SOIL LOSSES FROM OLUR MICRO-CATCHMENT IN THE CORUH RIVER BASIN USING GEOWEPP MODEL

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ABSTRACT

Soil is a very important resource for protecting productive agricultural lands and for ensuring their sustainable use. In this context, it is important to take the necessary measures to prevent the losses of soil by erosion and to determine amount of soil losses with relevant models. In this study, by using the Geo-Spatial Interface for Water Erosion Prediction Project (GeoWEEP) model, both surface (hillslope) and channel erosions were estimated to evaluate the total soil loss from the Olur Micro-catchment (37517 ha) within the Coruh River Basin. Additionally, for the conservation purposes, areas with high erosion potential in the micro-catchment were also identified and mapped by the model. The land uses of Olur Micro-catchment, which has a slope of 28.07%, consist of approximately 45% grassland, 19% forest and 14% agriculture. In this study, GeoWEPP model was run with 2 different simulation programs. In the first run, only one-year climate data from the year 2018 was utilized for the soil loss estimation. The total precipitation amount for the 2018 was 561 mm/yr. In the second run, 20-year climate data were utilized and the estimated soil loss values were obtained for 20 years. The recorded average precipitation over 20-year period was 426 mm/yr, which was much lower than in 2018. Based on this information, the total soil loss (sediment yield) in 2018 determined by the GeoWEPP model from the catchment was found to be 89123 tons/yr (2.8 tons/ha/yr). As for the 20-year simulation, a soil loss of 9501 tons/yr (0.27 tons/ha/yr) was estimated by the model. Results revealed that the higher amount of precipitation in 2018 caused soil loss to be 10.4 times higher than the 20 years average soil loss. The surface erosion (136525.2 ton/yr) was found to be almost 7 times higher than the channel erosion (19989.4 ton/yr) indicating the dominant pathway of erosion in the Olur micro-catchment. Additionally, the areas with high erosion risk in the study area were predicted very accurately and showed in the produced soil loss map. In conclusion, an idea with the study was obtained about the amount of soil loss from the Olur Micro-catchment to Ayvalı Dam, and the recommendations were made for soil protection measures to reduce the amount of soil loss in the erosion-sensitive areas that were identified over the the Olur micro-catchment.

Key words: GeoWEPP model, Surface and Channel Erosion, Soil Loss, Sediment Yield.

INTRODUCTION

Soil erosion is one of the most important environmental problems worldwide that should be emphasized more in terms of sustainable uses of soil and protecting water resources and also ensuring sufficient food production as well. As a matter of fact, Turkiye is one of the countries most susceptible to soil erosion due to its rugged topographic and changing climatic conditions across the country (Tüfekçioğlu, 2018). In addition to natural factors, erosion is accelerated by human misuse of lands (Zafirah et al., 2017). As a result, soil organic matter is transported with the soil erosion that results in decrease of soil fertility and agricultural production. Moreover, soil erosion and flooding reduce the economic life span of dams that are filled with sediment sooner than expected (Anonymous, 2013).

Climate change scenarios for the future prediction have revealed that the susceptibility to erosion across the world regions would be dramatically increased, especially for the Mediterranean countries including Turkiye (Anonymous, 2020). According to a recent study in Turkiye, 642 million tons of topsoil is eroded by surface water erosion in every single year, of which 154 million tons are loss from the terrestrial system throughout the existing river and stream networks (Erpul et al., 2018). According to the Turkish Ministry of Forestry and Water Affairs, 73% of Turkiye's land is under severe erosion threat. In terms of soil loss per square kilometer of land area, transported soils are 84 tons in Europe, 273 tons in Australia, 491 tons in America, 610 tons in Asia, 715 tons in Africa and 800 tons in Turkiye (Aydınalp, 2000).

Some cases in the nature, soils transported by the natural erosion without any human impacts nourish and rejuvenate the lands they are settled. Thus, soil erosion plays a major role in the formation of fertile agricultural lands, especially in the storage areas of alluvial landscape (Sarı, 1997). The main causes of human induced erosion can be listed as; mismanagement of land, wrong agricultural techniques, overgrazing in pastures, forest fires and production of wood products in forests (Topçu, 1998). On the other hand, monitoring and assessing of erosion would help to understand the ecological function of ecosystem and prevent potential economic damages by implementing the restoration plans. To reduce the erosion, factors of erosion should be taken into consideration during land restoration and planning. The most effective and fast way to mitigate erosion consist of both field measurements and simulation programs that are commonly used in today's erosion calculation.

The erosion phenomena in Turkiye is a significant social, economic and ecological concerns, with various studies highlighting the risk and impact of erosion in different regions of Turkiye. By utilizing the RUSLE model, Aykir (2022) found that the Çıldır Lake Basin faces a moderate to very high erosion risk, with the potential for increased erosion risk without any interventions. Similarly, Kasap (1998) noted that the majority of agricultural land in Turkiye has a slope of over 10%, resulting significant amount of surface erosion. Haciyakupoglu (2005) emphasized the need for reliable data on erosion rates, particularly in catchment areas like the Buyukcekmece Reservoir in Istanbul, where the dam used for drinking water. Usta (2018) further underscored the susceptibility of degraded scotch pine forest soils to erosion, particularly in the semi-arid highlands of Turkiye. These studies have collectively highlighted the urgent need for comprehensive measures to address erosion problem in Turkiye. A large part of the Çoruh River Basin is subject to excessive soil erosion. Of the entire Coruh River Basin, 3.8% is under low, 25.3% under moderate, 51% under high, and 19.9% under very high erosion risk (Anonymous, 2012). In a five-year study conducted in the Oltu Micro-catchment of the Coruh River Basin, it was determined that the contribution of gully erosion to soil loss was the highest with 78% compared to 1st and 2nd order streams (Tufekcioglu et al., 2020). During the gully rehabilitation studies conducted in the same basin, it was determined that the most effective way to reduce gully erosion is to utilize grade stabilization structures such as wire-cage and dry-stone sills (Tufekcioglu, 2018). Reducing all types of erosions including surface, gully and channel were critically important for the Coruh River Basin since the Basin has been designated for the hydraulic energy production with 10 dams on the Coruh River, 6 on the tributaries, and many other (162) small hydraulic plants on the other branches of the Coruh River (Eroğlu, 2013).

The implications of erosion are vast and can have detrimental effects on various aspects of the environment. Erosion control is a vital component of land management to prevent degradation of soil and water resources and the overall ecosystem. Through effective erosion control measures and collaborative efforts, we can mitigate these impacts on soil and water resources and ensure sustainable land management for future generations. By implementing erosion control measures, we can prevent the loss of fertile topsoil, protect water quality by reducing sediment runoff, and preserve the stability of slopes and landscapes. On the other hand, the detection of erosion is of great importance in determining the economic life span of dams.

Soil erosion poses a significant threat to agricultural productivity, environmental sustainability and water quality worldwide. To effectively manage soil loss, it is important to understand soil loss processes. GIS-based (geographic information system) spatial modeling has emerged as an important tool in soil erosion studies and consequently in the development of appropriate soil conservation strategies, especially at the watershed scale (Memarian et al. 2012, Sorooshian, 1995). Among these solutions, Geo-Spatial Interface for Water Erosion Prediction Project (GeoWEPP) is emerging as a promising tool that offers a comprehensive approach to soil erosion prediction and management.
GeoWEPP model takes into account factors such as land cover, slope, soil type, and rainfall to calculate the erosion risk in a given area (Rigol-Sánchez et al., 2015). By utilizing both remote sensing and GIS technologies, the GeoWEPP erosion model offers a comprehensive approach to evaluating and managing soil erosion (Nigel & Rughooputh, 2010). Furthermore, the use of the GeoWEPP erosion model can greatly enhance land use planning by providing valuable information on erosion risk (Prairie et al., 2008). In addition to these erosion components, it also incorporates climatic data, infiltration status, daily water balance between plant-soil and water, plant growth and dead cover status, and irrigation processes as well. The WEPP model reveals where and when soil losses from a rainfall basin or a hillslope are likely to occur and be stored, and thus plays a decisive role in determining which soil conservation measures should be taken in practice (Okatan et al., 2007). The disadvantage of the model is that it requires long-term continuous data. Therefore, it is difficult to obtain the data required to run the model in a short time (Yazidhi, 2003). As a study area, the most important factors for the selection of Olur Micro-catchment in this study are; 1) the negative effects of improper land uses including agricultural cropping and grazing livestock on grasslands and the resulting severe erosion, 2) natural resources in the catchment have been degraded by erosion due to low fertility shallow soil, bare land, lack of rainfall and harsh winters (Anonymous, 2012), 3) the excessive amount of soil erosion from the Olur-cathment is critical problem because it can fill the Ayvalı dam, built below the catchment, much shorter time than expected. For this reason, it is of great importance to determine the potential erosion risk in the Olur Micro-catchment and to identify the necessary control measures. In this context, the objective of this study is to determine the soil losses and its spatial distributions in the Olur-catchment by using GeoWEPP erosion prediction model with an integrated approach.

MATERIALS AND METHODS

Description of the study area

Olur Micro-catchment is located in the northeastern region of the Turkiye and has an area of 37517.28 ha. The study area is located between 40.78° and 40.98° north latitude and 42.05° and 42.40° east longitude. The catchment is 27 km long and 20 km wide. The average slope of the studied catchment is 28.07% and the average elevation is 1996 meters (fig. 1). The hydrology network of the area consists of the Alabalık Stream coming from the northeast to the south and the tributaries connected to the main Olur Stream coming from west to east.

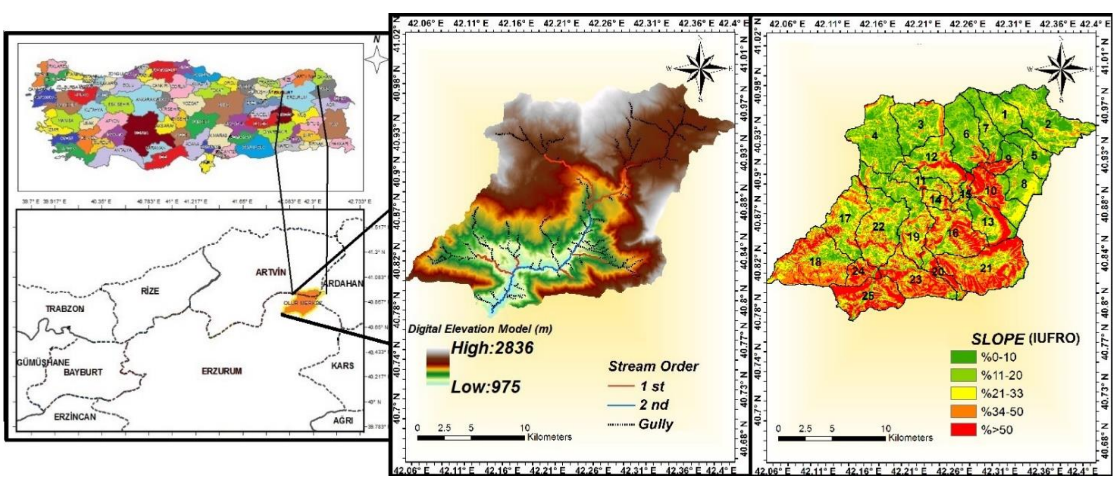


Figure 1. The Study Area, Olur micro-catchment, Located in Northeastern Turkiye Presented by Elevation and Slope Changes

The elevation change in study area ranged from 975 m to 2836 m. Due to the high altitude in the study area, the climate in the northern areas is harsh and mostly snowfall during the fall and winter seasons. (Anonymous, 2017). According to the Thorntwaite method, it was revealed that the climate type is "semi-arid, closer to the continental type without mesothermal water surplus". According to the meteorological station data of 1990-2010, the average precipitation amount is 426.99 mm/yr (Tüzemen, 1991). While arid and semi-arid climate type prevail at the lower altitudes of study areas ranged from 975 m to around 1700 m, semi-humid, humid and very humid climate types prevail in the middle and upper parts ranged from 1700 m to 2836 m (Duman, 2017). The land use types of the study area consist of 7013.41 ha (18.79%) forest, 16836.52 ha (45.10%) grassland, 5212.08 ha (13.96%) agriculture and 8267.14 ha (22.15%) bare land.

The geological structure of the Olur Micro-catchment consists of andesite, siplite and porphyry semi-deep neutral volcanic rocks of unknown age, phyllite of Lower Cretaceous and Eocene age, sedimentary rocks of Upper Cretaceous and Paleozoic age and gypsiferous facies sedimentary rocks of Oligo-Miocene age (Duman, 2017). The study area is covered with sandy loam, thus the water infiltration of the soil is high that can result higher soil-water absorption. However, the soil, which reaches high saturation, has a high tendency to erode due to its coarse grain with weak cohesion structure (Çepel, 1997).

Soil Loss Prediction with GeoWEPP Model

The GeoWEPP model works with the integration of TOPAZ (Topographic Parameterization), GIS and the WEPP program. The function of GIS results in the mapping of soil loss and sediment yield (Flanagan, D.C. and Nearing, M.A. 1995). Since it is difficult to analyze topography alone in the application of the model, its compatibility with ArcGIS is one of the most preferred reasons.

In addition, using TOPAZ of GeoWEPP, it determines the sub-basin or area boundaries in the studied basin from digital elevation model (DEM) maps according to hill, stream and ridge. It also determines the slope and stream network of the sub-basins according to the CSA (Critical Source Area) and MSCL (Minimum Source Channel Length) values (Garbrecht, J., & Martz, L.W., 1997). In this study, the CSA and MSCL values were selected as 50 ha and 100 m. Tolerable soil loss was taken as 1 ton/ha/year.

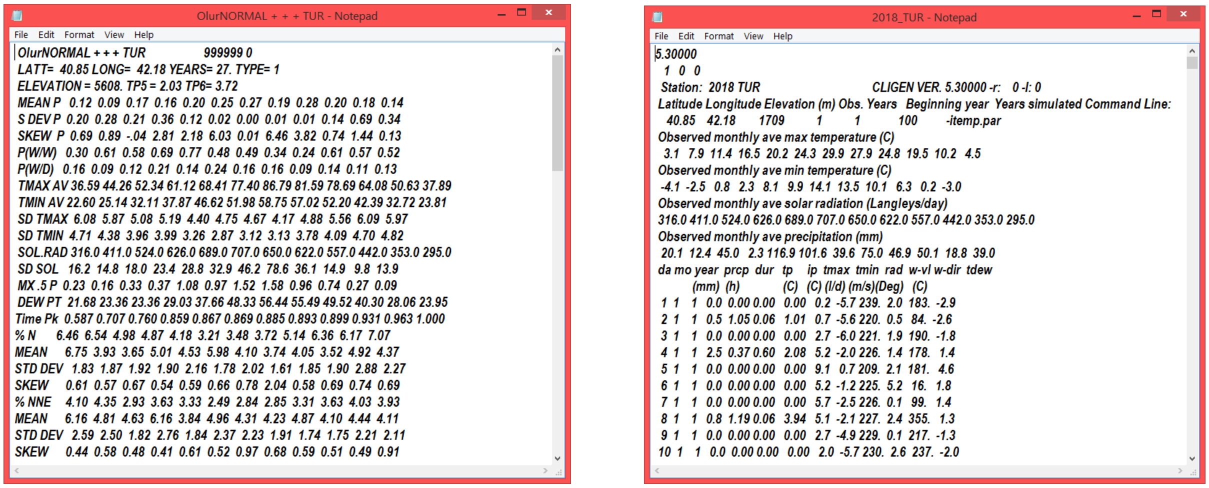
The only negative aspect of the GeoWEPP program is that it cannot work for larger areas. In order to run the program in our studied catchment, 25 separated sub-areas were obtained by dividing our catchment according to streams, hills and ridges with ArcSWAT program. The GeoWEPP model has several data inputs; climate, soil, topography and land management data. These are sensitive parameters for analyzing erosion occurrence and sedimentation processes (Flanagan et al. 2013). The maps used as a base for the model including the DEM, land uses and soil maps of each sub-area that were cut by the ArcGIS program with the "Extract by Mask" command. The program was run separately for each sub-area and the soil loss of the whole catchment was summarized with the predicted results. In this study, GeoWEPP simulation program was run with 2 different schedules. In the first one, only a single year of climate data from 2018 was used and simulated for all 25 sub-areas. In the second run plan, 20-year climate data was used and the estimated erosion values were obtained for all the 25 sub-areas in the catchment.

GeoWEPP starts by simulating the hydrological processes that drive soil erosion, such as precipitation, infiltration, runoff generation and sediment yield. Using input data on topography and soil properties, the model calculates the distribution of water across the landscape and estimates the amount and timing of runoff generation. With simulated hydrological processes, GeoWEPP estimates soil erosion rates across the study area. The model takes into account factors such as slope steepness, land cover type, soil erodibility and rainfall intensity to estimate the amount of soil likely to be removed, transported and deposited over a given time period. GeoWEPP detects erosion values occurring in surface runoff and stream channels._In addition_to estimating soil erosion rates, GeoWEPP also estimates sediment yield, which refers to the amount of sediment delivered to downstream water bodies. Sediment yield calculations take into account factors such as channel characteristics, sediment transport capacity and storage. Sediment yield is calculated by multiplying the soil losses occurring both on the land surfaces and in the stream channels with the sediment delivery rates. Sediment yield refers to the soil losses reaching the outlet of the basin. Once the simulation is complete, GeoWEPP provides users with a variety of outputs for analysis and visualization. These can include erosion risk maps, sediment yield estimates, flow patterns and erosion control recommendations. These outputs are examined to identify areas at high risk of erosion, assess the effectiveness of different land management practices, and prioritize conservation efforts.

Climate Files

Two climate files in GeoWEPP were created, one for one year (2018) and one for twenty (1990-2010) years with the only available data set to use. Climate data were obtained from meteorological stations located in the city of Olur

(MGM, MEVBIS). Rainfall, which is the most important factors in erosion prediction, was recorded 561 mm in 2018 and 426 mm in 20-year average. The parameters include in the climate files were precipitation, temperature, wind, humidity and rainfall intensities. At the first stage, the data was entered into the program as monthly averages in .par format. GeoWEPP then converts this data into cligen (.cli) format (fig. 2).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MEAN P   0.12  0.09  0.17  0.16  0.20  0.25  0.27  0.19  0.28  0.20  0.18  0.14
S DEV P  0.20  0.28  0.21  0.36  0.12  0.02  0.00  0.01  0.01  0.14  0.69  0.34
SKEW  P  0.69  0.89  -.04  2.81  2.18  6.03  0.01  6.46  3.82  0.74  1.44  0.13
P(W/W)   0.30  0.61  0.58  0.69  0.77  0.48  0.49  0.34  0.24  0.61  0.57  0.52
P(W/D)   0.16  0.09  0.12  0.21  0.14  0.24  0.16  0.16  0.09  0.14  0.11  0.13
TMAX AV 36.59 44.26 52.34 61.12 68.41 77.40 86.79 81.59 78.69 64.08 50.63 37.89
TMIN AV 22.60 25.14 32.11 37.87 46.62 51.98 58.75 57.02 52.20 42.39 32.72 23.81
SD TMAX  6.08  5.87  5.08  5.19  4.40  4.75  4.67  4.17  4.88  5.56  6.09  5.97
SD TMIN  4.71  4.38  3.96  3.99  3.26  2.87  3.12  3.13  3.78  4.09  4.70  4.82
SOL.RAD 316.0 411.0 524.0 626.0 689.0 707.0 650.0 622.0 557.0 442.0 353.0 295.0
SD SOL   16.2  14.8  18.0  23.4  28.8  32.9  46.2  78.6  36.1  14.9   9.8  13.9
MX .5 P  0.23  0.16  0.33  0.37  1.08  0.97  1.52  1.58  0.96  0.74  0.27  0.09
DEW PT  21.68 23.36 23.36 29.03 37.66 48.33 56.44 55.49 49.52 40.30 28.06 23.95
Time Pk 0.587 0.707 0.760 0.859 0.867 0.869 0.885 0.893 0.899 0.931 0.963 1.000
% N      6.46  6.54  4.98  4.87  4.18  3.21  3.48  3.72  5.14  6.36  6.17  7.07
MEAN     6.75  3.93  3.65  5.01  4.53  5.98  4.10  3.74  4.05  3.52  4.92  4.37
STD DEV  1.83  1.87  1.92  1.90  2.16  1.78  2.02  1.61  1.85  1.90  2.88  2.27
SKEW     0.61  0.57  0.67  0.54  0.59  0.66  0.78  2.04  0.58  0.69  0.74  0.69
% NNE    4.10  4.35  2.93  3.63  3.33  2.49  2.84  2.85  3.31  3.63  4.03  3.93
MEAN     6.16  4.81  4.63  6.16  3.84  4.96  4.31  4.23  4.87  4.10  4.44  4.11
STD DEV  2.59  2.50  1.82  2.76  1.84  2.37  2.23  1.91  1.74  1.75  2.21  2.11
SKEW     0.44  0.58  0.48  0.41  0.61  0.52  0.97  0.68  0.59  0.51  0.49  0.91
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 Observed monthly ave max temperature (C)
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 Observed monthly ave min temperature (C)
 -4.1 -2.5  0.8  2.3  8.1  9.9 14.1 13.5 10.1  6.3  0.2 -3.0
 Observed monthly ave solar radiation (Langleys/day)
 316.0 411.0 524.0 626.0 689.0 707.0 650.0 622.0 557.0 442.0 353.0 295.0
 Observed monthly ave precipitation (mm)
  20.1 12.4 45.0  2.3 116.9 101.6 39.6 75.0 46.9 50.1 18.8 39.0
 da mo year prcp dur  tp   ip tmax tmin rad w-vl w-dir tdew
            (mm) (h)           (C)  (C) (l/d) (m/s)(Deg)  (C)
  1  1   1  0.0 0.00 0.00  0.00  0.2 -5.7 239.  2.0  183.  -2.9
  2  1   1  0.5 1.05 0.06  1.01  0.7 -5.6 220.  0.5   84.  -2.6
  3  1   1  0.0 0.00 0.00  0.00  2.7 -6.0 221.  1.9  190.  -1.8
  4  1   1  2.5 0.37 0.60  2.08  5.2 -2.0 226.  1.4  178.   1.4
  5  1   1  0.0 0.00 0.00  0.00  9.1  0.7 209.  2.1  181.   4.6
  6  1   1  0.0 0.00 0.00  0.00  5.2 -1.2 225.  5.2   16.   1.8
  7  1   1  0.0 0.00 0.00  0.00  5.7 -2.5 226.  0.1   99.   1.4
  8  1   1  0.8 1.19 0.06  3.94  5.1 -2.1 227.  2.4  355.   1.3
  9  1   1  0.0 0.00 0.00  0.00  2.7 -4.9 229.  0.1  217.  -1.3
 10  1   1  0.0 0.00 0.00  0.00  2.0 -5.7 230.  2.6  237.  -2.0
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Figure 2. (.par) and (.cli) Climate Data Files.

Elevation and Slope Files

The slope file was obtained by means of contour curves on 1/25.000 scale country maps. A DEM was created from the contour curves and input to the model (fig. 3). The DEM map, which is the first input of the GeoWEPP program, was extracted in ArcGIS environment. The program integrates the DEM file with TOPAZ and uses it for slope purposes.

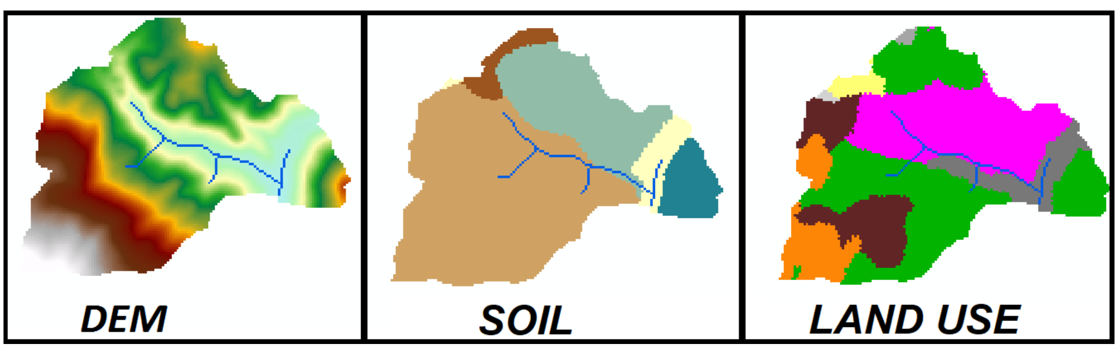

Figure 3. Basemaps Used for GeoWEPP Simulation (An Example of Sections in the Catchment).

Land Use Files

Nineteen percent (19%) of the basin with 33% slope is classified as forest, forty five (45%) as grassland with 22% slope, fourteen (14%) as agricultural land with 30% slope and twenty two (22%) as bare land, rocky and residential areas. The land cover file (.rot) was prepared as a separate file for each land use type (fig. 4). There are 13 different land use types in our area including urban structure, arable land, grassland, mixed agricultural area, agricultural vegetation, broad-leaved forest, coniferous forest, natural grassland, mixed forest, temporary forest, bare rock, sparsely vegetated areas and wetland. Land use pattern data from USDA (United States Department of Agriculture), which is available in the database of the WEPP program, was used (fig. 4).

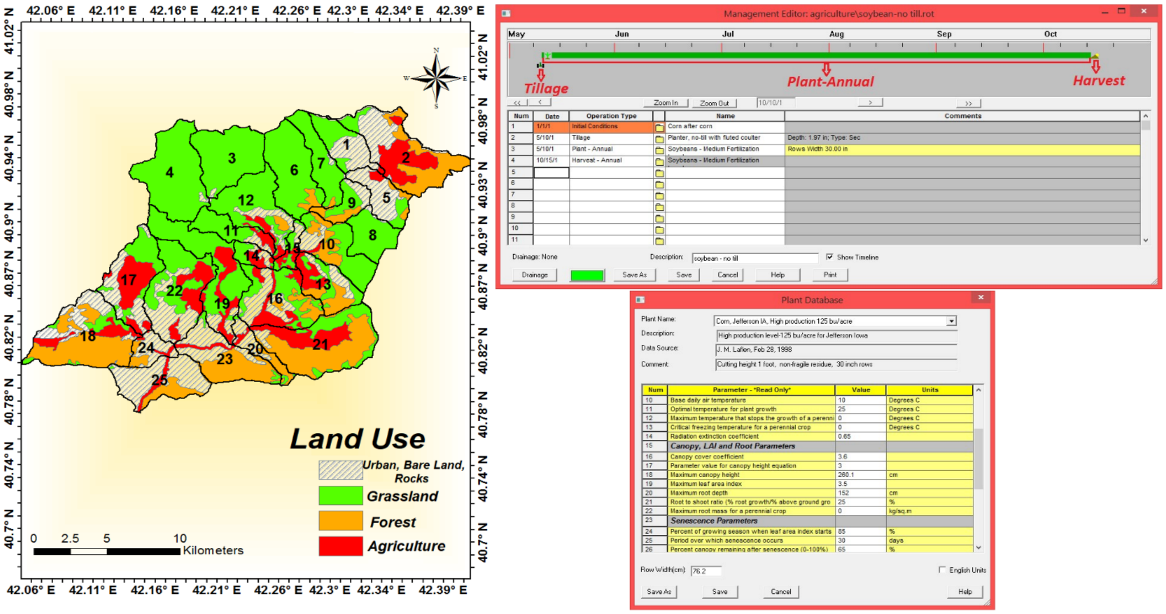

Figure 4. Olur-microcatchment Land Use Map and Its Input to GeoWEPP Program in (.rot) Format

Soil Files

There are 6 different large soil groups in the study area, including chestnut soils (32%), brown forest soils (15%), colluvial soils (2%), basaltic soils (24%), high mountain meadow soils (23%) and bare rocks (4%) (TRGM, 2014). Within the scope of the Coruh River Basin Rehabilitation Project carried out in Olur catchment between 2013 and 2020, a total of 46 soil samples (19 from grassland and 27 from degraded forests) were taken at 0-15 cm and 15-30 cm depths from the catchment. (Duman, 2017). Of those 46 soil samples, 35 falls within the borders of our study area. The overall average texture values of 35 soil samples are 65.8% sand, 14.5% clay, 19.7% silt (Duman, 2017). Based on the soil classification, 9 soil samples were classified as basaltic soils, 8 samples as brown forest soils, 12 samples as chestnut soils, 5 samples as colluvial soils and 1 soil sample as high mountain meadow soils. The soil samples values fall into to the same type of soil classes were averaged and a single value was applied to each soil class. The amount of soil organic matter was found to be 3% on average. These values for each soil group were entered into the WEPP program and a separate file in .sol format was created for each soil group (fig. 5).

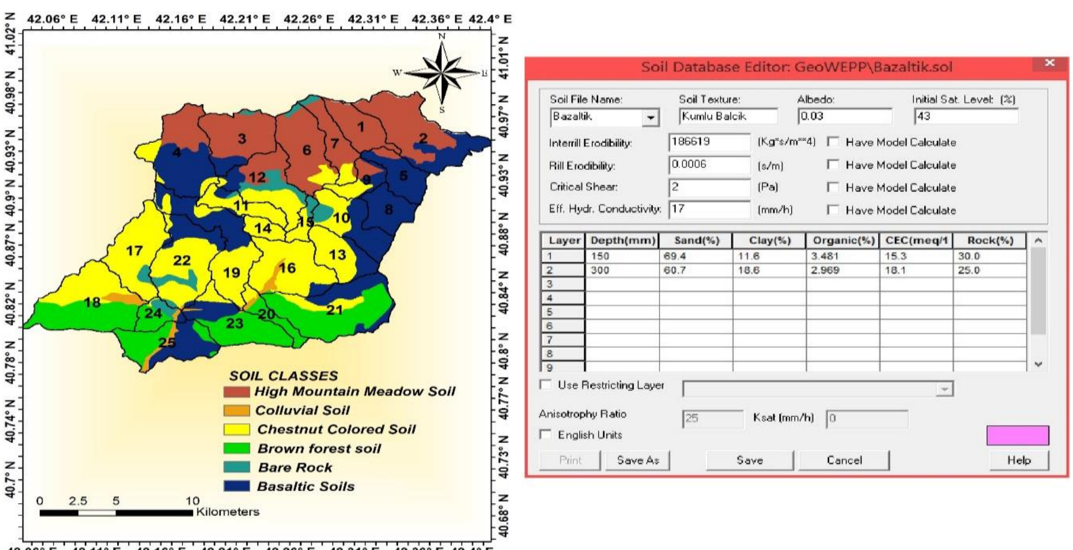

Figure 5. Olur Microcatchment Soil Map and its input to GeoWEPP program in (.sol) format

RESULTS AND DISCUSSION

Sediment Yield Values Obtained by GeoWEPP Simulation

In GeoWEPP simulation, the total numbers of hillslopes and channels were calculated as 845 and 334, respectively (Table 1). In the simulation year 2018, the estimated total soil erosions from the hillslopes and channels were 136525.2 tons/yr and 19989.4 tons/yr, respectively (Table 1). The annual sediment yield (total soil loss) estimated based on the sediment delivery ratio (0.78) was 89123.6 tons/yr. The unit area mean sediment yield for 2018 was 2.80 tons/ha/year (Table 1). According to the 20-year simulation results, very low amount of erosion and sediment yield values were predicted by the model compared to one year (2018) simulation; the 20-year mean soil losses from the hillslopes and channels were 18212 tons/yr and 2492 tons/yr, respectively. The annual sediment yield (total soil loss) estimated based on the sediment delivery ratio (0.544) for 20-year run was 9501.2 tons/yr. The unit area sediment yield in 20-year run again was much lower (0.27 tons/ha/yr) than the year 2018 run (Table 1). In 2018 run, the high values of unit area soil losses were obtained from the following sub-areas (tons/ha/yr) as; [1 (3.8), 11 (5.7), 13 (6.4), 14 (4.8), 16 (5.7), 17 (5.2), 19 (3.4), 20 (6.6), 22 (6.4), 23 (2.8), 24 (2.8), 25 (4.8)]. In the 20-year simulation, the highest erosion values (tons/ha/year) were obtained in following sub-areas as well; [11 (0.7), 13 (0.5), 14 (0.4), 16 (0.8), 17 (0.6), 19 (0.4), 20 (0.4), 22 (1.2)] (table 1). When the land uses, slopes and soil types of these sub-areas were analyzed, it was found that the sub-areas with the higher soil losses overlap with the other sub-areas with higher slopes (> %34; fig 1), which is also coupled with higher percent of land uses as either agriculture or grassland and/or bare surface (fig 4). Based on this information, the GeoWEPP program was found to be very successful in detecting and mapping the spatial distribution of erosion particularly in areas with poor vegetation cover, bare soil, and high slopes (fig 6).

Table 1. GeoWEPP Simulation Results by Year 2018 and 20-years

Sub-area No (ha)	Total Hillslope&Channel	Hillslope Erosion (ton/yr) **2018**-*20 Years*	Channel Erosion (ton/yr) **2018**-20 Years	Sediment Delivery Ratio **2018**-20 Years	Sediment Yield/Soil Loss (ton/yr) **2018**-20 Years	Sediment Yield/Soil Loss (ton/ha/yr) **2018**-20 Years
1(863)	23&9	**5741.6** – *106.8*	**468.9** – *34.5*	**0.534** – *0.805*	**3316.6** – *113.6*	**3.8** – *0.1*
2(2182)	63&25	**9969** – *1371.8*	**726.1** – *132.5*	**0.294** – *0.261*	**3145** – *392.7*	**1.4** – *0.2*
3(1626)	43&17	**20.6** – *0*	**681.8** – *0.8*	**1.000** – *0.04*	**703.5** – *0*	**0.4** – *0*
4(2164)	48&19	**2.2** – *0*	**335.4** – *0*	**1.000** – *0*	**338.2** – *0*	**0.2** – *0*
5(786)	31&12	**3974.1** – *61.5*	**145.5** – *12.4*	**0.522** – *0.42*	**1259.7** – *28.3*	**1.8** – *0.1*
6(1618)	42&17	**19** – *0*	**632.4** – *0.4*	**1.000** – *0.857*	**652.7** – *0.4*	**0.4** – *0*
7(858)	18&7	**1.9** – *0*	**383.2** – *7.7*	**1.000** – *0.691*	**385.4** – *5.3*	**0.4** – *0*
8(784)	17&7	**67.3** – *1.8*	**89.3** – *0.1*	**0.995** – *0.9*	**155.8** – *1.7*	**0.2** – *0*
9(495)	8&3	**700.1** – *10.4*	**335.3** – *16.4*	**0.976** – *0.96*	**1010.2** – *25.7*	**2** – *0.1*
10(1293)	38&15	**352.2** – *107.2*	**339.9** – *6.2*	**0.925** – *0.519*	**640.1** – *58.8*	**0.5** – *0*
11(647)	13&5	**2995.5** – *705.7*	**669.1** – *44.7*	**1.000** – *0.591*	**3675.8** – *443.3*	**5.7** – *0.7*
12(1576)	28&11	**158.3** – *47.2*	**1218.2** – *42.3*	**0.97** – *0.623*	**1334.6** – *55.7*	**0.8** – *0*
13(1045)	23&9	**6125.5** – *477*	**854** – *76.4*	**0.956** – *0.891*	**6669.5** – *493*	**6.4** – *0.5*
14(326)	8&3	**1350.7** – *89.7*	**214.9** – *64.3*	**1.000** – *0.768*	**1568.8** – *118.2*	**4.8** – *0.4*
15(224)	3&1	**18.9** – *25.9*	**18** – *4.4*	**0.988** – *0.981*	**36.4** – *29.7*	**0.2** – *0.1*

16(1791)	51&20	**15528.1** – *2802.2*	**862.3** – *118.4*	**0.62** – *0.466*	**10166** – *1361.4*	**5.7** – *0.8*
17(1658)	50&20	**6809.4** – *1098.5*	**2404.6** – *268.7*	**0.941** – *0.715*	**8670.1** – *977.1*	**5.2** – *0.6*
18(2540)	77&31	**6322.1** – *480.3*	**1643.3** – *397.8*	**0.675** – *0.257*	**5380.2** – *225.7*	**2.1** – *0.1*
19(1974)	43&17	**5416.8** – *1274*	**1842.4** – *170.8*	**0.933** – *0.57*	**6775.8** – *823.1*	**3.4** – *0.4*
20(419)	8&3	**4111** – *275.8*	**520.5** – *28.4*	**0.601** – *0.56*	**2783.2** – *170.5*	**6.6** – *0.4*
21(2573)	73&29	**1842.2** – *1109.1*	**1872.8** – *537.8*	**0.991** – *0.451*	**3679.9** – *742.6*	**1.4** – *0.3*
22(2152)	43&17	**14435.9** – *3933.7*	**2348.7** – *425.8*	**0.827** – *0.57*	**13885.4** – *2484.2*	**6.4** – *1.2*
23(1551)	38&15	**17752.1** – *2863.6*	**194.3** – *25.3*	**0.239** – *0.187*	**4289.8** – *538.8*	**2.8** – *0.3*
24(480)	18&7	**5361.9** – *416.5*	**111.6** – *10*	**0.25** – *0.17*	**1367.5** – *72.4*	**2.8** – *0.2*
25(1499)	38&15	**27448.8** – *953.3*	**1076.9** – *65.9*	**0.254** – *0.333*	**7233.4** – *339*	**4.8** – *0.2*
Total	845&334	**136525.2** – *18212*	**19989.4** – *2492*		**89123.6** – *9501.2*	
Mean				**0.780** – *0.544*		**2.8** – *0.27*

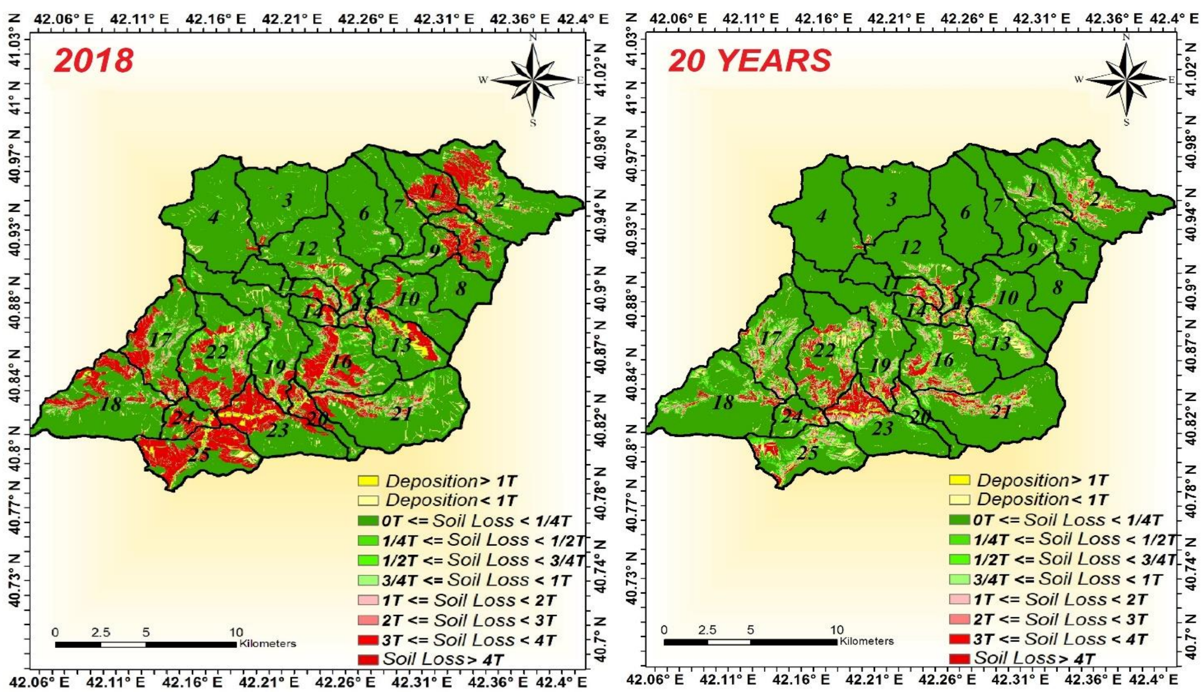

Figure 6. 2018 and 20 Years Soil Loss Maps by GeoWEPP Model

The study results revealed that the soil loss for 2018 simulation was 10.4 times higher than the 20-year simulation. The most important factor attributes this result was the higher amount of rainfall (561.1 mm) recorded in 2018. When look at the details of this data, the number of precipitations over 10 mm or more in 2018 was accounted as 13 and these precipitation amounts were as 30.5, 25.2, 23.9, 22.4, 21.1, 19.3, 16.5, 13.9, 11.2, 10.7, 10.7, 10.7, 10.4, 10.4 mm and their average was 17.4 mm. As a result of these extreme precipitations, the values were found to be much higher than the 20-year climate data simulation. Along with the high amounts of precipitation, during the field visits, it was observed that major flood events occurred in the area during 2018 (fig 7). On the other hand, in the 20-year climate data, the total annual precipitation was recorded very low as 426.9 mm.

Figure 7. High Rainfall and Associated Flooding and Bank Erosion; Olur Micro-catchment in 2018.

However, as it was mentioned in the method section, the forecasting program by the GeoWEPP model does not only use precipitation data, but also other parameters such as temperature, humidity, insolation, wind intensity, number and direction of wind gusts, dew point, rainfall intensity, number of wet days, and consecutive wet and dry days. Because of that, it would be an incomplete assessment to relate all the estimated values to the amounts of precipitation alone.

In a similar GeoWEPP study conducted in the lower part of the Coruh River Basin, in the Artvin Borcka Dam catchment, the annual total sediment amount was found to be 360431.70 tons/yr and the annual average unit area sediment yield was 4.16 tons/ha/yr (Erdoğan Yüksel 2015). This funding is somewhat similar to this study result in 2018 where it was reported soil loss as of 2.8 tons/ha/yr and precipitation amount of 561 mm. The average annual precipitation amount of Borçka Dam was 698.7 mm/yr, and the average slope was 56.3%. The land uses of Borcka Dam were recorded as 56.42% forest, 16.39% pasture, 14.49% national park, 7.71% agriculture and 4.99% other areas. In a study using GeoWEPP in the Orcan Creek watershed in Kahramanmaras, sediment yield was found to be 6.95 tons/ha/yr, which was twice higher than this study (Yüksel et al. 2008). However, the amount of precipitation (730 mm) was also higher than this study (561 mm). It is seen that as the amount of precipitation increases, the sediment yield per unit area increases. The land uses of the Orcan Creek Basin consisted of 175 hectares of forest, 165 hectares of pasture, 150 hectares of agricultural land. The average slope of the Basin was 34%. In a 20-year GeoWEPP study conducted in Arhavi Kapisre watershed in Arhavi, a sediment yield of 1.06 tons/ha/yr was recorded which was much lower than the sediment yield of this study (Yağcı, 2024). The average annual precipitation of the Arhavi watershed was 2265 mm/yr, while the average slope was 53%. The land uses found in the Kapisre watershed were 56% forest, 30% grassland and 14% both tea and hazelnut fields. The lower rate of soil loss from the Arhavi watershed may be related to very dense vegetative cover and higher percent of land use as a forest (56%). In a GeoWEPP study conducted in Gumushane-Torul, an average soil loss of 7 tons/ha/yr was determined as 1.86 from forest areas, 7.66 from pasture areas and 11.48 from agricultural areas (Aydın, 2009). The area has an average annual precipitation of 304 mm and an average slope of 71.43%. The result found in forested areas is close to our study. However, higher soil losses were found in agricultural and pasture areas. Yüksel et al. (2007) estimated sediment production with 5 ha CSA in GeoWEPP model in Ayvalı Dam Watershed in Kahramanmaraş region. The watershed has a total area of 11531 ha, of which 60% is forest, 14% is pasture and 24% is agricultural land. The average slope is 35% and the average rainfall is 552.42 mm. The estimated soil losses values for forest, pasture and agricultural land uses in the area were 1.32, 4.69 and 23.95 tons/ha/yr, respectively. Forest areas have similar soil loss results with this study. High soil loss values were found in agriculture and pastures compared to this study. Using the GeoWEPP, Reis et al. (2017) studied erosion in only pasture areas of Kahramanmaraş Keklik Basin, which has average slope of 45.7%. The average annual precipitation of the Basin was 976.5 mm, and the average elevation was 1600 meters, the sediment yield reaching the basin outlet was 34533.5 tons and the unit area sediment yield was 44.2 tons/ha/yr, which is much higher than this study. According to the study results, high rainfall, slope and land use conditions can increase the soil loss much higher than expected.

Ebrahimpour et al. (2011) simulated GeoWEPP model in the Lui watershed on the upstream of Langat River in Malaysia. The sediment yield estimated by the model was 1.1 tons/ha/yr. The study area has average slope of 35%

and the annual rainfall of 2188 mm/yr. Most of the area (80%) consists of forest. A study by Magalhães et al. (2023), conducted in small areas in Brazil, found that the GeoWEPP program gave similar erosion prediction results to field measurements in grassland and native vegetation. In agricultural areas, GeoWEPP obtained much higher soil loss values than the soil loss values measured in the field. The measured soil loss values in the field were 0.11 tons/ha/yr in agriculture, 0.06 tons/ha/year in pasture and grassland, and 0.10 tons/ha/year in native vegetation. The GeoWEPP soil loss values for the agriculture, pasture and grassland, and native vegetation were 5.78, 0.03, 0.10 tons/ha/year, respectively.

CONCLUSION

- In 2018, the high rainfall intensity and numerous individual rainfall events, totaling up to 561 mm/yr, increased soil loss from the Olur sub-catchment. As results, it was revealed that the most important factor affecting the high soil loss in 2018 compared to the 20-year simulation was the increase of precipitation amounts, magnitudes and frequencies. Additionally, it was also found that the predicted higher soil loss from the 2018 was partially contributed to the higher sediment delivery ratio (0.78) determined by the model calculation.
- Areas with high risk of erosion and their spatial distribution over the sub-catchment, which was the primary objective of the study, were successfully determined and mapped by the model. In order to make these areas more protected, erosion control practice should be implemented with the guidance of this study results. The numbers of dry-stone and wire-cage sills constructed within the scope of the Coruh River Basin Rehabilitation Project in the Olur Micro-catchment should be increased more to ensure that the excessive amounts of sediment will be stored within the gully and stream channels. Terracing, tillage and afforestation practices should be utilized in bare areas susceptible to erosion by runoff. Areas of grasslands with the weak vegetative cover should be protected and rehabilitated by the reduced grazing intensity, stone collection, watering, canopy shading, erosion control such as terracing and stone-walls to reduce erosion by surface runoff. The implementation of all the relevant rehabilitation practices at those erosion sensitive areas would reduce the soil losses from the Olur sub-catchment that, in return, increase the economic life span of the Ayvalı dam, 23 km below the Olur sub-catchment.

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