. They determined that 19.09% of the watershed is exposed to soil loss of more than 12 tons/ha, and the annual soil loss is 10.14 tons/ha.

All streams carry a fair amount of suspended sediment (SS) under natural conditions (Ryan 1991). However, high amounts of SS transported by streams cause various problems downstream, such as impairment of water quality, reservoir sedimentation, and channel and harbor silting (Bayram et al. 2014; Mete et al. 2022). Sedimentation is a grave problem, especially for lakes and reservoirs (Kondolf et al. 2014; Schleiss et al. 2016; Ren et al. 2021, Shrestha et al. 2022). Several measures are implemented on streams carrying a high amount of sediment to prevent sedimentation in reservoirs and lakes. Although sediment-storage dams (SSDs), one of these measures, are prevalently used to store the transported sediment before it reaches downstream. Mekonnen et al. (2015) investigated the effects of SSDs built in northwest Ethiopia on sediment transport. They concluded that the SSDs trapped a significant amount of sediment and reduced sediment movement downstream. Addisu and Mekonnen (2019) researched the amount of sediment stored by SSDs in northwest Ethiopia. They determined that the sediment trapped by SSDs includes soil organic carbon that could release into the atmosphere. They concluded that SSDs could be used as climate change mitigation measures in addition to trapping sediment. Wang and Sun (2021) examined the variability of annual sediment load and runoff in the Yellow River Basin, China, between 1919 and 2018. They determined that the terraces, SSDs, and dam lakes constructed in the basin significantly decreased the annual sediment loads.

Direct measurements are one of the most reliable methods of determining SS concentrations. In the streams of Turkey, the sediment monitoring studies, which were initiated in 1961 with one station in the Tunca River (the Meriç River Basin, northwest Turkey), have been conducted by the State Hydraulic Works (DSİ). SS concentration data are unavailable for all streams because establishing monitoring stations in desired locations and collecting data for a long time are laborious and costly (Mete et al. 2023a). The sediment annuals (RTMAF 2021) published by DSİ showed that SS monitoring was conducted monthly at only three stations (Değirmendere, Karadere, and Fol streams) between 2006 and 2012 in Trabzon Province, northeast Turkey. Apart from DSİ, there are also monitoring studies conducted by Turkish researchers (Bayram et al. 2014; Satılmış 2015; Bayram and Kenanoglu 2016; Bayram 2017; Korkanc et al. 2017; Koralay et al. 2018).

Many studies using the RUSLE method have been conducted in Turkey, but studies on the validation of the obtained the RUSLE results have been quite limited. There are three main aims of this study: (i) determination the impact of SSDs on SS transport, (ii) estimation of the average annual soil loss using the RUSLE model, and (iii) estimation of the yield sediment amount by results of monitoring studies to check the validation of the applied model. This study is a unique contribution, not only to the understanding of the watershed, but also to the field of study in Turkey.

Study area

Turkey is divided into 25 hydrological basins to ensure the sustainable management of water resources. With its 22,846 km^2 rainfall area and 16.43 km^3 surface water potential (DSİ 2020), the Eastern Black Sea Basin is one of the primary basins in Turkey. With an average annual precipitation of 1198 mm, the basin having a mountainous topography is the most rainfall place in Turkey (RTMAF 2016). Due to its rainy climate, the northern sides have evergreen and dense vegetation. Approximately, 37 and 22% of the basin area are covered by forests and pastures, respectively. Majority of the rest has been used as agricultural lands. Almost all the streams in the basin originate from the peaks of the mountains parallel to the coast. Due to their very steep beds, they have a potential to carry large amounts of sediment. In addition, there are many artificial and natural lakes as well as waterfalls, which has attracted domestic and foreign tourists, in the basin. With a total population of 816,684 (TSI 2023) and its airport, port, marina, and harbors, Trabzon Province is the most popular destination in the basin. The province, which has a surface area of 4685 km^2, is surrounded by Gümüşhane in the southwest, Bayburt in the southeast, Giresun in the west and Rize in the east (Bayram 2017). According to the records between 1927 and 2021 belonging to the Turkish State Meteorological Service (TSMS), Trabzon Province receives an average annual rainfall of 828.9 mm ranging from 35.6 mm in July to 114.3 mm in October, and its average monthly air temperature changes between 7.3 °C February and 23.0 °C in July (TSMS 2023). Compared with the adjacent provinces, Trabzon has a lower annual rainfall depth.

The Sera Lake Watershed (Fig. 1), located between latitudes 40° 51′–40° 54′ N; 39° 37′–39° 28′ E, is one of the watersheds in Trabzon with approximately 127 km^2 drainage area (Mete et al. 2023b). The main branch of the watershed is the Sera Stream, and the tributaries are Zavurdiya, Ortaburun, Kalaycı, Uçarsu, and Hocarat streams (Hacısalihoğlu 1995). A great landslide event blocked the main branch, and led to the formation of a lake, namely Sera, in 1950 (Beret 1955). The Sera Lake, which has 1200 m in length and 20 m in depth, was designated as a natural projected area in 2005. Then, 940,000 m^2 area around the lake was declared as a nature park in 2010. There has been a massive increase in number of foreign tourists since 2010 (Duzgunes et al. 2017). In addition, there are also various enterprises and a

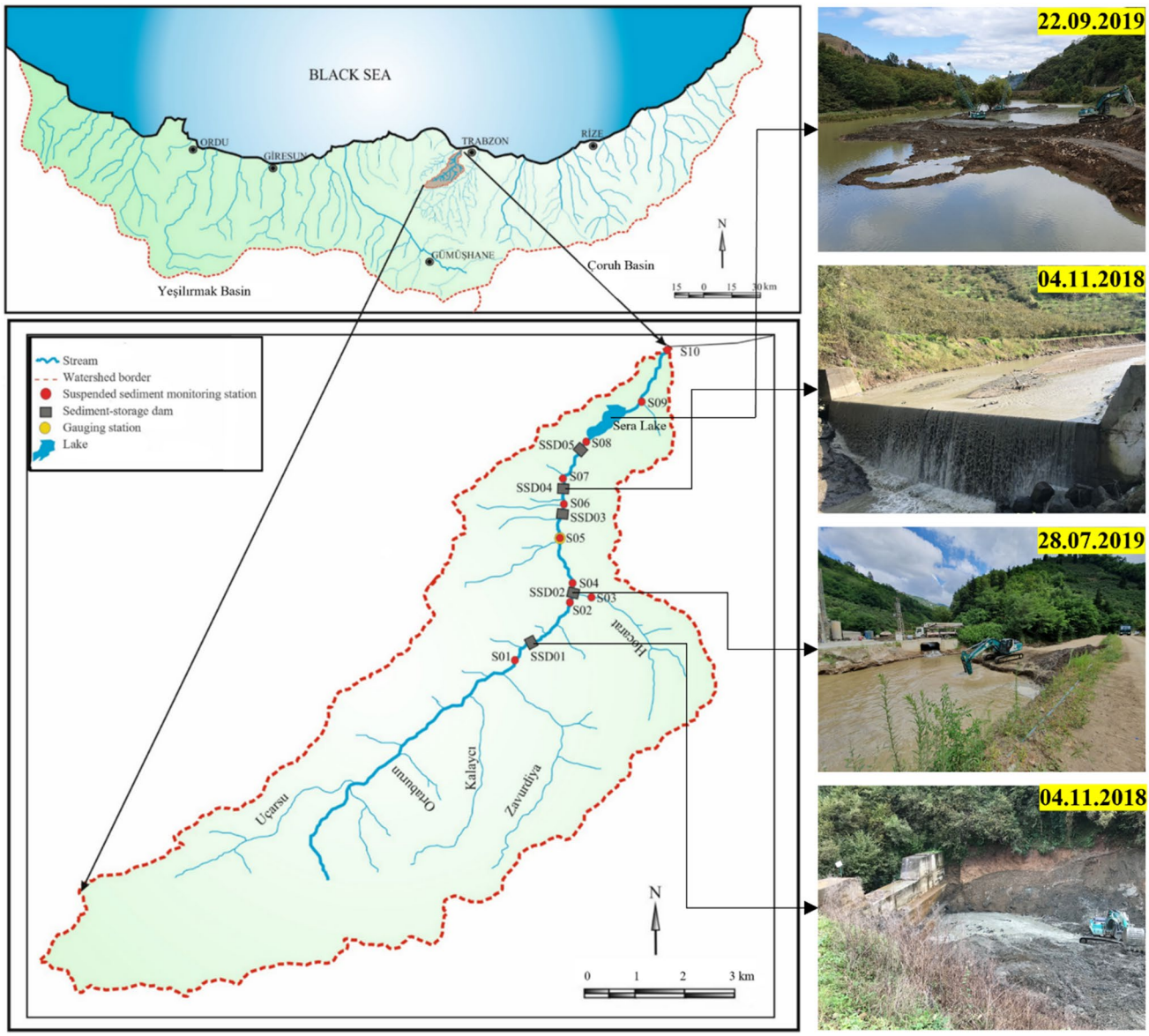


Fig. 1 The locations of suspended sediment monitoring stations, sediment-storage dams, and gauging station in the Sera Lake Watershed, Trabzon Province, northeast Turkey

hydroelectric power plant, which has an installed power of 1.2 MW and an annual energy production of approximately 5.64 GW, downstream of the watershed. To prevent the Sera Lake from sedimentation, five SSDs were constructed on the main branch in the watershed.

The Sera Stream (main branch) and the Zavurdiya Stream (tributary) had caused the reservoir of the SSD1 to fill up with the sediment that they carried. For the refunctionalization of the SSD1, removal efforts were carried out for the stored materials just before the field studies. Similar studies were carried out for SSD4, which was substantially filled during the floods in 2018 and then became completely dysfunctional with the transported material by streamflow. The Hocarat stream, where rubble flows are effective, carries a large amount of coarse material as well as fine material, and thus plays a major role in becoming dysfunctional of the SSD2. Increasing drought and flood events due to global climate change cause a decrease in reservoir capacities by increasing sediment yield (Hung et al. 2022). A large portion of the material transported by flood flows reaches the Sera Lake and causes serious silting problems. To determine the effects of SSDs and the Sera Lake on the SS transport in the watershed, ten SS monitoring stations, from upstream (S01) to downstream (S10), were selected for the study considering the locations of the SSDs and Sera Lake (Table 1).

Table 1 The locations of suspended sediment monitoring stations and sediment-storage dams in the Sera Lake Watershed, northeast Turkey

	Coordinates	Altitude (m)	Distance (km) from the coast
S01	40° 55′ 15.84″ N–39° 35′ 21.50″ E	299	11.4
SSD1	40° 55′ 24.26″ N–39° 35′ 37.59″ E	286	10.8
S02	40° 56′ 10.56″ N–39° 36′ 16.14″ E	214	9.1
S03	40° 56′ 11.28″ N–39° 36′ 16.08″ E	204	9.1
SSD2	40° 56′ 13.69″ N–39° 36′ 14.60″ E	202	9.0
S04	40° 56′ 16.26″ N–39° 36′ 14.39″ E	201	8.9
S05	40° 57′ 42.84″ N–39° 36′ 08.25″ E	134	6.2
SSD3	40° 57′ 39.53″ N–39° 36′ 06.81″ E	133	6.1
S06	40° 57′ 57.38″ N–39° 36′ 04.99″ E	120	5.9
SSD4	40° 58′ 07.71″ N–39° 36′ 05.56″ E	119	5.3
S07	40° 58′ 12.37″ N–39° 36′ 05.27″ E	116	5.0
SSD5	40° 58′ 34.15″ N–39° 36′ 18.69″ E	110	4.2
S08	40° 58′ 36.31″ N–39° 36′ 23.43″ E	109	4.1
S09	40° 59′ 17.16″ N–39° 37′ 09.31″ E	107	2.3
S10	41° 00′ 22.93″ N–39° 37′ 51.48″ E	5	0

Materials and methods

Surface water sampling and suspended sediment determination

Surface water samples were hand-collected from the SS monitoring stations four times a month. High-density polyethylene terephthalate bottles, which have 1-l volumes, were used for sampling. The bottles were prepared (washed, rinsed, dried, and dated) for each study. The bottles were shaken twice with the stream water in case of probable particles before the sampling. They were filled from approximately mid-depth of flow. Large-volume sample containers equipped with ice cassettes were used to transport surface water samples collected from the stream to the laboratory under specified conditions. Sampling, preservation, and transportation of the collected surface water samples to the laboratory were carried out according to standard methods (APHA 1992).

The glass microfiber filters, which have a 1.2 µm pore size, were prepared (washed with distilled water, dried in the oven at 105 °C for 1 h at least, weighed, recorded all measurements to 0.0001 mg precision, and stored in a desiccator) for the filtration. The water samples were shaken vigorously, and poured into the graduated cylinder. The filters kept the suspended solids and clarified the water. The filters were dried in the oven at 105 °C for 12 h. After the filters reached a constant weight, they were come out of the oven and were weighed again. Dried residue weights were obtained by subtracting the first weight from the last weight. Finally, SS (mg/L) was determined by dividing dried sample weight by sample volume. This process was carried out at the Hydraulic and Water Resources Laboratory, located in Karadeniz Technical University, Trabzon Province, northeast Turkey.

Stream discharge determination

Derecik gauging station, D22A153 numbered by DSİ, is located at 40° 57′ 42.84″ N–39° 36′ 08.25″ E coordinates in the same location as S05 in the Sera Lake Watershed. The station has a 105.7 km^2 drainage area representing 83.20% of the watershed. The water stages were recorded simultaneously with the sampling studies at the gauging station. The stream discharge values (L/s) belonging to the sampling times in the related section were computed using the monitored and recorded water stages and the rating curve of the gauging station.

RUSLE method

The RUSLE method, updated version of the universal soil loss equation (USLE), is an erosion model estimating long-time average annual soil loss. The method represents how climate, soil, topography, and land use affect soil erosion caused by raindrop impact and surface runoff. The RUSLE equation is given below (Renard and Ferreira 1993; Wishcmeier and Smith 1978).

$$A = R \times K \times \mathrm{LS} \times C \times P \quad (1)$$

where A is average annual soil loss (ton/ha, R is the rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is slope length and steepness factor, C is cover-management factor, and P is supporting practices factor. The R factor was obtained from the rainfall-runoff erosivity maps produced for Turkey by analyzing approximately 200 million minutes of precipitation data belonging to 329 automatic meteorological observation stations operated by the Turkish State Meteorological Service. In the determination of K factor, Soil Erosion Sensitivity Maps of Turkey, prepared by the General Directorate of Erosion and Desertification Prevention with 23,000 soil samples from soil depths ranging from 0 to 30 cm, were used.

The K factor was derived from the information provided by this comprehensive data set. The LS factor was generated with the help of GIS, considering the digital elevation model of the study area, land surface drainage network distribution, and flow direction and intensity. The C factor was obtained by evaluating stand data maps and coordination of information on the environment (CORINE) land cover maps. Since digital no data on soil conservation methods were available, the P factor was assumed to be 1 in the calculations.

Sediment delivery ratio

The sediment delivery ratio (SDR) is an essential parameter in predicting soil erosion rates, managing sedimentation in reservoirs, and evaluating the impacts of land use and land management practices. It refers to the proportion of eroded sediment that reaches the downstream of a watershed (Merritt et al. 2003). Various empirical equations and GIS methods have been used to estimate SDR, as well as traditional methods based on watershed characteristics and measured sediment yield divided by estimated gross erosion (Demir et al. 2022). In this study, the SDR is determined using the following equation.

$$SDR = SY/SE \quad (2)$$

where SY is sediment yield, which was obtained from the field studies in the Sera Lake Watershed, and SE is amount of gross soil erosion, which was obtained from the RUSLE method.

Results

Soil erosion is among the vital issues worldwide. Various empirical equations and several models have been used to determine amount of soil erosion. However, field measurements are the most reliable method (Genet and Sebhat 2018; Yu et al. 2022). The results of SS and discharge monitoring studies, as well as annual average soil loss amount calculated by the RUSLE method, in the Sera Lake Watershed were presented in this section.

Descriptive statistics were calculated, the minimum, mean, maximum, and standard deviation (SD) for the SS concentrations (mg/L) for each station seasonally (Table 2). The data for the spring season includes only 4 monitoring studies conducted in March 2020. The highest concentration was obtained from the S08 (2302.5 mg/L), located downstream of the SSD5 and upstream of the Sera Lake, in summer 2019, while the lowest concentration was obtained from the S02 (0.2 mg/L), located between the SSD1 and SSD2, in autumn 2019. The maximum seasonal average concentrations were obtained from the S08 (229.2 mg/L), the S10 (115.4 mg/L), and S09 (100.1 mg/L) in summer 2019, autumn 2019, and winter 2020, respectively. The minimum seasonal average SS concentrations were obtained from the S09 (41.6 mg/L) in summer 2019 and the S02 (7.7 and 5.6 mg/L) autumn 2019, and winter 2020, respectively. The maximum concentration obtained from the S08, just upstream of the Sera Lake, was caused by the transported SS because of excessive rainfall in summer 2019, while the maximum concentrations obtained from the stations downstream of the Sera Lake resulted from human interventions to the stream in autumn 2019 and winter 2020. Similarly, summer SS concentrations for the first eight stations (except S06 with missing data) have the highest values due to the fact that the concentrations reached 2300 mg/L during a flood caused by excessive rainfall in June 2019. Due to human activities in the watershed, the highest SS concentrations were monitored in S09 and S10 during winter and autumn seasons, respectively.

SSD1 trapped 18% of the SS transport and prevented it from reaching downstream during the study period. When examined seasonally, these rates were calculated as 15.4% in summer 2019, 34.2% in autumn 2019, and 51.7% in winter 2020. Generally, downstream SS concentrations of SSD2 were higher compared to upstream. This situation is linked to high concentrations in the S03 on the Hocarat Stream (tributary) connecting to the Sera Stream. Due to the excessive rainfalls that occurred in June 2019, the materials carried by the tributary caused the reservoir of the SSD2 to be filled up. The reservoir was emptied by DSİ in July 2019 and became functional again. The resuspended and transported materials during the sediment removal operations also caused an artificial increase downstream concentration. For the SSD3 located between S05 and S06, it was determined that downstream concentration was 25.8% higher than upstream. When examined seasonally, the SSD3 trapped 2.4% of the SS concentration in summer 2019, but downstream concentrations increased by 9.6 and 40.5%, respectively, in autumn 2019 and winter 2020. The SS monitoring studies in the S06 could be started with the seventh study due to the harsh field conditions. The first six monitoring studies for the S05 were excluded from the averages to comment on the data simultaneously. Since the reservoir of the SSD3 was full, the SS carried by the streamflow could not be trapped in the reservoir. On the contrary, the deposited sediment was resuspended and transported downstream. Upstream concentrations of the SSD4 were 44.0% higher than downstream concentrations. Seasonally, the SSD4 trapped 78.4% of the SS transport in winter 2020. It is thought that these values were caused by the sedimentation of transported SS due to the low bed slope between the stations, and so SSD4 did not play an active role in the decrease of SS concentration. On the other hand, downstream concentrations increased by 18.2 and 14.6%, respectively, in summer and autumn 2019. These values

Table 2 Basic statistics of the suspended sediment concentration in the Sera Lake Watershed, northeast Turkey (Mete 2020)

Stations	S01	S02	S03[a]	S04	S05	S06[b]	S07	S08	S09	S10
Summer										
Min	1.2	2.3	5.1	3.4	4.9	10.5	6.5	3.4	5.7	7.7
Mean	185.8	157.3	210.6	185.8	204.1	44.8	209.6	229.2	41.6	95.4
Max	2048.0	1639.0	2109.8	1656.5	1981.8	128.3	1995.2	2302.5	107.5	596.1
SD	561.8	447.5	601.0	449.1	538.3	41.4	540.8	627.0	30.9	156.7
Autumn										
Min	0.3	0.2	1.2	0.2	2.8	3.2	2.7	1.2	15.7	15.2
Mean	11.8	7.7	27.5	12.0	22.8	25.0	28.6	27.4	37.0	115.4
Max	64.8	29.4	143.8	39.6	112.4	83.1	67.5	114.0	130.0	878.2
SD	17.1	8.7	42.2	12.4	29.8	20.4	22.5	33.4	29.2	232.8
Winter										
Min	0.3	0.7	1.3	0.7	1.3	2.9	2.5	1.3	6.8	10.3
Mean	11.6	5.6	33.0	9.2	70.1	98.4	21.3	13.3	100.1	33.2
Max	63.7	17.5	228.0	48.0	634.0	981.8	62.8	42.5	909.0	131.3
SD	18.0	5.9	62.1	13.1	171.3	267.0	22.1	13.5	245.7	32.8
Spring										
Min	7.3	6.8	9.3	12.0	13.0	15.7	8.8	12.5	9.0	9.5
Mean	19.1	18.2	19.0	20.5	17.4	21.6	27.9	33.7	28.1	19.5
Max	40.5	30.5	35.0	32.7	24.2	30.2	59.0	57.8	50.3	46.3
SD	13.4	10.3	9.9	8.4	4.3	5.4	19.1	16.1	17.7	15.5
All data										
Min	0.3	0.2	1.2	0.2	1.3	2.9	2.5	1.2	5.7	7.7
Mean	64.7	53.0	79.9	64.2	90.8	54.0	80.6	84.4	56.4	75.2
Max	2048.0	1639.0	2109.8	1656.5	1981.8	981.8	1995.2	2302.5	909.0	878.2
SD	322.2	257.8	336.5	262.1	323.3	166.0	312.5	361.4	141.5	161.5

[a]The station has one missing data

[b]The station has six missing data

were associated with the wastewater discharge between S07 and SSD4 during the field studies. It was determined for the SSD5 that downstream concentration was 4.6% higher than upstream. It is thought that the wastewater discharge between SSD5 and the downstream station was effective in this situation. Seasonally, downstream concentrations were higher than upstream at 9.4% in summer 2019, but SSD5 trapped 4.2 and 37.4% of SS transport in autumn 2019 and winter 2020, respectively. The Sera Lake trapped 33.2% of the SS transported in the upstream during the study period. It was determined that a part of 81.9% of the SS was deposited in the Sera Lake in summer 2019. Excessive rainfalls in June 2019 caused the concentrations from upstream to the lake to increase continuously. The SS concentration was determined as 2,302.50 mg/L in the S08 and 107.50 mg/L in the S09 on June 18, 2019. A part of 95% of the transported SS was deposited in the lake. The dredging operations initiated by DSİ in the lake at the end of July 2019 lasted for 20 weeks, and 180,000 m^3 of material was removed from the lakebed. Downstream concentrations of the Sera Lake increased by 134.8 and 649.6%, respectively, in autumn 2019 and winter 2020. It is thought that the transport of resuspended material in the lake during the dredging operations played a great role in this situation. Finally, it is thought that 66.8 and 30.4% reductions in average seasonal concentrations in the S10 for the winter and spring (only March) 2020 is linked with a lower bed slope between the last two stations. Average seasonal concentrations in the S10 were 129.5% and 212.3% higher than the S09 for summer and autumn 2019, respectively. This is due to the wastewater discharges to the stream just before the S10 and the regulation works carried out in the streambed during the sampling studies in the watershed.

The SS data were analyzed using the IBM SPSS statistic 23 computer program and the probability values were constituted. The Spearman correlation coefficients varied from 0.924 to 0.192. It was determined that upstream and downstream stations of the Sera Lake were apart from each other considering the SS concentrations, and the correlations between the stations were low. It is thought that the hydraulic retention time was effective in this case.

According to the discharge values were obtained from rating curve of the gauging station, the average daily discharges and SS loads were computed as 99,000 m^3 and 24.589 tons in summer 2019, 83,945 m^3 and 2.505 tons in autumn 2019,

and 69,040 m^3 and 4.094 tons in winter 2020, respectively. The monthly average sediment load at the S05 was calculated as 181.13 tons. The monthly average sediment yield was 181.13 tons. The monthly average potential erosion amount obtained from the RUSLE method is 1746.25 tons. In this case, the SDR was calculated as 0.104. The sediment rating curve for S05 was obtained using the discharge and SS concentration data obtained from the stream stage measurements and sampling studies (Fig. 2). Although it was expected that there would be a strong relationship between discharge and SS concentration, it is not found such a relationship. In addition, the correlation between SS concentration and discharge data was calculated as 0.592. This value, lower than the expected, is thought to be caused by the SSD1 and SSD2 remaining upstream of the gauging station, and the deterioration of the naturalness of the watershed due to human factors, such as agricultural practices, overgrazing, interventions in stream channels, and discharge of untreated municipal wastewater.

The RUSLE method was used to determine the soil losses in the watershed. For the *R*, *K*, LS, and *C* factors to be used in the RUSLE method, the maps obtained for the Sera Lake Watershed are presented in Fig. 3. The *R* factor was calculated pointwise with meteorological observation station data. Then, unknown points were estimated using inverse distance weighting method in GIS, and R factor maps were obtained with 10 m × 10 m resolution. The R values ranged from 478.4 and 688.5 MJ mm^{-1} ha^{-1} h^{-1} yr^{-1} in the Sera Lake watershed (Fig. 3a). The rainfall-runoff erosivity energy is more in the north of the watershed in parallel with the precipitation distribution. The *K* factor is an important component of soil erodibility. The *K* values vary between 0.019 and 0.027 t h MJ^{-1} mm^{-1} in the watershed. According to the classification by Foster et al. (1981), these values are categorized as "moderately erodible and easily erodible". Especially in mountainous areas, the LS factor is quite effective on soil erosion. The LS values varied from 0.0 to 41.2 in the Sera Lake Watershed. While the LS value is 0 in flat regions, it reaches up to 41.5 in high slope regions. The C factor is a parameter having the greatest role in reducing the amount of soil erosion (Farhan and Nawaiseh 2015). It is lower in areas with high soil biomass and vegetation cover compared to areas with low biomass and vegetation-free areas. The C values varied between 0.0035 and 0.0300 in the watershed.

The levels of soil erosion risk map, generated with the RUSLE method for the Sera Lake Watershed, are given in Fig. 4. According to the results of RUSLE method, 63.8, 24.0, 10.8, and 1.4% of the study area are exposed to very light, light, moderate, and severe erosions, respectively (Table 3). The average annual soil loss of the watershed was calculated as 1.65 tons/ha.

Discussion

There were several limitations in this study. First, field studies, conducted four times a month, were planned for 12 months or more, started in June 2019 but terminated in March 2020 due to the COVID-19 pandemic. Second, only SS was taken into consideration in the sampling studies and no study on bed load was carried out. Finally, the P value in the RUSLE method was assumed to be 1 for the whole watershed. However, it is thought that the results obtained within all these limitations will provide useful information to the literature.

According to the results of the RUSLE method, the average annual soil loss in the Sera Lake Watershed was

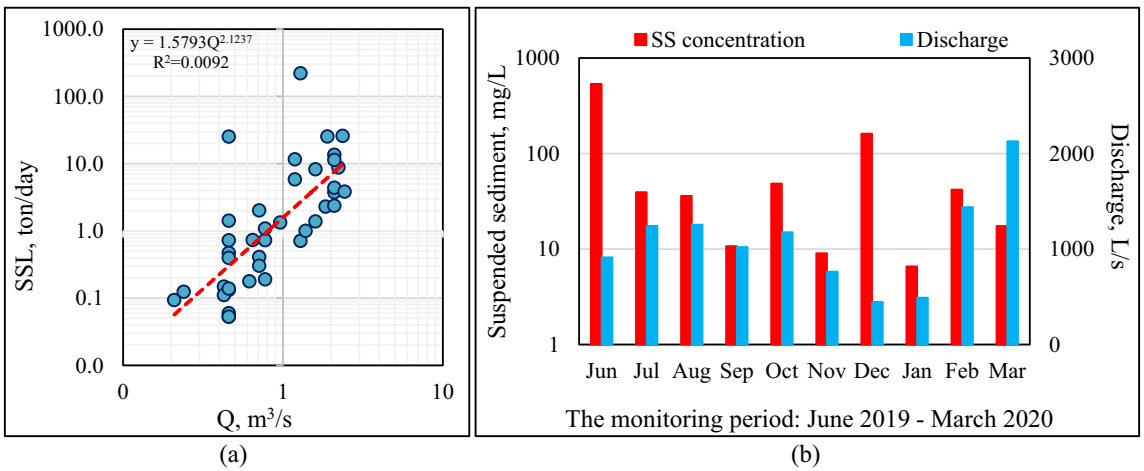


Fig. 2 **a** The sediment rating curve and **b** temporal variation of suspended sediment versus discharge for gauging station, the Sera Lake Watershed, northeast Turkey

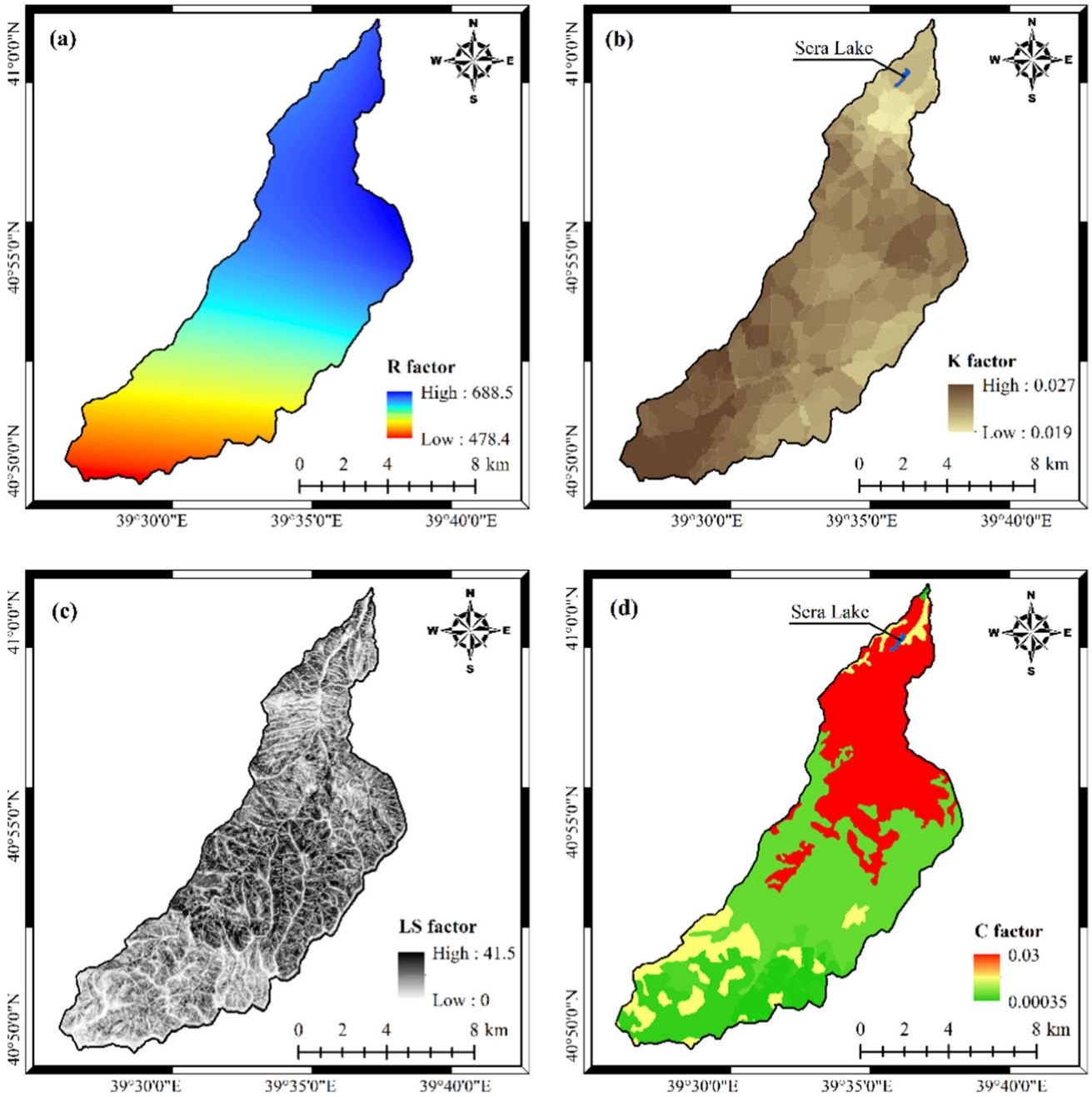


Fig. 3 Maps of **a** rainfall-runoff erosivity (R) factor, **b** soil erodibility (K) factor, **c** slope length and steepness (LS) factor, and **d** cover-management (C) factor for the Sera Lake Watershed, northeast Turkey

calculated as 1.65 tons ha^{-1}. When compared with the average of Turkey (6.50 tons ha^{-1}), it is seen that the soil loss in the watershed is quite low. Forested lands in the watershed have been effective on this situation. Kara et al. (2018) calculated the annual average soil loss as 3.76 tons ha^{-1} in the Fol Stream Watershed (Trabzon). They stated that the very low soil loss values in forested areas covering 62% of the watershed were effective on this value. Similarly, Sthiannopkao et al. (2006) found that the amount of erosion was high in paddy fields and low in forest areas in the Phong River Basin (Thailand).

Considering the results of the RUSLE method, it is seen that especially the Zavurdiya and Hocarat tributaries pass through areas with high erosion risk and have the potential to carry a large amount of material. SS concentration values at S01, S02, and S03 stations and the filling of SSD1 and SSD2 reservoirs with transported material during the study period support this situation. Saygin et al. (2014) estimated

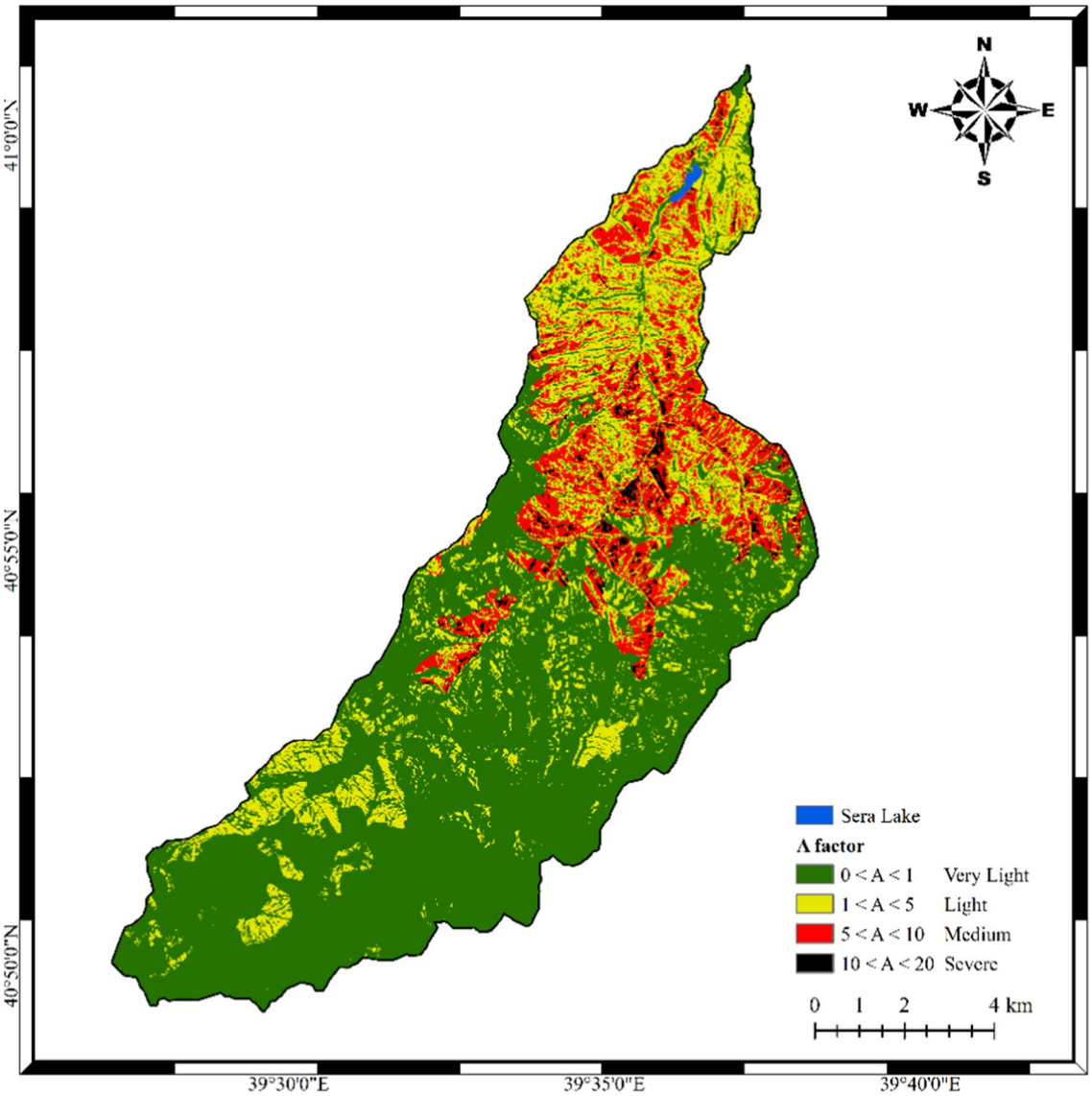


Fig. 4 Soil erosion severity map of the Sera Lake Watershed, northeast Turkey

Table 3 Percentages of soil erosion classes in the Sera Lake Watershed, northeast Turkey

Erosion class	Erosion rate (tons ha^{-1} yr^{-1})	Area (ha)	Percentage (%)
Very light	0–1	8102.2	63.8
Light	1–5	3045.1	24.0
Moderate	5–10	1372.9	10.8
Severe	10–20	179.7	1.4
Very severe	> 20	0.0	0.0

the annual sediment flux rate in the Sarayköy II Dam watershed using the RUSLE and SDR combined model. They determined that the economic life of the dam will not be sustainable if soil and water conservation measures are not taken in areas with high erosion risk and SDR rate.

The SDR value in the watershed was calculated as 0.104. The difference between gross and net erosion is due to the trapping of the transported material by the SSDs constructed in the watershed. Considering the SDR value, it is understood that SSDs are effective in trapping the transported material. Pal et al. (2018) reported that control dams built in the Shejiagou Watershed (China) reduced the SDR value of the watershed from 40 to 5%.

Excessive rainfalls, snow melt, and human activities are among the phenomena triggering floods in mountainous areas, where floods carry large amounts of woody material, i.e., roots, trees, and branches, as well as water and sediment (Mazzorana et al. 2009). Among the reservoir management

strategies, control dams and dredging operations may be insufficient to protect the reservoirs due to the large amount of material carried during floods due to heavy rainfalls. The results of RUSLE method indicate that especially in severe erodible areas have high erosion and transportation amount of sediment, so some precautions should be taken to reduce the erosion occurred in these areas.

Conclusions

The Sera Lake Watershed (Trabzon Province, northeast Turkey) has been subject to intense sediment transport. The sediment-storage dams (SSDs) constructed in the watershed have been filled up with the transported material and become dysfunctional from time to time. Transported material has caused sedimentation in the Sera Lake. In this study, the temporal variation of suspended sediment (SS) transport was examined by conducting field studies, and the effects of the SSDs on SS transport in the Sera Lake Watershed were investigated. In addition, sediment erosion was computed by the RUSLE method. The most important conclusions of the study are given below.

Since the average SS concentrations range from 53 to 91 mg/L and exceed 2000 mg/L during excessive rainfalls in the Sera Lake Watershed, the SSDs occasionally fill up and lose their functions. As a result of scouring by high flows, the sediment trapped upstream causes to increase in downstream concentration. To prevent this situation, it has been concluded that the SSDs in the watershed should be checked periodically, and the filled ones should be emptied without losing time. It has been observed that the rubbles and excavated soils have also been illegally dumped on the stream beds and have caused the SS concentration to increase artificially. Therefore, the available SSDs have been inadequate in number as much as they succeed to trap the SS. There are need to additional SSDs, as well as open check dams and debris flow barriers in the upper subwatersheds having a land with a very steep slope.

The RUSLE method has shown successful results in identifying potential erosion risk zones in the watershed. The average monthly soil loss was calculated as 1746.25 tons by the RUSLE and sediment load as 181.13 tons by the field studies in the Sera Lake Watershed, where SSDs have a strong influence on the difference between gross and net erosion.

It was suggested that a holistic and sustainable watershed management plan should be established, which includes combating erosion, stream regulation, planning of cleaning and dredging operations and construction of SSDs, open control dams, debris flow barriers, sediment sluice structures as well as sewage systems.

Author contributions All the authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Betul Mete and Adem Bayram. The first draft of the manuscript was written by Betul Mete and Adem Bayram, and all the authors commented on previous versions of the manuscript. All the authors read and approved the final manuscript.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Data availability Data sets generated during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Addisu S, Mekonnen M (2019) Check dams and storages beyond trapping sediment, carbon sequestration for climate change mitigation, Northwest Ethiopia. Geoenviron Disasters 6(1):1–8. https://doi.org/10.1186/s40677-019-0120-1

American Public Health Association [APHA] (1992) Standard methods for the examination of water and wastewater, 18th edn. American Public Health Association, Washington (DC)

Bayram A (2017) Water quality of the Degirmendere stream, drinking water source of Trabzon Province, Turkey. Desalin Water Treat 62:120–139. https://doi.org/10.5004/dwt.2017.1761

Bayram A, Kenanoglu M (2016) Variation of total suspended solids versus turbidity and Secchi disk depth in the Borcka Dam Reservoir, Coruh River Basin, Turkey. Lake Reserv Manage 32:209–224. https://doi.org/10.1080/10402381.2016.1160168

Bayram A, Onsoy H, Kankal M, Komurcu MI (2014) Spatial and temporal variation of suspended sediment concentration versus turbidity in the stream Harsit Watershed, NE Turkey. Arab J Geosci 7:4987–4996. https://doi.org/10.1007/s12517-013-1122-z

Beret B (1955) Sera Heyelanı. Türk Coğrafya Dergisi 13–14:155–161 (**in Turkish**)

Borrelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, Meusburger K, Modungo S, Schutt B, Ferro V, Bagarello V, Oost VK, Montanarella L, Panagos P (2017) An assessment of the global impact of 21st century land use change on soil erosion. Nat Commun 8(1):2013. https://doi.org/10.1038/s41467-017-02142-7

Bridges EM, Oldeman LR (1999) Global assessment of human-induced soil degradation. Arid Soil Res Rehabil 13(4):319–325. https://doi.org/10.1080/089030699263212

Chen CN, Tsai CH, Tsai CT (2011a) Simulation of runoff and suspended sediment transport rate in a basin with multiple watersheds. Water Resour Manag 25(3):793–816. https://doi.org/10.1007/s11269-010-9727-4

Chen T, Niu RQ, Li PX, Zhang LP, Du B (2011b) Regional soil erosion risk mapping using RUSLE, GIS, and remote sensing: a case study in Miyun Watershed, North China. Environ Earth Sci 63:533–541. https://doi.org/10.1007/s12665-010-0715-z

Darama Y, Yılmaz K, Melek AB (2021) Land degradation by erosion occurred after irrigation development in the Harran plain, Southeastern Turkey. Environ Earth Sci 80:211. https://doi.org/10.1007/s12665-021-09372-5

Demir Y, Meral A, Demir AD (2022) Estimation of soil losses in Çapakcur watershed (Bingol, Turkey) using RUSLE method and comparison of predicted soil losses with sediment yield. Kahramanmaraş Sütçü İmam Univ J Agric Nat 25(2):523–537 (**in Turkish with English abstract**)

Duzgunes E, Bayramoglu E, Duran M (2017) Evaluation of Sera Lake Nature Park (Trabzon/Turkey) in respect to ecological and socio-economic structure. J Environ Prot Ecol 18:225–234

DSİ, State Water Works (2020) Annual average surface water potential by basin, 2013–2019. General Directorate of State Hydraulic Works, Ankara, Turkey. https://www.dsi.gov.tr/Sayfa/Detay/1344. Accessed 13 Jul 2023.

Farhan Y, Nawaiseh S (2015) Spatial assessment of soil erosion risk using RUSLE and GIS techniques. Environ Earth Sci 74:4649–4669. https://doi.org/10.1007/s12665-015-4430-7

Foster GR, McCool DK, Renard KG, Moldenhauer WC (1981) Conversion of the universal soil loss equation to SI metric units. J Soil Water Conserv 36(6):355–359

Genet AT, Sebhat MY (2018) Rainfall, Runoff and soil loss, relationship on different land uses in the Upper Lake Tana Basin. J Agric Environ Int Dev 112(1):3–23. https://doi.org/10.12895/jaeid.20181.642

Hacısalihoğlu S (1995). Investigations on some physical, chemical and hydrological properties of soils under different land use types in Trabzon-Sera Deresi Watershed. MS thesis. Karadeniz Technical University, Graduate Institute of Natural and Applied Sciences, Trabzon, Turkey **(in Turkish with English abstract)**

Hung CC, Lai JS, Huang CC (2022) An efficient and economic desilitation strategy for reservoir sustainable development under the threat of extreme flooding threaten. J Water Clim Chang 13(3):1257–1274. https://doi.org/10.2166/wcc.2022.353

Irvem A, Topaloglu F, Uygur V (2007) Estimating spatial distribution of soil loss over Seyhan River Basin in Turkey. J Hydrol 336:30437. https://doi.org/10.1016/j.jhydrol.2006.12.009

Kara Ö, Çakıroğlu K, Koralay N (2018) Determining of soil erosion in Foldere Stream Watershed according to RUSLE method. J Bartın Faculty for 20(3):638–652. https://doi.org/10.24011/barofd.445985. (**in Turkish with English abstract**)

Kondolf GM, Gao Y, Annandale GW, Morris GL, Jiang E, Zhang J, Cao YT, Carling P, Fu KD, Guo QC, Hotchkiss R, Peteuil C, Sumi T, Wang HW, Wang ZM, Wei ZL, Wu BS, Wu CP, Yang CT (2014) Sustainable sediment management in reservoirs and regulated rivers: experiences from five continents. Earth's Future 2(5):256–280. https://doi.org/10.1002/2013EF000184

Koralay N, Kara O, Kezik U (2018) Effects of run-of-the-river hydropower plants on the surface water quality in the Solakli Stream Watershed, northeastern Turkey. Water Environ J 32:412–421. https://doi.org/10.1111/wej.12338

Korkanc SY, Kayikci S, Korkanc M (2017) Evaluation of spatial and temporal water quality in the Akkaya dam watershed (Niğde, Turkey) and management implications. J Afr Earth Sci 129:481–491. https://doi.org/10.1016/j.jafrearsci.2017.01.034

Martin A, Gunter JT, Regens JL (2003) Estimating erosion in a riverine watershed Bayou Liberty-Tchefuncta River in Louisiana. Environ Sci Pollut Res 10:245–250. https://doi.org/10.1065/espr2003.05.153

Mazzorana B, Zischg A, Largiader A, Hübl J (2009) Hazard index maps for woody material recruitment and transport in alpine catchments. Nat Hazards Earth Syst Sci 9(1):197–209. https://doi.org/10.5194/nhess-9-197-2009

Mekonnen M, Keesstra SD, Baartman JE, Ritsema CJ, Melesse AM (2015) Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia. Cuad Investig Geogr 41:7–22. https://doi.org/10.18172/cig.2643

Merritt WS, Letcher RA, Jakeman AJ (2003) A review of erosion and sediment transport models. Environ Model Softw 18(8–9):761–799. https://doi.org/10.1016/S1364-8152(03)00078-1

Mete B (2020). Effects of sediment storage dams on suspended sediment transport: a case study for the Sera Stream Watershed (Trabzon, Turkey). MS thesis. Karadeniz Technical University, Graduate Institute of Natural and Applied Sciences, Trabzon, Turkey **(in Turkish with English abstract)**

Mete B, Baki OT, Bayram A (2022) Monitoring and assessing the transport of total suspended solids in the Sera Stream Watershed (Trabzon, Turkey). Uludağ Univ J Faculty Eng 27(1):419–436. https://doi.org/10.17482/uumfd.970338. (**in Turkish with English abstract**)

Mete B, Nacar S, Bayram A, Baki OT (2023a) Estimation of total suspended solids in the Sera Stream Watershed, Trabzon Province. 11. Ulusal Hidroloji Kongresi. Gaziantep, Turkey, pp 386–395 **(in Turkish with English abstract)**

Mete B, Nacar S, Bayram A, Baki OT (2023b) Estimation of total suspended solids concentration in streams using regression and artificial neural networks methods. J Nat Haz Environ 9(1):125–135. https://doi.org/10.21324/dacd.1133981. (**in Turkish with English abstract**)

Özşahin E (2014) Using GIS-based RUSLE model in erosion risk assessment in Tekirdağ Province. J Tekirdag Agric Fac 11(3):45–56 (**in Turkish with English abstract**)

Pal D, Galelli S, Tang H, Ran Q (2018) Toward improved design of check dam systems: a case study in the Loess Plateau, China. J Hydrol 559:762–773. https://doi.org/10.1016/j.jhydrol.2018.02.051

Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R, Blair R (1995) Environmental and economic costs of soil erosion and conservation benefits. Science 267(5201):1117–1123. https://doi.org/10.1126/science.267.5201.1117

Ren S, Zhang B, Wang WJ, Yuan Y, Guo C (2021) Sedimentation and its response to management strategies of the Three Gorges Reservoir, Yangtze River. China Catena 199:105096. https://doi.org/10.1016/j.catena.2020.105096

Renard KG, Ferreira VA (1993) RUSLE model description and database sensitivity. J Environ Qual 22(3):458–466. https://doi.org/10.2134/jeq1993.00472425002200030009x

RTMAF, Republic of Türkiye Ministry of Agriculture and Forestry (2016) Impact of Climate Change on Water Resources Project - Project Final Report. https://www.tarimorman.gov.tr/SYGM/Belgeler/iklim%20de%C4%9Fi%C5%9Fikli%C4%9Finin%20su%20kaynaklar%C4%B1na%20etkisi/Iklim_NihaiRapor.pdf. Accessed 13 Jul 2023.

RTMAF, Republic of Türkiye Ministry of Agriculture and Forestry (2021) Suspended sediment observations in Turkish rivers (2006 - 2012). https://cdniys.tarimorman.gov.tr/api/File/GetFile/425/KonuIcerik/767/1115/DosyaGaleri/t%C3%BCrkiye-akarsular%C4%B1nda-s%C3%BCspanse-sediment-g%C3%B6zlemleri-2006-2012.pdf. Accessed 13 Jul 2023.

Ryan PA (1991) Environmental effects of sediment on New Zealand streams: a review. N Zealand J Mar Fresh Res 25:207–221. https://doi.org/10.1080/00288330.1991.9516472

Satılmış U (2015) A study on spatial and temporal variation of surface water quality in the stream Değirmendere Watershed (Trabzon). MS thesis. Karadeniz Technical University, Graduate Institute of Natural and Applied Sciences, Trabzon, Turkey **(in Turkish with English abstract)**

Saygın SD, Ozcan AU, Basaran M, Timur OB, Dolarslan M, Erpul YFE, G, (2014) The combined RUSLE/SDR approach integrated with GIS and geostatistics to estimate annual sediment flux rates in the semi-arid catchment, Turkey. Environ Earth Sci 71:1605–1618. https://doi.org/10.1007/s12665-013-2565-y

Schleiss AJ, Franca MJ, Juez C, De Cesare G (2016) Reservoir sedimentation. J Hydraul Res 54(6):595–614. https://doi.org/10.1080/00221686.2016.1225320

Shrestha JP, Pahlow M, Cochrane TA (2022) Managing reservoir sedimentation through coordinated operation of a transboundary system of reservoirs in the Mekong. J Hydrol 610:127930. https://doi.org/10.1016/j.jhydrol.2022.127930

Sthiannopkao S, Takizawa S, Wirojanagud W (2006) Effects of soil erosion on water quality and water uses in the upper Phong watershed. Water Sci Technol 53(2):45–52. https://doi.org/10.2166/wst.2006.037

Tanyas H, Suzen KC, ML, (2015) A new approach to estimate cover-management factor of RUSLE and validation of RUSLE model in the watershed of Kartalkaya Dam. J Hydrol 528:584–598. https://doi.org/10.1016/j.jhydrol.2015.06.048

TSI, Turkish Statistical Institute (2023) Population and Demography. https://cip.tuik.gov.tr/#. Accessed 13 Jul 2023.

TSMS, Turkish State Meteorological Service (2023) General statistics of the Trabzon Province. https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=TRABZON. Accessed 13 Jul 2023.

Wang H, Sun F (2021) Variability of annual sediment load and runoff in the Yellow River for the last 100 years (1919–2018). Sci Total Environ 758:143715. https://doi.org/10.1016/j.scitotenv.2020.143715

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration, Maryland, ABD

Yu S, Ye Q, Zhao Q, Li Z, Zhang M, Zhu H, Zhao Z (2022) Effects of driving factors on forest aboveground biomass (AGB) in China's Loess Plateau by using spatial regression models. Remote Sens 14(12):2842. https://doi.org/10.3390/rs14122842

Zhou P, Luukkanen O, Tokola T, Nieminen J (2008) Effect of vegetation cover on soil erosion in a mountainous watershed. CATENA 75(3):319–325. https://doi.org/10.1016/j.catena.2008.07.010

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.