Pol. J. Environ. Stud. Vol. 26, No. 5 (2017), 2135-2146
DOI: *10.15244/pjoes/69171*

Original Research

Subdividing Large Mountainous Watersheds into Smaller Hydrological Units to Predict Soil Loss and Sediment Yield Using the GeoWEPP Model

Mehmet Özalp*, Esin Erdoğan Yüksel, Saim Yıldırımer

Artvin Coruh University, Faculty of Forestry, Artvin, Turkey

Received: 18 January 2017
Accepted: 25 February 2017

Abstract

The number of studies using prediction models on measuring soil loss and/or sediment yield has been continuously increasing since these models are considered timely and cost-effective. Similarly, in this study, we used the GeoWEPP model to determine how much soil is being lost and the amount of sediment being yielded from Godrahav Creek Watershed (GCW) located in northeastern Turkey. Because the watershed is large (5,298.21 ha) and has mountainous and steep terrain, it was subdivided into smaller hydrological units (SHUs) so that the model can run easily and give detailed findings. The results revealed that out of 18,596.8 t of soil loss generated from both hillslopes and channels within the whole GCW, approximately 9,854.8 t y^{-1} reached Borcka Dam reservoir as sediment. The model also predicted annual average soil loss and sediment yield as 1.73 t $ha^{-1}y^{-1}$ and 1,86 t $ha^{-1}y^{-1}$, respectively. In addition, with a sediment delivery ratio (SDR) of 0.530, the results indicated that almost half of the detached soil particles were carried away as sediment. Despite the dominant vegetation coverage, relatively high SDR and soil loss – particularly in certain SHUs – can be associated with steep terrain and conversion of natural lands in the watershed.

Keywords: soil loss, sediment yield, GeoWEPP model, sediment delivery ratio, watershed

Introduction

Natural vegetation cover, specifically forests and grasslands, are undoubtly the most effective and cheapest way to prevent detachment of topsoil in lands against the physical forces of water (runoff). It is a well-known fact that soil erosion and associated sedimentation processes are natural phenomena in both forming and changing general landscapes around us. However, inappropriate management practices, illegal logging, conversion, and overuse of forest and grasslands have caused the delicate balance among soil, water, and plants to be broken in these natural ecosystems both in Turkey and the world. This, in turn, has resulted in several ongoing environmental problems, including accelerated soil erosion and increased sedimentation rate that have already reached serious levels in some regions of the world. Moreover, when human-induced improper practices occur, especially in mountainous watersheds, the negative outcomes become even worse since these watersheds generally have steep terrain.

---

*e-mail: mozalp@artvin.edu.tr

In Turkey, human activities including illegal logging, forest openings, and conversion to agricultural areas – especially in mountainous forest watersheds with steep terrain – are still present mostly due to improper land use management, cadastral issues, and lack of inspection [1], causing not only soil degradation [2] but also accumulation of sediments – particularly in the reservoirs of large dams, disturbing their capacity and functions [3].

Coruh River Watershed (CRW), where large dam projects are currently being implemented [4-5], contains areas at high risk of erosion due to its steep terrain, weak vegetation cover (specifically in the middle and upper sections of the basin), and restrictive climate characteristics in some sections [6]. The reservoir of Borcka Dam, one of several large dams being built within CRW, has been affected by this problem since there have been several sediment deposits observed due to the great amount of material entering the reservoir [7]. Sediments settling to the bottom of dam reservoirs reduce capacities of reservoirs and impair their functions. Reports have revealed that about half of the worldwide storage capacities in the world's reservoirs might be lost by 2100 due to the high sedimentation rates of 31 km^3 (0.52%), filling up the reservoirs annualy and threatening the sustainability of water supply and energy production [8].

The fact that determining and interpereting soil loss and sedimentation of an area requires analyzing many factors is making such efforts difficult and both time- and money-consuming. Thus, recently, several prediction models have been developed and universally applied on estimating and/or predicting soil loss/sediment yeild of an area [9-13], including scenarios used to compare present and prehistoric times [14-15]. However, previous studies [12, 14] indicated that, especially in large watersheds, these prediction models may not properly measure soil loss and/or sediment amounts in some cases. They reported that programs of the models are sometimes facing difficulty to run and analyze the entered data for the whole watershed. Therefore, we used an approach of spatially dividing a large watershed into smaller hydrological units (SHUs) so that the GeoWEPP model can easily run and predict the quantities and severity of soil loss and sediment yield. In general, soil erosion models can be divided into empirical and physically based models. While former ones generally establish relationships among runoff, sediment yield and precipitation, plants, and soil and land use types, the latter ones can describe the physical mechanism of soil loss and sediment yield; thus, it is claimed that the physical-based models are more preferred in recent studies [12]. For similar reasons, one of the most-used physical-based models, the WEPP (Water Erosion Prediction Project), was also chosen for this research.

The WEPP is a continuous simulation model that can predict the spatial and temporal distribution of large-scale net soil loss and sedimentation, taking characteristics such as positional changes in topography, surface roughness, soil characteristics, hydrology, and land use into account. It predicts where and when soil loss and sedimentation occur in a precipitation basin or on sloped land, and is an effective method for the identification of places where soil protection measures need to be taken, as well as for identifying the most suitable measures [12, 16]. It also estimates soil loss along a hillslope or across a watershed as well as on a continuous time basis. Moreover, the model reveals results regarding runoff amounts based on storm events and texture fractions and amount of organic matter in sediments lost from watersheds. In this study, the WEPP model was integrated with ArcGIS 10.2 and TOPAZ software to develop the GeoWEPP interface [9, 17], preferred particularly in large precipitation basins for better management of complex data. The TOPAZ tool generates hillslope profiles by parameterizing topographic data using a given digital elevation model (DEM) [9]. The WEPP model requires four input files, including slope (generated from DEM data), climate, soil, and management files.

The main objective of this study was to apply the GeoWEPP model for the first time to Godrahav Creek Watershed, one of the main tributaries of the CRW to predict soil loss and sediment yield amounts. More specifically, we aimed to: a) predict the amount of precipitation in the watershed and surface runoff in the hillslopes, b) calculate soil loss from the hillslopes and in the drainage channels of the study area, and c) find out sediment delivery ratio (SDR) and sediment yield reaching from the GCW to Borcka Dam reservoir in order to evaluate the factors affecting soil loss and sediment yield at the watershed scale. Results from this study will help quantify the current rate of soil erosion within the GCW and determine hot-spot areas in respect to accelerated erosion, as well as the amount of sediments filling the reservoir.

Material and Methods

Godrahav Creek Watershed is located within the borders of the province of Artvin, in the Eastern Black Sea region of Turkey at a site called Sacinka, which is part of the Karcal Mountains and located between coordinates 41º12'35" to 41º14'15" North and 41º51'27" to 41º51'18" East (Fig. 1). The study site has a total surface area of 5,298.21 hectares and an altitude that varies between 200 and 3,450 m. In terms of climate, Artvin and its vicinity are located in a transitional zone. Artvin contains Black Sea coastal (oceanic), Black Sea interior (semi-continental), and Eastern Anatolian (continental) climate belts. According to the Artvin Meteorology Station, the average temperature in Artvin for the last 59 years (1954-2013) was 12.2ºC and the average annual precipitation was 698.7 mm. As for 2013 alone, the year when the study was completed, the GeoWEPP model predicted that the whole study area of the GCW had 735.80 mm precipitation while it was about 660 mm according to the Artvin Meteorology Station. Artvin is located within the Northern Anatolian orogenic belt. Brown forest soil and non-calcareous brown forest soil has been observed in the study site. Brown forest soil and non-calcareous brown forest soil in Coruh Basin

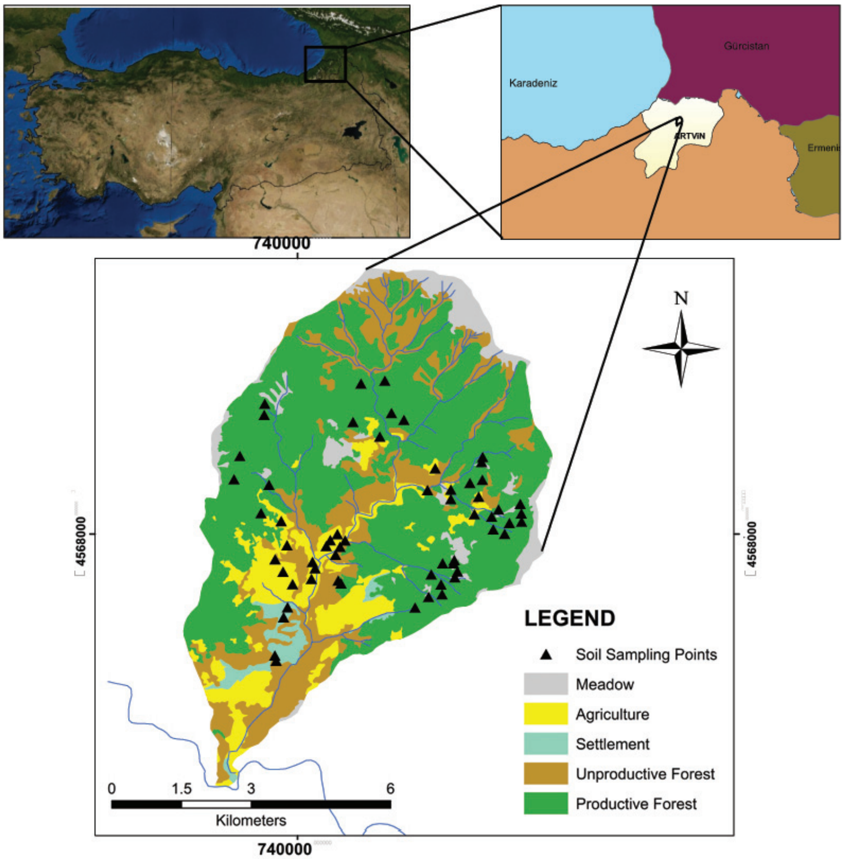

Fig. 1. Location, land use types and soil sampling points of the Godrahav Creek Watershed (GCW).

is mostly located on steep slopes. Most of this soil is subject to heavy, or very heavy, erosion. Brown forest soil, found close to the city center of Artvin and extending northeast toward the study site, was mostly formed on metamorphic rocks and Jurassic-Cretaceous limestone. Non-calcareous brown forest soil is found under a forest cover dominated by spruce, beech, and fir trees, consisting of Upper Cretaceous basaltic, andesitic, and dacitic lavas, tuffs and agglomerates, and Eocene andesites, basalts, and trachytes. In terms of vegetation cover and flora, Artvin is part of the Colchis section of the Euro-Siberian region. Forest vegetation in the region mostly consists of broad-leaved species and coniferous taxa in some parts, depending on altitude.

Research and Laboratory Methods, Creation of GeoWEPP files

To generate the necessary bases that are required to conduct the study we used topographic maps with a scale of 1:25,000 (sections F47-b3, F47-b4, F47-c1, F47-c2), a geological map with a scale of 1:25,000, and forest stand maps of the Artvin Regional Directorate of Forestry. Using these maps, river networks, digital elevation models, slope classes, aspect maps, and land use maps were created. In addition, the Godrahav Watershed was divided into sub-watersheds using the Archydro module of ArcGIS. ArcGIS/ArcInfo 10.2 software (Environmental System Research Institute-ESRI, Redlands, California) was used to computerize, store, process, analyse, and access these data.

Following the division of the study area into three sub-watersheds, soil sampling points were selected on the basis of bedrock, land use, slope, and aspect characteristics. A total of 120 soil samples were collected (using Eijelkamp 100 cm^3 rings), 60 of them disturbed and 60 undisturbed, from 60 separate points in study parcels selected from forest, meadow, and agricultural lands (30 from forest, 24 from agricultural, and six from meadow land), from depths of 0-10 cm and 10-30 cm. Because forested land makes up 77.88%, agricultural land makes up 12.25%, and meadows make up 6.11% of the basin, an effort was made for the soil samples to reflect land use patterns.

The soil samples were first dried for analysis, and their textures examined using Bouyoucos's hydrometer method and texture triangle [18]. The amount of organic matter in the soil samples was measured using Walkley-Black's wet incineration method with 0.5 gr samples filtered through a 2 mm sieve [19].

Data Files Needed for the WEPP Model

The input parameters for the WEPP erosion model are slope, soil, cropping/management, and climate files. The slope file shows the topography of the watershed or slope, and is created on the basis of the digital elevation model generated from the contour map using GIS. The soil file was created using sand and clay ratios, texture classification and organic matter content, measured in laboratory analyses, and soil depth measured on the field. Cation-exchange capacity and albedo, calculated using the formulae and indicators identified in the WEPP user manual, and hydraulic conductivity, shearing resistance, erodibility, stoniness, and levels of saturation, calculated by WEPP on the basis of existing data, are the other soil characteristics used to complete the soil file. The management file was created by identifying land use patterns, using the forest stand maps in a GIS environment, and was defined as forest, agricultural, or meadow for each OFE, following the integration of the digital elevation model (DEM) of the watershed with TOPAZ. The GeoWEPP program also needs land cover (landcove) and land cover definer (landcovdb) files to process cropping/management data. The landcove file was created using the forest stand maps for the area, and land uses in different sections were defined. The Landcovdb file was created using the bases in the database of the WEPP model. Finally, the climate file was created using average daily precipitation values for the last 13 years, and the highest precipitation values observed in standard units of time (30 minutes and six hours). The average maximum temperature, average minimum temperature, average daily humidity, average daily global solar radiation, average hourly wind speed and direction, and monthly number of directions were taken from the climate data for 2013 and used in the model. The file with the extension "par," which contains the required average climate data, was converted into the "cli" format used by GeoWEPP, using the "add climate location" function of the WEPP program.

Geological and Topographic Features of Godrahav Watershed

Geology: Four different types of bedrock groups were identified in the study area: basalt, rhyodacite, granite, and limestone. Basalt bedrock dominates the area, making up 63.3% of the watershed, while granite, rhyodacite, and limestone made up 16.01%, 15.66%, and 4.98% of the watershed, respectively.

Land use: Examination of land use in the study area showed that forests made up 77.88% of the watershed, most of which is classified as productive forests with a high percentage of canopy closure/cover (Fig. 1). The classification between unproductive and productive forests used in this study was based on their canopy cover. We used this difference to indicate that in productive forests – with a high density of trees and limited human impact – soil loss is expected to be within the natural amount (less than 1 t/ha/yr), while in unproductive forests – usually with less coverage and some degree of human impact – soil loss can be high. In the Godrahav Creek Watershed, there are some portions of coppice forests that can also be characterized as unproductive forests. The watershed also contains about 12.25% of land used for local agricultural purposes. There are also little over 6% meadows generally found in the high altitudes of the research area, while the least land use type belongs to the settlements with only 3.75% of the whole GCW (Table 1).

Slope: As in most of the Eastern Black Sea region and Artvin, the study area also contains very steep terrain [6]. After examining the watershed in terms of soil classification by slope factor, it was found that as much as 87.82% of the watershed area had slopes steeper than 30%, and only 4.25% of the area had a slope of 20% or less (Table 2).

Aspect: Finally, the study area was also examined in terms of aspect and it was found that most of the watershed had a sunny aspect with 63.71% while the shadow aspects made up about 36.29%.

Hydrological Subdivison of the Godrahav Creek Watershed

The river class map of the area was created by digitizing the topographical map of the Godrahav Creek Watershed, and the study area was first divided into three sub-watersheds based on bedrock, land use, slope, and aspect characteristics using the ArcHydro module integrated into ArcGIS. However, the sub-watersheds were still too large (total surface area of 1st, 2nd, and 3rd sub-watersheds were 1,413.27 ha, 936.54 ha, and 2,948.4 ha, respectively) to be properly run with the GeoWEPP program as our attempts failed several times. Therefore, as applied in previous studies [11, 20-21], in order to both run the program easily and obtain detailed data on soil loss and sediment yield in the GCW, all three sub-watersheds were further sub-divided into smaller hydrological units (SHUs) using the hydrologic

Table 1. Areal (ha) and percentile (%) distribution of land use types within the GCW.

Sub-watersheds	Forests		Meadows	Agriculture	Settlements	Total
	Productive	Unproductive				
1	860.4	373.50	144.72	34.65	-	1,413.27
2	698.94	102.78	90.99	43.83	-	936.54
3	1,480.59	607.50	88.11	570.42	198.9	2,945.52
Total (ha)	3,039.93	1,083.78	323.82	648.9	198.9	5,295.33
Ratio	57.41 %	20.47 %	6.12 %	12.25 %	3.75 %	100.00 %

Table 2. Areal and percentile slope classification based on the three land use types in the Godrahav Creek Watershed.

Sub-watersheds	Slope Classifications					
	Agriculture (% 0-20)		Forests and meadows (% 20-100)		Total	
	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)
1	98.73	6.99	1,314.54	93.01	1,413.27	100.00
2	128.61	13.73	807.93	86.27	936.54	100.00
3	794.34	26.94	2,154.06	73.06	2,948.40	100.00
Total	1,021.68	19.28	4,276.53	80.72	5,298.21	100.00

modeling tools in ArcGIS Spatial Analyst. The hydrologic tools allowed us to determine flow direction, delineate watersheds, and create stream networks. After the hydrologic tool subdivided the watershed into SHUs, we redesigned them based on land use types (forest, meadow, agriculture) so that each subdivided SHU has only one. However, due to diversity of land use types in the study area, there were only a few SHUs that were made up with only one single land use type. Since the GeoWEPP does not give any results based on land use types, this approach allowed us to associate the prediction outcomes directly to land use types of each SHU. As an example, Fig. 2 shows how the 3rd sub-watershed looks after further dividing it into 16 SHUs.

In this subdivision approach, we believe that running each SHU with GeoWEPP resulted in better and more detailed soil loss and sediment yield data [22] since we could enter detailed soil, land cover, and management data for each SHU specifically compared to entering one large data set (e.g., climate) for the whole study area. In addition, this method allowed us to better evaluate the areas experiencing soil loss and sediment amounts as we can easily see some basic characteristics (land use, soil properties, slope, elevation, and bedrock type, etc.) of each SHU.

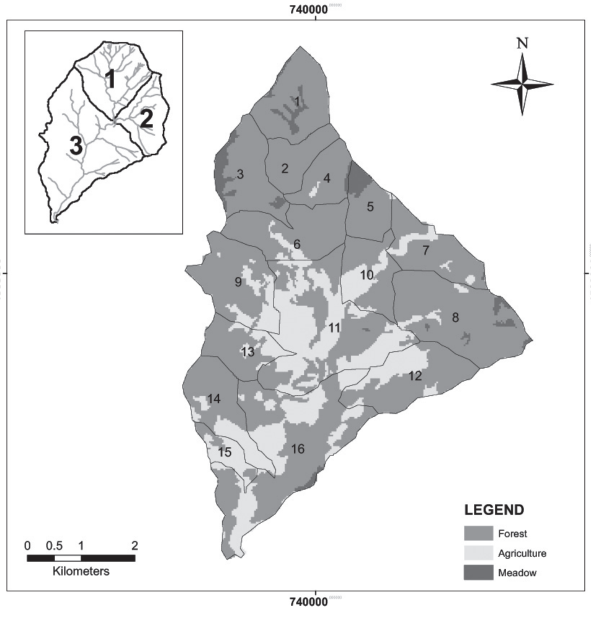

Fig. 2. The map showing the division of GCW into three sub-watersheds by ArcHydro software and further subdivision of 3rd sub-watershed into 16 SHUs by the ArcGIS Spatial Analyst.

Results and Discussion

Evaluation, Sensitivity Analysis, and Calibration of GeoWEPP Model

One of the biggest challenges for applying models for the first time on a study area is the lack of measured data to test a model's performance through evaluation and calibration [23]. For the present study, since there was not any measured runoff data available, we used only annual sediment measurements done by the General Directoriate of State Hydraulic Affairs (DSI) for the Deviskel Watershed between 1988 and 2001 using monthly sampling and filtering. The Deviskel Watershed, approximately 17,877 ha in size and 27 km long, is located between the coordinates of 41°22'44"-41°16'3" north and 41°40'46"-42°0'2" east. One of the main reasons for choosing the Deviskel Watershed as a model for this watershed was its close proximity to the Godrahav Creek Watershed (GCW), the selected watershed for this study. Therefore, there are many similarities, including topograpy, vegetation cover, and land use types between the model watershed and the actual study area, indicating that the Deviskel Watershed can be characterized as a good representation of the research area in respect to calibrating the GeoWEPP model. Another major limitation for this study was that the performance of the model was assessed with the data gathered at the watershed level because unlike GeoWEPP, there was no runoff, discharge, and sediment data available at the sub-watershed level [14, 23].

In respect to model evaluation, observed (O_i) and predicted (P_i) annual sediment values were compared by using the percent deviation (Dv) [24], Nash and Sutcliffe (1970) simulation coefficient (ENS), and the coefficient of determination (R^2) [20, 23, 25]. The deviation of sediment values, Dv, given by the following equation is one criterion for goodness-of-fit:

$$Dv\ (\%) = [\frac{\sum_{\mathrm{i=0}}^{\mathrm{n}}\ (\mathrm{O}i - \mathrm{P}i)}{\sum_{\mathrm{i=0}}^{\mathrm{n}}\ (\mathrm{O}i)}]\ x\ 100$$

…where O_i is the measured annual sediment and P_i is the model computed annual sediment for this study. The smaller the value of Dv, the better the model results. Dv would equal zero for a perfect model. According to Donigian and Rao (1990), annual simulation results are very good when percentage error (*Dv*) is less than 10, good when it is between 10 and 15, and fair when it is between 15 and 25. Another goodness-of-fit criterion is Nash–Sutcliffe coefficient or coefficient of simulation efficiency (ENS) [26] formulated as:

$$ENS = 1 - \frac{\sum_{i=1}^{n}(\mathrm{O}i - \mathrm{P}i)^2}{\sum_{\mathrm{i=0}}^{\mathrm{n}}(\mathrm{O}i - \emptyset)^2}$$

…where O_i is the measured annual sediment, P_i is the model predicted annual sediment, and is the average annual measured sediment amount. The ENS values result in between 0 and 1, but the performance of the model is considered satisfactory if the resultant value is higher than 0.4 [27].

The performance and the accuracy of GeoWEPP was assessed by comparing the observed annual average sediment amounts measured by the State Hydraulic Affairs (SHA) of the Republic of Turkey for 14 years (between 1988 and 2001) to those predicted by the GeoWEPP model for the same years. Out of these 14 years, we selected 10 (1988-94, 1996, 1999, and 2000) that had all the monthly measurements done by the SHA in order to make the comparison properly with the predicted values. Initial analyses of model performance were out of the acceptable ranges set by Dv, NSE, and R^2 due to underprediction of the GeoWEPP model. Literature suggest that several key soil characteristics including effective hydraulic conductivity (K_e), rill erodibility (K_r), interrill erodibility (*Ki*), and critical shear stress (τ_{cr}) can be calibrated by ±10, ±25, or ±50 in order to reduce the differences occuring between observed and predicted values in the cases of under/over prediction of the model [21, 23, 28-30]. In particular, the majority of these studies suggested that especially K_e and *Ki* are highly sensitive to soil loss and sediment yield among others; thus, in this study the values of these two soil features were first changed during the calibration process. Using a trial-and-error approach, it was determined that a +50% increase in values of both K_e and *Ki* resulted in the best fit for GeoWEPP's prediction of annual sediment yield for this study. The outcomes of the criterion for goodness-of-fit also proved this since the Dv and ENS were estimated to be 15.28 and 0.877, respectively. According to literature [27], these values seem to be within the acceptable range, indicating that the GeoWEPP model can be applied to the selected area of this study. In addition, the results of the coefficient of determination (R^2) with 0.93 (Fig. 3) was also in agreement with the outcomes of Dv and ENS.

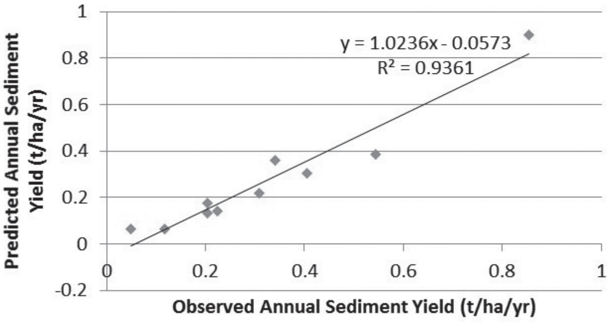

Fig. 3. The coefficient of determination (R2) for the average annual sediment yield between the observed and the GeoWEPP's predicted values.

Table 3. Estimated runoff, soil loss, and sediment yield amounts from the first sub-watershed of the GCW.

SHUs	Land use types			Runoff (mm)	Soil lost from hillslopes (t/yr)	Soil lost from channels (t/yr)	Sediment Delivery Ratio	Avg. Ann. sediment discharge from outlet (t/yr)	Area (ha)	Avg. Ann. Sed. delivery per unit area of watershed (t/ha/yr)
	Forest (%)	Meadow (%)	Ag-ric. (%)							
1	91.5	8.5	-	128.35	160.4	140.5	0.565	170.1	260.83	0.7
2	74.1	25.9	-	126.86	640.5	193.2	0.278	232.0	179.56	1.3
3	84.8	15.2	-	126.47	649.7	788.9	0.262	376.4	264.15	1.4
4	99.9	0.1	-	127.74	54.3	113.7	0.965	162.0	377.51	0.4
5	100	-	-	128.60	18.2	25.3	1.005	43.7	110.78	0.4
6	79.2	5	15.8	106.24	2,061.8	586.3	0.180	476.7	220.44	2.2
Total					3,584.9	1,847.9		1,460.9	1,413.27	

Table 4. Estimated runoff, soil loss, and sediment yield amounts from the second sub-watershed of the GCW.

SHUs	Land use types				Soil lost from hillslopes (t/yr)	Soil lost from channels (t/yr)	Sediment Delivery Ratio	Avg. Ann. sediment discharge (t/yr)	Area (ha)	Avg. Ann. Sediment yield (t/ha/yr)
	Forest (%)	Meadow (%)	Agric. (%)	Runoff (mm)						
1	98.1	1.9	-	127.24	19.8	77.9	0.990	96.7	251.27	0.4
2	95.1	4.9	-	122.15	34.8	60.5	1.001	95.4	208.03	0.5
3	82.3	12.4	5.3	123.34	987.2	551.5	0.376	578.4	320.11	1.8
4	72.9	10.2	16.8	122.98	49.9	38.8	0.715	63.4	157.13	0.4
Total					1,091.7	728.7		833.9	936.54	

Predicted Sediment Yields in the Godrahav Creek Watershed

Following the creation of the four input files required by the GeoWEPP model and their input into the program, the predicted values for soil loss and sediment yield for each SHU and consequently for the whole of the GCW were calculated. In addition, it should be noted that the process of subdividing large watersheds into smaller SHUs should be implemented in similar studies since it helps the GeoWEPP program to run better, as in the present study. With the subdivision process, the first sub-watershed was divided into six SHUs and the results revealed that the total amount of soil loss was 5,432.8 t while sediment generated from the whole of the first sub-watershed was predicted to be 1,460.9 t y^{-1} (Table 3). In detail, the sixth SHU produced the most soil loss and sediment amounts among others, most probably due to consisting of the only agricultural area (15% of the total areal coverage) within the first subwatershed. As for the second sub-watershed, divided into four SHUs, the total soil loss was about 1,820.4 t y^{-1}, whereas the total average annual sediment discharge was estimated as 833.9 t y^{-1} (Table 4). Finally, the model predicted that the highest soil loss among all three sub-watersheds occurred from the third one with 11,343.6 t annually, an expected outcome since this is

Table 5. Estimated runoff, soil loss, and sediment yield amounts from the third sub-watershed of the GCW.

SHUs	Land use types			Runoff (mm)	Soil lost from hillslopes (t/yr)	Soil lost from channels (t/yr)	Sediment delivery ratio	Avg. Ann. sediment discharge from outlet (t/yr)	Area (ha)	Avg. Ann. sediment yield (t/ha/yr)
	Forest (%)	Meadow (%)	Agric. (%)							
1	89.4	10.6	-	140.36	-	26.2	0.957	25.1	167.56	0.2
2	100.0	-	-	141.10	-	26.3	1.001	26.3	106.55	0.3
3	88.3	11.7	-	137.94	92.5	63.0	0.543	84.5	162.41	0.5
4	94.1	3.3	2.6	139.84	-	10.8	1.000	10.8	91.28	0.1
5	82.8	17.1	0.1	139.27	105.4	60.7	0.335	55.7	92.27	0.6
6	91.8	-	8.2	133.45	734.1	426.9	0.401	465.2	194.96	2.4
7	84.3	-	15.7	121.95	-	21.7	1.000	21.7	117.49	0.2
8	92.9	-	7.1	138.50	0.8	5.9	1.000	6.7	40.98	0.2
9	92.4	3.6	4.0	140.30	1.7	85.2	1.001	87.0	294.61	0.3
10	75.1	-	24.9	104.66	1,298.1	251.6	0.424	657.1	196.20	3.3
11	53.9	-	46.1	223.26	0.9	5.1	1.688	10.1	40.17	0.3
12	70.9	-	29.1	215.10	26.1	278.1	0.895	272.2	113.56	2.4
13	44.0	0.1	55.9	58.60	367.3	2,308.9	0.641	1,716.3	424.68	4.0
14	69.2	-	30.8	114.07	151.9	974.7	1.004	1,130.8	194.28	5.8
15	75.8	-	24.2	206.91	26.9	420.2	0.995	445.0	111.84	4.0
16	68.4	-	31.6	76.40	1,383.3	84.1	0.378	555.3	149.72	3.7
17	25.1	-	74.9	6.81	17.9	14.8	1.004	32.8	58.37	0.6
18	62.9	0.2	36.9	170.79	181.3	1,891.2	0.944	1,957.4	391.47	5.0
Total					4,388.2	6,955.4		7,560.0	2,948.40	

Table 6. Estimated soil loss and sediment yield values among three sub-watersheds of the GCW.

Sub-watersheds	Total soil lost from hillslopes (t/yr)	Total soil lost from channels (t/yr)	Area (ha)	Average annual soil loss (t/ha/yr)	Total sediment amounts (t/yr)	Average sediment delivery ratio (SDR)	Avg. ann. sediment yield (t/ha/yr)
1	3,584.9	1,847.9	1,413.27	2.54	1,460.9	0.267	1.03
2	1,091.7	728.7	936.54	1.17	833.9	0.458	0.89
3	4,388.2	6,955.4	2,948.40	1.49	7,560.0	0.666	2.56
Total (The whole GCW)	9,064.8	9,532.0	5,298.21	1.73*	9,854.8	0.530**	1.86***

*estimated by dividing the total soil loss from hillslopes to the total area of the whole watershed

**estimated by dividing the total sediment amount to the total soil lost from both hillslopes and channels of the whole watershed

***estimated by dividing the predicted total sediment amount to the total area of the whole watershed

the largest sub-watershed in respect to both size (with 16 SHUs) and agricultural land use (Table 5).

In the whole of GCW, covering a total area of 5,298.21 ha, the total soil loss generated from both the hillslopes (9,064.8 t) and the channels (9,532 t) was estimated to be 18,586.8 t (Table 6). Out of this total soil detached within the watershed, approximately 9,854.8 t of it was carried as total sediment yield. In other words, with the SDR (sediment delivery ratio) of 0.530, it can be conluded that almost half of the detached particles were carried away and either deposited within the watershed or reached the reservoir of Borcka Dam.

When looking at the annual average amounts per unit area, the model predicted both soil loss and sediment yield as 1.73 t $ha^{-1}y^{-1}$ and 1,86 t $ha^{-1}y^{-1}$, respectively (Table 6). Parallel results of soil loss and sediment yields were reported by other studies that also took place in watersheds with similar features (e.g., mountanious, hilly, steep terrain). For example, two pieces of research initiated in the same mountanious and mostly forested Kasilian Watershed in Iran [11] found that the average erosion rate was 1.2 t $ha^{-1}y^{-1}$, while Meghdadi [31], on the other hand, reported a higher average soil loss rate of 1.88 t $ha^{-1}y^{-1}$.

Overall, the distribution of soil loss amounts within the GCW can be seen in Fig. 4a, revealing that the whole watershed experiences some degree of soil erosion even though approximately 84% of the GCW is covered with natural vegetation (forests and meadows). In addition, as the map shows (Fig. 4b), it is clear and also expected that most of the areas with high soil loss amounts (more than 4 t $ha^{-1}y^{-1}$) were within the disturbed and/or converted natural lands (forests and meadows) that are currently being used for the purposes of agriculture or settlements. As literature has stated, the degradation of both forests and grasslands mostly due to illegal logging, opennings, forest roads, and overgrazing has been known as a common practice in the region [1]. A similar outcome has been reported by Saghafian et al. [11] as they concluded that converting natural land use into other uses, particularly dry-farming, played the dominant factor in increasing the amount of sediment load within the Kasilian Watershed in Iran. In another study, the results of a GeoWEPP-applied experiment on a hilly watershed in southern China indicated that land use type changing from forest to agriculture caused sediment amount to increase by 42.6% [32]. Morover, in a research investigating how soil loss and sediment yields were affected by the land-use/land-cover scenarios using a GeoWEPP model, Maalim et al. [14] found that the average annual sediment yields increased from 0.13 t/ha to 2.15 t/ha for current agricultural lands and pre-settlement land-use/land-cover, respectively, within the Le Sueur Watershed in Minnesota.

The importance of natural land use and/or better vegetation cover on lowering soil loss can also be seen from the results of similar research conducted in watersheds with less vegetation cover in Turkey using the WEPP model. For example, sediment yields per unit area were found to be 7.42 t $ha^{-1}y^{-1}$ [33] and 8.66 t $ha^{-1}y^{-1}$ [34] in Kahramanmaraş-Ayvalı Dam Watershed and Gümüşhane-Torul Dam Watershed, respectively. Both watersheds resulted in higher sediment yields than the present study, mostly due to weak plant coverage caused by the semi-arid climate conditions of the region.

Evaluating Soil Loss and Sediment Yields within the GCW

When the sediment yields per unit area were examined at the level of three subwatersheds, we found that the third subwatershed had the highest amount with 2.56 t $ha^{-1}y^{-1}$ followed by first and second subwatersheds with 1.03 t $ha^{-1}y^{-1}$ and 0.89 t $ha^{-1}y^{-1}$, respectively. As for the annual average soil loss amounts, the results indicated that the highest soil loss (2.54 t $ha^{-1}y^{-1}$) was observed from the first subwatershed, followed by the third and second with 1.49 t $ha^{-1}y^{-1}$ and 1.17 t $ha^{-1}y^{-1}$, respectively. One of the reasons for this outcome can be associated with the fact that the lands used for agriculture and settlement makes up about 26% in the third sub-watershed, which is the highest compared to 7% and 14% for the first and second sub-watersheds, respectively (Table 1). In addition, this outcome can also be associated with the fact that the third subwatershed consisting of the lowest forest area, possibly leading to more soil loss from the

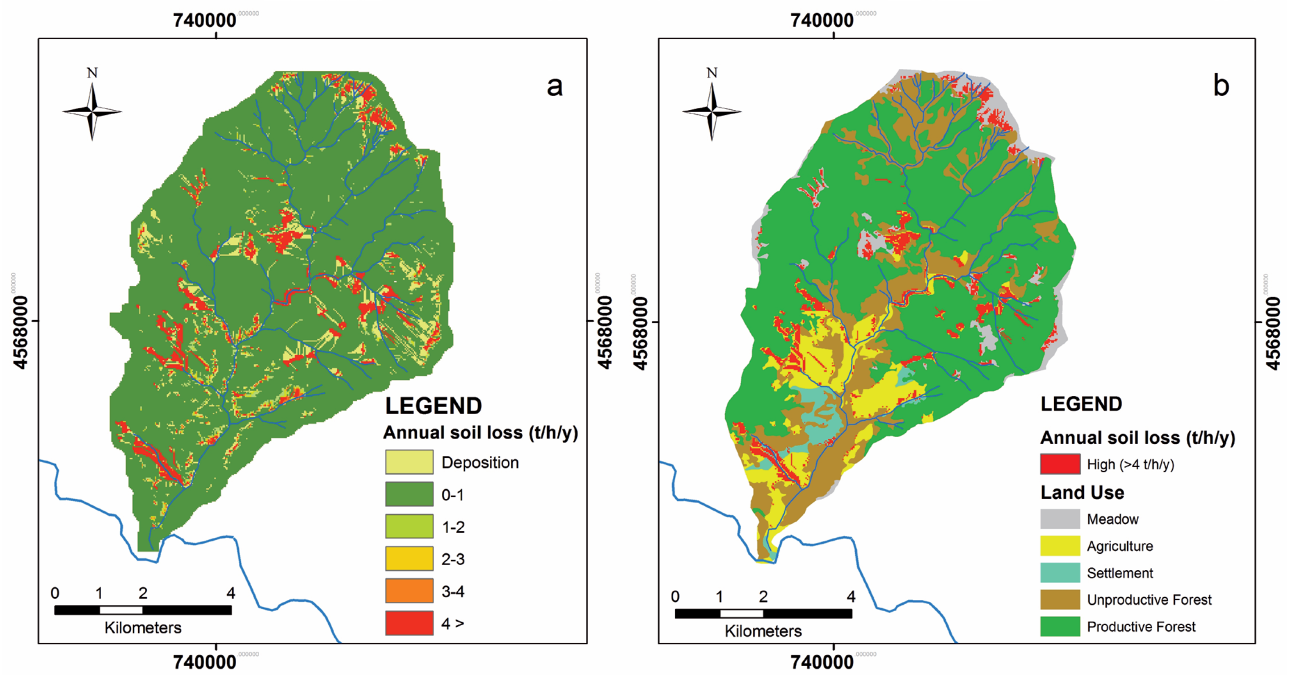

Fig. 4. The distribution of annual soil loss amounts a) and the land use types experiencing soil erosion above 4 t/ha/yr b) within the whole GCW.

hillslopes. In fact, since 85% of the GCW is covered with both forests and grasslands, considered as the major factor in limiting soil loss especially from hillslopes [14, 35-36], it was unexpected to see the certain SHUs (for example SHUs of 6, 10, 12, 13, 14, 15, 16, and 18 within the third subwatershed; Table 5) to have higher sediment yields than the threshold value of 1 t $ha^{-1}y^{-1}$. One of the reasons can be given as the fact that most of the sediment (about 61%) produced within the third watershed originated from the channels and as it can be seen in Fig. 2 that the third watershed makes up the mid- and lower portions of the GCW, indicating that there are larger channels carrying high volumes of running waters to cause more soil loss and sediment yield. This can be seen from the fact that some of the largest soil loss – especially for certain SHUs such as 12, 13, 14, 15, and 18 – occurred from the channels compared to the hillslopes of the third sub-watershed according to the results of the GeoWEPP model.

The results indicated that 4.73% of the study area experienced sediment deposition while the rest of the watershed showed some degree of soil loss (Table 7). For the present study, it was determined that the majority of the watershed (about 86%) demonstrated soil loss of lower than the threshold value of 1 t $ha^{-1}y^{-1}$, which is set as the default tolerable soil loss amount by the WEPP program. On the other hand, the rest of the area, making up approximately 9% of the whole GCW, had the soil loss amounts higher than 1 t $ha^{-1}y^{-1}$, an amount that is considered to be natural/geologic erosion by most researchers in the field. In respect to evaluating erosion processes in the study area, we set the limit of 1 t $ha^{-1}y^{-1}$ as T-value since we have considered the impact of soil erosion/sediment production particularly on the quality of natural waters

Table 7. Annual soil loss rates (t/ha/yr) and deposition amounts based on land use types in the Godrahav Creek Watershed.

Annual soil loss rate (t/ha/yr)	Land use type (%)					
	Meadow	Agriculture	Settlement	Unprod. forest	Prod. forest	Total
0-1	3.62	7.16	1.93	18.84	54.13	85.68
1-2	0.51	0.87	0.11	0.26	0.51	2.26
2-3	0.33	0.54	0.07	0.10	0.18	1.22
3-4	0.26	0.33	0.06	0.04	0.07	0.76
4 >	1.32	3.07	0.26	0.15	0.55	5.35
Deposition	0.16	0.34	0.02	1.14	3.07	4.73
Total	6.20	12.31	2.45	20.53	58.51	100

in the watershed. This approach has been used as an important criteria for setting a T-value by similar literature [35] because of the fact that some of the detached soil particles may reach aquatic ecosystems, causing both physical and chemical contamination. In this context, we can state that close to 10% of the watershed experiences soil loss over 1 t $ha^{-1}y^{-1}$ (Table 7), indicating possible water pollution for some of the riverine systems in the research area. In addition, the average annual soil loss (1.74 t $ha^{-1}y^{-1}$) and sediment yield (1.86 t $ha^{-1}y^{-1}$) predicted by the model is also a little over "the tolerable soil erosion (T)" of 1.4. t $ha^{-1}y^{-1}$ based on "soil formation rates" set by Verheijen et al. [35] after detailed evaluation of scientific studies for determining T rates in Europe. However, various studies accept different threshold T-values, including Pandey et al. [23] recommending no need for imposing soil control measures for subwatersheds unless they produce soil loss amounts higher than 2.5 t $ha^{-1}y^{-1}$. In this case, it sould be noted that the first sub-watershed should be paid attention in respect to soil erosion control efforts as it generated soil loss of 2.54.

As for the average sediment delivery ratio (SDR), it was estimated that for the whole GCW the SDR was about 0.580, higher than what [37] reported (SDR: 0.40) in a small watershed in the Sichuan Hilly Basin of China, but a little lower than what [14] found (SDR: 0.84) in the Le Sueur Watershed of Minnesota. The SDR estimated in this study clearly means that little over the half of the detached particles from the hillslopes of the upper section of the watershed is carried away to the drainage channels and consequently to the reservoir of Borcka Dam. The main reason for this high SDR can be easily associated with the steep terrain of the watershed, since slopes steeper than 30% made up as much as 87.82% of the watershed while only 4.25% of the watershed area was classified as cultivable land (Table 2). Literature proves that steeper slopes can be clearly associated with significantly higher levels of surface runoff and soil loss. For example, in a study examining the effects of soil detachment and slope in a watershed on the Greek island of Lesvos [38], the main factor affecting sediment loss was found to be slopes steeper than 40% while the effects of land use, although they changed soil and vegetation characteristics, were negligible.

Conclusions

Forest and grassland ecosystems have been facing serious perturbations mainly by human-induced practices, leading to many environmental problems, including accelerated soil loss and associated sedimentation, and they have already reached serious levels, especially in certain regions of the world. In fact, both of these processes are considered major environmental problems in Turkey and more specifically, they are responsible for several reservoirs of dams being filled in less time than expected. Similarly, the reservoir of Borcka Dam, one of several large dams being built within the Coruh River Watershed in Artvin, Turkey, has been affected by the sedimentation problem. However, in order to take necessary precautions against these problems, sufficient scientific data regarding the quantities and severity of soil loss and sediment yield within the Borcka Dam Watershed must be obtained. Therefore, in this study, one of the tributary watersheds flowing into Borcka Reservoir, the Godrahav Creek Watershed (GCW), was chosen as the study area in order to predict soil loss and sediment yield within the watershed using the GeoWEPP model as well as GIS techniques. For the purposes of an easier run of the program and detailed results, the GCW was first divided into three subwatersheds and further 28 SHUs.

The results revealed that the total soil loss generated from both the hillslopes (9,064.8 t) and the channels (9,532 t) was estimated to be 18,586.8 t, indicating that almost the same amount of soil is being detached from two sources. Overall, out of this total soil detached within the watershed, approximately 9,854.8 t of it was carried as sediment yield, meaning that the SDR (sediment delivery ratio) is equal to 0.530 and almost half of the detached particles were carried away and either deposited within the watershed or ended up in the reservoir. In addition, the annual average amounts of soil loss and sediment yield per unit area were predicted to be 1.73 t ha^{-1y-1} and 1.86 t ha^{-1y-1}, respectively, by the GeoWEPP model. Finally, it can be concluded that most of the watershed (85%) is experiencing soil loss of less than the generally accepted T-value of 1 t/ha/yr mostly due to abundant natural forest and grasslands, suggesting no need for any precautions to prevent soil erosion. However, the GeoWEPP model has also revealed that close to 10% of the whole watershed have higher than 1 t/ha/yr soil loss amounts, requiring detailed investigation in order to decide whether to apply any soil erosion control efforts. Moreover, it is also important to note that similar research should be repeated for other sub-watersheds surrounding Borcka Dam in order to determine which SHUs are adding higher-than-acceptable amounts of sediments into the reservoir so that the necessary precautions for maintaining a longer lifespan for such facilities can be considered.

Acknowledgements

Our research was funded by Artvin Coruh University, Coordinatorship of Scientific Research Projects (project No: 2011.F10.02.13).

References

1. YÜKSEK T., KURDOĞLU O., YÜKSEK F. The effects of land use changes and management types on surface soil properties in Kafkasör protected area in Artvin, Turkey. Land Degradation & Development. **21** (6), 582, DOI: 10.1002/ldr.1000, **2010**.
2. ÖZALP M., ERDOĞAN YÜKSEL E., YÜKSEK T. Soil property changes after conversion from forest to pasture

in mount Sacinka, Artvin, Turkey. Land Degradation & Development. **27** (4), 1007, DOI: 10.1002/ldr.2353, **2016**.

3. MEKONNEN M., KEESSTRA S.D., BAARTMAN J.E., RITSEMA C.J., MELESSE A.M. Evaluating sediment storage dams: Structural off-site sediment trapping measures in northwest Ethiopia. Cuadernos de Investigación Geográfica. **41** (1), 7, DOI: 10.18172/cig.2643, **2015**.
4. ÖZALP M., YILDIRIMER S., ERDOĞAN YÜKSEL E. Environmental and social effects of both large dams and run-of-river hydroelectric power plants within the Coruh River Watershed in Artvin, Turkey. in New Frontiers in Environmental and Water Management. Kavala, Greece. **2015**.
5. YILDIRIMER S., ÖZALP M., ERDOĞAN YÜKSEL E. Determining loss and degradation of lands as a result of large dam projects and associated road constructions within the Coruh River Watershed. Artvin Coruh University, Journal of Forestry Faculty. **16** (1), 1, DOI: 10.17474/acuofd.00766, **2015** [In Turkish].
6. YAVUZ ÖZALP A., AKINCI H., TEMUÇIN S. Determining topographic and some physical characteristics of the land in Artvin city and investigating relationship between these characteristics with land cover. Artvin Coruh University, Journal of Forestry Faculty **14** (2), 292, DOI: 10.17474/acuofd.77100, **2013** [In Turkish].
7. TURGUT B., ÖZALP M., KÖSE B. Physical and chemical properties of recently deposited sediments in the reservoir of the Borçka Dam in Artvin, Turkey. Turkish Journal of Agriculture and Forestry. **39**, 663, DOI: 10.3906/tar-1404-60, **2015**.
8. SABIR M.A., SHAFIQ-UR-REHMAN S., UMAR M., WASEEM A., FAROOQ M., KHAN A.R. The impact of suspended sediment load on reservoir siltation and energy production: A case study of the Indus River and its tributaries. Polish Journal of Environmental Studies. **22** (1), 219, **2013**.
9. GONZÁLEZ V.I., CARKOVIC A.B., LOBO G.P., FLANAGAN D.C., BONILLA C.A. Spatial discretization of large watersheds and its influence on the estimation of hillslope sediment yield. Hydrological Processes. **30** (1), 30. DOI: 10.1002/hyp.10559, **2016**.
10. ZIVOTIC L., PEROVIC V., JARAMAZ D., DORDEVIC A., PETROVIC R., TODOROVIC M. Application of USLE, GIS, and remote sensing in the assessment of soil erosion rates in southeastern Serbia. Polish Journal of Environmental Studies. **21** (6), 1929, **2012**.
11. SAGHAFIAN B., MEGHDADI A.R., SIMA S. Application of the WEPP model to determine sources of run-off and sediment in a forested watershed. Hydrological Processes. **29** (4), 481, DOI: 10.1002/hyp.10168, **2015**.
12. SHEN Z.Y., GONG Y.W., LI Y.H., HONG Q., XU L., LIU R.M. A comparison of WEPP and SWAT for modeling soil erosion of the Zhangjiachong Watershed in the Three Gorges reservoir area. Agricultural Water Management. **96** (10), 1442, DOI: 10.1016/j.agwat.2009.04.017, **2009**.
13. PANDEY A., HIMANSHU S.K., MISHRA S.K., SINGH V.P. Physically based soil erosion and sediment yield models revisited. Catena. **147**, 595, DOI: 10.1016/j.catena.2016.08.002, **2016**.
14. MAALIM F.K., MELESSE A.M., BELMONT P., GRAN K.B. Modeling the impact of land use changes on runoff and sediment yield in the le sueur watershed, Minnesota using GeoWEPP. Catena. **107**, 35, DOI: 10.1016/j.catena.2013.03.004, **2013**.
15. GONZÁLEZ-ARQUEROS M.L., MENDOZA M.E., VÁZQUEZ-SELEM L. Human impact on natural systems modeled through soil erosion in GeoWEPP: A comparison between pre-hispanic periods and modern times in the Teotihuacan valley (Central Mexico). Catena. **149**, 505, DOI: 10.1016/j.catena.2016.07.028, **2017**.
16. DEFERSHA M.B., MELESSE A.M., MCCLAIN M.E. Watershed scale application of WEPP and erosion 3d models for assessment of potential sediment source areas and runoff flux in the Mara river basin, Kenya. Catena. **95**, 63, DOI: 10.1016/j.catena.2012.03.004, **2012**.
17. FLANAGAN D.C., FRANKENBERGER J.R., COCHRANE T.A., RENSCHLER C.S., ELLIOT W.J. Geospatial application of the water erosion prediction project (WEPP) model. Transactions of the Asabe. **56** (2), 591, **2013**.
18. GÜLÇUR F. Methods for soil physical and chemical analyses. Istanbul University, Faculty of Forestry Publication number: 201. Kutulmuş Printing, Istanbul, 225. **1974** [In Turkish].
19. KAÇAR B. Chemical analyses of plant and soil: III. Soil analyses. Ankara University, Faculty of Agriculture Publication number: 3. Ankara. **1994** [In Turkish].
20. FASHI F.H., EJLALI F. Evaluating spatial distribution of soil erosion using WEPP erosion model and GIS tools: A review. Agricultura, Agricultural Practice and Science Journal. **95** (3-4), DOI: 10.15835/arspa.v95i3-4.11790, **2015**.
21. AL-MUKHTAR M., DUNGER V., MERKEL B. Runoff and sediment yield modeling by means of WEPP in the Bautzen Dam catchment, Germany. Environmental Earth Sciences. **72** (6), 2051, DOI: 10.1007/s12665-014-3113-0, **2014**.
22. SADEGHI S.H.R., SEGHALEH M.B., RANGAVAR A.S. Plot sizes dependency of runoff and sediment yield estimates from a small watershed. Catena. **102**, 55, DOI: 10.1016/j.catena.2011.01.003, **2013**.
23. PANDEY A., CHOWDARY V.M., MAL B.C., BILLIB M. Runoff and sediment yield modeling from a small agricultural watershed in India using the WEPP model. Journal of Hydrology. **348** (3-4), 305, DOI: 10.1016/j.jhydrol.2007.10.010, **2008**.
24. MARTINEC J., RANGO A. Merits of statistical criteria for the performance of hydrological models. Journal of the American Water Resources Association. **25** (2), 421, DOI: 10.1111/j.1752-1688.1989.tb03079.x, **1989**.
25. PIERI L., POGGIO M., VIGNUDELLI M., BITTELLI M. Evaluation of the WEPP model and digital elevation grid size, for simulation of streamflow and sediment yield in a heterogeneous catchment. Earth Surface Processes and Landforms. **39** (10), 1331, DOI: 10.1002/esp.3527, **2014**.
26. NASH J.E., SUTCLIFFE J.V. River flow forecasting through conceptual models part I – a discussion of principles. Journal of Hydrology. **10** (3), 282, DOI: 10.1016/0022-1694(70)90255-6, **1970**.
27. MORIASI D.N., ARNOLD J.G., VAN LIEW M.W., BINGNER R.L., HARMEL R.D., VEITH T.L. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE. **50** (3), 885, **2007**.
28. SINGH R.K., PANDA R.K., SATAPATHY K.K., NGACHAN S.V. Runoff and sediment yield modelling for a treated hilly watershed in eastern Himalaya using the water erosion prediction project model. Water Resources Management. **26** (3), 643, DOI: 10.1007/s11269-011-9937-4, **2011**.
29. FLANAGAN D.C., FRANKENBERGER J.R., J.C. ASCOUGH I. WEPP: Model use, calibration, and validation. Transactions of the ASABE. **55** (4), 1463, DOI: 10.13031/2013.42254, **2012**.

30. AMINI H., HONARJOO N., JALALIYAN A., KHALILIZADEH M., BAHARLOUIE J. A comparison of EPM and WEPP models for estimating soil erosion of Marmeh Watershed in the south Iran. Agriculture & Forestry. **60** (4), 299, **2014**.
31. MEGHDADI A.R. Identification of effective best management practices in sediment yield diminution using GeoWEPP: The Kasilian Watershed case study. Environ Monit Assess. **185** (12), 9803, DOI: 10.1007/s10661-013-3293-1, **2013**.
32. ZHANG Z., SHENG L., YANG J., CHEN X.-a., KONG L., WAGAN B. Effects of land use and slope gradient on soil erosion in a red soil hilly watershed of southern China. Sustainability. **7** (10), 14309, DOI: 10.3390/su71014309, **2015**.
33. YÜKSEL A.K. Research on planning Ayvalı Watershed in K. Maraş, Turkey in terms of watershed management within the concept of GIS (Geographical Information Systems) (Ph.D. Dissertation). Graduate School of Natural and Applied Sciences. Karadeniz Technical University. Trabzon, **2001** [In Turkish].
34. AYDIN M. Research on determining amount of soil loss from Torul Dam Watershed in Gümüşhane using WEPP and providing solutions (Ph.D. Dissertation) Graduate School of Natural and Applied Sciences. Karadeniz Technical University. Trabzon, **2007** [In Turkish].
35. VERHEIJEN F.G.A., JONES R.J.A., RICKSON R.J., SMITH C.J. Tolerable versus actual soil erosion rates in Europe. Earth-Science Reviews. **94** (1-4), 23, DOI: 10.1016/j.earscirev.2009.02.003, **2009**.
36. ZHONGMING W., LEES B.G., FENG J., WANNING L., HAIJING S. Stratified vegetation cover index: A new way to assess vegetation impact on soil erosion. Catena. **83** (1), 87, DOI: 10.1016/j.catena.2010.07.006, **2010**.
37. LI M., YAO W., LI Z., LIU P., YANG E., SHEN Z. Using 137cs to quantify the sediment delivery ratio in a small watershed. Appl Radiat Isot. **70** (1), 40, DOI: 10.1016/j.apradiso.2011.07.010, **2012**.
38. KOULOURI M., GIOURGA C. Land abandonment and slope gradient as key factors of soil erosion in mediterranean terraced lands. Catena. **69** (3), 274, DOI: 10.1016/j.catena.2006.07.001, **2007**.