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Spatial-Temporal Response of Sediment Loads to Climate Change and Soil Conservation Practices in the Northern Aegean Watershed, Türkiye

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Abstract: Climate change and agricultural activities are significant sources of stress to the natural environment and water resources. These also affect erosion and the associated estimation of sediment yields, which is also a crucial task in the hydrological models. The presented study is significant for the development of sustainable watershed management practices. It also aims to determine the effects of climate change and different agricultural best management practices (BMPs) on the sediment loads of the North Aegean Basin in Türkiye by using the Soil and Water Assessment Tool (SWAT) model. While sediment calibration was performed for 2014, streamflow calibration and verification were performed using the SWAT Calibration and Uncertainty Program (SWAT-CUP) for the period 2012–2013 and 2014–2015, respectively. The obtained results showed that the climate change scenarios reduce the surface waters of the basin and sediment yield in accordance with the hydrological transport processes. During the 2012–2030 time period, runoff in the basin for the RCP4.5 and RCP8.5 climate change scenarios decreased by 38.5% and 31.8%, respectively, and the basin sediment yield decreased by 55.7% and 50.7%, respectively. The sediment yields to water resources had distinctive reductions due to BMPs such as zero tillage, vertical tillage, cover crop, and terracing. Considering the RCP4.5 and RCP8.5 scenarios, BMPs reduced the sediment yield in the range of 0.93–4.03% and 0.89–3.85%, respectively. Determining the sediment transport by using hydrological modeling and the effects of climate change for different agricultural practices on erosion will be useful for decision-makers.

Keywords: soil erosion; sediment yield; SWAT; climate change; BMP

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1. Introduction

Erosion is a serious issue that threatens water and soil resources and precautions need to be taken. Hydrological conditions and erosion vary depending on changing environmental conditions that are also affected by numerous factors such as changes in land use, agricultural practices, and the climate crisis [1,2]. Therefore, changes in cloud microstructure, solar radiation, precipitation, and temperatures due to the climate crisis and intensification of agricultural practices cause an increase in nutrient materials such as nitrate and phosphorus in water resources [3–5]. These situations cause changes in basin hydrology and ecological functions. In addition to environmental problems, it also brings economic and social problems [6–8]. In order to protect and sustain water resources, sediment transport must be controlled and appropriate measurements taken against erosion in critical areas. In the present study, the effects of climate change and soil conservation practices on sediment yield were investigated. Determining the best management practices by considering the effects of climate change contribute to the solution of basin erosion problems.

Erosion has a significant impact on water resources. Natural disasters such as landslides, floods, and earthquakes can cause ground deformation, but human actions such as urbanization and mining have a great impact on erosion (Figure 1). Especially in recent years, the increase in human effects and pressures on the environment (such as agricultural practices, overgrazing, and deforestation) caused both the rapid depletion of environmental resources and increased sediment transport in the basins [9–11]. Rapid population growth also increases the demand for food, which intensifies agricultural practices and causes sustainable development problems [12]. Intensive agricultural activities increase soil erosion and cause the soil to lose water and nutrients [13,14]. Cultivated areas, forests, and wetlands have especially distinctive changes in the dynamics of organic and inorganic substances in the soil [15]. Changing nutrient ratios also affect soil-dwelling organisms [16]. In addition to the intensive use of fertilizers, some pollution, such as point-source wastewater and antibiotic resistance, threatens public health [17].

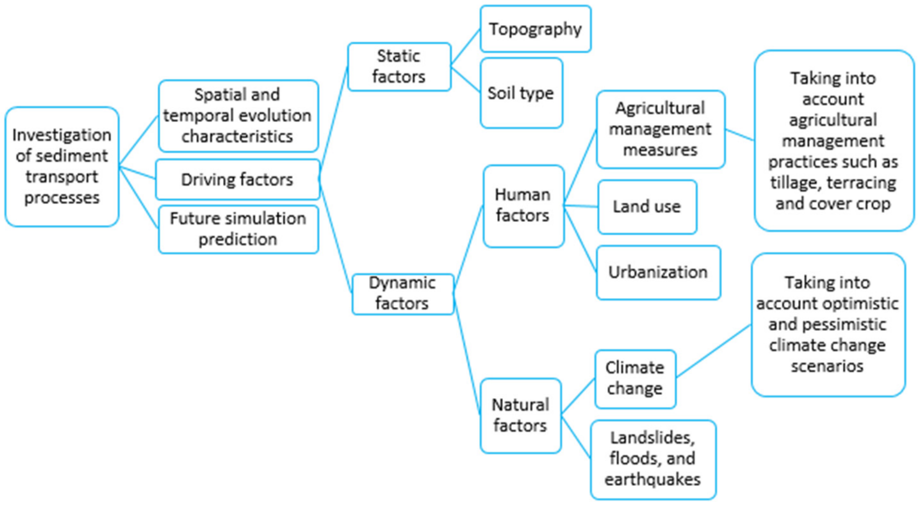


Figure 1. Summary of the literature review.

Erosion is also the main component of non-point pollution [18]. Therefore, erosion is one of the most crucial problems in water quality because the sediment is transported to the aquatic environments by the effect of wind and surface flow [19]. The downstream of the ecosystem is harmed by the sediment that is transported into aquatic environments. It also causes eutrophication and harmful algae blooms by increasing nutrient pollution [20,21]. In addition to water pollution, soil pollution is an important environmental problem, and the cleaning of polluted soil resources is a challenging process [22]. Furthermore, erosion causes the degradation of soil structure, reduces arable land capacities, lowers crop yields, and increases production costs [11,14]. Increasing sediment yield reduces the dam storage capacity, adversely affects dam efficiency, and increases the risk of flooding [2]. In addition, sediment accumulation in bridge piers, channels, and culverts causes flow imbalance.

It is necessary to determine the sediment yield in order to determine the areas where erosion is high and to carry out erosion-reducing management practices in such areas. It is a clear fact that hydrological models are used to analyze sediment yield. They are useful tools that provide an understanding of the physical, chemical, and biological processes of the basin. With the help of these models, sediment transport and accumulation processes, especially those caused by precipitation and runoff, are predicted [2]. There are many studies in the literature to understand climatic and environmental changes [23,24]. Especially in determining sediment yield, the SWAT model is widely preferred [14,19,25,26]. Most of these studies demonstrated that the model is successful in simulating watershed erosion [27–29]. The SWAT model is a physically based hydrological model that operates on daily, monthly, and yearly periods [30]. In addition, there are many studies in the literature where the SWAT model is used for different purposes; it can simulate the effects of climate change and land use changes [18] and non-point-source pollution (agriculture and livestock practices) [31,32] on watershed hydrology. Additionally, it is widely used to determine the best management practices of watersheds [3,33].

Consequently, in the present study, the medium-term effects of climate change and various BMPs on the sediment yield of the North Aegean Basin were investigated. There are numerous studies in the literature regarding investigating the impact of climate change on the water potential of the North Aegean Basin [34,35]. There is also a study examining the effects of BMPs on the surface water quality of the North Aegean Basin [3]. However, there are no comprehensive studies including both effects of climate change and BMPs on sediment yield in the literature [29,36]. This study aims to fill important gaps in the literature and presents new perspectives and applications by considering the impact of both climate change and different soil conservation practices. This study contributes to the comprehensive evaluation of the basins and the creation of indexes that will quantitatively evaluate the status of the basins [37]. Furthermore, the SWAT model is able to model with a suitable accuracy watersheds that are missing data or lack measurement data [2,38]. For this reason, in the North Aegean Basin, where there is insufficient sediment measurement data, the SWAT model was preferred to identify critical areas where erosion is high, to examine the effects of climate change on sediment yield, and to evaluate the effects of different agricultural practices on erosion. This study also guides the preparation of robust watershed management plans.

2. Materials and Methods

The North Aegean Basin has an important place for Türkiye in agricultural production with its fertile lands. Additionally, the basin is home to numerous dams and lakes. Unfortunately, the use of fertilizers in agricultural activities leads to their transportation into lakes and reservoirs through surface flow and erosion, causing a significant decline in water quality. Another crucial factor that affects water quality in the basin is sediment transport. The transportation of sediment not only diminishes water quality but also reduces the storage capacity of dams and lakes in the area. Furthermore, climate change plays a noteworthy role in influencing water resources and, consequently, sediment transport. Therefore, it is imperative to assess the potential of water resources and identify erosion-prone areas within the basin to ensure the sustainability of agricultural practices, soil health, and water resources.

2.1. Methodology

The SWAT model, which is capable of simulating the water potential, water quality, and sediment yield in large and complex basins, was used in this study. In order to analyze the amount of sediment coming to the dams and lakes in the basin and to examine the effects of climate change and agricultural practices on erosion, the study was carried out on a micro-basin scale. After the sub-basins were created, land use and soil characteristics were introduced to the model and hydrological response units (HRUs) were created. Meteorological data, irrigated areas, well, and reservoir data were defined in the model. Calibration and verification processes were performed using the observation data, and thus the setup of the baseline model was completed (Figure 2). The data used in the model was obtained from the sources given in Table 1. First, high erosion areas in the baseline model simulation were determined. The annual average sediment yield for the reservoirs and lakes was also calculated. Then, by applying two different climate change scenarios, the effects of climate change on basin erosion in the medium term (until 2030) were examined. Four different soil-conservation practices were used as BMPs. The aforementioned practices were applied to the baseline model simulation and climate change model simulations, and their effects on basin erosion were evaluated. The outcomes of the presented study will provide valuable insights for addressing erosion issues in the basin and comprehending the impacts of climate change and BMPs on erosion. Thus, it contributes to solving vital problems regarding water and soil pollution, which threaten public and environmental health and reduce agricultural productivity.

2.2. Study Area

The North Aegean Basin is an open basin located in the northwest of Anatolia and empties its waters into the sea (Figure 3). The basin has many large and small rivers that feed water resources. Mediterranean climate is observed in the basin. The North Aegean Basin, which has fertile lands, has an important place for Türkiye in agricultural production. Apart from many vegetables and fruits, tropical products with high economic value are also grown in the basin, and most of these agriproducts are exported to the world [41]. Moreover, various industrial plants can be produced [42]. The basin covers the provinces of Izmir, Balikesir, Manisa, and Canakkale. Non-point pollutants in the North Aegean Basin are carried to water resources by the effect of runoff and erosion and increase water pollution in some parts of the basin [41]. The identification of highly eroded areas of the North Aegean Basin, which has such a high agricultural value, is important for the basin's soil and water resources. In addition, climate change is a factor affecting the watershed hydrological cycle. For this reason, the effects of climate change and agricultural land protection practices on watershed erosion were investigated in the present study.

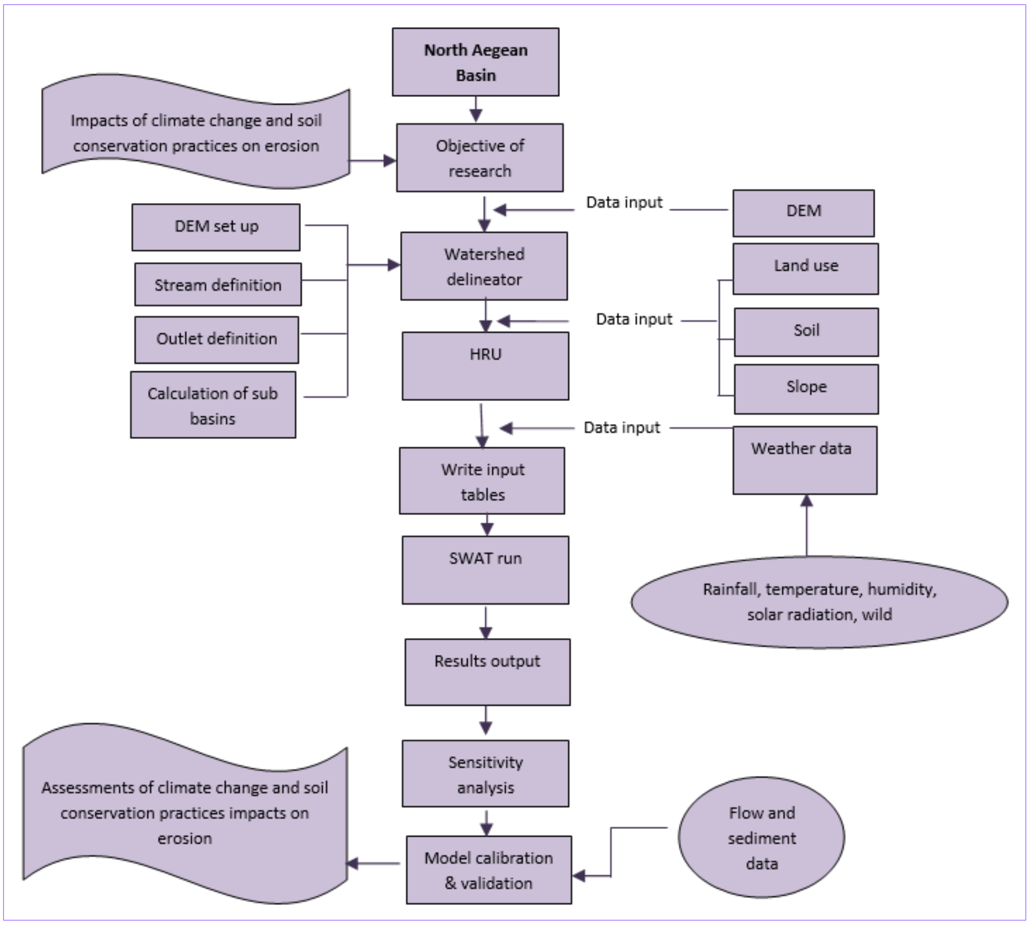


Figure 2. Methodology of the SWAT model.

Table 1. Description of data used in this study.

Data	Description	Period	Source
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM) Global: Raster resolution of 30 m	-	United States Geological Survey's (USGS's) Earth Explorer (https://earthexplorer.usgs.gov/ (accessed on 20 April 2021)
Land-use data	Raster resolution of 100 m	2018	CORINE Land Cover (https://land.copernicus.eu/pan-european/corine-land-cover (accessed on 4 May 2021))
Soil data	Raster resolution of 100 m	-	FAO–UNESCO global soil map (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/ (accessed on 27 May 2021))
Meteorological data	Monthly meteorological data	2010–2014	Turkish State Meteorological Service (https://mgm.gov.tr/kurumsal/istasyonlarimiz.aspx (accessed on 5 April 2021))
	Climate change projection data	2010–2030	Bogazici University Center for Climate Change and Policy Studies (http://climatechange.boun.edu.tr/ (accessed on 5 October 2022))
Hydrological data	Monthly discharge data of D04A017 and D04A032 stations	2012–2015	General Directorate of State Hydraulic Works (DSI)
	Well data and the irrigated areas in the basin	-	T.R. Ministry of Agriculture and Forestry, General Directorate of Water Management [39] and TUBITAK MAM Environment Institute [40]
Sediment data	Sediment data for IST_KEN003, IST_KEN005 and IST_KEN023 stations	2014	General Directorate of State Hydraulic Works (DSI)

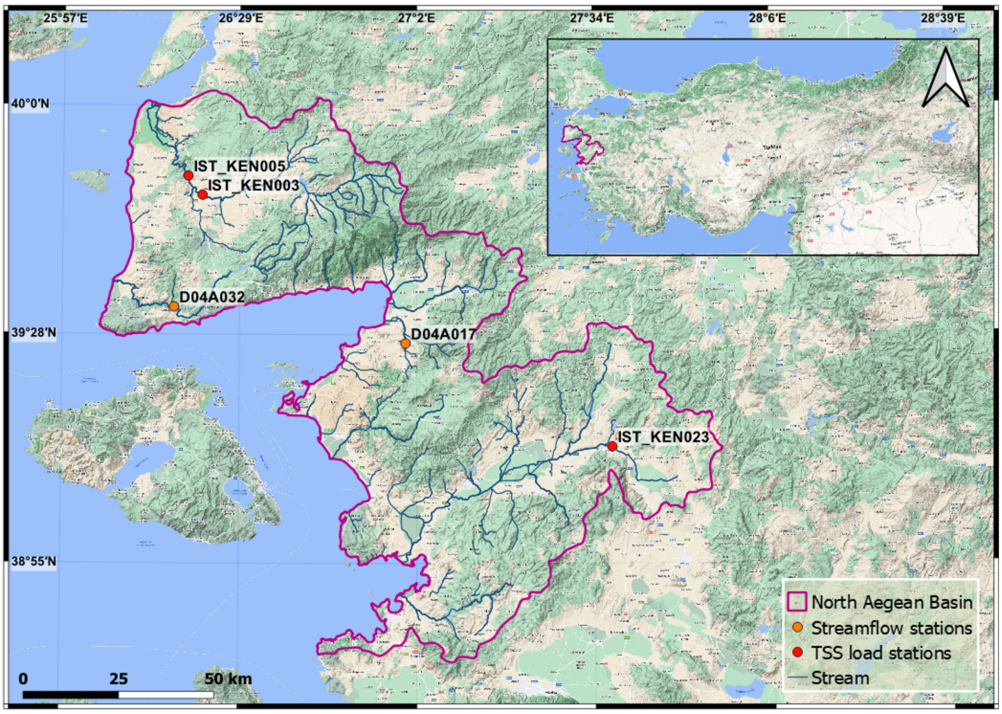


Figure 3. The location of the study area and gauging stations.

2.3. Climate Change Projections

RCP4.5 and RCP8.5 projections were applied in the presented study since there is not yet a high-resolution dynamically scaled data set for the study region at the regional scale. Intergovernmental Panel on Climate Change (IPCC)'s (the Sixth Assessment Report (AR6)) new scenario sets are combined with the Shared Socioeconomic Pathway (SSP) (in terms of socio-economic) and Representative Concentration Pathway (RCP) (in terms of radiative forcing) sets. If there were data, they would be a priority to study the SSP2-4.5 and SSP3-7.0 scenarios. However, especially within the scope of the Coordinated Regional Climate Downscaling Experiment (CORDEX), since regional climate studies are already continuing within the scope of new scenario sets and there is no publicly accessible data set, the study continued with RCPs (The Fifth Assessment Report (AR5)), which are still valid in the literature. RCP4.5 (optimistic) represents a medium-emission scenario, while RCP8.5 (pessimistic) represents a high-emission scenario [43]. Low-resolution MPI-ESM-MR global climate model outputs were rendered in high resolution (10 km) using the RegCM4.4 regional climate model. Regional climate models (RegCMs) are often used to scale down climate simulations of a particular area [44,45]. In the present study, precipitation, minimum temperature, and maximum temperature obtained from dynamically reduced climate data for the period between 1 January 2010 and 31 December 2014 were compared with in situ records. Then, it was aimed to reduce the margin of error in the climate data and to provide realistic data to the hydrological model by using the univariate quantitative mapping bias correction method. Thus, the possible future hydrological conditions of the basin were obtained and the change in the basin erosion under these conditions was tried to be determined.

2.4. Application of Hydrological Model

The SWAT model is a physically based hydrological modeling tool that simulates soil and water interactions, agricultural applications, and sediment and nutrient dynamics. The SWAT input data can be divided into spatial and temporal data. DEM, soil structure, and land use are spatial data; meteorological data (such as precipitation (mm), minimum-maximum temperature (°C), and wind speed (m/s), solar radiation (MJ/m^2)) and hydrological data (surface flow, sediment yield) are temporal data. There are two types of units in the SWAT model, the sub-basin and the HRU [46]. HRU is created based on slope, land use, and soil characteristics in the watershed [38]. Sub-basins may have one or more HRUs. While creating the model, first of all, watershed delineation is made using DEM, and the main basin and sub-basins are obtained. Then, HRUs are created by introducing land use and soil properties to the model. The model setup is completed by entering meteorological data into the model and writing input tables. The SWAT model considers meteorological data, surface, and lateral flow, infiltration, and evaporation, and generates a hydrological forecast for each HRU [47]. Evaporation is calculated by using one of the Priestley Taylor [48], Hargreaves [49], or Penman-Monteith [50] methods in the model. Moreover, flow is calculated using the SCS curve number [51] or Green and Ampt [52] methods.

The model shapes the sediment yield of a basin based on the flow characteristics. Sediment data such as sediment flow and transportation monitoring are needed for sediment yield estimation. However, in the case of limited sediment measurement data, models can be used to estimate sediment yield [53]. The SWAT model is successful in simulating the sediment yield in basins with insufficient data [2]. Moreover, there are methods for modeling sediment transport in the canal network and erosion in the SWAT model. In the Universal Soil Loss Equation (USLE) method, soil loss is estimated based on layers and streams in areas where there is erosion but no accumulation. In the Modified Universal Soil Loss Equation (MUSLE) method, the sediment yield caused by precipitation and runoff can be calculated for each HRU [54]. HRU area, surface runoff volume, and peak runoff rate are used when estimating sediment yield with MUSLE.

The rainfall energy factor is replaced by a flow factor in MUSLE. The flow factor in question refers to the energy used during sediment separation and transport, improves the model's prediction of sediment yield, and allows the equation to be applied to individual storm events [53]. MUSLE is [55];

$$sed = 11.8 \times \left(Q_{surf} \times q_{peak} \times A_{HRU}\right)^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \quad (1)$$

where sed is the daily sediment yield in metric tons. CFRG and LS_{USLE} indicate coarse fragment factor and USLE topographic factor, respectively. P_{USLE} represents management and support practice components while C_{USLE} represents USLE land cover. C_{USLE} is the ratio of erosion from cropped land to the erosion from clean-tilled and continuous fallow land [56]. P_{USLE} is the ratio of erosion caused by support applications such as terrace systems, contour tillage, and strip-cropping on the contour to erosion caused by up-and-down slope culture. K_{USLE} is the erosion rate per erosion index unit, it indicates USLE soil erodibility factor. A_{HRU} is the HRU area, q_{peak} is the peak runoff rate in m^3/s and Q_{surf} is the watershed's surface runoff in mm/ha.

Model calibration can be performed manually or using the SWAT-CUP, an automatic calibration tool. Five different automatic calibration algorithms are available in SWAT-CUP [57]. Sequential Uncertainty Fitting-2 (SUFI-2) is frequently preferred for the hydrological calibration of basins [57,58]. In order to analyze the hydrology of the North Aegean Basin in the short and medium term, the SWAT model was run in the 2010–2030 time period. The first 2 years (2010–2011) were chosen as the warm-up period. While sediment calibration was performed for 2014, streamflow calibration and verification were performed using SWAT-CUP for the periods 2012–2013 and 2014–2015, respectively. As a result of the model, a total of 3965 HRUs and 668 sub-basins were created.

2.5. Calibration and Validation

Before calibrating the hydrological model, first, the calibration parameters are determined. They must be determined according to the hydrological characteristics of the basin or by sensitivity analysis. After determining the most sensitive parameters for the basin, calibration is performed. It is important to keep the parameters within a realistic uncertainty range throughout the calibration [38]. With the calibration process, it is aimed to reduce the estimation uncertainty in the model. Model simulation results and observation results are compared. The validation process includes comparing the simulation results with the observation results by running the model with the calibration parameters. Therefore, it is necessary to analyze model uncertainty using comprehensive uncertainty analysis methods [59]. In this study, the SUFI-2 was used to reduce model uncertainty and provide the best prediction of hydrological processes.

2.6. Agricultural BMPs

BMPs, or best management practices, were developed as measures to combat erosion. These practices typically involve implementing protective techniques such as cover crops and terracing as well as making changes in agricultural activities such as crop rotation [60]. By employing these methods, the impact of precipitation on the soil surface is reduced, resulting in decreased flowrates and increased resistance against erosion. The use of cover crops shields the soil surface from rain and enhances infiltration. Terracing and tillage techniques also contribute to minimizing erosion. In the presented study, BMPs were devised specifically to mitigate erosion in the North Aegean Basin. Initially, sediment yields were assessed under different scenarios: baseline simulation and climate change scenarios (RCP4.5 and RCP8.5). Subsequently, various BMPs, including zero tillage, vertical tillage, cover crop, and terracing applications (Table 2), were implemented to evaluate their impact on watershed erosion. The agricultural areas in the basin encompass approximately 4183.89 km^2, while the North Aegean Basin as a whole covers 9861.2 km^2. Given the diversity of agricultural products cultivated, there are also areas within the basin that consist of woodlands and shrubs. As a result, it is not feasible to implement the aforementioned soil protection practices across all agricultural lands.

Table 2. Description of Agricultural BMPs.

Soil-Conservation Practices	Application Area (km^2)	Application Area to Total Watershed Area (%)
Zero tillage	2514.05	25.49
Vertical tillage	2595.08	26.32
Cover crops	2595.08	26.32
Terracing	2594.59	26.31

The SWAT database used the mgt files to implement soil protection measures in the model. Initially, the sub-basins suitable for applying these measures were identified. Subsequently, based on the agricultural lands and slope characteristics within the chosen sub-catchments, appropriate HRUs were selected where the relevant protective practices could be implemented. In summary, soil protection practices were not universally implemented across all selected sub-catchments but rather in specific areas deemed suitable within those sub-catchments. Consequently, the resulting sediment yield from the simulations only reflects the changes attributable to the sub-basin areas where soil protection measures were applied. As a result, the agricultural lands that could be utilized for each practice were investigated and evaluated separately. In this context agricultural areas where protective tillage methods can be applied were investigated; zero tillage was applied in 2514.06 km^2 areas, vertical tillage in 2595.09 km^2 areas, cover crops in 2595.09 km^2 areas, and terracing in 2594.59 km^2 areas. To incorporate best management practices (BMPs) into the model, certain adjustments have been applied to the management (.mgt) file within the SWAT database. The objective is to utilize tillage and cover crop applications for filtering runoff and controlling sediment in the fields. These applications are represented in the SWAT model by the tillage implement code (TILLAGE_ID) and the biomass (dry weight) target (BIO_TARG) parameters. Additionally, terracing is employed on sloping areas to manage the flow, which is indicated in the model by the USLE_P parameter. For instance, when implementing the tillage application, the management operation number (MGT_OP) parameter is set to 6. Subsequently, the TILLAGE_ID parameter is assigned as 4 for zero tillage and 3 for vertical tillage. Regarding the cover crop application, modifications are made to the BIO_TARG parameter. Similarly, adjustments are made to the USLE_P parameter for the terracing application. As a result, the BMPs are implemented by modifying these specific parameters.

3. Results and Discussion

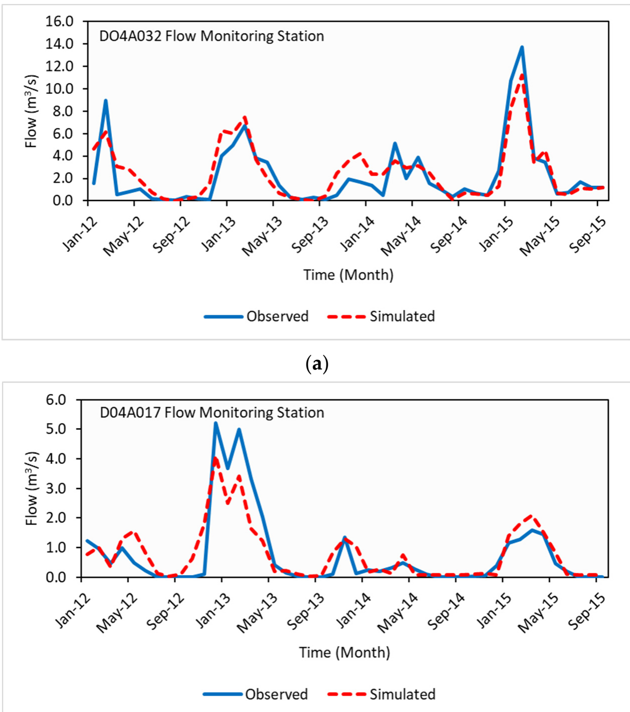
Identifying the erosion-sensitive areas of the basin is critical for the protection of water resources and the development of sustainable watershed management practices. In a previous model study conducted on the North Aegean Basin [3], the focus was solely on evaluating water quality and associated best management practices, without examining sediment yield. However, this study takes a different approach by addressing both climate change and erosion issues in the basin while also exploring effective soil conservation practices. Moreover, the calibration and validation stations used in this study differ, and sediment calibration was conducted at three distinct stations to enhance the model's accuracy. Consequently, this study distinguishes itself from previous research by incorporating these unique elements.

3.1. Model Performance Evaluation

Sensitivity analysis, calibration, and verification processes were performed for both flow and sediment using SWAT-CUP software and the SUFI-2 algorithm. After the completion of the calibration processes, the flow verification process was also carried out. The flow calibration was carried out at D04A032 and D04A017 stations for the 2012–2013 time period. Model verification was performed at the same stations for the 2014–2015 time period. Sediment calibration was performed at IST_KEN003, IST_KEN005, and IST_KEN023 stations using total suspended solids (TSS) loads. Measurement data from 2014 were used in sediment calibration. The mentioned data consist of instantaneous measurements taken during the months of May, July, November, and December. The calibration parameters were fixed after the successful completion of the flow and sediment calibration processes.

To assess the model's performance after calibration and verification, statistical metrics such as R2, PBIAS, and NS were used. A thorough review of relevant literature sources [61–65] was conducted, and a total of 15 flow calibration parameters and 5 sediment calibration parameters were selected for the basin [3]. The most sensitive parameters in the model for hydrological calibration are curve number (CN2), average slope steepness (HRU_SLP), baseflow alpha factor (ALPHA_BF), and saturated hydraulic conductivity (SOL_K). As a result of the calibration, the D04A032 station yielded NS, R2, and PBIAS values of 0.54, 0.63, and −22.9, respectively. On the other hand, the D04A017 station exhibited NS, R2, and PBIAS values of 0.72, 0.76, and 1.4, respectively. During model validation, the NS, R2, and PBIAS values for the D04A032 station were 0.61, 0.70, and −17.5, while for the D04A017 station, these values were 0.75, 0.78, and 3.8, respectively.

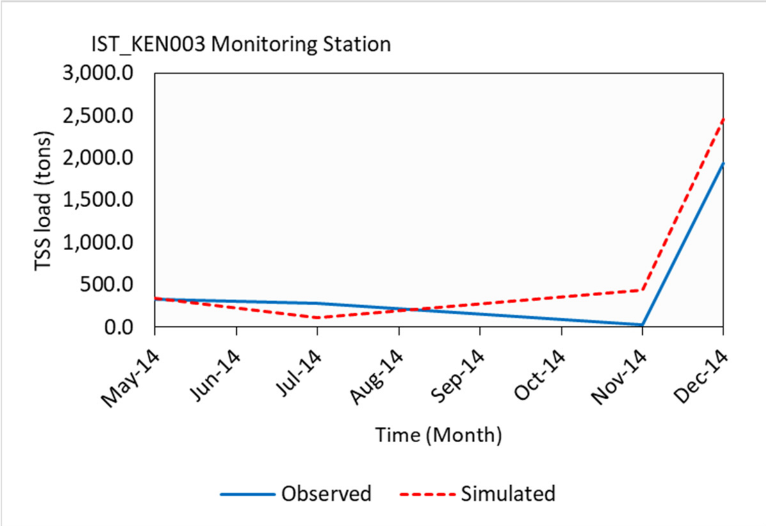
Regarding sediment calibration, the most sensitive parameters in the model were identified as the USLE soil erodibility factor (USLE_K), the USLE support practice factor (USLE_P), and the exponent parameter for sediment re-entrainment (SPEXP). Following the sediment calibration process, the IST_KEN003 station yielded NS, R2, and PBIAS values of 0.79, 0.94, and −30.64, respectively. The IST_KEN005 station exhibited NS, R2, and PBIAS values of 0.80, 0.96, and −46.96, respectively, while the IST_KEN023 station had values of 0.70, 0.90, and 44.89, respectively (Table 3). To evaluate the model's performance, certain criteria were considered: NS ≥ 0.5, PBIAS within ±25%, and R2 ≥ 0.5 for flow calibration and NS ≥ 0.5, PBIAS within ±55%, and R2 ≥ 0.5 for sediment calibration [66]. Based on these criteria, the calibration and verification results for both streamflow and sediment demonstrated that the model's performance is satisfactory (Figures 4 and 5).



(**a**)

(**b**)

Figure 4. Observed and simulated streamflow (**a**) calibration (2012–2013) and (**b**) validation (2014–2015).



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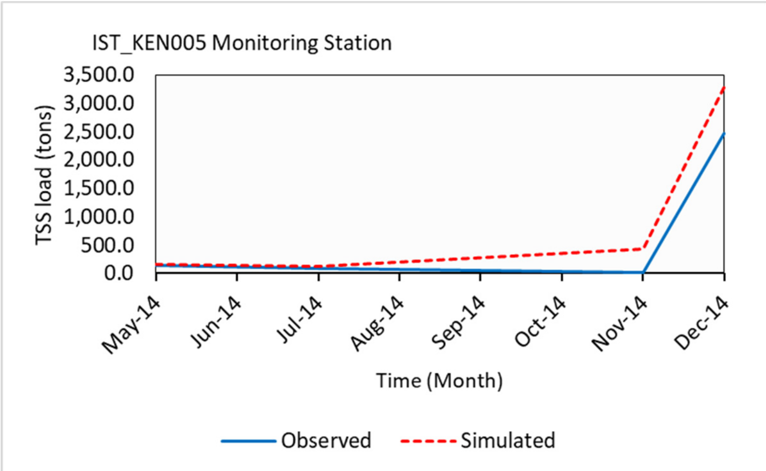

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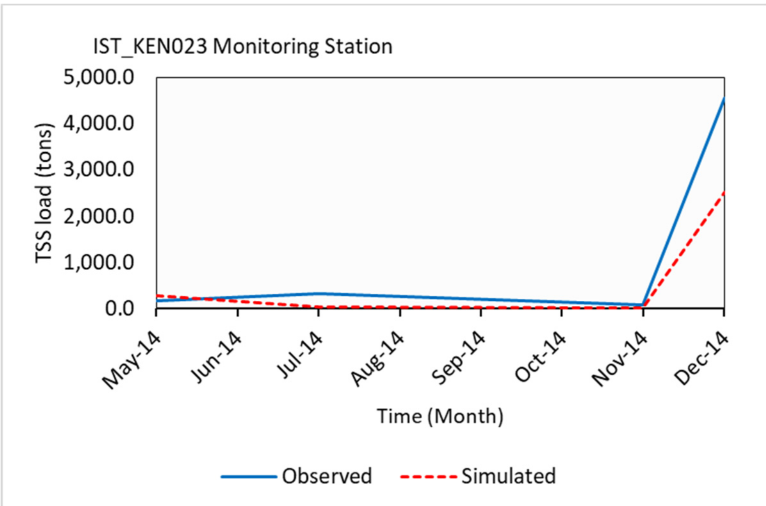


(**c**)

Figure 5. Observed and simulated total suspended solid loads for different monitoring stations (**a**) IST_KEN003, (**b**) IST_KEN005, (**c**) IST_KEN023.

Table 3. Statistical summary for streamflow and total suspended solid loads.

Analysis	Station	R^2	NS	PBIAS
Streamflow calibration	D04A017	0.76	0.72	1.40
	D04A032	0.63	0.54	−22.91
TSS load calibration	IST_KEN003	0.94	0.79	−30.64
	IST_KEN005	0.96	0.80	−46.96
	IST_KEN023	0.90	0.70	44.89
Streamflow verification	D04A017	0.78	0.75	3.80
	D04A032	0.70	0.61	−17.52

3.2. Basin Hydrology and Sediment Yield

The sediment yields of the North Aegean Basin were obtained for the years 2012–2030 by using the baseline model. The mean annual sediment loads in the sub-basins during the simulation period ranged from 0 to 1325.43 kg/ha. It is seen that the sediment yield is generally lower in the coastal areas, and the sediment loads from the coastline to the inner parts of the basin also increase (Figure 6).

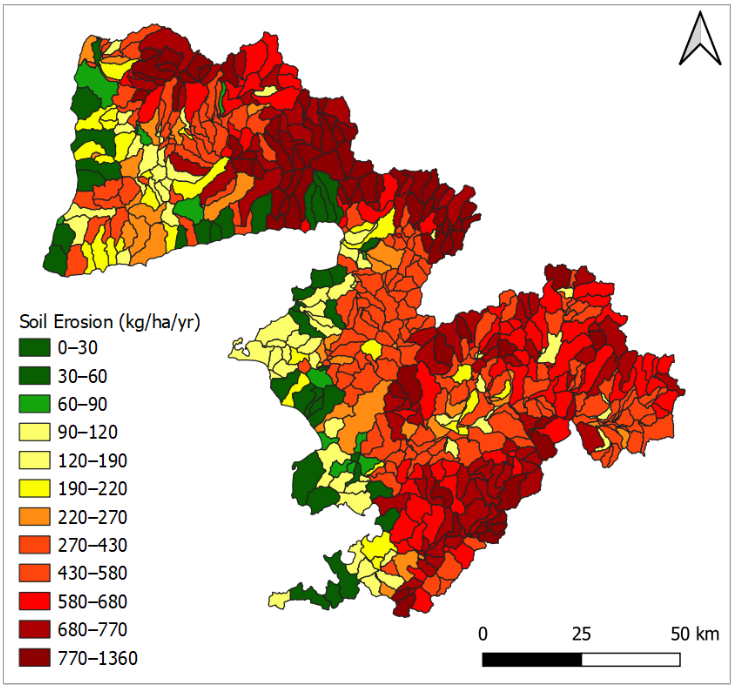
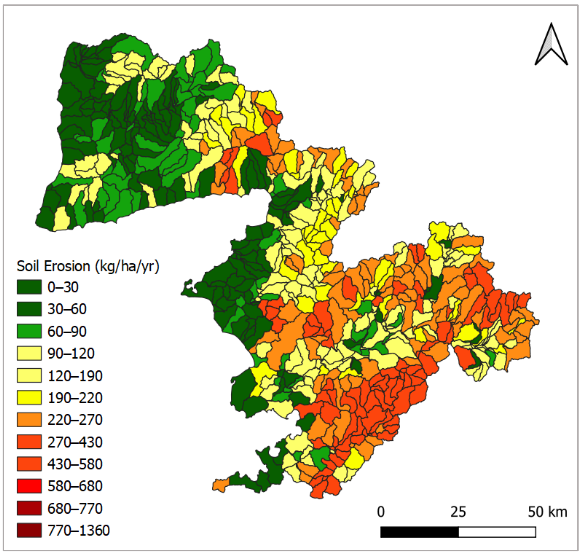


Figure 6. Mean annual sediment yield for baseline model simulation (2012–2030).

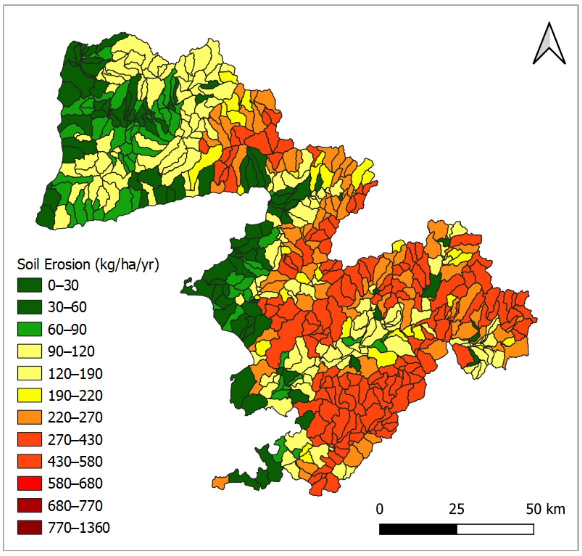
There are many factors affecting the erosion in the basin. The distribution of eroded areas in the basin is directly related to the basin slope, geology, soil structure, land use, precipitation, and climate change factors. Hence, these factors significantly affect the flow characteristics and erosion of the basin [5,11]. The low erosion is usually due to the tight soil structure and the presence of hard rock in the region while the high level of erosion depends on the effectiveness of surface flows [2]. Therefore, soil erosion and sediment yield generally tend to increase in sub-basins close to the river network [67]. Agricultural lands are dense in the North Aegean Basin and the basin has many tributaries of various sizes. Thus, sediment loads can be easily carried by the surface flow and are affected by agricultural activities.

3.3. Impacts of Climate Scenarios on Basin Hydrology and Sediment Yield

RCP4.5 and RCP8.5 scenario simulations show that precipitation, evapotranspiration, and runoff tend to decrease compared to the baseline model simulation. During the 2012–2030 time period, precipitation decreased by 14.86% in the RCP4.5 scenario, while it decreased by 11.02% in the RCP8.5 scenario. The amount of evapotranspiration decreased by 10.21% and 8.13% for the RCP4.5 and RCP8.5 scenarios, respectively. Additionally, while the amount of runoff decreased by 38.53% in the RCP4.5 scenario, it decreased by 31.84% in the RCP8.5 scenario. Decreased surface runoff also reduces sediment-carrying capacity [2]. This is an expected result that flow volume has a direct effect on sediment transport [68]. As a result of RCP4.5 and RCP8.5 simulations, with the decrease in surface flows, changes in sediment transport occurred in accordance with hydrological transport processes (Figure 7). During the 2012–2030 time period, sediment yield in the basin for the RCP4.5 and RCP8.5 climate change scenarios decreased by 55.73% and 50.71%, respectively.



(**a**)



(**b**)

Figure 7. Mean annual sediment yield (2012–2030) for RCP4.5 simulation (**a**) and RCP8.5 simulation (**b**).

3.4. Evaluation of BMPs

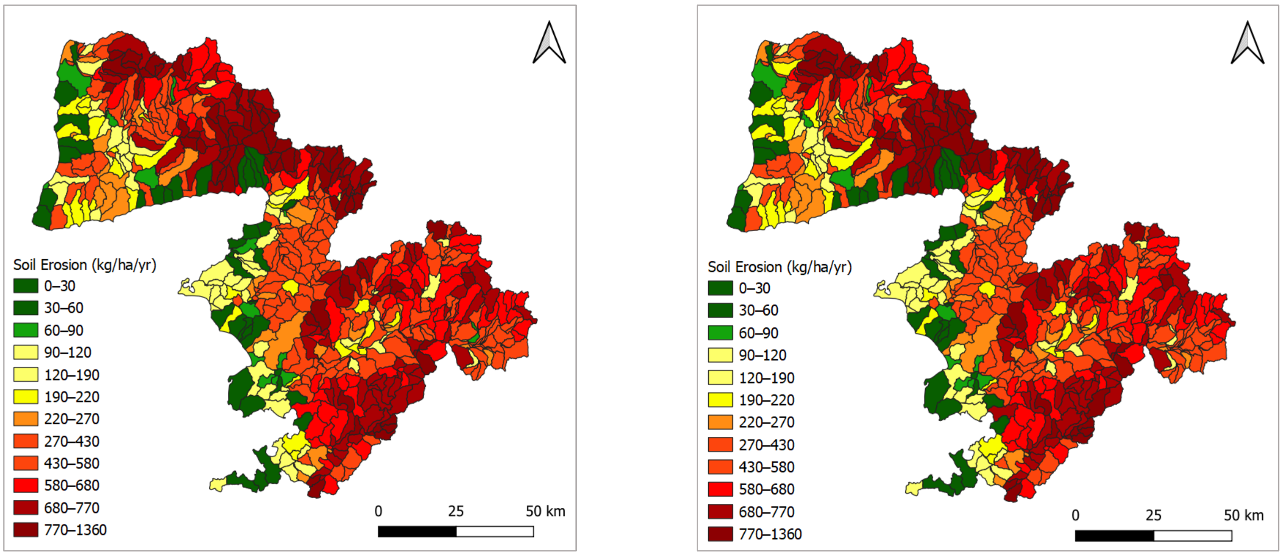
In order to reduce sediment loss in the North Aegean Basin and thus protect water resources, various soil-conservation practices were used in the present study. Developed management applications include zero tillage, vertical tillage, cover crop, and terracing methods. Soil-conservation practices were first applied to the baseline model simulation.

In the baseline model simulation, zero tillage application decreased the basin erosion by 0.71%, while the application of vertical tillage decreased it by 0.32%, cover crop use decreased it by 0.78%, and terracing application decreased it by 4.22% during the model study period. Thus, it has been seen that the use of cover crops and terracing are more effective for the basin in reducing erosion (Table 4). Then, these watershed management applications were tested under the climate change simulations of RCP4.5 and RCP8.5. Under the RCP4.5 scenario, the zero tillage application reduced the basin erosion by 1.16%, while the application of vertical tillage decreased it by 0.43%, cover crop use decreased it by 2.18%, and terracing application decreased it by 4.01%. Under the RCP8.5 scenario, the zero tillage application reduced the basin erosion by 1.12%, the vertical tillage decreased it by 0.40%, the cover crop use decreased it by 2.15% and the terracing application decreased it by 3.96%. As a result, it was seen that cover crop and terracing practices for both climate change simulations were more effective in reducing erosion than zero tillage and vertical tillage. Although some BMPs seem to be less effective on erosion corresponding to climate change impacts, increasing BMP application rates in the future has distinctive contributions to balancing erosion in the basins [69].

Table 4. Sediment yield reduction rates for BMPs in the North Aegean Basin in the 2012–2030 time period (for Baseline Model simulation, RCP4.5 simulation, and RCP8.5 simulation).

Soil-Conservation Practices	Baseline Model (%)	RCP4.5 (%)	RCP8.5 (%)
Zero tillage	−0.71	−1.16	−1.12
Vertical tillage	−0.32	−0.43	−0.40
Cover crop	−0.78	−2.18	−2.15
Terracing	−4.22	−4.01	−3.96

The use of cover crops and terracing practices, which have a greater effect on reducing erosion, were examined on a sub-basin basis. In the baseline model simulation, it was identified that the erosion reductions on the sub-basin basis for cover crop and terracing practices ranged from 0 to 21.14 kg/ha/yr and 0 to 8.17 kg/ha/yr, respectively (Figure 8). The areas with the least erosion are generally located in the western parts of the basin.

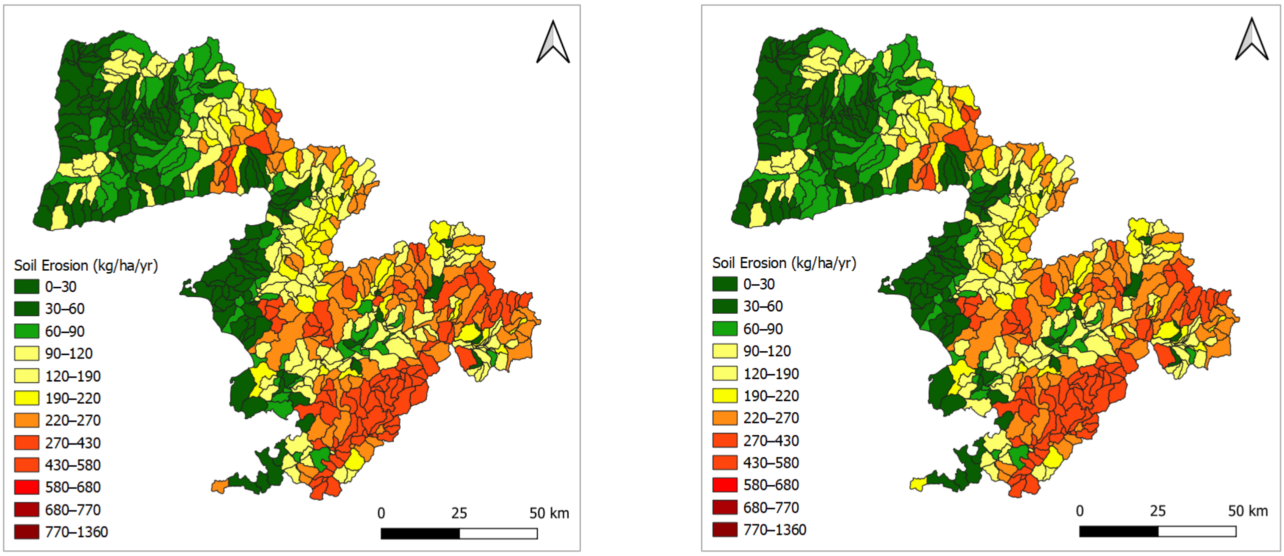


(**a**) (**b**)

Figure 8. Mean annual sediment yield (2012–2030) for cover crop (**a**) and terracing (**b**) practices applied to baseline model simulation.

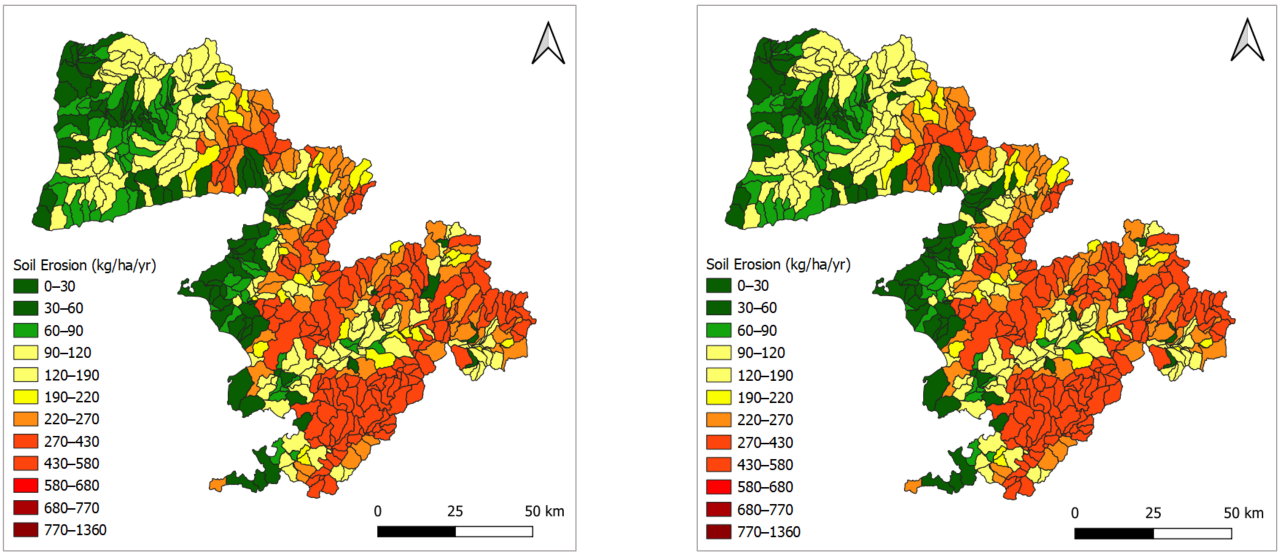
In the RCP4.5 climate change model simulation, the erosion reductions on the sub-basin basis cover crop and terracing practices ranged from 0 to 21.43 kg/ha/yr and 0 to 10.87 kg/ha/yr, respectively (Figure 9).

Finally, in the RCP8.5 climate change model simulation, the use of cover crops and terracing applications was evaluated on a sub-basin basis. It was determined that the erosion reductions on the sub-basin basis for cover crop and terracing practices ranged from 0 to 27.35 kg/ha/yr and 0 to 12.17 kg/ha/yr, respectively (Figure 10). The erosion reduction rates were obtained by considering the difference between the erosion after the implementation of the practices and the erosion in the baseline model simulation.



(**a**) (**b**)

Figure 9. Mean annual sediment yield (2012–2030) for cover crop (**a**) and terracing (**b**) practices applied to RCP4.5 simulation.



(**a**) (**b**)

Figure 10. Mean annual sediment yield (2012–2030) for cover crop (**a**) and terracing (**b**) practices applied to RCP8.5 simulation.

Sediment yields for water bodies such as reservoirs and lakes in the North Aegean Basin were also investigated in the basin. This analysis included a natural lake, 2 ponds, and 11 reservoirs which are used for various purposes such as drinking and utility water and industrial and irrigation water supplies [70]. Accordingly, the annual average sediment yields and reduction rates of soil-conservation practices were calculated for the baseline model simulation and climate change simulations. The selected water bodies and the sediment yield reduction rates of the soil-conservation practices are given in Table 5 for different simulations. It is inferred that cover crop and terracing practices reduce the average annual sediment yields to water resources between ‰0.06 and ‰7.23. As a result, the dam where the sediment yield decreased the most is Sevisler Dam with ‰7.23 (baseline model simulation with cover crop application), while the pond where the sediment yield decreased the most was Madra Dam with ‰5.62 (baseline model simulation with cover crop application). Moreover, Yukarikiriklar Pond with ‰5.47, Caltikoru Dam Lake with ‰3.51, Guzelhisar Dam with ‰1.54 and Kemerdere Pond with ‰1.28 are among the other water sources where the sediment yield has decreased.

Table 5. Sediment yield reduction rates (‰) for different simulations.

Water Body	Subbasin No	Baseline Model Simulation with S3	Baseline Model Simulation with S4	RCP4.5 Simulation with S3	RCP4.5 Simulation with S4	RCP8.5 Simulation with S3	RCP8.5 Simulation with S4
Boz Lake	92	...	−0.158	...	−0.126	...	−0.065
Yukarikiriklar Pond	147	−5.471	−0.363	−0.315	−0.643	−0.109	−0.714
Kemerdere Pond	262	...	−0.122	...	−1.280	...	−0.918
Kestel Dam	270	...	−0.514	...	−0.213	...	...
Guzelhisar Dam	367	−1.540	−0.406	−0.845	−0.703	−0.060	−0.321
Bayramic Dam	465	...	−0.319	...	−0.601	...	−0.308
Saribeyler Dam	526	...	−0.357	...	−0.512	...	−0.851
Kul Dam	546	...	−0.541	...	−0.461	...	−0.732
Havran Dam	568	...	−0.258	...	−0.234	...	−0.815
Ayvacik Dam Lake	617	...	−0.339	...	−1.023	...	−0.864
Yortanli Dam Lake	634	−0.758	−0.158	−0.296	−0.321	−0.837	−0.845
Madra Dam	643	−5.62	−0.236	−1.677	−0.614	−1.769	−0.741
Caltikoru Dam Lake	649	−3.51	−0.472	−2.619	−0.788	−3.057	−0.715
Sevisler Dam	657	−7.23	−0.412	−0.981	−0.956	−0.445	−0.868

4. Conclusions

In the presented study, the hydrological process and sediment yield of the North Aegean Basin were comprehensively investigated. The effects of climate change and agricultural practices on erosion were evaluated. As a result of the RCP4.5 and RCP8.5 scenarios, the flow amount in the basin decreased by 38.5% and 31.8%, respectively, and in parallel, the amount of sediment decreased by 55.7% and 50.7%. After determining the effects of climate change on erosion, various management application practices were developed which contain zero tillage, vertical tillage, cover crop use, and terracing. While all practices were effective in reducing basin erosion, particularly the use of cover crops (0.78% to 2.18%) and terracing (3.96% to 4.22%) showed the most effective reduction.

The present study demonstrated a useful modeling approach by testing management practices to reduce erosion. The study, which was prepared using a very large data set, evaluated the erosion status of the North Aegean Basin in the near future (until 2030), and also created erosion maps. The annual average sediment yields to major water resources of critical importance for the basin were also investigated. The effect of soil conservation practices on reducing sediment yield was investigated under baseline model simulation and climate change scenarios. It was determined that the annual average sediment yield to the selected water bodies decreased with the help of cover crops and terracing. It was also obtained that the highest decrease in the annual average sediment yield is for Sevisler Dam

(7.23‰), Yukarikiriklar Pond (5.47‰), Madra Dam (5.62‰), Caltikoru Dam Lake (3.51‰), Guzelhisar Dam (1.54‰), and Kemerdere Pond (1.28‰). On the other hand, since there are many large and small water resources in the North Aegean Basin, it is highly recommended that the placement of sediment measurement stations will provide high-performance basin erosion models in future works.

The development of best management practices is a very important issue for environmental governance. The results obtained will be a guide for decision-makers in the development of soil protection and management plans, the use of alternative agricultural practices, and the development of sustainable watershed management practices. Additionally, this study showed the usefulness of the SWAT in assessing the effects of climate change and soil conservation practices on watershed erosion. According to the results of the study, cover crop use and terracing applications are recommended for the North Aegean Basin since they perform more effectively than other protective soil applications in reducing basin erosion.

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