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Climate Change Effect on Soil Erosion in Vjosa River Basin

Oltion Marko[1], Konalsi Gjoka[1], Neritan Shkodrani[2], Joana Gjipalaj[1*]

[1] Department of Environmental Engineering, Faculty of Civil Engineering, Polytechnic University of Tirana, Rruga Muhamet Gjollesha No. 54, 1023, Tirana, Albania

[2] Department of Civil Engineering, Faculty of Civil Engineering, Polytechnic University of Tirana, Rruga Muhamet Gjollesha No. 54, 1023, Tirana, Albania

* Corresponding author's e-mail: joana.gjipalaj@fin.edu.al

ABSTRACT
Soil erosion is closely related to climate changes, because changes to temperature and precipitation regimes may alter the erosivity of rainfall. The present study aimed to project future soil erosion phenomena in the Vjosa River Basin (VRB) using climate projections under the Representative Concentrations Pathway (RCP) 4.5 and 8.5 scenarios. SimCLIM model was used to perform the climate projection for the years 2035 and 2050, based on historical temperature and precipitation data (2000–2015). This investigation was carried out by using Erosion Potential Method EPM to estimate the effects of climate change on soil erosion in Vjosa River Basin, Albania. Results show an increase in average min and max annual temperature for both scenarios RCP4.5 and 8.5 by the end of 2050. The evaluation of the monthly precipitations for all RCPs reveals a likely decrease in summer precipitation, and a slight positive trend of winter precipitation for all time periods up to 2050. An increase in terms of eroded material and specific eroded material was estimated from the results of RCP4.5 and RCP8.5 scenarios. Thus, it can be stated that the study area has and will have a moderate erosion risk under these climate conditions.

Keywords: climate change, RCP4.5, RCP8.5, Vjosa river basin, erosion potential method (EPM), soil erosion.

INTRODUCTION

Soil erosion phenomena can occur naturally or by different factors depending on human activity [Mohammed et al. 2020; Zhao et al. 2019; Rothacker et al. 2018]. Among the many factors affecting soil erosion in watersheds, the rainfall intensity, temperature, land use and climate changes are listed as the most important ones. Nowadays, climate change is considered as a very important factor with a high relevance in erosion when taking into consideration the future estimated climate developments [Eekhout et al. 2022; Belay et al. 2021; Borrelli et al. 2020; Wang et al. 2018]. These changes can interfere with the quantity and intensity of rainfalls, directly interacting with watershed erosion [Chen et al. 2020]. This can lead to severe erosion in some areas and in a decrease of the phenomena in others. Sediment yields as a result of erosion can affect rivers basins, flow rate, crop productivity and flood prevention safety [Issaka et al. 2017; Lal et al. 2008]. Thus, an estimation of soil erosion in watersheds taking into consideration actual and future climate changes would be of great interest in order to prevent the phenomena. Regardless which scenario is the most accurate, climate changes are expected to highly interfere with erosion. Many authors have been using different methods to perform such estimation in various countries. The Soil and Water Assessment Tool (SWAT) [M'Barek et al. 2021] is one of the most used methods to estimate the effects of climate change in erosion in a watershed. Other methods, such as Universal Soil Loss Equation (USLE) [Wischmeier et al. 1965], Modified Universal Soil Loss Equation (MUSLE) [Williams et al. 1975], Physiographic Soil Erosion-Deposition (PSED) [Chen et al. 2006], Revised Universal Soil Loss Equation (RUSLE) [Renard et al. 1991], can be used for this purpose. Another method used for the estimation of soil erosion in relation with climate changes is the Erosion Potential Method (EPM) [Stefandis et al. 2018].

In Albania, EPM has been previously used to estimate the erosion phenomena in some areas of the country [Marko et al. 2022], but to the best of the author's knowledge, there are no investigations using the EPM to estimate the soil erosion caused by climate changes.

In this study, the investigation of the effect of climate change on soil erosion in the Vjosa river basin was done using the 'Representative Concentration Pathways' (RCP4.5 and 8.5) scenarios. The Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emission) trajectories adopted by the IPCC for its Fifth Assessment Report (AR5). The four RCPs, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 (of 2.6, 4.5, 6.0, and 8.5 W/m^2, respectively)

MATERIALS AND METHODS

Study area

Flowing from the Pindos mountains in Greece and discharging in the southern Albania, the Vjosa river represents one of the longest transboundary rivers in the Balkan area with a total length of 272 km; 80km of Vjosa are located in Greek territory, where it is known as the Aoös (Αώος) River and the other part in Albania. Its basin is calculated to be approximately 6500 km^2, classified as the second largest river basin in Albania. Moreover, Vjosa is one of the last wild and free flowing rivers in Europe (ref). Shushica, Drino and Bënça are the most important tributaries of the Vjosa River. VRB has a mean elevation of about 855 m a.s.l and a perimeter of about 906.13 km. Furthermore, the Vjosa river has a high biodiversity importance, since it is the natural habitat for many species.

Methodology

Climate simulation

Scenarios RCP4.5 and RCP8.5 are developed by using SimCLIM4.0 model, where an ensemble of 63 General Circulation Models (GCMs) was used to generate the temperature changes for each RCP, while for the generation of the projections of precipitations an ensemble of 40 GCMs was used.

The historical data were derived by the nearest meteorological stations in the study area with available temperature (t, °C) and precipitation (h, mm) data, respectively Brataj, Frataj, Kelcyre, Krahes, Kuc, Llongo, Permet, Polican, Selenice, and Tepelene.

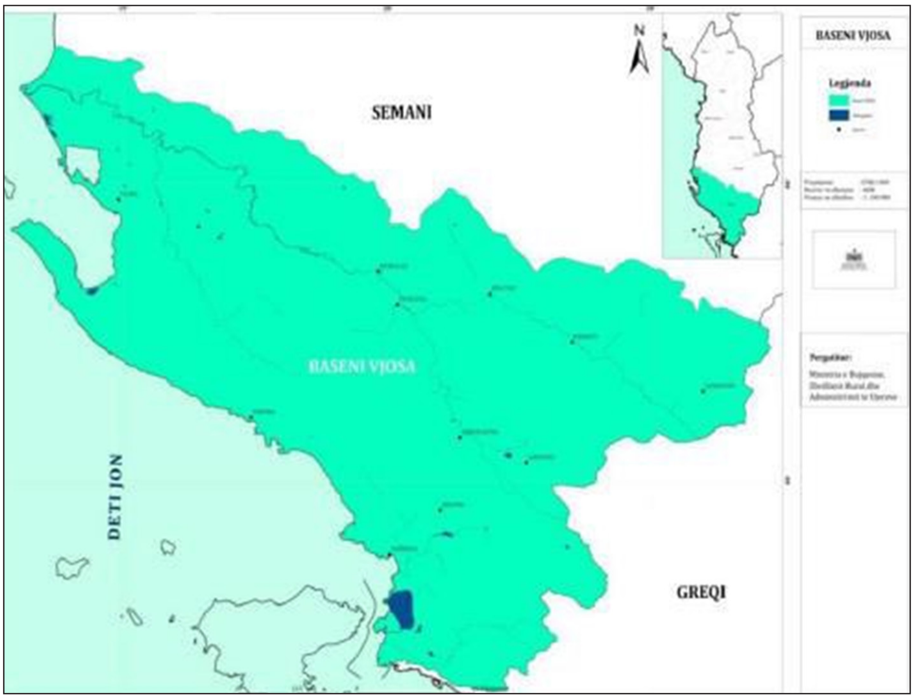


Figure 1. Location of the Vjosa River Basin, Albania

The erosion potential model EPM

In 1972, Gavrilovic designed a semi-quantitative method to evaluate the erosion coefficient in order to estimate the sediment production and transportation [Gavrilovic, 1988].

The erosion potential model has been used firstly in the Balkan area followed by other countries in Europe and in other continents [Marko et al. 2022; Gocic et al. 2020; Tazioli 2009; Emmanouloudis et al. 2003; Stefanidis et al. 2018; Lense et al. 2019; Maliqi et al. 2019]. Parameters, such as the temperature coefficient, the actual sediment yield, sediment delivery ratio and the annual volume of soil loss, were calculated according to the Gavrilovic method. In order to evaluate the land use coefficient, soil erodibility and active erosion processes, the classification was based on the Zemljic system [Zemljic, 1971].

The equations followed by detailed description of the data set used to evaluate the Erosion Potential Method are shown in Table 2.

Data description and sources

Information gathered from different field surveys and satellite sources were used for the estimation of soil erosion in the Vjosa River Basin.

The CORINE Land Cover (2018) map was used for the evaluation of the land cover coefficient x (data in Table 1). The slope map of the Vjosa River Basin generated by a Digital Elevation Model (DEM) was used to evaluate the mean slope of each sub-basin i_m. The coefficient of soil erodibility (y) of the studied area was determined from Geological maps of the Albanian Geological Service.

Table 1. Descriptive variables used in the Erosion Potential Model (EPM). Classification based on Zemljic (1971)

Coefficient of land cover	x
Mixed and dense forest	0.05–0.20
Thin forest with grove	0.05–0.20
Coniferous forest with little grove, scarce bushes, bushy prairie	0.20–0.40
Damaged forest and bushes, pasture	0.40–0.60
Damaged pasture and cultivated land	0.60–0.80
Areas without vegetal cover	0.80–1.00
Coefficient of soil erodibility	y
Hard rock, erosion resistant	0.2–0.6
Rock with moderate erosion resistance	0.6–1.0
Weak rock, schistose, stabilized	1.0–1.3
Sediments, moraines, clay and other rock with little resistance	1.3–1.8
Fine sediments and soils without erosion resistance	1.8–2.0
Coefficient of type and extent of erosion	ϕ
Little erosion on catchment	0.1–0.2
Erosion in water ways on 20 to 50% of the catchment area	0.3–0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6–0.7
50 to 80% of catchment affected by surface erosion and land slides	0.8–0.9
Whole catchment affected by erosion	0.9–1.0

Table 2. Equations and descriptive variables used in the Erosion Potential Model (EPM)

Equation		Parameters description
1	$W = \pi \times S \times T \times h \times \sqrt{Z^3}$	W – the annual volume of soil loss (m^3/year) S – the sub-basin area (km^2) T – the temperature coefficient (-) h – the mean annual precipitation (mm) Z – the erosion coefficient (-)
2	$T = \sqrt{\frac{t}{10} + 0.1}$	t – the mean annual temperature (°C)
3	$Z = x \times y \times (\varphi + \sqrt{i_m})$	x – land cover coefficient y – soil erodibility φ – active erosion processes im – the mean slope (%)

RESULTS AND DISCUSSION

Analysis of the Vjosa River Basin land cover map (Figure 2a) showed that the entire surface contains mixed and coniferous forest, agriculture crops, pastures, olive groves, vineyards, irrigated and non-irrigated lands, etc. Moreover, the Vjosa River Basin has high ecological values due to the diversity of areas part of it, and to the presence of rare flora species. The coefficient of land cover for VRB was determined based on the data of Table 1.

Regarding the slope of the study area it was generated by a Digital Elevation Model (DEM), and it was found that it varies from 2% to 28%. The higher slope belongs to the upper part of the VRB, while the low slope to the lower part of the VRB.

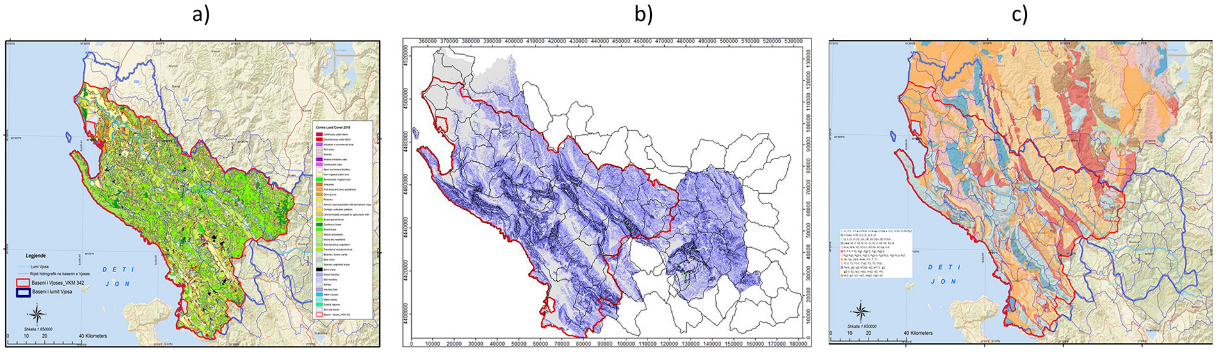


Figure 2. Land cover map (a), slope mean in percentage (b), and geological map (c) of the Vjosa River Basin

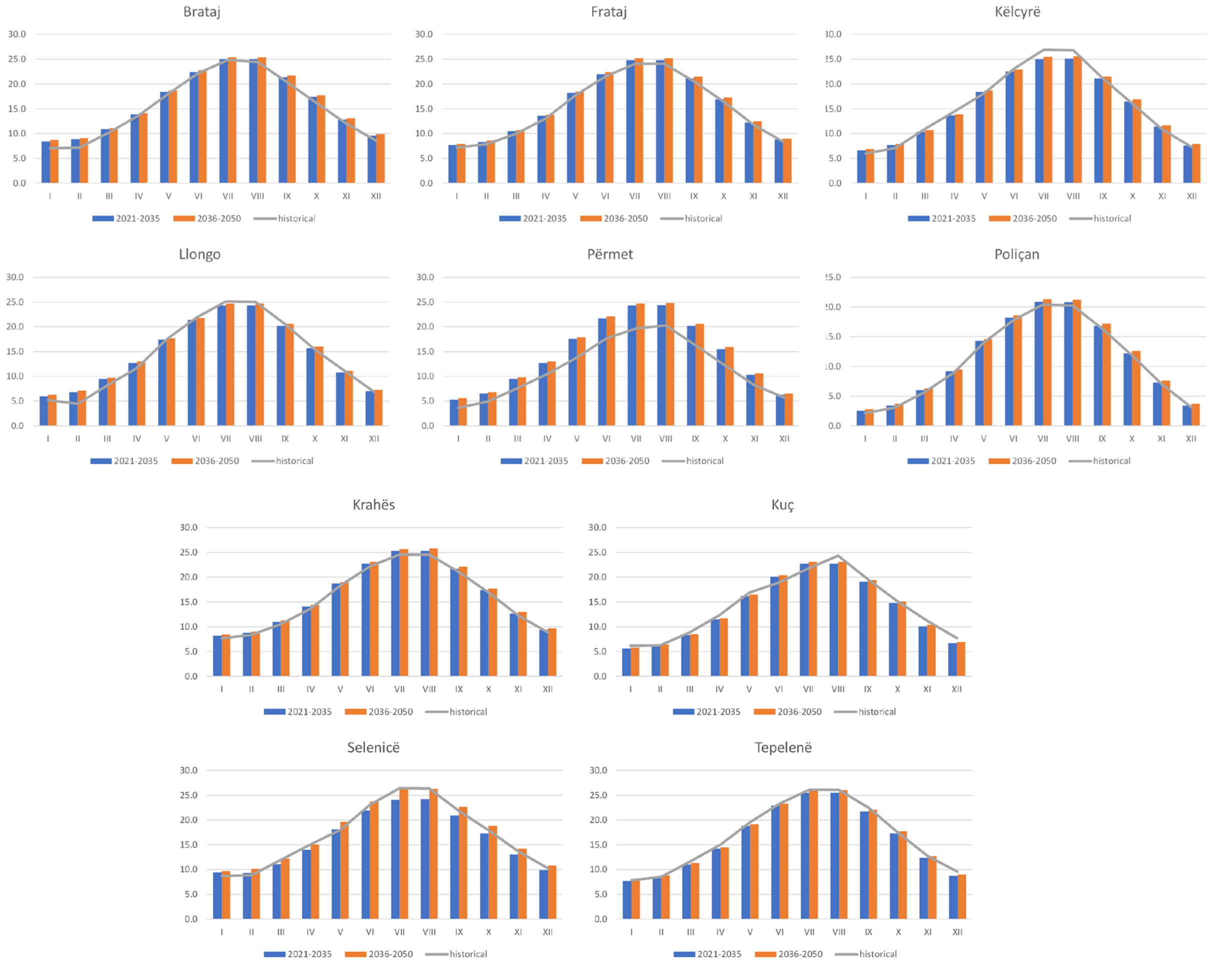


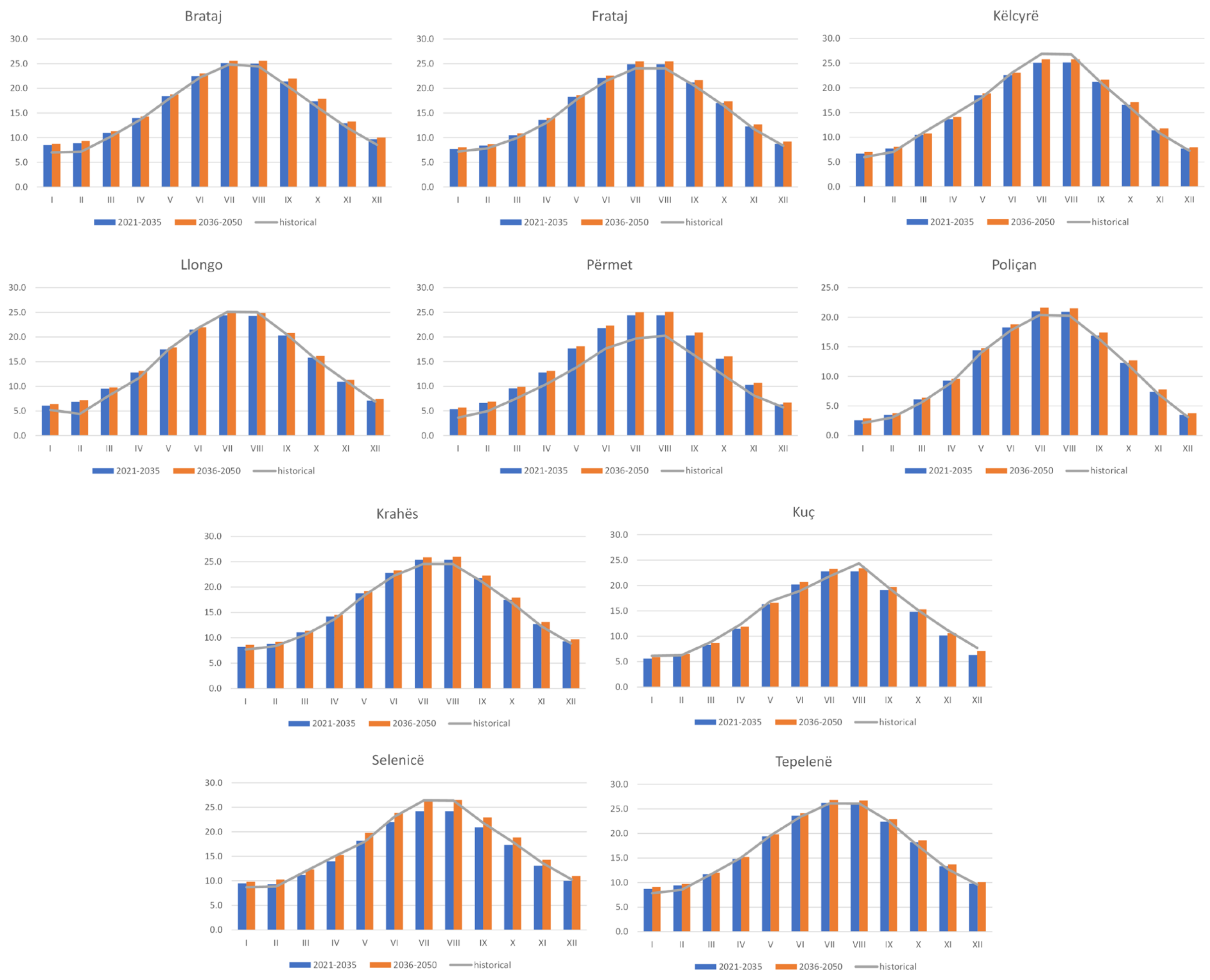
Figure 3. RCP4.5 scenario in all meteorological stations of the Vjosa River Basin: Comparison of average monthly temperatures between historical data and simulated data for the periods 2020–2035 and 2036–2050

The major part of the geology of the Vjosa River Basin belongs to the Ionian zone, which mainly consists in Neocene's deposits (sandstone, siltstone, conglomerate and partly marlstone), Flysch deposits, Karstic calcareous deposits, and ultrabasic rock [Schiemer et al. 2018]. The maps of land cover, slope and geology of the study area are given in Figure 2.

The climate of the VRB was evaluated in terms of temperature (°C) and precipitation (mm) based in two scenarios RCP4.5 and RCP8.5 for the periods 2020–2035 and 2036–2050. The results obtained from the SimCLIM4.0 model shows the expected changes in monthly temperature and precipitations for all stations and scenarios. Figures 3–6 show the comparison of these results with the data of the historical period (2000–2015).

As it can be seen from the graphs the RCP4.5 scenario projects, there is an increase in average monthly temperatures by 2050 at almost all stations of VRB. Figure 3 shows clearly not only the increase of temperature compared to the historical period but also the increase of these values from 2035 to 2050. Permet station has the most significant change on average monthly temperatures for all seasons for the periods 2020–2035 and 2036–2050. The analysis highlighted an increase in average min annual temperature of (+0.5 °C) by 2035, and (+0.8 °C) by 2050. The average max annual temperature is expected to increase (+0.6 °C) by the end of 2050.

A similar increase in average monthly temperatures by 2050 at almost all stations of VRB is projected for the RCP8.5 scenario. Figure 4 shows the increase of average monthly temperature for the periods 2020–2035 and 2036–2050 compared to the historical data. Even in this projection, Permet station shows the most significant change on average monthly temperatures for all seasons. The analysis highlights an increase in average min annual temperature of (+0.7 °C) by


Brataj

Frataj

Këlcyrë

Llongo

Përmet

Poliçan

Krahës

Kuç

Selenicë

Tepelenë

Figure 4. RCP8.5 scenario in all meteorological stations of the Vjosa River Basin: Comparison of average monthly temperatures between historical data and simulated data for the periods 2020–2035 and 2036–2050

Figure 5. RCP4.5 scenario in all meteorological stations of the Vjosa River Basin: Comparison of average monthly precipitations between historical data and simulated data for the periods 2020–2035 and 2036–2050

2035, and (+1.0 °C) by 2050. The average max annual temperature is expected to increase with (+0.2 °C) by the end of 2035 and (+0.9 °C) by the end of 2050.

The evaluation of the monthly precipitations for all RCPs reveals a likely decrease in seasonal (summer months) precipitation relative to the 2000–2015 period for all time horizons up to 2050.

In general, RCP4.5 and RCP8.5 project a slight positive trend of winter precipitation for all time periods up to 2050 as it is shown in Figure 5 and 6, respectively. These positive trends may be attributed to higher winter temperatures, resulting in more rainfall than snow.

On the basis of the results and parameters of Vjosa river basin presented above, the EPM method was used for the estimation of the erosion coefficient, the amount of eroded sediment (m^3/year), and the specific eroded sediment (m^3/ha/year) for the baseline (2000–2015) and future (2020–2035 and 2036–2050) periods, for the RCP4.5 and 8.5 scenarios.

Table 3 presents the results obtained for Vjosa River Basin from the calculations made according the Erosion Potential Method, where the results about the specific eroded sediment were obtained as a report of eroded material and the surface of the VRB expressed in ha.

The results obtained from the use of the EPM model were compared between them in order to quantify the effects of climate change on soil erosion in the Vjosa River Basin. For both scenarios, RCP4.5 and RCP8.5, an increase in terms of eroded material and specific eroded material can be noticed. Specifically, the RCP4.5 scenario projects an increase of 510 m^3/year by 2035, and 547.4 m^3/year by 2050, while the increase of the specific eroded sediment is expected to be 0.79 m^3/ha/year by 2035 and 0.85 m^3/ha/year by 2050.

Regarding the RCP8.5 scenario, the projection shows an increase of 508.8 m^3/year by 2035, and 540.5 m^3/year by 2050, while the increase of the specific eroded sediment is expected to be

Figure 6. RCP8.5 scenario in all meteorological stations of the Vjosa River Basin: Comparison of average monthly precipitations between historical data and simulated data for the periods 2020–2035 and 2036–2050

0.79 m^3/ha/year by 2035 and 0.84 m^3/ha/year by 2050. On the basis of the values of the specific eroded sediment it can be stated that the study area has and will have a moderate erosion risk under these climate conditions.

It is evident that the increase trends are similar in all projections RCPs and periods, with slight differences due to temperature and precipitation changes. Moreover, climate changes affect even other characteristics of the study area which are related to the data set used for this evaluation.

Table 3. Results of the EPM method for baseline and future climate conditions (RCP4.5 and RCP8.5) at the Vjosa River Basin

Scenarios	Period	*W* (m^3/year)	*E* (m^3/ha/yr)
	2020	3,976,382	6.14
RCP4.5	2035	4,486,407	6.93
	2050	4,523,731	6.99
RCP8.5	2035	4,485,136	6.93
	2050	4,516,896	6.98

CONCLUSIONS

This investigation has been carried out as the first study using Erosion Potential Method EPM to estimate the effects of climate change on soil erosion in the Vjosa River Basin, Albania. On the basis of historical temperature and precipitation data (2000–2015), the climate projection for the years 2035, and 2050 under RCP4.5 and RCP8.5 scenarios, was performed using SimCLIM model. It was found that all scenarios for the Vjosa River basin suggest that the area is likely to become warmer. The results for RCP4.5 scenario show an increase in average min annual temperature of (+0.8 °C) by 2050, and the average max annual temperature is expected to increase by (+0.6 °C) by the end of 2050.

In turn, the results for RCP8.5 scenario show an increase of (+1.0 °C) by 2050 in average min annual temperature, and (+0.9 °C) by the end of 2050 in the average max annual temperature.

The evaluation of the monthly precipitations for all RCPs reveals a likely decrease in summer precipitation, and a slight positive trend of winter precipitation relative to the 2000–2015 period for all time periods up to 2050.

For both scenarios, RCP4.5 and RCP8.5, an increase in terms of eroded material and specific eroded material was estimated. Specifically, RCP4.5 scenario projects an increase of 547.4 m^3/year and 0.85 m^3/ha/year by the end of 2050.

Regarding the RCP8.5 scenario, the projection shows an increase of 540.5 m^3/year 0.84 m^3/ha/year by the end of 2050. On the basis of the values of the specific eroded sediment, it can be stated that the study area has and will have a moderate erosion risk under this climate conditions.

Finally, considering these results it can be stated that more investigations of the effect of climate change on other areas are necessary for adaption and mitigation measures.

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