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Modeling the Impact of Climate Change on the Hydrology of Eurotas Basin †

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Abstract: Climate change (CC) has altered the hydrological cycle, mainly due to changes in temperature and precipitation, leading indirectly to regional water shortage issues, especially in the Mediterranean areas. The objective of this work was the investigation of the CC impact on water resources. Hydrological simulations under several CC scenarios were performed for the Vivari subbasin, located in the Eurotas river basin, Peloponnese, Greece. The analysis was carried out by applying the Thomas ABCD water balance model on a monthly basis, initially for the period between 2005 and 2009, to calibrate the model using available runoff measurements. Then, CC scenarios were incorporated into the model and the results are presented indicatively for three periods: a historic period (1970–2000), which was used as the reference period for comparisons; and two future periods: 2031–2060 and 2061–2090. Simulations for the three periods were based on freely available monthly precipitation and temperature timeseries, which were provided by the Data Extraction Application for Regional Climate (DEAR-Clima) web application tool. Results regarding average values, trends, and other statistics for monthly runoff are provided for the three periods and for several scenarios.

Keywords: climate change; ABCD water balance model; water shortage; runoff; Eurotas

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1. Introduction

Climate change (CC) is a global phenomenon, which effect has a significant impact on water resources and aquatic ecosystems. The system complexity is linked to the fact that, despite recent advances in climate change science, great uncertainty remains as to how and when climate will change and how these changes will affect the supply and demand for water at the river basin and watershed levels, which are of most interest to planners [1]. To deal with this uncertainty, in the frame of long-term integrated water resources management, it is of high significance to perform simulations regarding the hydrological conditions of watersheds in a changing climate. Generally, hydrologic modeling has become an indispensable tool for the assessment, management, and use of water resources and, for hydrologists, such models are especially useful in the evaluation of assumptions and theories about the dominant hydrologic processes in a basin [2], especially when hydrological modeling is combined with CC scenarios. This work therefore aims to study the hydrologic regime of one subbasin in Eurotas Basin, namely Vivari (Figure 1), using the Thomas ABCD hydrologic model (Figure 2). Eurotas Basin is a complex environment from a hydrogeological and geomorphological perspective [3,4], and it is located in Peloponnese, a particularly dry area in Greece for which most CC scenarios indicate positive trends in future temperature and reductions in precipitation. At the same time, this work intends to illustrate the different estimates for the future hydrologic regime in relation to the investigated CC scenario. This study mainly focuses on establishing deviations in the values of estimated runoff in comparison with those already observed.

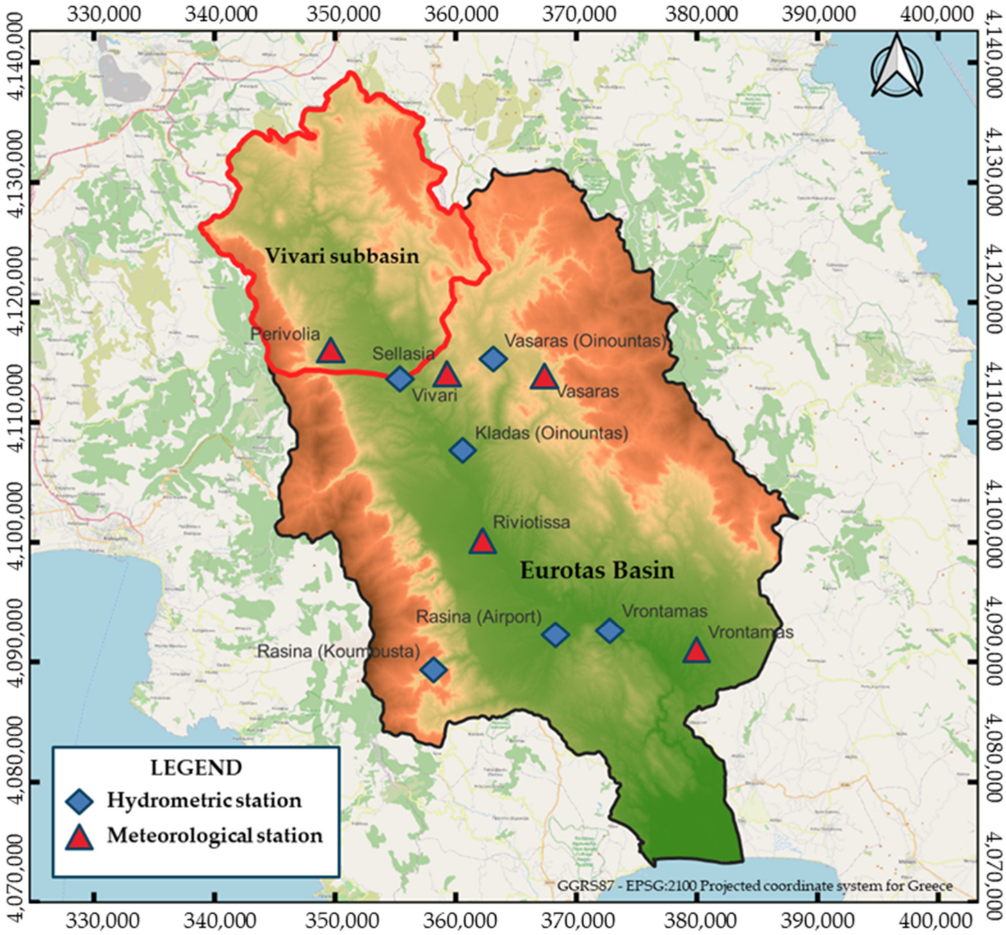

Figure 1. Study area map.

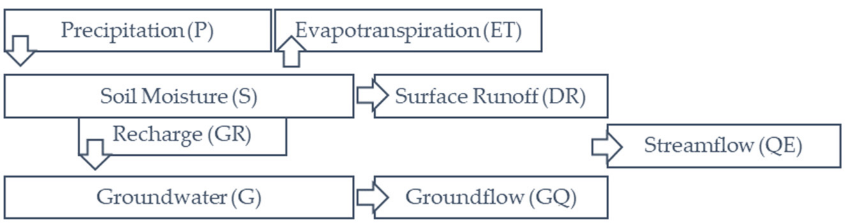

Figure 2. Streamflow simulation by Thomas (1981)—ABCD model (Source: [5], with modifications).

2. Study Area and Datasets

2.1. Eurotas Basin

The catchment area of the Eurotas river is located in the southern part of the prefecture of Peloponnese (Figure 1). The river is 90 km long and passes through the Taygetus and Parnonas mountains. Then, it passes through Sparta and ends up in the Laconian Gulf, where it finally forms a delta, being one of the most important water habitats in Southern Greece. The importance of the delta is profound as it belongs to the Natura 2000, the largest network of protected areas in the world. The local water resources of Eurotas Basin are of great value for the wider region as they provide water to settlements, irrigate the largest part of the agricultural land, and support other activities [6]. Most of the watershed administratively belongs to the prefecture of Laconia and a small part to the prefecture of Arcadia. The total area of the Eurotas basin is around 2418 km^2, of which 371.48 km^2

corresponds to the study area, the subbasin of Vivari in the NW. This area has an average altitude of 562 m and an average surface slope equal to 19%, and there are several stations operating since 2005 that provide daily data.

2.2. Timeseries

In Vivari subbasin, there is one hydrometric station operating in the outlet, for which the available monthly rainfall data for the period of 2005–2009 were used, as provided by Marinou et al. [5]. This dataset was used for the calibration of the Thomas ABCD model. Further analysis regarding a wider historic period and for several CC scenarios was performed after using timeseries of the EURO-CORDEX program [7,8]. Under the same framework, the GEO-CRADLE [9] project supports the Data Sharing Authority, through which the web was developed, which facilitates the access of interested users to climate change data. The application provides climate data and time series from simulations made using CORDEX. The latter is a program funded by the World Climate Research Program (WRCP), which aims to have a framework to produce regional climate change projections covering all land areas of the world. The simulations are products derived from Regional Climate Models (RCMs) driven by Global Climate Models (GCMs). The RCM covering the regions of Europe has a spatial resolution of 0.11 and is provided for the period from 1950 to 2100. The historical data refer to the time period of 1950–2004 and future data up to 2100. Timeseries for the study area (longitude: 36.82°, latitude: 22.68°) were downloaded from the "DEAR-Clima" application [10], which performs an online downscaling technique to provide the timeseries in the point of interest. Timeseries for precipitation and temperature were analyzed for both periods monthly for all combinations (scenarios) among the models recorded in Table 1.

Table 1. List of RCM and GCM models used.

Regional Climate Model (RCM)	Global Climate Model (GCM)
CLMcom-CCLM4-8-17	CNRM-CERFACS-CNRM-CM5
CNRM-ALADIN53	MOHC-HadGEM2-ES
SMHI-RCA4	MPI-M-MPI-ESM-LR
KNMI-RACMO22E	
IPSL-INERIS-WRF331F	
MPI-CSC-REMO2009	
CLMcom-CCLM4-8-17	
CNRM-ALADIN53	

In the context of the work, for the historical period, the time period from 1 October 1970 to 1 September 2000 was chosen as the thirty-year reference period. The future period was divided into two parts: (i) the first one concerns the time period from 1 October 2030 to 1 September 2060 and (ii) the 2nd starts from 1 October 2060 to 1 September 2090. Each period corresponds to 30 hydrological years, and for each of them, the runoff was calculated for two CC scenarios: (i) the RCP4.5 as the moderate one and (ii) the RCP8.5, which corresponds to adverse conditions.

3. Methodology

The present work was based on the application of the Thomas ABCD water balance model [11,12], which is schematically presented in Figure 2. The model was initially applied using the available historical data of monthly precipitation, temperature, and runoff for a four-hydrological-year period (October 2005–September 2009). To apply the Thomas ABCD water balance, it is necessary to incorporate timeseries of precipitation and evapotranspiration that were calculated according to the Thornthwaite method, due to the limited number of available data points. This method calculates monthly evapotranspiration given only the average monthly temperature. Subsequently, an investigation was carried out in the 60–70% of the total length of the timeseries, based on which the model was calibrated.

Similarly, verification was performed for the remaining timeseries (40–30%). Through this investigation, the optimal values (Figure 3) of the model parameters were selected for further simulations. Then, after the selection of the optimal values for the model parameters, the sensitivity analysis of the parameters was performed with the "one [factor] at a time" (O[F]AT) method (Figure 3), to illustrate the changes that were observed after altering the optimal parameters' values. The sensitivity analysis of the model parameters was carried out in order to form a comprehensive picture of the influence of the parameter values determined as "optimal" on the final result. In other words, having calculated the optimal values of the model parameters, the sensitivity analysis can be carried out, the purpose of which is to focus on how it affects the model and what changes the change in a coefficient causes, that is, each time one variable is changed while keeping the other optimal values constant and the percent change in efficiency coefficient (EC) resulting from the specific change of the parameter is calculated. The greater the effect that the change in the parameter has on the coefficient, the more sensitive it is considered. This method is called one factor at a time (OFAT) because the effect is examined individually per parameter. The goal of this process is to determine the degree to which each variable affects the results. In this analysis, to implement the procedure, we changed only one input variable of the model (i.e., a, b, c, S_0) each time and with a constant step, keeping all other parameters constant at their initial (optimal) value, and we investigated the percentage change in EC. We then returned the variable to its original (optimal) value and repeated the process for the next input model parameter.

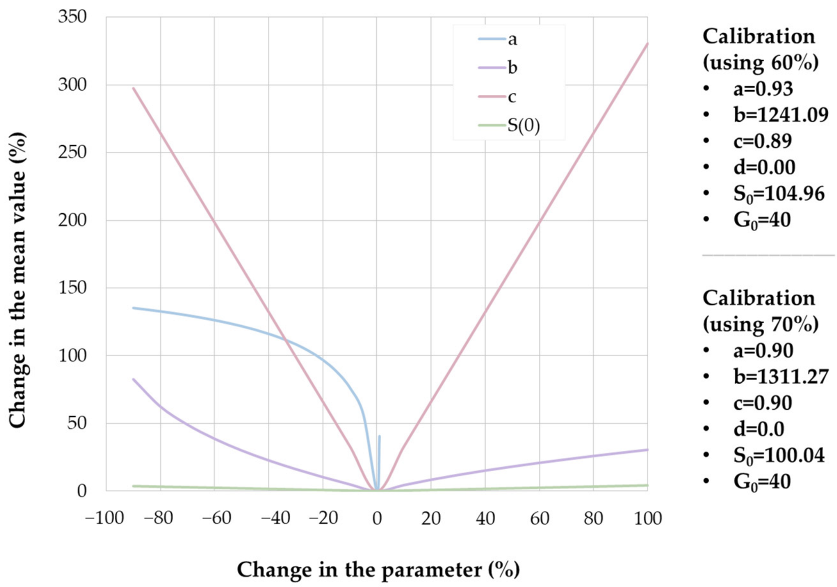

Figure 3. The Thomas ABCD model parameters and OFAT sensitivity analysis.

4. Results and Discussion

The model simulation was initially performed for a historical period between 2005 and 2009, using available records for the study area for the purpose of model calibration. Then, the model for the study area was used to obtain results for several simulations, as shown in Figure 4. The overall results were compared with regard to the reference period and to the CC scenario. For the period 2030–2060, we observed that there was a decrease in the highest runoff values in both CC scenarios compared to the historical period. However, the high-emissions scenario (RCP8.5) was expected to lead to lower values compared to the moderate ones (RCP4.5), which was not observed systematically, due to the non-systematic future decrease in the region's precipitation in all investigated scenarios. Particularly, for the RCP4.5 scenario and the period of 2030–2060, the CLMcom-CCLM4-8-17/MOHC-HadGEM2-ES scenario showed a higher mean runoff value of just over 2.8 mm. For the RCP8.5 scenario and the period of 2030–2060, the CLMcom-CCLM4-8-17/MPI-M-MPI-ESM-

LR scenario, as in the historical period, showed the highest runoff value, near 3 mm. For the period of 2060–2090, we observed that the values for both emission scenarios showed a decrease in relation to the historical period, but also to the period of 2030–2060, which, in this case, was also generally expected. As previously mentioned, the most favorable scenario RCP4.5 (2060–2090) was expected to bring higher values than the worst-case (RCP8.5, 2060–2090), which is illustrated in the two related graphs. Particularly, for RCP4.5 and for the period of 2060–2090, the CLMcom-CCLM4-8-17/MPI-M-MPI-ESM-LR scenario was linked to the highest values for runoff with the maximum value near 2.8 mm. For RCP8.5 and the period of 2060–2090, the IPSL-INERIS-WRF331F/IPSL-IPSL-CM5A-MR scenario corresponded to the highest values for mean monthly runoff with the maximum value near 1.8 mm, corresponding to a reduction of 1 mm compared to the most favorable scenario. The investigation regarding the SMHI-RCA4/IPSL-IPSL-CM5A-MR scenario, as for the historical period, as well as for the future ones (2030–2060 and 2060–2090), resulted in very small average monthly runoff values that were close to zero.

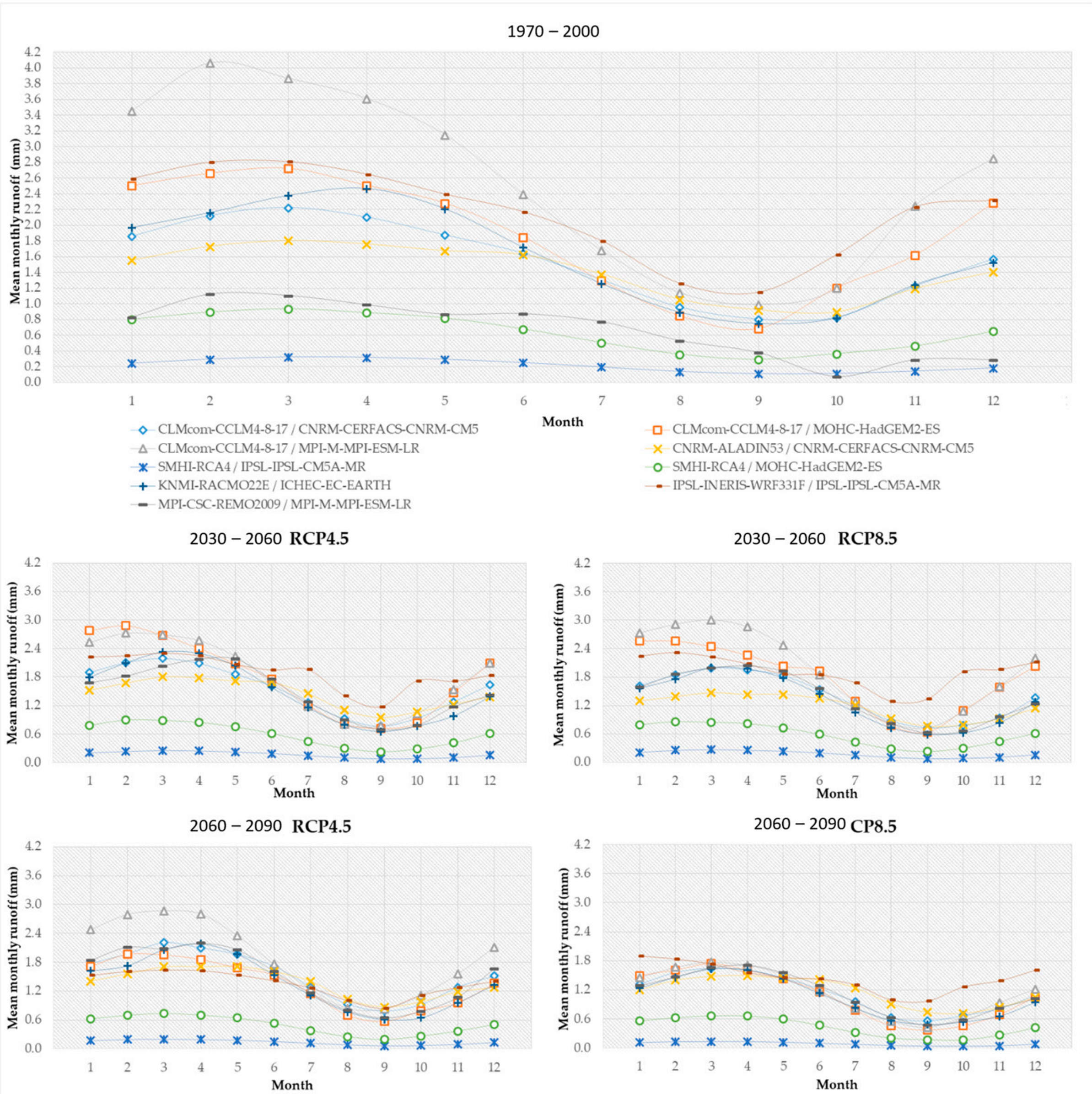

Figure 4. Mean monthly runoff per scenario and period of study (45 simulations).

5. Concluding Remarks

In the frame of investigating the influence of CC on the local water resources of the Vivari subbasin, an area in the NW part of Eurotas Basin, 45 independent simulations were performed, using the Thomas ABCD monthly water balance model. The results revealed that the increase in average monthly temperature had a direct impact on the average monthly evapotranspiration. Further, the average monthly runoff showed strong fluctuations within a hydrologic year, but also regarding the fluctuations in the average monthly value among the scenarios presented. As a general conclusion, after comparing the values for the study periods, it was found that the average runoff showed a significant decrease in future periods compared to the historic ones.

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