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Modelling Climate Change Impact on Soil Loss in Tokat

Saniye Demir[1,*], Halis Şimşek[2], Ersin Ersoy[3]

[1]*Department of Soil Science, Tokat Gaziosmanpasa University, Taşlıçiftlik, 61100, Turkey,*
[2]*Department of Agricultural & Biological Engineering, Purdue University, West Lafayette, IN, 47906, USA*
[3]*Department of Computer Engineering, Tokat Gaziosmanpasa University, Taşlıçiftlik, 61100, Turkey*

Abstract

Understanding the potential impact of climate change requires implementing effective planning strategies in hillside terrain and mountainous areas. Many studies have been carried out using erosion models in the Tokat region, much less with the WEPP model. Thus, keeping this in view, the study aims to estimate the possible impact of projected climate change scenarios on soil loss and erosion vulnerability using the Statistical Downscaling Model (SDSM), MarkSim Weather Generator, and Water Erosion Prediction Project (WEPP) model. The present study downscaled four climate scenarios on the near future, noted the 2020 s (2010), mid-future, 2035 s, and 2065, far-future, and 2095 s under GFLD-CM3 with four Representative Concentration Pathway (RCP), 2.5, 4.5, 6.5 and 8.5 scenarios. GFLD-CM3 and RCP scenarios predicted increased temperature and annual rainfall depth during the 21st century. The calibrated WEPP model was used to simulate future soil loss. The study's results showed a possibility for climate change to increase the rate of soil loss unless conservation strategies or proper land use plans are implemented.

Key Words: *WEPP, MarkSIM-DSSAT model, GFLD-CM3, RCP Model, Tokat*

Tokat Yöresinde Toprak Kayıpları Üzerine İklim Değişikliğinin Modellenmesi

Özet

İklim değişikliğinin olası etkilerini anlamak, yamaç arazileri ve dağlık bölgelerde etkili planlama stratejilerinin uygulanmasını gerektirir. Tokat bölgesinde erozyon modelleriyle birçok çalışma yapılmış olmasına rağmen, WEPP modeli ile çok daha az sayıda çalışma gerçekleştirilmiştir. Bu nedenle, bu çalışma, İstatistiksel Alan Küçültme Modeli (SDSM), MarkSim Hava Durumu Üreteci ve Su Erozyonu Tahmin Projesi (WEPP) modelini kullanarak projeksiyon senaryolarına dayalı olarak iklim değişikliğinin toprak kaybı ve erozyon hassasiyeti üzerindeki olası etkilerini tahmin etmeyi amaçlamaktadır. Çalışmada, GFLD-CM3 altında dört Temsili Konsantrasyon Yolu (RCP) senaryosu ile 2010, 2035, 2065 ve 2095 olmak üzere dört iklim senaryosu geleceğe yönelik olarak tahmin yapılmıştır. GFLD-CM3 ve RCP senaryoları, 21. yüzyılda sıcaklık artışı ve yıllık yağış derinliğinde bir artış öngörmüştür. Kalibre edilmiş WEPP modeli, gelecekteki toprak kaybını simüle etmek için kullanılmıştır. Çalışmanın sonuçlarına göre, gerekli koruma önlemleri ve uygun arazi kullanım planı yapılmadığı sürece, toprak kayıplarında belirgin bir artış söz konusu olduğu görülmüştür.

Anahtar Kelimeler: *WEPP, MarkSIM-DSSAT model, GFLD-CM3, RCP Model, Tokat*

Introcdution

Climatological analyses conducted in various regions of Turkey have revealed an upward trend in total precipitation and a shift towards more intense rainfall events over the past century (SWCS, 2003). Moreover, all general circulation models (GCMs) considered in the SWCS report project that global mean temperature, precipitation, and the intensity of precipitation events will increase in the future with increasing greenhouse gas concentrations (IPCC Working Group I, 2001; US NAS, 2001). The increasing frequency and intensity of extreme precipitation events demand more accurate simulation in soil erosion modeling. The most significant soil loss is often caused by infrequent, severe storms (Edwards and Owens, 1991). The projected changes in climate present a substantial risk of increased soil erosion and subsequent environmental impacts, the severity of which remains to be quantified (SWCS, 2003). This information is needed to determine (i) whether a change in soil and water conservation practices is necessary under a changing climate and (ii) what practices should be adopted to adequately protect soil and water resources if a change is necessary.

The effects of projected changes in precipitation, temperature, and CO_2 on crop yields have been assessed by many researchers (e.g., Rosenzweig and Parry, 1994; Semenov and Porter, 1995; Mearns et al., 1997; Mavromatis and Jones, 1998). These studies have considered both mean and variance changes in precipitation and temperature.

Some results have shown that changes in climate variability (measured by variance) can profoundly affect crop yields. It's important to consider not only the average changes in precipitation and temperature but also the changes in the variance of these climate parameters that can affect crop yields. Climate variability and changes in mean climate conditions are crucial for crop production. Understanding their impacts on agricultural systems is vital for adapting to climate change.
The effects of global climate change on soil erosion and surface runoff have been assessed considering changes in precipitation intensity or frequency. It has been assumed that changes in mean precipitation occur due to changes in storm frequency, storm intensity, or a combination of both (Favis-Mortlock vd., 1991; Boardman ve Favis-Mortlock, 1993; Savabi vd., 1993; Pruski ve Nearing, 2002a,b). Pruski ve Nearing (2002a). Researchers have decomposed changes in average rainfall into components attributable to changes in storm frequency, storm intensity, or both, enabling them to compare the effects of varying storm characteristics. They found that changes in precipitation amount and intensity have a much greater impact on soil erosion and runoff production than changes in storm frequency. Specifically, a 1% change in precipitation that accounted for all changes in precipitation amount and intensity resulted in an average of 2.4% soil loss and 2.5% change in runoff. However, when changes in storm frequency alone explained all changes in precipitation, it led to only 0.9% soil erosion and 1.3% runoff change. Some other studies conducted in the US (Savabi et al., 1993) and the UK (Favis-Mortlock et al., 1991) have shown that a 1% rise in precipitation, caused only by changes in storm intensity, led to an average increase in soil erosion of 2-4%.
MarkSim is a significant climate scenario generation tool used to assess the impacts of climate change on agricultural production. This application is based on the widely used MarkSim stochastic climate model, developed by Jones and Thornton (2000; 2002). MarkSim can generate high-resolution (30 arc-seconds) climate scenarios for any region in the world. The model utilizes climate data from the global WorldClim dataset developed by Hijmans et al. (2005). The model's key features include powerful statistical methods for modeling daily and seasonal changes in climate variables such as precipitation and temperature. The ability to generate climate projections based on IPCC greenhouse gas emission scenarios (RCPs), direct data integration with the DSSAT crop modeling software, and a user-friendly web interface. Thanks to its comprehensive features, MarkSim emerges as a powerful tool for assessing the agricultural impacts of climate change, developing effective adaptation strategies, and conducting robust crop modeling.
This study assesses the impacts of climate change on agricultural production specifically in Tokat province. The study utilized the GFDL-CM3 general circulation model and RCP greenhouse gas emission scenarios in recent climate change experiments conducted by the Turkish State Meteorological Service. The GFDL-CM3 general circulation model has produced monthly climate projections for the Tokat region spanning the next 100 years. The RCP 2.5, 4.5, 6.5, and 8.5 scenarios, which represent a wide range of potential greenhouse gas emission pathways were utilized in this study.
The primary aim of the study is to assess the potential impacts of climate changes projected by the GFDL-CM3 model for the periods of the 2010s, 2035s, and 2065, 2095s on soil loss, in USLE-K parcel in Tokat province. The MarkSim climate scenario generator tool was used. MarkSim utilizes high-resolution climate data obtained from the WorldClim dataset to reflect both mean and variance changes in projected monthly precipitation and temperature variability into daily weather data.

Materials and Methods

Future Climate Scenarios

Daily weather data including solar radiation, precipitation, and temperature extremes was generated for the Tokat region using the MarkSim DSSAT model (http://gisweb.ciat.cgiar.org/MarkSimGCM/) with 1967-1995 as the reference period. The GFDL-CM3 model's 50 replications were averaged and a spatial resolution of 1.2587 × 2.5 (latitude × longitude) was used. The data was downloaded in DSSAT format for the years 2010, 2035, 2065, and 2095 under the RCP 2.6, 4.5, 6.0, and 8.5 scenarios. The weather data generated for the year 2010 based on the RCP 2.6, 4.5, 6.0, and 8.5 scenarios was used as a baseline for assessing the impacts of climate change in future years (2035, 2065, and 2095).

- The RCP 2.6 model represents a low greenhouse gas emissions scenario, aiming to stabilize atmospheric greenhouse gas concentrations at 450 ppm CO_2 equivalent by 2100. This scenario is projected to limit global temperature rise to 1.5-2 °C above pre-industrial levels. Due to less pronounced climate change impacts, it predicts a more stable and less uncertain precipitation pattern. (IPCC, 2013)
- RCP 4.5 represents a moderate greenhouse gas emissions scenario, projecting that greenhouse gas concentrations will reach approximately 650 ppm CO_2 equivalent by 2100. This scenario anticipates a global

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temperature rise of around 2 °C. While both increases and decreases in precipitation are possible, overall, a more variable climate is expected (IPCC, 2013).

- The RCP 6.0 scenario represents a high greenhouse gas emissions pathway, projecting that greenhouse gas concentrations will reach approximately 850 ppm CO_2 equivalent by 2100. This scenario anticipates a global temperature rise of 2-3 °C, leading to significant climate change impacts. Extreme weather events and irregular precipitation patterns are likely to increase, putting pressure on water resources (IPCC, 2013).
- The RCP 8.5 scenario represents a very high greenhouse gas emissions pathway, projecting that greenhouse gas concentrations will reach approximately 1370 ppm CO_2 equivalent by 2100. This scenario anticipates a global temperature rise of 4 °C or more, leading to severe climate change impacts. The frequency of extreme weather events, such as heavy precipitation and prolonged droughts is expected to increase, causing significant problems for ecosystems and water management. These scenarios are crucial for assessing the potential impacts of climate change and its consequences for precipitation and temperature patterns (IPCC, 2013).

The modified parameters were used as inputs for the CLIGEN (V5.111) model to generate 20-year daily weather datasets corresponding to each emissions scenario. A control simulation using unmodified reference parameters was also conducted to produce a baseline climate dataset.

Study Area

This research was carried out at the Middle Black Sea Transit Belt Agricultural Research Institute Directorate, which is situated 10 kilometers from Tokat province on the Research Tokat-Turhal highway. The study utilized three different slope land areas. The research parcels are located at the coordinates N 40.19°and E 36.92° The research site is located at an altitude of 601 meters above sea level. Tillage and weeding operations were carried out on the K plots in May, July, August, and October. The soil in plot A contains 25% sand and 45% clay and is classified as a clay texture. The Universal Soil Loss Equation (USLE) was applied to plots K, C, and P during the period 1975-1996. This study utilized the observed soil loss data from plot K for model calibration. No plants were grown on plot K, and the land was plowed parallel to the contour in May, July, August, and October.

Discussion and Conclusions

The table 1 presents the results of the analysis of both observed and projected rainfall data under various climate scenarios. The RCP 2.6 scenario indicates a decreasing trend in observed rainfall from the baseline year 2010 to the years 2035 and 2065 (Fig 2). However, a significant increase in rainfall observed in 2095. This situation could suggest that successful climate change policies can contribute to the restoration of the water cycle equilibrium. The RCP 4.5 scenario indicates a decreasing trend in rainfall from 2010 to 2035, followed by a significant increase in 2065. This increase suggests that extreme rainfall events may become more frequent due to changes in the climate system. However, the subsequent decrease in 2095 suggests that the impacts of climate change are complex and involve long-term uncertainties. The RCP 6.5 scenario indicates a decreasing trend in the observed data from 2010 to 2035. The increase in rainfall in 2065 suggests that rainfall patterns have significant variations as a result of climate change. The renewed decrease in 2095 highlights the long-term variability of climate conditions. The scenario's projection of the lowest rainfall in 2095 highlights the severe impacts of climate change and the pressure on water resources. This situation presents significant threats to agricultural productivity and water management.

Tablo 1. Projected precipitation using observed weather data of Tokat district for future years

Precipitation				
Years	Model 2.6	Model 4.5	Model 6.5	Model 8.5
2010	432.79	492.2	437.26	480.21
2035	420.2	455.4	422.67	443.8
2065	417.91	500.73	458.58	410.59
2095	495.17	460.09	425.02	367.52

It's concerning to see the continuous increase in average temperatures in Tokat province (Fig 2), as revealed by studies and future climate scenarios. The impact of climate change seems to be becoming more pronounced in the region, as indicated in Table 2. It's evident that events occurring in the ecosystem, such as the destruction of forest lands for construction and irresponsible irrigation of farmland, are contributing to this situation and negatively impacting air quality. It's crucial to address these issues to mitigate the effects of climate change in Tokat province

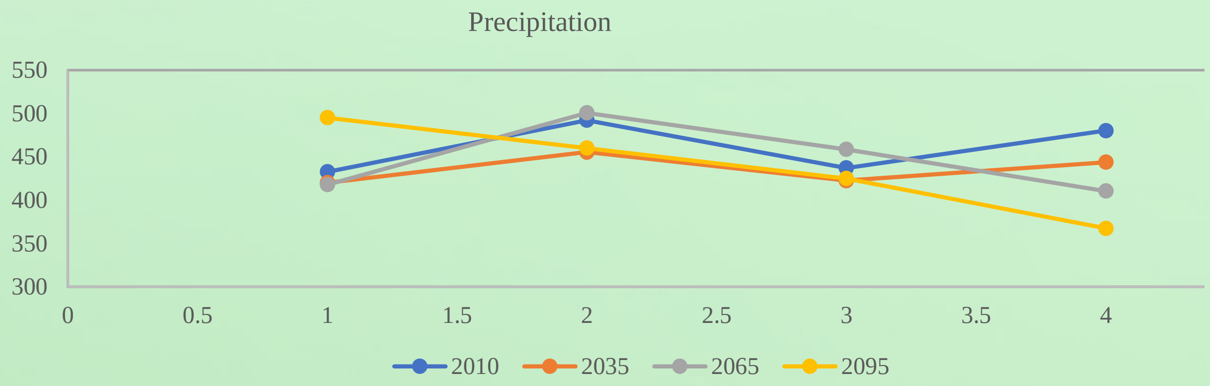

Figure 1. Impact of climate change on precipitation

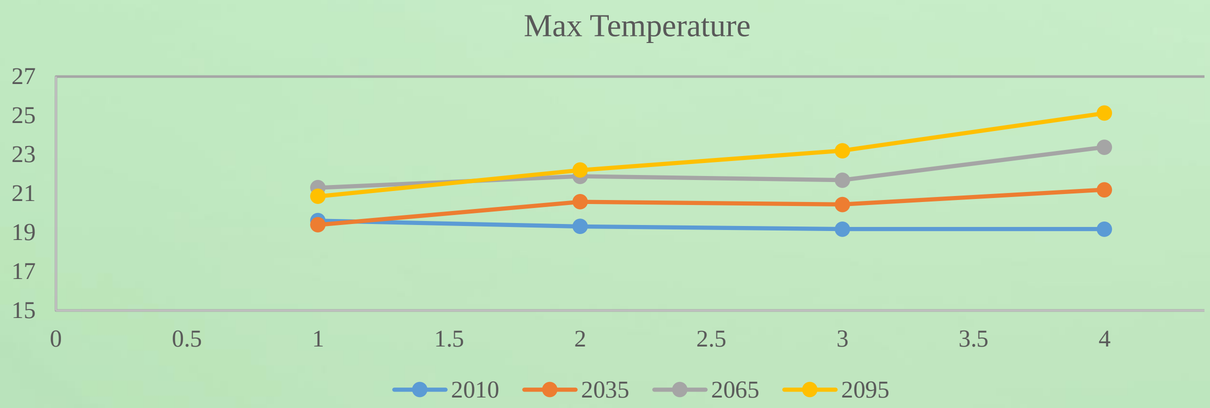

Figure 2. Impact of climate change on Max Temperature

Tablo 2. Projected Max Temperature using observed weather data of Tokat district for future years

Max Temperature				
Years	Model 2.6	Model 4.5	Model 6.5	Model 8.5
2010	19.6	19.31	19.17	19.17
2035	19.39	20.57	20.43	21.19
2065	21.29	21.88	21.68	23.37
2095	20.85	22.2	23.19	25.12

All models show notable increase in minimum temperatures throughout the study period (Table 3). This situation indicates that global warming is a problem for Tokat province too, leading to the projection of warmer winters in the future. Different climate models are based on varying assumptions about future greenhouse gas emissions and climate sensitivity. Therefore, every model presents a different scenario for temperature increase (Fig. 3). Model 8.5 projects a higher temperature increase compared to other models. This indicates that higher emission scenarios could lead to more severe consequences.

WEPP Model Results

The study utilized observed soil loss data for Tokat province between 1971 and 1995. The study used an uncalibrated WEPP Hillslope model to predict soil loss during this period. The obtained results are presented in Table 4 and the relationship between them is illustrated in Figure 4. The observed and predicted soil losses were found to be 0.639 and 1.359 kg/m², respectively. Although no soil loss was recorded in 1978, the model a prediction for that year. There is no observed or simulated soil loss data for both 1979 and 1990. When comparing the differences between observed and simulated data, it was found that the observed soil loss in 1975 (1.181 t/ha) was very close to the simulated value (1.36 t/ha). This indicates that the uncalibrated WEPP Hillslope model performed well in the initial years. However, the significant difference between the observed soil loss of 0.708 t/ha and the simulated value of 2.43 t/ha in 1981 suggests that the model was unable to adequately represent the actual conditions for that year. The maximum observed soil loss of 4.5666 t/ha and simulated value of 4.85 t/ha in 1983 for that year was quite accurate. These results demonstrate that the model accurately simulated the high soil loss for that year. In contrast, the measured soil loss in both 1984 and 1986 was significantly lower, at 0.6083 t/ha and 0.389 t/ha, respectively. This indicates that either effective soil conservation measures were being followed or the weather conditions were better during those years. Therefore, the simulated soil loss for the years 1985 and 1991 was higher than the observed values. The model overestimates soil loss ın some years, suggesting that its predictions may not accurately reflect the actual situation. Although observed data is missing for 1995, the simulated value of 1.38 t/ha suggests that significant soil loss may have occurred in that year.

Tablo 3. Projected Min. Temperature using observed weather data of Tokat district for future years

Minimum Temperature				
Years	Model 2.6	Model 4.5	Model 6.5	Model 8.5
2010	8.13	7.88	7.69	7.82
2035	7.9	8.94	8.77	9.27
2065	9.54	9.95	9.67	10.98
2095	9.25	9.99	10.73	12.29

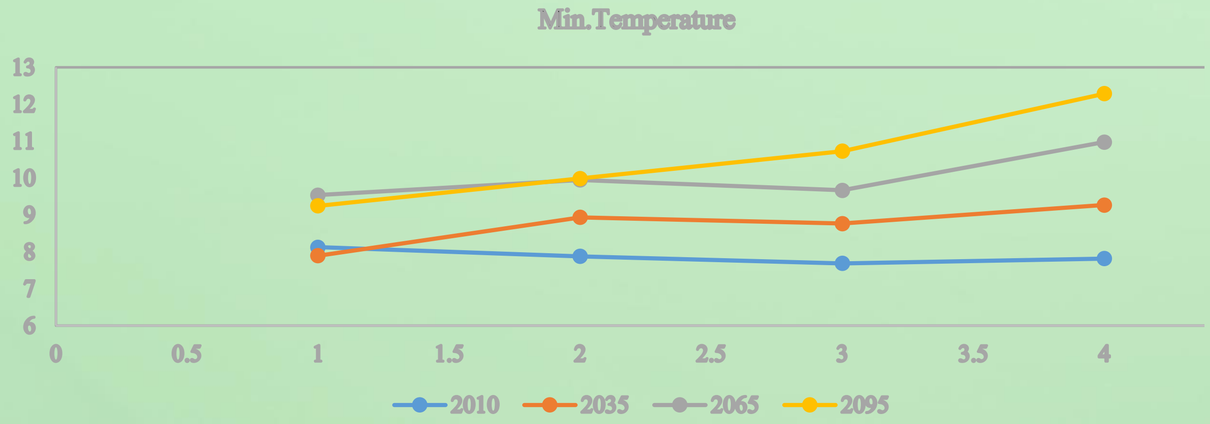

Figure 3. Impact of climate change on Min Temperature

Table 4. The uncalibrated WEPP Hillslope model results

Years	Observed Soil Loss	Uncalibrated WEPP Model Soil Loss
1975	1.181	1.36
1976	0.337	0.49
1977	0.553	0.62
1978	-	0.14
1979	-	-
1980	0.0007	0.32
1981	0.708	2.43
1982	0.0177	0.06
1983	4.5666	4.85
1984	0.6083	0.18
1985	0.1949	2.97
1986	0.389	0.04
1987	0.071014	0.1
1988	1.98119	3.34
1989	1.8986	3.56
1990	-	-
1991	0.12137	2.53
1992	0.12052	3.27
1993	0.2009	0.68
1994	0.46922	0.16
1995		1.38
Average	0.639	1.356

Figure 4 shows that the uncalibrated WEPP Hillslope model's estimates of soil loss are mostly consistent with the actual measurements, but there are significant differences at some points. The coefficient of determination was found to be 0.4685. This value indicates how well the model fits the observed data. An R^2 value below 0.5 indicates that the model is unable to establish a strong relationship between the variables, suggesting that the model's reliability is limited. An R^2 value below 0.5 indicates that the model cannot establish a strong relationship between the variables, meaning that the reliability of the model is limited.

Most of the points lie above the 1:1 line, indicating that the uncalibrated WEPP Hillslope model generally overestimates the observed soil loss. The model is especially overestimates low soil loss values and underestimates high soil loss values. These results are commonly observed for the uncalibrated WEPP Hillslope model. The hillslope is bare and has been plowed parallel to the contour. These findings indicates that the model has difficulty accurately representing the actual conditions, especially in erosion-prone conditions like these. It requires further development to better accommodate these unique conditions and improve the model's performance in these specific cases. Improving the model may require making structural changes, which could involve adding new parameters or adjusting existing ones. Furthermore, it is essential to calibrate the model's parameters to match the local conditions. The model's NSE value of 0.64 suggests that the model performs well, but there is potential for further improvement.

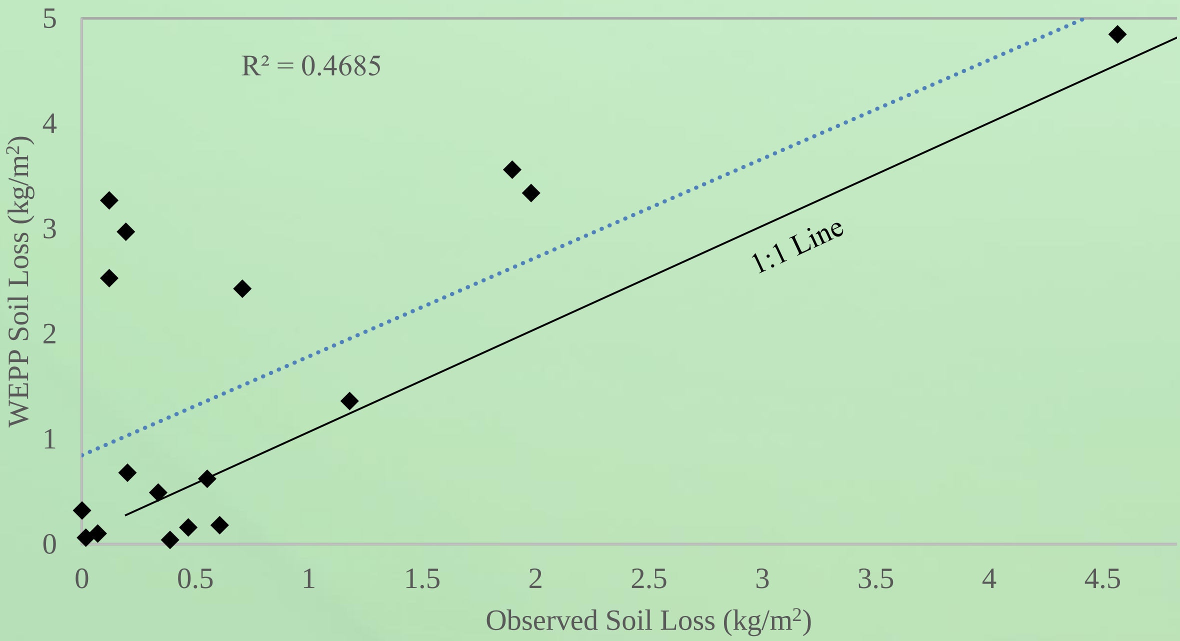

Figure 5. Comparison of Observed and Simulated Soil Loss Results

Evaluating Soil Loss with Future Climate Models

Climate files were generated using the GFLD-CM3 climate model under RCP 2.6, 4.5, 6.5, and 8.5 scenarios. The uncalibrated WEPP Hillslope model was utilized to predict soil erosion up to 2010, 2035, 2065, and 2095. The results are presented in Table 6. When Table 6 is examined, the lowest climate change severity is observed under the RCP 2.6 scenario. Soil loss remained constant from 2010 to 2035. However, it shows a significant increase in 2065 and 2095. This situation represents the impact of measures taken to address climate change and also indicates a long-term increase in soil erosion. However, a more moderate increase is observed compared to other scenarios. In the RCP 4.5 scenario, a slight decrease is observed from 2010 to 2035 (Fig 6). In 2065, there was a sudden increase of 2,614 kg/m². The impacts of climate change are becoming increasingly noticeable. A reduction in soil erosion is noticeable ın 2095 and this value is still above the 2010 level. The soil loss decreases from 2010 to 2035 and 2065 in the RCP 6.5 scenario. However, there was a significant increase again by 2095. These results indicate that the impact of the climate change process varies from year to year. In the RCP 8.5 scenario, there is a substantial decrease from 2010 to 2035. An increase was observed again in 2065. In 2095, there was a significant decrease in soil loss. The results indicate that the impacts of climate change are complex.

The risk of soil erosion can become very serious, particularly under medium and high emission scenarios (RCP 4.5 and RCP 8.5). Even under the low emission scenario (RCP 2.6), soil loss cannot be completely prevented in the long term. Therefore, it is crucial to consider soil management strategies in conjunction with emission control.

Table 6. Soil Loss Results from Future Climate Models

Years	Soil loss	
	Rate	Change
	kg/m²	%
	RCP 2.6	
2010	0.485	-24.1
2035	0.485	-24.1
2065	0.796	24.57
2095	0.878	37.4
	RCP 4.5	
2010	0.874	36.75
2035	0.846	32.4
2065	1.614	152.42
2095	1.445	126.12
	RCP 6.5	
2010	0.875	36.84
2035	0.862	-34.91
2065	0.817	27.86
2095	1.390	117.6
	RCP 8.5	
2010	1.171	83.27
2035	0.837	30.95
2065	1.178	84.34
2095	0.533	-16.62

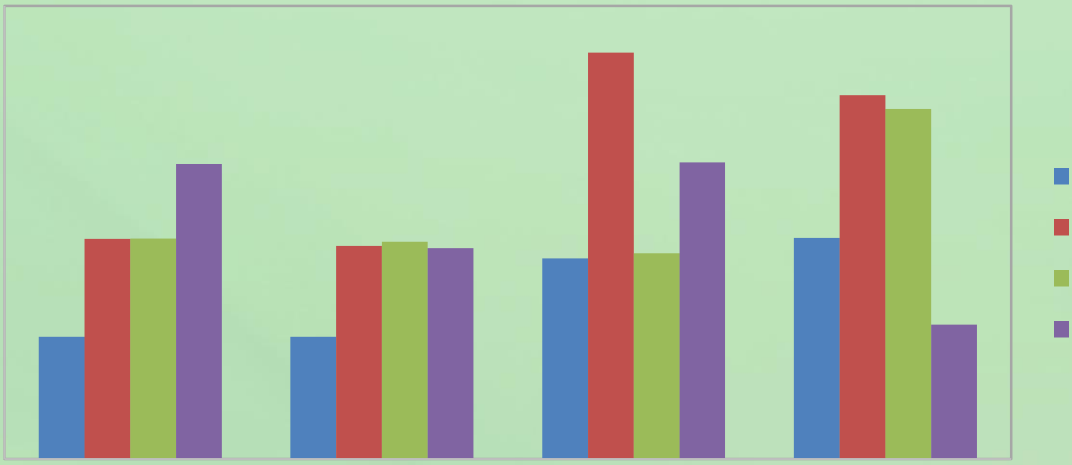

Figure 6. Relationship between Soil Loss and Climate Models

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