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Sediment Yields of Basins in the Western Black Sea Region of Turkey

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Abstract

Soil loss and sediment yield are estimated for the basins of the Western Black Sea region of Turkey with different prediction models. The universal soil loss equation (USLE) is the first model applied in this study. Due to the lack of reliable measurement data, the results determined by the application of the USLE using weighted average factors are compared with the results from geographical information system supported USLE predictions undertaken in the TEFER studies performed in the region. Secondly, the modified universal soil loss equation (MUSLE) is applied for direct determination of sediment yield. Finally, the universal equation is expressed with various proposed powers to increase accuracy after regression analysis is applied to the data obtained from the USLE method with weighted averaged factors. It is concluded that the prediction of sediment yield by the USLE using weighted average factors gives quick and accurate estimates.

Key words: Soil loss, Sediment yield, Universal soil loss equation, USLE, MUSLE.

Introduction

Soil is an erodent material and due to its nature, with the impact of an erosive agent such as water or wind, erosion occurs. The responsibility of a hydraulic engineer is to know and control the amount of soil erosion so that no harm to civil engineering structures or residential areas can occur. A certain amount of sediment approaching a hydraulic structure as a design value must be evaluated during the design steps of that structure. This determination is very important especially in areas with a high risk of flooding, as floods increase the rate of erosion. The determination can be made either by field observations or by calculation in other words by estimation.

The Western Black Sea region in Turkey is highly prone to flooding. After seasonal heavy rainfall, a large amount of soil erosion takes place and this endangers civil engineering structures, and thus human life. A number of bridges and other hydraulic structures were destroyed after major floods in the region. Sediment yield is an important parameter that has to be considered during the planning and design stages of flood measures and hydraulic structures. It plays an especially important role during the determination of the active and dead volumes of the reservoirs of large dams. The main aim of this study is to show that regression models for sediment yield prediction can give quick and accurate results.

Theory

Erosion is the loosening or dissolving and removal of earthy or rocky materials from the earth's surface. Soil erosion can be defined as the detachment of soil particles from the surface after the impact of an erosive agent such as wind, water or rain-splash. If water is the erosive agent, the type of erosion is called water erosion. Precipitation is a main variable affecting water erosion. Raindrops have a great impact on the surface of the earth, causing the detachment of soil particles. After the soil is eroded, the sediment particles are transported through runoff until deposition occurs. Surface runoff is therefore another main variable.

It is not possible to measure all the variables causing erosion and deposition rates in order to develop a complete deterministic model. Therefore, probabilistic values based on measurements must generally be allocated to these variables to obtain estimates of erosion and deposition. Prior to making an estimation of erosion, the type of erosion and sediment sources in the watershed have to be determined. The types or sources of erosion can be classified as sheet, interrill, rill and gully erosion (Simons and Şentürk, 1992).

Soil loss is the amount of soil actually removed by erosion. Sediment yield, on the other hand, is the total suspended sediment outflow from a watershed, which is sometimes measurable at a cross-section of reference and in a specific period of time. It must be realized that not all the eroded material is transported if the amount of sediment carried exceeds the transport capacity of the flow. Sediment deposition occurs in those cases, which is why the sediment yield results are lower than the amount of soil loss. A sediment delivery ratio (DR) therefore, has to be assigned and used to distinguish the amount of sediment yield from that of soil loss. It is simply the ratio of the sediment yield to the soil loss.

Sediment yield prediction techniques can be classified under 3 headings: (1) regional regression equations, (2) physically based simulation models and (3) regression models. Due to the type of erosion in the catchments and the available data, regression models are selected and the universal soil loss equation (USLE) and the modified universal soil loss equation (MUSLE) were applied in this study.

The Universal Soil Loss Equation

The USLE is the most widely used regression model for predicting soil erosion. It is an empirical equation and predicts gross soil loss due to sheet and rill erosion. The USLE contains 5 major factors that have been proved to affect soil loss and sediment yield. It was expressed by Williams and Berndt (1972) as

$$A = R.K.LS.C.P \tag{1}$$

where A is the computed soil loss per unit area, (metric ton)/(hectare.year); R is the rainfall factor, also called the factor for rainfall erosivity (megajoule.millimeter)/(hectare.hour.year); K is the soil-erodibility factor (metric ton.hectare.hour)/(hectare.megajoule.millimeter); LS is the slope length and gradient factor; C is the cropping management factor and P is the erosion-control-practice factor (Johnson *et al.*, 1984). The factors other than R and K are dimensionless.

The rainfall erosivity factor, R, expresses the erosion potential of average annual rainfall in the locality. It is also called the index of erosivity or erosion index. After studying different climatic zones, Arnoldus developed an equation to estimate the R factor (Renard and Freimund, 1994),

$$R = 4.17\sum_{i=1}^{12}(p_i^2/P_{ave}) - 152 \tag{2}$$

where the R factor is dependent only on average monthly precipitation, p_i, and average yearly precipitation, P_{ave}.

The soil erodibility factor, K, represents the average soil loss from a specific area of soil in cultivated continuous fallow with a standard plot length selected as 22.13 m and a standard percentage slope selected as 9% . The K factor is determined using a soil erodibility nomograph based on particle size, organic matter, soil structure, and permeability data (Johnson *et al.*, 1984).

The following formula may be used to evaluate the nomograph readings:

$$K = \frac{\frac{2.73M^{1.14}}{10^4}(12-a) + 3.25(b-2) + 2.5(c-3)}{100} \tag{3}$$

where K is the soil erodibility, M is the particle size diameter given as the production of (silt% + very fine sand%) with (100% clay), a is the % of organic matter, b is the soil structure code and c is the profile permeability code. This estimation of soil erodibility for nomograph estimations has been proved to give accurate results (DSI, 2000).

The slope length and gradient factor, LS, is defined as the ratio of soil loss from any slope length and gradient to soil loss from a 22.13 m plot on the same soil type with a 9% slope with all other conditions the same. This factor is defined by the multiplication of the L and S factors, (Moore and Burch, 1986),

$$L = (l/22.13)^m \tag{4}$$

$$S = (0.043x^2 + 0.3x + 0.43)/6.613 \qquad (5)$$

where L is the slope length factor and S is the slope gradient factor, l is the slope length in meters and m is an exponent depending upon slope; m is equal to 0.3 for slopes smaller than 3%, 0.4 for slopes smaller than 4% and 0.5 for slopes smaller than 5%, and x is the land gradient slope measured as a percentage.

The cropping management factor, C, represents the ratio of soil loss from land with specific cropping and management to that from tilled and fallow conditions on which the K factor is evaluated. The C factor, also called the cover and management factor, varies between zero and unity and depends on type of vegetation cover, crop season, and other management techniques. The erosion-control-practice factor, P, represents the effect of conservation practices. The P factor is determined as the ratio of soil loss using one of the conservation practices to the soil loss using straight row farming. Therefore, the P factor for straight row farming is equal to unity.

As described before, the USLE predicts gross soil loss from sheet and rill erosion; in other words it estimates the amount of soil detached by surface erosion. After determining the soil loss using the USLE, sediment yield can be determined by multiplying its value by the delivery ratio.

The modified universal soil loss equation

It has been shown that delivery ratios to determine sediment yield from soil loss predictions can be predicted accurately but that they vary considerably. The reason for this is the variation in rainfall distribution over time from year to year. As a result of the uncertainty in the delivery ratio, the MUSLE was proposed by Williams and Berndt (1972) and the replacement of the rainfall factor with a runoff factor was recommended.

The MUSLE increases sediment yield prediction accuracy, eliminates the need for delivery ratios, and is applicable to individual storms. It is expressed by Williams and Berndt (1977) as

$$Y = 11.8\,(Qq_p)^{0.56}\,K.LS.C.P \qquad (6)$$

where Y is the sediment yield from an individual storm in metric tons, Q is the storm runoff volume in m^3, q_p is the peak runoff rate in m^3/s, and K, LS, C and P are all the USLE factors described in the previous section: 11.8 and 0.56 are coefficients determined by optimization studies by Williams in 1975 and additional studies by Williams in 1982 and by Smith *et al.* in 1984 (Johnson *et al.*, 1985). As the only difference between USLE and MUSLE is the replacement of the rainfall factor with the runoff factor, the runoff volume, Q, and the peak runoff rate q_p have to be determined. Since measured runoff volumes or peak runoff rates are not available most of the time in water resources planning, runoff is generally predicted with a hydrologic model. The other required input, the peak runoff rate, can be determined from predicted hydrographs.

MUSLE is used to predict sediment yield on a single storm basis, but it can also be used to predict sediment yield on an annual basis. This may be accomplished by determining the soil loss for events in varying return periods. The sediment yields are calculated with return periods of 2, 10, 25, 50 and 100 years. The results are then weighted according to their incremental probability and the result gives a weighted storm average. To compute the annual sediment yield, the weighted storm yield is multiplied by the ratio of annual water yield to an incremental probability-weighted water yield. The computation of annual sediment yield after using MUSLE can be expressed as

$$A_s = \frac{Q_A(0.01Y_{s_{100}} + 0.01Y_{s_{50}} + 0.02Y_{s_{25}} + 0.06Y_{s_{10}} + 0.4Y_{s_2})}{0.01Q_{V_{100}} + 0.01Q_{V_{50}} + 0.02Q_{V_{25}} + 0.06Q_{V_{10}} + 0.4Q_{V_2}} \qquad (7)$$

where A_s is the annual sediment yield, and Q_A is the average annual water yield, and Y_s and Q_v are single storm event sediment yield and water yield with corresponding return periods, respectively (Simons and Şentürk, 1992).

Present study

The Western Black Sea region is composed of catchments that are steep and prone to erosion and landslides. Combining this characteristic of the area with the fact that the region is highly prone to heavy rainfall and massive flooding, the question of long-term risk and damage to human beings and their property arises as erosion and landslides may become dangerous if the necessary flood measures are not taken. In order to make a proper design of new structures, improvements, the repair and recovery of structures damaged in floods and flood management strategies, one of the main concerns will be the amount of sediment carried and deposited in the vicinity of the flood defense structures during large floods which may reduce channel capacity and cause overtopping.

The main aim of this study is to make an accurate, quick and easy determination of sediment yield in the Western Black Sea region. The Turkish government carried out a program of investigations and rehabilitation works for flood mitigation under the Turkish Emergency Flood and Earthquake Recovery Project (TEFER). To prove the convergence of the results of the present study, they are compared with the results of the TEFER studies, which were intended to lead to the recommendation of flood defense structures and strategies in the area (DSI, 2000). In the TEFER study, sediment yield is predicted using the USLE, but the equation is empowered with the capabilities of the geographical information system (GIS). With the help of GIS each and every factor of the USLE is distributed to each catchment as layers and to every grid of the catchments with its corresponding value, where the grid size is chosen by the user with computational simplicity and usability. After each variable is distributed to the area, sediment yield values from each grid of a catchment can be evaluated with its corresponding factors. This method certainly gives a better estimation of the sediment yield than that used in this present study, although it is a costly and time consuming one (Cambazoğlu, 2002).

The Study Area

The study area covers the provinces of Kastamonu, Bartın, Zonguldak and Bolu in the Western Black Sea region. A total of 14 sub-catchments have been studied that were chosen by the TEFER to lead the action on rehabilitation for flood protection projects. These include a total of 31 locations where channel constraints and other factors have led to major flooding with erosion and sedimentation problems. Sediment yield predictions were conducted for these locations in this study. A total of 85 catchments were studied and their sediment yields were predicted.

Determination of the R factor

The R factor of the catchments can be determined from the iso-erodent maps prepared for Turkey by the Ankara Research Institute of the Directorate General of Rural Services. However, this map is fairly crude and only 4 average values for rainfall erosivity are given for the provinces of Bolu, Çankırı, Kastamonu and Zonguldak for the project area. In order to determine R factor values more accurately, Eq. (2) is used, which is the estimation formula developed by Arnoldus using average monthly and annual rainfall. R factors were calculated for 50 meteorological stations with monthly and yearly precipitation measurements located in the area. An iso-erodent map of the project area was prepared during the TEFER studies. During the calculations this iso-erodent map was used to determine the R factor values of the catchments (DSI, 2000). The R factors calculated for each station were observed to be the same as the TEFER results and the same R values were used in both studies. The R factor values for basins in the Western Black Sea region have maximum and minimum values of 258 and 34, respectively (Cambazoğlu, 2002).

Determination of the K factor

Soil erodibility depends on the physical and chemical properties of the soil. These are its texture, aggregate size and stability, organic carbon content and permeability. Eq. (3) is used for the determination of K factor values for a total of 13 soil types existing in the study area. K factors for soils in the study area were derived from information provided by the Ankara Research Institute of the Directorate General of Rural Services during the TEFER studies. Fifteen to twenty samples were taken from the topsoil, which is 0-15 cm from the surface, and from the sub-soil, which is 15-30 cm from the surface. A total of 161 samples taken from the provinces of Bolu, Kastamonu, Zonguldak, Kayseri, and Çankırı in the Western Black Sea region were analyzed in the laboratory to determine soil texture and organic matter content. Soil structure and permeability were determined during sampling studies in the field (DSI, 2000).

Knowing the K values for all soil types in the area, an area-weighted average K value can be determined for each catchment using Eq. (8),

$$K = \frac{\sum_{i=1}^{n} K_i DA_i}{DA_T} \tag{8}$$

where K is the soil erodibility factor for the watershed, K_i is the soil erodibility factor for an individual soil, i, DA_i is the drainage area covered by an individual soil, i, DA_T is the total drainage area of the watershed and n is the number of different soils in the watershed. The K factor values of the existing soils in the study area have a range of 0.2 to 0.337 (Cambazoğlu, 2002).

Determination of the LS factor

The slope length and gradient factor is divided into its constituent parts and these are calculated separately. Six different slope classes are determined for calculations and field observations. These slope classes are 0–2%, 2–6%, 6–12%, 12–20%, 20–30%, and >30%. The L factor, named the topographic factor, is determined for Bolu, Düzce, Filyos, Bartın and Seben using Eq. (4). For the determination of slope length values, average slope lengths are found from land capability maps for the slope classes chosen (DSI, 2000). To determine the S factor for the chosen slope classes, the S factors for the upper and lower boundaries of the classes are calculated initially with the corresponding slope of the boundary using Eq. (5). Then, the averages of the results are taken to find average S factor values for each slope class. After both L and S factor values are determined for each slope class, the LS factors are determined by multiplying them. The only thing then left to find the LS factor of a catchment is to determine the distribution of different slope classes in the area. Finally, area-weighted average LS factors can be determined by Eq. (9) for the catchments in the study area,

$$LS = \frac{\sum_{j=1}^{n} LS_j DA_j}{DA_T} \tag{9}$$

where LS is the slope length and gradient factor for the watershed, LS_j is the length and gradient factor for an individual slope class, j, DA_j is the drainage area covered by an individual slope class, j, DA_T is the total drainage area of the watershed and n is the number of different slope classes in the watershed. In the present study, the LS factor values varied between 5.49 and 10.077 (Cambazoğlu, 2002).

Determination of the C factor

The crop-management factor, C, of the USLE is generally established on experimental plots or estimated with equations. C factor values for different land use types in the study area were proposed in the TEFER study by comparing the previously proposed C factor values. The existing land use types in the area are irrigated agriculture, dryland agriculture, mixed gardens, grazed and ungrazed pastures, forests, bush and hazelnut plantations (DSI, 2000).

The main crops grown on irrigated lands are potatoes and other tubers, sugar beet, vegetables, fruit trees and fodder crops. Each crop has a different C factor proposed for it, and an average value of the C factor for irrigated agriculture can be determined by taking the area-weighted average of C factors of crop types with their corresponding areas in 4 different districts in the study area. The main crops grown in dryland agriculture are maize, cereals (wheat, barley, oats), pulses (chick beans, dry beans, lentil, cow peas), fruit trees and fodder crops.

One important surface cover existing in the region is forest. Forests are the most important protection cover type against erosion. They can be classified into 2 groups: good, undisturbed forests and poor, disturbed forests. Undisturbed forests contain soils with high infiltration rates and organic matter content and much of the surface is covered with forest duff and litter. These layers on the surface protect the soil from erosion by surface runoff and raindrop impact. In disturbed forests, the tree and litter cover is incomplete and the protection against erosion is less effective, although there is still protection by undergrowth canopies. Therefore, the C factor for disturbed forests varies with the percentage of ground and canopy cover. In nearly all the forests in the study selective logging takes place. Therefore, they are regarded as disturbed forests (DSI, 2000).

Mixed gardens are well kept lands and the vegetation cover is mostly quite complete. Therefore C factor values are small in these land use types. Another land use type existing in the area is pasture grazed by cattle and sheep. Pastures can be divided into 2 categories: good pastures and degraded pastures. These pastures are composed of brush canopy cover, herbaceous cover and bare soil in differing percentages. Good pastures usually have almost complete ground cover whereas degraded pastures have at least 15% of unprotected surface cover without any vegetation. Some pastures are not grazed but are used for production of hay. This land use usually has a good surface cover providing effective protection against erosion. The last land use type in the area is the hazelnut plantation. In hazelnut plantations, the trees are planted in rows. The surface between these rows is covered either with herbaceous cover or with maize. The C factor for bush also depends on the percentage of ground cover. The cropping management factor, C, for a watershed is determined by weighting the C values of each crop and management level according to the size of the area growing the crop with the same management level,

$$C = \frac{\sum_{k=1}^{n} C_k DA_k}{DA_T} \tag{10}$$

where C is the cropping management factor for the watershed, C_k is the cropping management factor for an individual crop, k, DA_k is the drainage area covered by an individual crop, k, with a particular management level, DA_T is the total drainage area of the watershed and n is the number of different crops and management levels in the watershed. The C factor values used in the present study are between 0.035 and 0.449 (Cambazoğlu, 2002).

Determination of the P Factor

In the study area, the only conservation practice applied is terracing (DSI, 2000). This is only applied to irrigated agricultural areas, hazelnut plantations where the trees are planted on back sloping terraces, and in mixed gardens. There is no exact information on the amount of conservation practices applied in the study area. Therefore, the erosion-control-practice value, P, is considered as unity in order to be on the safe side.

Determination of soil loss, delivery ratio and sediment yield

After the R, K, LS, C and P factors are determined, they are multiplied in order to determine the amount of soil loss using the USLE. After the soil loss rate is determined, the transported sediment, that is the suspended sediment, is calculated using the delivery ratio for each catchment. Assessment of sediment delivery ratio can be made by gauged catchments. Not all the catchments in the area are gauged, so that sediment delivery ratios can be determined as a function of catchment area, average annual erosion rate and whether or not a river crosses a major plain. Starting from an average initial value of 12.5% and making the necessary adjustments, the sediment delivery ratio for very large catchments with high erosion rates and a large alluvial plain has a minimum value of 2.5%, and for small catchments with low erosion rates it has a maximum value of 20%. After the sediment delivery ratio is determined, annual sediment yield rates can be calculated from annual soil loss rates by multiplying them by delivery ratios (Simons and Şentürk, 1992).

Determination of total sediment transport rate

Sediment yield only accounts for the suspended load transport. However, a high percentage of bed load transport occurs during flood events. As stream velocities are high in such cases, it is difficult to make bed load measurements. This requires the estimation of bed load material. Field surveys were undertaken during the TEFER project studies around Hasanlar Dam to find a ratio of suspended load to total load. The erosion rates are compared with the sedimentation rates of the reservoir. This is a comparison of sediment yield rate and the total load, respectively. The actual average soil loss rate in the Hasanlar Dam catchment is determined as 44.6 (t/ha)/year. The sediment delivery ratio of the catchment is estimated as 10%. Therefore, the sediment yield rate is 446 (t/km^2)/year. The surveys conducted between the first 10 operating years of the dam (1969-1979) showed that the total sediment load from the 665 km^2 catchment is 790 (t/km^2)/year. The sediment yield accounting for the suspended load is 56.5% of the total sediment inflow, i.e. the total load. As a result, total load can be determined considering a bed load/suspended load ratio of 43.5/56.5.

Determination of sediment yield by modified universal soil loss equation

The second prediction method applied in the present study is the MUSLE. This predicts sediment yield without requiring the application of a sediment delivery ratio as the USLE does. The MUSLE (Eq. (6)) consists of the USLE factors, except for the rainfall erosivity factor where it is replaced by a runoff factor. Therefore, the same values for K, LS, C and P factors used in the determination of soil loss by the USLE are again used in the determination of sediment yield by MUSLE. The storm runoff volume, Q, and the peak runoff rate, q_p, are the additional variables that have to be determined in this part of the study. They are determined after the regional flood frequency analysis applied to the area (DSI, 2000).

The result of the MUSLE gives the sediment yield rate for a single storm event with a specified return period. Sediment yield estimations are applied by the MUSLE for storms with different return periods of 2, 5, 10, 25, 50, and 100 years. From these results, the increasing trend of sediment yield values with increasing return periods of storm events can be observed. If a storm event occurs in the Western Black Sea region, the sediment yield accumulating to the project locations of the present study can be determined using those figures considering that the return period of the event is known (Cambazoğlu, 2002).

Although the MUSLE is developed for single storm events, annual yield needs to be found in the present study in order to include MUSLE results in comparison studies. For that reason, Eq. (7) is used to determine the annual sediment yield rates from sediment yield results of different return periods.

Comparison of Results and Discussions

In order to confirm the accuracy of predictions, the annual soil loss values predicted using the USLE in the present study have to be compared with measurements taken from the locations for which they are predicted. However, it is unfortunate that there are no sediment transport gauging stations and observations of sediment yield in the catchments of the area and locations of interest. Therefore, the annual soil loss rate results obtained in the present study are compared with the annual soil loss rate results from the TEFER studies. Both studies predict the soil loss with the application of the USLE. However, the main difference is that the USLE is applied using weighted average values for its factors in the present study, while it is used with the application and help of the GIS, in the TEFER studies. The latter certainly gives better estimates of sediment yield rates compared to the application of the USLE using only a single value for the factors averaged over the area of the catchments.

Average values for the USLE factors K, LS, C and P are also given in the TEFER studies. These average values for each factor are compared with the values in the present study. Most of the differences between the average values given in the TEFER studies and the weighted average values determined in this study result from rounding off errors. Thus 94% of LS factor differences are below 2%, 92% of K factor differences are below 2% and 74% of C factor differences are below 5%. The C factor differences are greater than the other 2 factors as the order of magnitude of C factor values is smaller than those of the other 2 factors.

Except for project locations 34, 35 and 36, all the predictions are performed for exactly the same catchments. Hasanlar Dam exists in or near those locations and the soil loss is predicted only for the downstream sections of the dam in the TEFER studies. However, the soil loss is predicted for all the catchment areas in this study. Therefore, the results in this study are at least 50% greater for those locations.

Comparing the soil loss findings, 79% of the results in this study are within a ± 25% range of the results from the TEFER studies, and 98% of the results are within ± 50%.

For some catchments, although the differences in average USLE factors of catchments are very small, the differences in annual soil loss rates are large and vice versa. The reason is that, the method applied in the TEFER study takes into account not the average values of the factors over the area of the catchment but their real values for every point on the catchment. They multiply the individual factors of each point by each other to determine the soil loss for each segment, while the present study uses USLE factor values as averaged over the areas of the catchments and multiplies these average values for all over the catchment areas.

A comparison of the 2 methods used for the prediction of annual soil loss rate values for the catchments in the study area is given in Figure 1. This presents the line of agreement, and the correlation coefficient for the best fit indicates that there is a good correlation between the results ($R^2 = 0.968$). It can be concluded that the annual soil loss rates of catchments in the Western Black Sea region can be accurately and quickly predicted using the USLE with its factors having weighted average values without the necessity of using GIS.

As the USLE is a formula of multiplication of several factors, it was decided to apply nonlinear regression analysis to the equation and the data set of results gathered from the compared studies. The aim is to input the values determined for the factors in the present study and to find the optimum exponents for the factors so that the resultant annual soil loss rates will be equal or closer to the results determined by the USLE with GIS as in the TEFER studies. As a result, our new equation for the prediction of annual soil loss rate will be

$$SL = R^{0.862}.K^{1.307}.LS^{1.562}.C^{1,058} \tag{11}$$

The results of the new equation show that 88% of the soil loss results are within ± 25% of the results from the TEFER studies by using the USLE with

GIS. Figure 2 shows the comparison chart of the annual soil loss rate results from the new equation and from the TEFER studies. It is observed that the accuracy of the new equation is better than that of the USLE with its factors having weighted average values (R^2= 0.978).

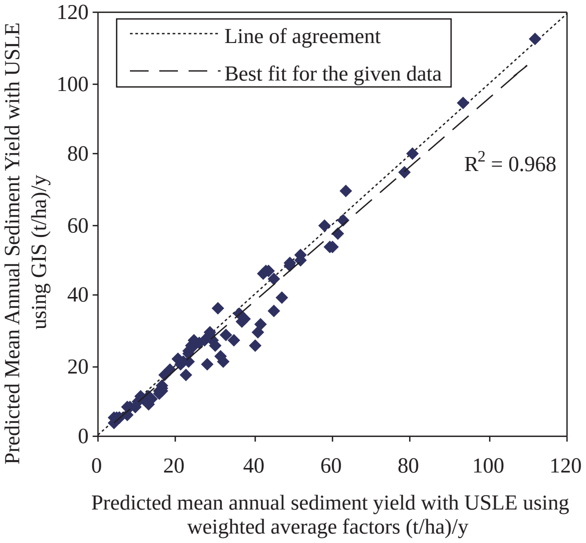

Figure 1. Comparison of the USLE predicted soil loss in the present study and the USLE predicted soil loss using GIS in the TEFER project for 81 sub-watersheds in the Western Black Sea region.

It can be expected that the use of the new equation for catchments showing characteristics similar to those of the Western Black Sea region catchments will give closer estimations of soil loss to those estimated with the USLE supported by GIS.

Annual sediment yield values determined by the MUSLE and the annual soil loss values determined by USLE are also compared. MUSLE predictions of sediment yield for storm events of different periods are greater than the USLE predictions of soil loss. Considering that USLE predictions of annual soil loss values will be multiplied by sediment delivery ratio values ranging between 5 and 25%, MUSLE estimates of sediment yield will be much higher than USLE estimates of sediment yield. MUSLE estimates for annual sediment yield rates are on average 4.5 times greater than USLE estimates for annual soil loss in the study area. This result may be taken into account in future design studies.

Sediment yield predictions for single storm events with different return periods are also determined. These values for 2, 5, 10, 25, 50 and 100 year storms are shown in Figure 3 for catchment no. 42 in project location 10 as an example. Even the smallest sediment yield prediction made for the smallest return period of 2 years is greater than the amount of annual sediment yield rate found by the USLE. This can be explained by the fact that a single storm event occurring in a short period can have a great impact compared to the annual average values. Another reason may be that during a year there will be high rainfall seasons and low rainfall seasons. Therefore, taking the average values for a whole season considering a number of years will result in smaller values for sediment yield compared to storm events like the May 1998 storm that occurred in the region. The May 1998 storm has a return period varying between 20 and 1000 years in the Western Black Sea region, and so it might be better to use the results from the MUSLE in design studies in order to ensure the safety of engineering structures. Consequently, appropriate and safe design values for sediment yields for hydraulic structures have to be determined considering the operating life of the structure and the return period of the possible storm events (Cambazoğlu, 2002).

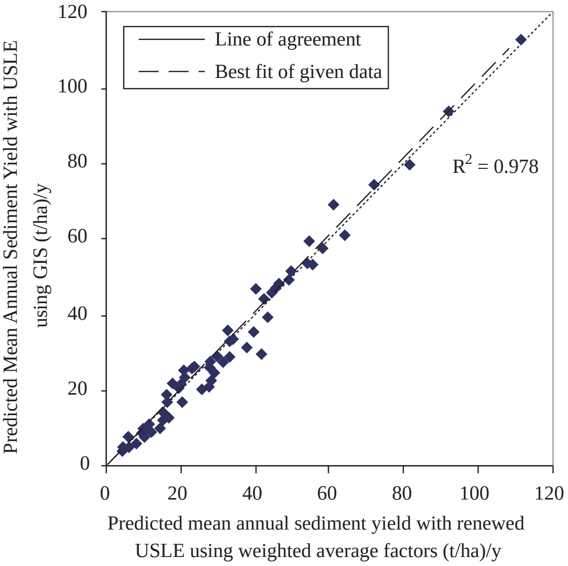

Figure 2. Comparison of the soil loss predicted by renewed USLE in the present study with that of the USLE using GIS in TEFER project for 81 sub-watersheds in the Western Black Sea region.

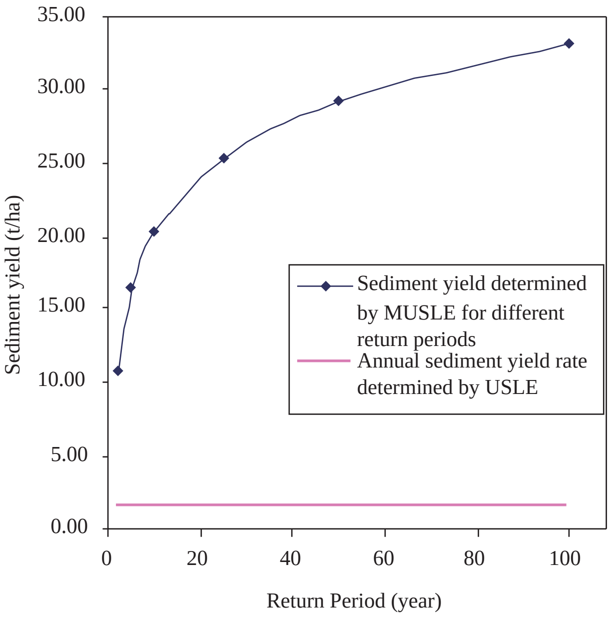

Figure 3. Comparison of sediment yields predicted by the MUSLE for storms with different storm periods with annual sediment yield predicted by the USLE for catchment 42 in project 10.

In order to give the reader an idea of the efficiency of prediction methods, the predicted results were compared with the measured values. There are 8 stream gauging stations in the Western Black Sea region. Daily sediment load data were collected once a month during the observation period and annual sediment yield measurements from those stations were reported (EİE, 1987).

The MUSLE predicts sediment yield directly, but it results in extreme results as storm values are used for calculations. For that reason, MUSLE predicted sediment yields were observed to give greater values than annual average values and they were not compared with the measurements.

USLE predicted sediment yield values for the project locations in the area were compared with the measurements. However, none of our project locations exactly coincide with the locations of the measurement stations. Therefore, the stations close to our project locations were chosen for comparisons. Table demonstrates the annual sediment yield values of several project locations predicted with the USLE and the measurement values from the stations closest to them.

There were 5 project locations used for the comparisons. The project location numbers and the closest measurement station numbers are given in columns 1 and 2 of Table. As can be seen from columns 3 and 4 of Table, the catchments used for the predictions are different from the catchments of the stations, i.e. measurements. However, it is considered that close locations might have similar catchments and predictions may be compared with the measurements since they are defined as annual sediment load per area. Figures 4 - 6 provide maps of several of these project locations together with the measurement stations in the region.

The ratios between predictions and measurements are also given in column 7 of Table. Predicted values are up to 11 times greater than the measurements. Although project location 61 and measurement station 1334 are very close to each other (Figure 5) and their catchments are almost the same size, the prediction of sediment yield for that location is not as accurate as for the other locations. This difference may be explained by the use of inaccurate delivery ratios in the predictions. Delivery ratios for

Table. Comparison of sediment yield predictions and measurements.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Project Location	Closest Measurement Station	Catchment Area of (1) (km^2)	Station Area (km^2)	USLE Predicted Sediment Yield $(t/km^2)/y$	Measured Sediment Yield $(t/km^2)/y$	Predicted/ Measured Ratio
61	1334	1108	1103	278	25	11
51/A	1343	227	125	157	54	3
67	1334	699	1103	235	25	9
92	1340	2053	1509	367	151	2
44/B	1314	8647	5087	135	135	1

all predictions were calculated according to the current situation and characteristics of catchments, while the measurements yield an average result of the same catchment with varying characteristics from year to year. On the other hand, the catchment area of project location 44/B covers the area of measurement station 1314 and the prediction made is the same as the measurement given.

Alternatively, the differences between predictions and measurements may be explained in terms of dissimilar catchments of the project locations and stations. In other words, predicted values do not exactly represent the measurements. In order to be able to make a reliable comparison, the prediction and the measurement must represent the same basin.

Finally, it must be stated that the reliability of the measurement stations is also questionable. Only monthly measurements are taken and this may result in missing large sediment yields occurring after storms.

Conclusions

In this study, the soil loss and the sediment yield from 85 catchments in the Western Black Sea region of Turkey were predicted by different prediction models and a new approach for a more accurate and also quick prediction of sediment yield is proposed.

The following points can be concluded:

The sediment yield rate obtained using the average results weighted over the area of the catchments for the K, LS, and C factors were compared with the results obtained with the application of GIS. The percentage differences between the results are presented. The results are close to each other in most of the catchments. The reasons for major differences were investigated and it was found that using average values for the factors over the area was the main reason for these. Comparing the methodologies of the 2 methods, it was assumed that the results from USLE with GIS are closer to the real values. The application of the USLE with its weighted average factors gives good results compared to the results from the application of USLE with the support of GIS. This proved that the sediment yield predictions in the Western Black Sea region catchments can be accurately and quickly estimated by USLE, as in the present study.

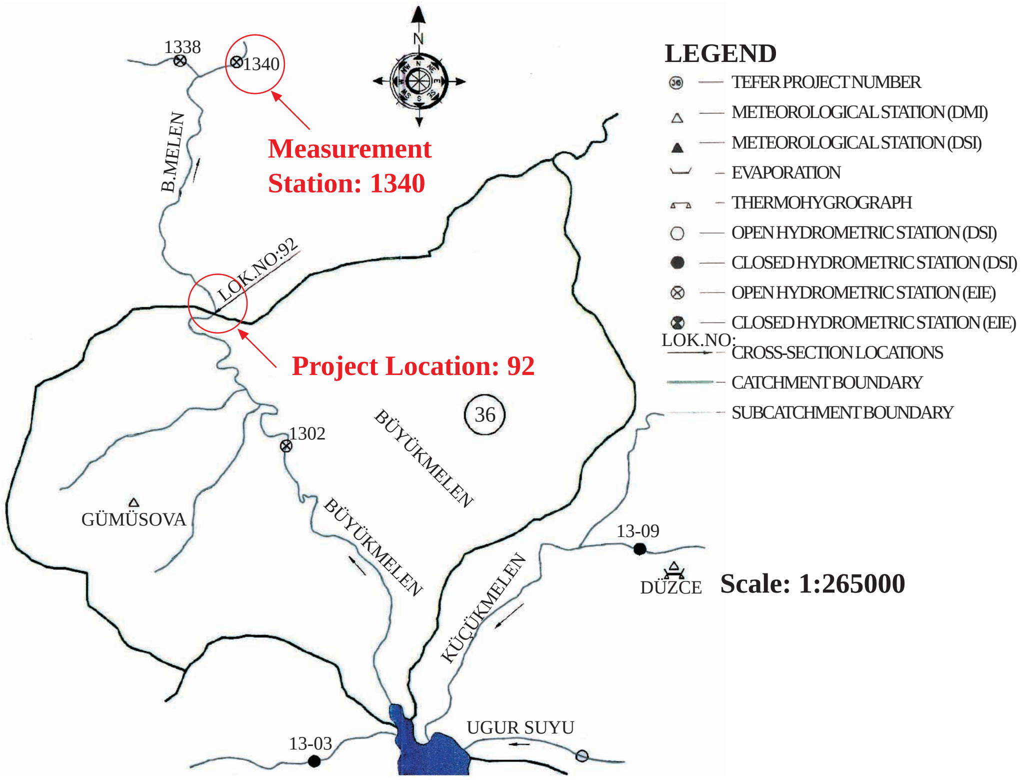

Figure 4. TEFER project No: 36, project locations, catchment areas, measurement stations.

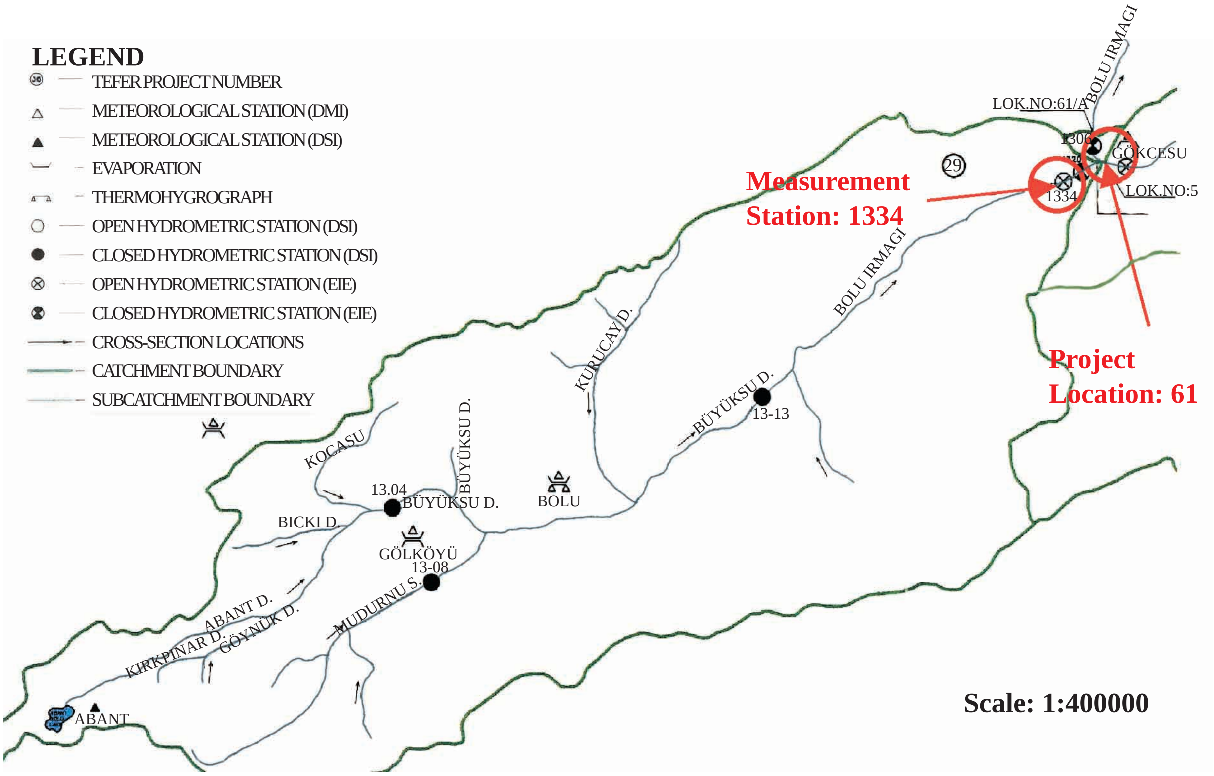

Figure 5. TEFER project No: 29, project locations, catchment areas, measurement stations.

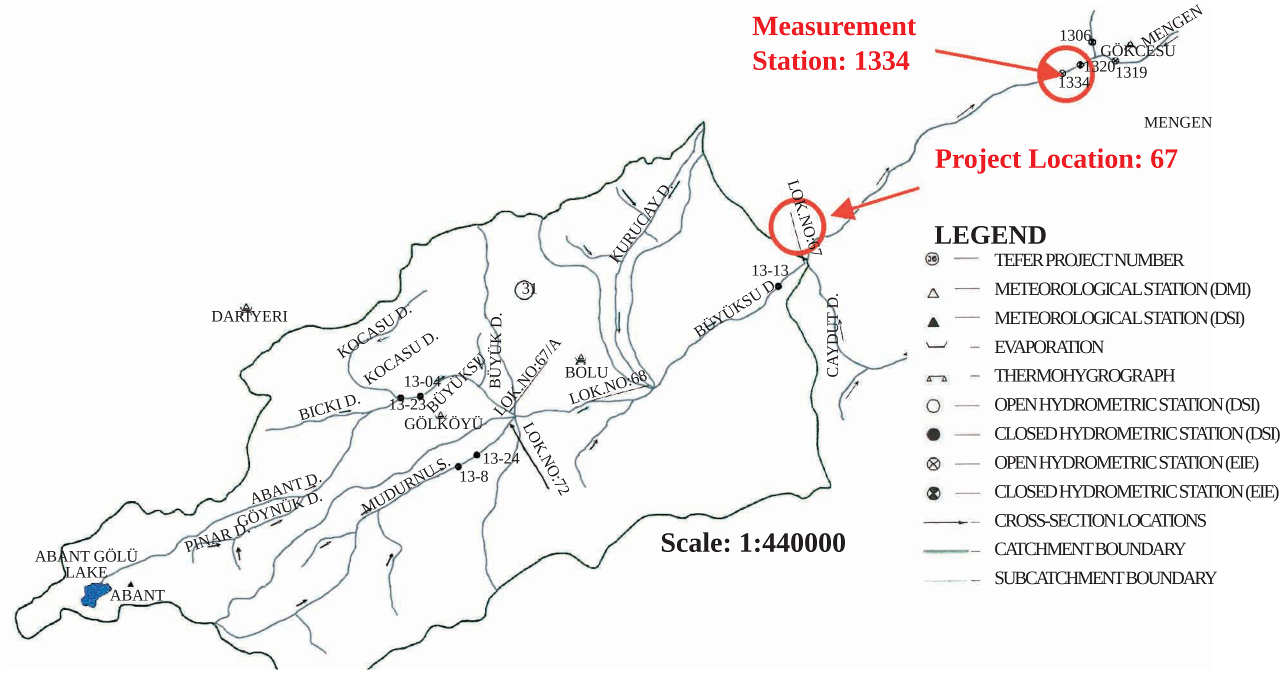

Figure 6. TEFER project No: 31, project locations, catchment areas, measurement stations.

It was observed that most of the results of the present study are greater than those from the TEFER studies. This may be interpreted as meaning that the sediment yield rate values predicted by USLE, as in the present study, are on the safe side for design studies considering that the USLE results have been proved to overpredict sediment yield by many studies in the literature.

The MUSLE was observed to give higher predictions than did the USLE. The main reason for this may be related to the application of a runoff factor estimated with a flood frequency analysis. The MUSLE model takes single storm events into account and results in higher sediment yields caused by the higher impacts of these events. It is recommended that MUSLE results be considered for design purposes.

The USLE was reviewed with regression analysis. The equation is reconstructed by determining exponents for the factors, and it was shown that the application of the proposed equation increases the accuracy of the predictions while reducing the percentage differences with the results from USLE with the support of GIS.

It should finally be emphasized that the prediction of sediment yield by regression models was applied in the present study and it is clear that the application of these is much easier compared to the application of GIS to interpret the data or the application of physically based simulation models that require large amounts of input data, although they are certain to give better estimates.

Nomenclature

The following symbols are used in this paper:

a	percentage of organic matter;
A	annual soil loss rate, annual soil loss per unit area;
A_s	annual sediment yield rate;
b	soil structure code;
c	profile permeability code;
C	cropping management factor;
C_{ave}	weighted average C factor over an area;
DA	drainage area;
DA_T	total drainage area of the watershed;
DR	sediment delivery ratio;
GIS	geographical information system;
K	soil erodibility factor;
K_{ave}	weighted average K factor over an area;
L	slope length factor;
l	slope length;
LS	slope length and gradient factor;
M	particle size diameter;
m	an exponent depending upon slope;
MUSLE	modified universal soil loss equation;
P	erosion-control-practice factor;
p_i	average monthly precipitation;
P_{ave}	average annual precipitation;
Q	storm runoff volume;
Q_A	average annual water yield;
Q_V	water yield for a single storm event;
q_p	peak runoff rate;
R	rainfall erosivity factor;
S	slope gradient factor;
TEFER	Turkish Emergency Flood and Earthquake Recovery project;
USLE	the universal soil loss equation;
x	land gradient slope measured as percentage;
Y	sediment yield;
Y_s	sediment yield for a single storm event;

Subscripts

i	of an individual soil type;
j	of an individual slope class; and
k	of an individual cropping type.

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