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What about reservoirs? Questioning anthropogenic and climatic interferences on water availability

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Abstract

Many semi-arid regions like Mediterranean Basin are highly vulnerable because of the high variability of weather systems and climate change is also altering the timing and pattern of water availability as well as growing populations place extra demands on water. However, it is poorly quantified how reservoirs and dams have influence on the amount of water resources, although climatic impact has investigated in detail by many researchers. Therefore, we examined the impact of reservoirs on water resources together with the impact of climate change on this study from the semi-arid Mediterranean catchment. We simulated the basin via the SWAT (Soil and Water Assessment Tool) model by assuming the basin has no any reservoir and has reservoirs (virtual) for current and future conditions using dynamically downscaled outputs of the MPI-ESM-MR general circulation model under two pathways in order to reveal coupled effect of reservoir and climate. Water resources were then converted to blue water, green water storage and green water flows instead of using single parameters like ground water, surface flow. The results demonstrate that all water resources, such as blue-green water storage and precipitation, are projected to decrease under all scenarios compared to the reference period both long-term and seasonal scale except the green water flow. Water scarcity indices for both reservoir cases experience scarcity, yet reservoirs hold water to overcome scarcity. Nevertheless, reservoirs reduce the availability of water, particularly in green water storage (soil moisture), and causes own drought by reducing water within soil and streamflow. Furthermore, reservoirs cause water loses by evaporating available water in surface. To build reservoirs due to public pressure in order to protect the society from economic damage have strong impact the land-atmosphere feedback mechanism of watersheds apart from effect of climate change on water resources.

Keywords: Reservoir effect, Water Scarcity, Climate change, Mediterranean, SWAT

1. Introduction

Accessibility and availability of water are vital for human activities. Therefore, the findings to be obtained on the water cycle are the crucial especially in terms of water supply, water demand, and water management. It is projected that many subcomponents of hydrological cycle and climate parameters at different spatio-temporal scales will be affected because of intensive greenhouse gas emissions to atmosphere since industrialization (Arnell & Gosling, 2013; Hagemann et al., 2013; Stocker et al., 2013). Many natural hazards, such as flood and landslides, as well as problems in water management which cause water scarcity and drought will emerge because of the changing hydrological cycle and its subcomponents (Arnell & Gosling, 2013; Alfieri, Burek, Feyen, & Forzieri, 2015; Dottori et al., 2018; Müller Schmied et al., 2016; Oki & Kanae, 2006; Samaniego et al., 2018; Sunde, He, Hubbart, & Urban, 2017; Vörösmarty, Green, Salisbury, & Lammers, 2000; Vörösmarty, Douglas, Green, & Revenga 2005; Vörösmarty et al., 2010). Many researchers have concluded that water scarcity is likely to be a serious problem by the end of the 21st century because of anthropogenic warming and growing demands on water resources caused by increasing population (i.e., Haddeland et al., 2014; Holland et al.; 2015; Schewe et al., 2014; Vörösmarty et al., 2000, 2010).

Mediterranean climate is characterized by dry summers resulting from stable anticyclonic circulations and wet winters caused by mid-latitude frontal cyclones (Arnell and Gosling, 2013; Hoerling et al., 2012; Gampe, Nikulin, & Ludwig 2016; Gao & Giorgi, 2008; Giorgi & Lionello, 2008; Peel, Finlayson, & McMahon, 2007; Samaniego et al., 2018). Studies on climate variability by simulating global and regional climate models based on both observation data and various greenhouse gas emission scenarios for the Mediterranean Basin show that the basin will be adversely affected by climate change in the future (Stocker et al., 2013; Ozturk, Ceber, Türkeş, & Kurnaz, 2015; Sen, Topcu, Türkeș, Sen, & Warner, 2012; Turp, Ozturk, Türkeş, & Kurnaz, 2014). It is also projected that the Mediterranean Basin particularly is one of the most vulnerable regions in the world in terms of anthropogenic warming impacts on the hydrological cycle. The Mediterranean region is defined as one of the primary hot spots (Giorgi, 2006). For instance, annual precipitation is likely to decrease across almost the entire region in the future (Ozturk et al. 2015). As a consequence of this decrease, Turkey, and especially coastal areas of the country adjacent to the Mediterranean, will face significant additional pressure on water resources (Aksoy, Unal, Alexandrov, Dakova, & Yoon, 2008; Fujihara, Tanaka, Watanabe, Nagano, & Kojiri, 2008; Onol & Semazzi, 2009). In addition to these drastic changes in coastal areas, in transition regions in the interior parts of Anatolia a significant decrease in future amounts of snowfall, surface runoff, and winter precipitation have been projected by Bozkurt & Sen (2013) because of the effect of climate change. It is estimated that in the Mediterranean Basin and southern Europe there will be a decrease in precipitation in winter, spring, and summer seasons. In addition, increase in precipitation extremes in autumn, winter, and spring seasons is predicted in the region (Goubanova & Li, 2007). When the long-term average annual and monthly total precipitation trends in Turkey, which is in the Mediterranean Basin, are analysed, it is seen that Turkey has a declining trend in general (Partal & Kahya, 2006). However, since 1980, there has been an increase in precipitation in the northern and eastern parts, while a decrease is observed in the central, southern and western parts (Türkeş et al., 2016). According to the regional climate model results, -0.8 mm/day and +1.2 mm/day changes in Turkey's precipitation amounts are envisaged. A significant decrease in precipitation is expected in the western and southern regions where the Mediterranean climate dominates, while precipitation is expected to increase in the Black Sea Region, where a moderate mid-latitude climate prevails (Ozturk, Türkeş, & Kurnaz, 2011). It is also concluded that some regions will experience water scarcity due to the increasing temperature and decreasing rainfall in the country as well as the increase in arid areas and rapidly increasing climate change. Furthermore, an increase in the number of dry days and an increase in the frequency of drought are anticipated (Sen, 2013). It is estimated that during the summer months between 2041-2070 and 2071-2099, there will be a decrease in precipitation in the Mediterranean region (Demircan, Gurkan, Eskioglu, Arabaci, & Coskun, 2017).

Global or regional climate models allow exploring the climate side of the problems outlined on a global or regional scale. Beside, incorporating GCM and RCM outputs with hydrological models is an important methodology to reveal the impact of climate change on hydrological processes. This approach takes the data from GCM or RGM outputs and drive into hydrological models to derive hydrological components of watersheds in which it is investigated the impacts by climate change (Angelina, Gado Djibo, Seidou, Seidou Sanda, & Sittichok, 2015; Chattopadhyay & Jha, 2016; Ertürk et al., 2014; Fujihara, et al., 2008; Sunde et al., 2017; Stehr, Debels, Romero, & Alcayaga, 2008; Zeng, Xia, She, Du, & Zhang, 2012). For example, Bucak et al. (2017) demonstrated the risk of drying of Beyşehir Lake due to climate change by using outputs of the SWAT hydrological model coupled with regional climate model outputs. However, outputs of the General Circulation Models (GCMs) are coarse to investigate the impact of climate change and for that reason, those climate outputs have to bedownscaled to reveal detailed impact of change. To overcome this problem, GCM outputs are downscaled either dynamically or statistically by using various methods (Chen, Xu, & Guo, 2012; Ertürk et al., 2014; Fowler, Blenkinsop, & Tebaldi, 2007; Maraun & Widmann, 2018; Sunde et al., 2017; Wilby & Wigley 1997; Wood, Leung, Sridhar, & Lettenmaier, 2004). In some cases, it can also be needed to use a hybrid approach, which means a combination of both techniques. In this study, we have used 10-kilometre high-resolution regional climate model outputs that dynamically downscaled from 50 kilometre, which is most detailed study for the basin in terms of hydrological studies.

Reservoirs and dams are one of the main management approaches in order to cope with water scarcity, drought and flood when the phenomenon has occurred (Gaupp, Hall, & Dadson, 2015; Vörösmarty et al., 2000). It is accepted that rising of number of reservoirs and dams is most effective way to combat against drought and water scarcity of basins for long-term water management strategies. On the other hand, it is also stressed that increase in number of these water infrastructures brings more dependence and makes societies more vulnerable when drought and scarcity conditions has experienced due to higher reliance and over trust on reservoirs (Di Baldassarre et al., 2018). In addition, dams and reservoirs have serious and important impact on environmental, aquatic and fluvial systems as well (Grill et al. 2019; Latrubesse et al. 2017). For instance, today, only %37 of rivers which is longer than 1000 km flow free without confront any barrier along its course and 23% of them reaches oceans without any stoppage and it causes to lost connectivity of rivers over the Earth (Grill et al. 2019). Di Baldassarre et al. (2018) have drawn a frame for reservoir, which can make worsen water shortages due to overreliance to them, and they stressed a misconception; it is assumed that water problem is solved after construction of reservoir. However, it is not well documented and quantified how reservoirs have impact on water resources by changing hydrological systems.

For that reasons, in the light of background mentioned above, the main objectives of this research are to:

a) show how different water resources can be affected and change under influence of two different reservoir scenarios, which is main strategy in water management in order to cope with water scarcity and long-term drought in semi-arid regions like Mediterranean.

b) investigate and quantify the impact of long-term and seasonal climatic variations on water resources such as green water flows and storage and blue water instead of using single parameters that important indication for water resources such as ground water, surface flow and streamflow and evaluate the availability in the future with different scenarios for a vulnerable large river basin, especially from the Eastern Mediterranean, by using dynamically downscaled high resolution regional climate model outputs.

2. Data and Methods

2.1. Study Area

Susurluk basin, which is situated in the northwest part of Turkey (Figure 1a), has about 23.779 km^2 area with changing elevation in between 2543m (Uludağ Mountain) and 0m m.s.l. Many streams such as Mustafakemalpaşa, Kocaçay, Nilüfer and Simav drain the Susurluk Basin.

Two big lakes namely Uluabat and Manyas are also situated in the basin. The Susurluk Basin generally represents the Mediterranean climate (Csa) that is characterized by wet winter and dry summer except the Nilüfer sub-basin where mountainous climate (Csb) is dominant according to Köppen climate classification system (Peel et al. 2007; Ozturk, Cetinkaya, & Aydin, 2017). The annual average runoff is about 5.43 km^3 (Ayaz, 2010) and the basin receives 570 mm average annual precipitation. Basin's water balance has negative values, especially during the summer period, due to high evaporation that causes water loses out of Uludağ (Akbas and Ozdemir, 2018).

---Figure 1 is here---

The basin has many aquifers types that contain (productive) and does not contain (non-aquifers) water inside the rocks. While Bursa, Balıkesir, MustafaKemalpaşa and Simav plains have very productive aquifers, other areas of the basin that drains by Simav and Kocaçay Streams consist of low and moderate productive and highly productive aquifers, respectively (Figure 1b). In contrast, Orhaneli and Emet Stream watersheds have non-aquifer rocks.

There are three main types of land use in the basin such as urban, agriculture, and forest. Susurluk Basin is one of the populated basins in Turkey and the urban areas cover almost 476 km^2 of the basin. Many big cities like Bursa, Balıkesir and Kütahya and their crowded counties are within the borders of the basin and total population is about 3.201.773 for 2017 census (GDWM, 2018). Agricultural activities (~9.997 km^2) and forest (~10.876 km^2) are predominant land use types in the basin (Figure 1d). Many big and small reservoirs such as Kayaboğazı (37.84 hm^3-1987), Çavdarhisar (38.8 hm^3 1991), Selahattin Saygı-Doğancı (41.27 hm^3-1984), İkizcetepeler (157.29 hm^3-1992), Çaygören (159.5 hm^3-1971), Manyas (423.39 hm^3-2002) and Çınarcık (304.75 hm^3-2003) were constructed in the basin for irrigation, flood protection, drinking water, energy demand and growing urbanization (Figure 1c). In particular, there are still going on projects, for example Kızkayası, for the construction of reservoirs due to growing population and their demand on water for many purposes like agricultural and energy (Koç, 2014; Yuksel, 2015).

2.2. General Methodology

Many datasets have been used to comprehend the impact of reservoirs and climate change in order to accomplish the main aims of this study. Climate models outputs, which have been used in SWAT rainfall-runoff model, are quite important to reveal the impact of long-term oscillations and trends of different kind of climatic parameters for water management. There are four main data sources such as digital elevation model, land use, soil and observed meteorological and hydrological data were used for the SWAT modelling.

Digital Elevation Model: HydroSHEDS (Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales) digital elevation model data was used in this study due to correct representing of river courses. Many sub-basins, river networks, watershed parameters (longest path, reach, outlets and monitoring points) and slope were extracted from the DEM (Lehner, Verdin, & Jarvis, 2008). 15,000 threshold value was used to obtain river networks and 58 sub-basins were extracted in the basin (Figure 1a).

Land use: Land use database is another data source to produce of Hydrological Respond Unit (HRU). In this study, Corine Land use-Landcover was employed for detecting Curve number values. However, SWAT has own land use classification system. For that reason, Corine Land use was converted to SWAT land use classification (Figure 1d).

Soil Database: Soil data, which is very important for SWAT model was obtained from 1:5.000.000 scaled Harmonized World Soil Database (1 km resolution) according to FAO-UNESCO world soil map (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/). Orthic Luvisol (47.5%) that covers almost half of the basin and Eutric Cambisols (27.6%) are dominant soil types. Other soil types such as Calcic Cambisols, Lithosols, Eutric Fluvisols and Chromic Vertisol cover 24.8% of the basin (Figure 1c).

Meteorological and Hydrological Database: Meteorological database, which were obtained Turkish Meteorological State (MGM) for the period of 1982-2005, have two types of structure for simulations. The first one comprises of daily and hourly time series which are daily precipitation (mm), daily relative humidity (%), daily wind speed (m/s), daily solar radiation (MJ/m^2) and daily minimum and maximum temperature (^{o}C) for Bandırma (17114), Bursa (17116), Edremit (17145), Balıkesir (17150), Akhisar (17184), Gönen (17674), Uludağ (17676), Keles (17695), Dursunbey (17700), Tavşanlı (17704), Simav (17748), Gediz (17750) (Figure 1a). Another database is monthly weather data, which is called WGN table that represent long-term averages of meteorological parameters. Hydrological database were obtained Turkish Hydraulic Service (DSI) for calibration of SWAT rainfall-runoff model. There are many stream gauges in the basin, but only gauges such as Nilüfer Çayı-Geçitköy (E03A021), Kocadere-Akçasusurluk (E03A017), Kocaçay-Kayaca (E03A014), Mustafa Kemalpaşa Çayı-Döllük (E03A002), Simav Çayı-Yahyaköy (E03A016), Atnos Çayı-Balıklı (E03A024), Emet Çayı-Dereli (E03A028), and Orhaneli Çayı-Küçükilet (E03A011) (Figure 1a) have no missing values were selected for calibration of the model(Figure 1a).

Methodology of this study is given in Figure 2. In first process, physical variables such as land cover, soil and slope were arranged and HRU was obtained. Later, SWAT rainfall-runoff model was carried out via meteorological station data and calibrated by using stream gauge stations. In second process, the global model MPI-ESM-MR was downscaled from 50 km to 10 km dynamically. After downscaling, the outputs of RegCM4.4 regional climate model were forced to use in the SWAT as input. Before running climate model data outputs in rainfall-runoff model, bias corrections for precipitation and temperature were utilized to eliminate overestimation of the data (see supporting information). Many studies (Bucak et al., 2017; Sunde et al., 2017) use only two parameters like temperature and rainfall to simulate future, but other parameters (solar radiation and wind speed) were obtained by weather generators from past (baseline) climate. However, this type of usage cannot represent the future climate. For that reason, all variables such as solar radiation, rainfall, wind speed, minimum and maximum temperature were used in this study. The last process of the analysis is running the model via the outputs of a regional climate model after finishing the calibration. Here, implementation of simulations was executed based on assumption. In reality, there are many reservoirs across the basin. It is asked that what if there was no any reservoir around the basin or how amount of water resources can be changed or not with the impact of climate change for current and future situation. Thus, the impact of reservoir with changing climate to the land-atmosphere feedback mechanism of the basins can be revealed. (Figure 2-Third process). Furthermore, Falkenmark indicator (1989) for water scarcity was used in each reservoir scenarios for whole basin to compare the amount of water.

--Figure 2 is here--

2.3. SWAT Rainfall-Runoff Model

ArcSWAT, which is the interface of SWAT (Soil and Water Assessment Tool) rainfall-runoff model, developed by USDA Agriculture Research Service (ARS) and Agricultural Experiment Station in Temple, was used in order to investigate the effect of climate change and reservoir on water components such as blue water and green water in the Susurluk Basin (Arnold, Srinivasan, Muttiah, Williams, 1998; Arnold et al., 2012). On the one hand, SWAT is a physically based model, which means that it requires physical data such as soil, vegetation, weather data and topography instead of black box model data requirement such as only rainfall and runoff. On the other hand, even if flood-caused event can be studied in SWAT, the model is feasible for long-term changes in watershed (Neitsch, Arnold, Kiniry, & Williams, 2011). For that reason, the SWAT model is feasible for climate change and long-term watershed management studies like agricultural activities, water infrastructures. The model categorizes and divides a watershed to many sub-basins and overlays three parameters, which is called HRU (Hydrological Response Unit).

Simulations of hydrological cycle in SWAT based on water balance equations is as it follows

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where, SW_t is final soil water content (mm H_2O), SW_0 is initial soil water content (mm H_2O), t is the times (days), R_{day} is amount of precipitation on day i (mm H_2O), Q_{surf} is amount of surface runoff on day i (mm H_2O), E_a is the amount of evaporation on day i (mm H_2O), $w_{seep}$is the amount of water entering the vadose zone from soil profile on day i (mm H_2O), $Q_{gw}$is the amount of return flow on day i.

2.3.1. HRU, Parameterization and Evaluation Tests Performance of SWAT Model

HRU values are determined during the overlaying of soil, land use and slope. The value of the soil was chosen as 0% for the land use, 0% for the slope and 0% for the soil. Thus, 3500 HRU values were obtained in the basin. Penman-Monteith method was selected to calculate evaporation and transpiration (Monteith, 1964) and SCS Curve Number method was used for surface runoff estimations in the sub-basins (SCS, 1956, 1964, 1971, 1985, 1993).

Some performance tests, which are frequently used in literature, were applied to evaluate the model result in order to calibrate basin parameters. The first one is Nash–Sutcliffe model efficiency (NSE) (Krause, Boyle, & Bäse, 2005, Nash & Sutcliffe, 1970) was employed to evaluate bias of projected and observed precipitation and simulation results with gauges that are situated in the Susurluk Basin (Figure 1a).

NSE coefficient can be expressed as:

$$NSE = 1 - \sum_{i=1}^{n} \frac{(Q_i - P_i)^2}{(Q_i - \overline{Q})^2}$$

where $\overline{Q}$ is the mean of observed discharges, and Q is modelled discharge. P_i is observed discharge at time *t*. The Nash-Sutcliffe efficiency (NSE) compares the residual variance of simulation with variance of observed. (Nash & Sutcliffe, 1970). Nash-Sutcliffe efficiencies range from -∞ to 1. NSE = 1, corresponds to a perfect match of modelled to the observed data. NSE = 0 indicates that the model predictions are as accurate as the mean of the observed data, -∞ < NSE < 0, indicates that the observed mean is better predictor than the model.

The second test is Percent BIAS test (Gupta, Sorooshian, & Yapo, 1999). PBIAS coefficient can be expressed as:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right) * 100}{\sum_{i=1}^{n} \left(Y_i^{Obs} \right)} \right]$$

where Y_i^{Obs} observed discharge at time *t, Y_i^{Sim}* simulated discharge at time *t.*

PBIAS based on the percentage of the difference of the model from observed. Zero is optimal number that shows reliability of model for simulation. Positive bias is the number bigger than zero; meantime negative bias is number smaller than zero. Moriasi et al. (2007) explain that the number of NSE that is bigger than 0.5 is satisfactory for simulation results. The number ±15 < PBIAS < ±25 is satisfactory for PBIAS.

The last test is linear regression that is extensively used in hydrological modelling studies. Regression coefficient can be expressed as:

$$R^2 = \left(\frac{\sum_{i=1}^{n} (Q_i - \overline{Q}) - (P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n} (Q_i - \overline{Q})^2} - \sqrt{\sum_{i=1}^{n} (P_i - \overline{P})}} \right)^2$$

where, R^2 is coefficient of determination, *Q* is observed, and *P* is modelled runoff from the simulation. Numbers of coefficient of determination ranges from 0 to 1 in which 1 is optimal value for this test.

2.4. Water Scarcity Indicator

Falkenmark indicator (1989) was employed to understand the availability of water in study area for comparing the scarcity with different reservoir and climate model scenarios. Despite there are numerous indicators of water scarcity, Falkenmark indicator is widely used in water scarcity index because of its simplicity and data that can reached easily. The indicator evaluates the amount of water with number of people and it can be expressed as:

$$FI\ (m^3/cap/yr) = \sum_{Day\,=\,1}^{365} m^3\ /Population$$

Where, m^3 is daily water amount which is summed for year and population is total capita who live in interested area. Water stress can be categorized based on fraction water for per capita usage. 1700 m^3 per capita is main thresholds in index. If water is below 1700 m^3 water stress begins. The water between 1000-500 m^3 is indicator of scarcity and below 500 m^3 is absolute scarcity for interested area. Data for population, in this study, was obtained from The Global Population Projection Grids Based on Shared Socioeconomic Pathways (SSPs) dataset (Jones & O'Neill, 2016, 2017). Projected population data, which has 7.5 arc-minutes resolution, for the Susurluk Basin was extracted from raster for 2010-2100 (FigureS4). Each pathway in population scenarios represents different trends, which indicate different socio-economic developments of countries. On the other hand, observed data of population for 1980-2000 was obtained from the TURKSTAT (Turkish Statistical Institute, 2018) in order to compare reference period with respect to future period of whole basin.

3. Result and Discussion

3.1. Calibrations of Runoff in Susurluk Basin

SWAT model was implemented and all the results, which represent water balance components, were obtained for the basin in between1983-2005. The model results, especially runoff, were calibrated with the observed data by using The Soil and Water Assessment Tool Calibration and Analysis Program (SWAT-CUP) was used to calibrate the runoff and water balance components more accurately for the Susurluk basin (Abbaspour, 2013). Sequential Uncertainty Fitting (SUFI-2) was utilized as the algorithm of calibration, which is mostly preferred method in literature for calibration of modelled watersheds (Abbaspour et al., 2007). The method has two options to calibrate these parameters. Replace is the option that changes original parameter values in ranges, whilst relative uses artificial ranges instead of original ranges of parameters to calibrate model according to SUFI-2. Another important thing is to select the calibration parameters that show the overestimation for the stream gauges. Eight different and sensitive parameters have been selected based on Abbaspour et al. (2015) in order to reduce the error in simulations. Simulations, which are consisted of 300 times, have been executed via SWAT-CUP and best parameters were obtained based on the results of these simulations as monthly time scale (Table 1).

---Table 1 is here---

The results obtained from SWAT-CUP show that Curve Number values of the sub-basins decrease in the entire basin. On the other hand, groundwater parameters were arranged and the Susurluk Basin was calibrated based on SWAT-CUP best value results.

Observed values of the gauges in the basin were compared with simulated runoff values through the model performance test (Figure 3). Simulation results are sufficient to represent or simulate the observed data according to the performance test results after the calibration. E03A017 gauge represents almost the whole basin except for the Nilüfer sub-basin and its value of NSE is 0.63, PBIAS is 0.15 and R2 is 0.68, which are sufficient values according to Moriasi et al. (2007). Other gauges with performance test are sufficient for simulating future. However, time series of runoff by simulations of SWAT in Simav and Kocaçay Streams (Figure 1b) cannot catch peak flow of observed runoff to simulate, even if excellently follow trends or oscillations of observed runoff (Figure 3). The gauges such as E0A014, E0A016, E0A024 represent Kocaçay and Simav sub-basins have underestimation for peak flow and monthly error plots illustrate that underestimation is higher in the winter season (Figure 6). This circumstance might be about groundwater abundance in these areas. Because, this underestimation corresponds to areas that are highly productive fissured aquifers which means karstic processes are dominant in terms of groundwater. Nevertheless, NSE value of these gauges ranges from 0.35 to 0.6 and PBIAS ranges from -0.19 to -0.5 which are sufficient and enough to simulate the basin’s water balance parameters. On the other side, the E03A021 and

E03A028 coded gauges, represents Nilüfer and Emet sub-basins respectively, cannot be simulated some peak flood events observed in spring season by the model, although the evaluation test results are sufficient according to Moriasi et al. (2007). It might be a consequence of a higher topography in which precipitation falls as snow in winter and timing of snowmelt corresponds to spring in the basin. Therefore, monthly error plot is an evidence to illustrate that underestimation is seen in spring because of the reasons mentioned above. Nonetheless, SWAT is a physical semi-distributed model and use many algorithms and parameters to simulate runoff. Therefore, these parameters are interconnected and sensitive to each other. We evaluated most sensitive parameters to runoff based on suggestion of Abbaspour et al. (2015), still there may be another less important but sensitive parameters that can have influence of runoff values. In addition, many unreported arrangements and changes in rivers and even uncertainties from rating curves (Coxon et al., 2015) can exacerbate uncertainty of simulations. In general, the entire gauges in the basin have sufficient scores (Figure 3) in terms of evaluation test based on Moriasi et al. (2007) and this study does not concern any single events like peak flows for floods. Instead, we concern long-term changes of water resources. Therefore, the results taken from evaluation test after calibrations are sufficient to accomplish aims of this study.

---Figure 3 is here---

3.2. Water Availability under Climate Change Scenarios

We evaluated the climate impact scenarios on water resources before investigating reservoir case scenarios. In order to understand water availability under different climate scenarios and time scales, water resources of whole Susurluk Basin have been calculated as blue water (deep aquifer recharge + water yield), green water storage (soil moisture), green water flow (evapotranspiration) instead of using many single parameters such as surface runoff and groundwater. Time scales of all parameters, which show water availability of the basin, were converted to monthly scale. Boxplot of all water resources was drawn to distinguish the gradient of all scenarios and Mann-Whitney U test or Wilcoxon rank-sum test (Lehmann & D'Abrera , 1975) was utilized to see how climate change would affect the amount of all water resources (Figure 4).

It is discerned that there is statistically significant decrease in all water resources in all scenarios and the future periods for RCP4.5 and RCP8.5 scenarios with respect to the reference period except green water flow. One the one hand, the out of RCP4.5 late century (2070-2099) scenario, decreases to precipitation were observed for all scenarios of RCP groups. Blue water, which characterizes freshwater availability, demonstrates that all scenarios of RCP have statistically significant decrease trend for future in comparison with the reference period, but blue water is going to be most affected water resources as seen in Figure 4. Median, 25th and 75th percentiles of this water resource were shrank more than other resources when comparing reference period with late century of scenarios. Outlier (extreme) values have high values, on the contrary of median and percentiles. Similarly, statistically significant decrease was obtained in green water storage for future in all scenarios of RCP with respect to reference period. On the other hand, there is no any statistically significant decrease or increase in green water flow for future scenarios of RCP's except RCP4.5 mid-century (2020-2049) in respect to the reference period and except median and 25th percentile, 75th percentile decreased in all scenarios. The distinction between scenarios of all water resources obtained in RCP8.5, which is known the worst-case scenario. Directions in terms of increasing and decreasing of precipitation and water resources are as expected (Stocker et. al., 2013; Van Vuuren et al., 2011). Beside, Gorguner, Kavvas, & Ishida (2019) have studied Gediz basin, which is so close to Susurluk Basin, in order to find out the impact of climate change on the streamflow of basin using different kind of model and ensembles for scenarios of RCP4.5 and RCP8.5. It is expressed that there will be a decrease in streamflow according to the ensemble of all projections as it is expected the same for blue water (fresh water) in this study.

---Figure 4 is here---

Kernel density plots were drawn as well in order to understand possible shifts in scenarios of the water resources at seasonal scale for the future, apart from boxplot of water resources. There is obvious dispersion in all parameters and all seasons even though magnitude or amplitude is different. For all parameters excluding green water flow, densities of RCP4.5 and RCP8.5 have moved to left side of reference period in entire seasons. Similarly, peak densities of RCPs have shifted either upward or downward of the reference period (FigureS5).

Peak densities of all parameters are salient especially in summer season in which the values of all water resources, which is spread around tale, are low because of drought season. Both peaks and tales of density plot of RCP4.5 and RCP8.5 precipitations for winter oscillate around of density of the reference period. Densities of mid-late century RCP4.5 and RCP8.5 for spring have shifted by moving to left side of the reference period. Summer precipitation of RCPs, which is dry season in the Mediterranean and the Susurluk basin, has decreased, although amplitude of peaks especially late century RCP8.5 has increased in the future by comparison with duration of the reference. Similar to winter, all scenarios of RCPs for autumn seesaw around the reference period curve, yet late century of RCP4.5 (2070−2099) has shifted of right side of the reference by increasing with amount. Not only amplitude of peak also shifting of densities at the tale of RCPs in the blue water have changed to left side, which indicate the decrease of amount of fresh water, compared to the reference period. Nevertheless, winter, summer and spring seasons are more vulnerable than autumn with regard to changing of densities. The conditions that are seen for blue water is the same for green water storage as well. On the other hand, winter season of the green water flow has opposite character than other parameters that before explained. Outside of other seasons of the green water flow, RCPs of winter tends to move right side of the reference period. Generally, autumn is more stable in terms of shifting and changing of curves around the reference period. The same changes, in particular for precipitation, around the basin have been detected by many researchers (Demircan et al., 2017; Giorgi, & Lionello, 2008; Lelieveld et., 2012; Onol & Semazzi; 2009; Ozturk et al., 2015; Turp et al., 2014). It is obviously seen that climate change has a strong impact on water resources by changing water amount. However, it is not well understood and documented how reservoir is changing available water in basins. Therefore, scenarios of reservoir with climate impact scenarios for water resources has compared in next section.

3.3. Reservoir Effect on Water Resources

Falkenmark indicator (Falkenmark 1989) was employed based upon climate model scenarios (RCPs), observed (TURKSTAT) and socio-economic population scenarios (SSPs) so that depicting the effect of reservoir and climate change scenarios on water scarcity. Bar graphs was originated dividing number of population to runoff from outlet by taking decadal average of yearly total runoff since population data is available only decadal (Figure 6). On the other hand, hydrological model was employed with two reservoir scenarios to illustrate the water that need to cope with scarcity based upon Falkenmark indicator. The threshold value of indicator for no water scarcity consists of 1700 m^3 per capita was added to bar plot as a dashed line and pie chart was constructed to show the proportions of runoff and the water that accumulated in reservoir.

Results demonstrate the different combination of climate and population and reservoir scenarios. As seen in Figure 5, the quantity of water for per capita with reservoir is less than without reservoir scenario. Water is especially abundant during the reference period because of a small population (Figure 5a and FigureS4). SSP3, which is the worst-case scenario (business as usual) in population scenarios and reaches almost 5 million by 2100s shows that water for per capita is going to be down almost 500 m^3 per capita. Even though SSP5, which is the best-case scenario for rising of population, demonstrate that water per capita does not cross dash line in neither result of reservoir nor without reservoir scenarios. In general, two reservoir scenarios for basin illustrate that except reference period that is lowest population lives during that time, all population scenarios will likely be experienced water scarcity due to lack of available water, which is explained previous section, and rising the number population up to 2100. According to bar graph and results of Falkenmark indicator, basin will have scarcity in terms of available blue water. However, this indicator focuses on the amount of water that is accessible from river courses and neglects the water accumulated in reservoirs.

---Figure 5 is here---

Hence, in this study, the water accumulated in reservoir in the Susurluk Basin was taken into consideration for water scarcity assessment. Figure 5b illustrate that the ratio of water from runoff for three decades in the reference period is higher than the future scenarios owing to reservoirs that built during this period such Çaygören (159.5 hm^3-1971), Kayaboğazı (37.84 hm^3-1987), Selahattin Saygı-Doğancı (41.27 hm^3-1984), İkizcetepeler (157.29 hm^3-1992), Çavdarhisar (38.8 hm^3 1991). Subsequent to the reference period, proportion of water from runoff are seen in decline compared with water from reservoir that build during reference period and after it such big reservoirs as Manyas (423.39 hm^3-2002) and Çınarcık (304.75 hm^3-2003) for irrigation, flood protection and drinking water and then proportion of waters stay in same. According to Falkenmark indicator, the Susurluk Basin was going to have water scarcity because of water from runoff that does not meet the water demand of population. However, the measures such as building reservoirs against drought and water scarcity indicate that focusing only scarcity from runoff can be misleading for basins. Especially, pie chart of runoff and water in reservoir shows that scarcity can be defeated with water in reservoir since water in reservoir is abundant 100 times than water from runoff (Figure 5b). For that reason, in classical water management, reservoirs can be seen as effective way to handle water scarcity and drought at first glance according to water results in this study. This perception drive society to make pressure on decision makers to build reservoirs in order to protect themselves from economic damages, yet according to Di Baldassarre et al. (2018) based on this perception, society can be more fragile due to overdependence on these water infrastructures and prevent societies to have another measures.

On the other hand, we quantified how reservoirs can affect the water resources and its hydrological mechanism apart from scarcity viewpoint. For that reason, simulations for the

Susurluk Basin were executed based upon with and without reservoir scenarios in order to understand and investigate the effect of reservoirs on water resources for long-time scale with climatic effects and for whole basin. For meaningful comparison, histograms of all water resources were composed based on two reservoir scenarios with the reference, RCP4.5 and RCP8.5 climate scenarios. The histogram results depict that the amount of water has significantly changed with reservoir in progress of time and scenarios in the Susurluk basin for the future and reference periods (Figure 6a-b). For blue water and green water storage, sign of change in bars of histograms is right side after construction of reservoirs even tough blue water has raised in between 0 and 25 millimetres. It indicates that water needs to recharge to soil (green water storage) and freshwater which decreases in river course and aquifer due to accumulation of waters in the reservoirs. In contrast, the green water flow increases during the reference and future periods. The accumulated water in extensive area accelerates the feedback mechanism for evapotranspiration by evaporating available water in the basin.

Error plot illustrate the difference between results of simulation with and without reservoir at monthly scale. The first thing that can be noticeable in graphs is the high seasonality between months as a result of Mediterranean climate (Peel et al., 2007) for the all water resources. It is seen that highest values of the blue water and green water storage are observed during winter months (DJF) in the Susurluk Basin, which might be associated with large-scale synoptic climatology properties such as Atlantic originated mid-latitude frontal cyclones caused by polar air masses coming through the Mediterranean Basin, which is also the negative phase of North Atlantic Oscillation (NAO) as well as the lowest values are seen during summer (JJA), which caused by high pressure system such as Azores High and extension Monsoon Low that known the positive phase of NAO (Barry & Chorley, 2009; Karaca, Deniz, & Tayanç, 2000; Tatli, Dalfs Nuzhet, Sibel Mentes, 2004; Tatli & Türkeş 2011; Türkeş & Erlat 2003, 2005; Sarış, Hannah& Eastwood, 2010).

--Figure 6 is here--

The simulation results demonstrate that values of reservoir are lower than without reservoir for the blue water and green water storage. Nevertheless, the gap between with and without reservoir simulation is higher in rainy season (winter) and lower in dry season (summer) for the blue water and green water storage in RCPs and reference period. On the contrary, the parameters that explained above, the highest values of green water flow are seen in April, May, and June while somewhat similarly lowest values are seen in July, August, and September. Furthermore, the interval of simulation result of reservoir is higher than without reservoir between the months from September to April. After August, interval of error plots with and without reservoir reversed from May to June. Therefore, values of without reservoir at that month are higher than reservoir. Consequently, reservoirs have strong impact on the water resources by changing amount of water but climate change also shapes the amount of water in the basin. Therefore, both of them has cumulative effect of all different kind of water resources by affecting both changing amount and shifting sign of them.

4. Conclusion

High seasonality in the climate of the Susurluk Basin, which is characteristics of the climate of the Mediterranean Basin, particularly makes the basin more vulnerable than other climates on the earth. Climate change will likely change the amount of all water resources such as precipitation, blue water, green water storage and flow with negative sign in future at long-term and seasonal scale according to climate and hydrological model results in the basin. It can be obviously said that, climate change exacerbates the vulnerability of the basins in these fragile semi-arid climates.

Water scarcity will likely be experienced in terms of water use until 2100 for the Susurluk Basin according to Falkenmark indicator with many scenarios of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). Especially, entire population and climate model scenarios illustrate that the basin will experience scarcity of water with below 1700 m^3 per capita for decadal changes. Nonetheless, indicator only takea runoff from river into account to quantify the scarcity of water in basin. Whereas, water in reservoirs is almost 100 times more than water in outlet of streamflow. On the other hand, reservoir makes its drought and scarcity by accumulating water that required recharging the river courses, aquifers, and soils. For that reason, the role of reservoirs in classical water management in drought and scarcity brings a dilemma for socio-hydrological systems. Di Baldassarre et al. (2018) have questioned water infrastructures in terms of the feedback mechanism of supply-demand cycle and reservoir effect. They have concluded that many feedback mechanisms of social factors make worse the water shortages since raising the high reliance on this source. Nevertheless, reservoirs affect the land-atmosphere physical feedback mechanism of watershed as well by changing amount of fresh waters such as blue water and green water storage due to accumulation water as it is proven in this study. Water in reservoir enhances the green water flow due to the existence of water that ready to be evaporated by radiation. Moreover, green water storage will be most impacted among the other water resources by shifting positive amounts to negative side. Whereas, Falkenmark (2013) suggests that many places like semi-arid or arid regions, which cover almost entire Mediterranean basin, has to protect green water storage in order to overcome drought and scarcity problem because water consumption is higher than blue water during the growing season of crops. In addition to measures against drought and water scarcity, owing to economic growing plans brings another dilemma for socio-hydrological systems because every country has right to combat against the poverty and supply the energy for their citizens. Hence, rising population and demand on water for energy, flood protection and economic growth plans (Koç, 2015), there will be new reservoirs for these purposes.

Consequently, water is necessary for human beings to ensure their needs in agriculture, industry, domestic use. Many reservoirs and dams have been built in order to tackle scarcity of water, flood and ensure the water availability. As it is proved in this study, many in infrastructures on rivers can change land-atmosphere physical feedback mechanisms of watersheds and rivers and today only 37 percent of rivers longer than 1,000 kilometres flows free without any barrier or infrastructure in front (Grill et al., 2019). Therefore, with the effect of climate change on hydrological systems, other human-made factors such as water pollution and water depletion due to overuse of water resources deepen the problems in water management of watersheds.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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TABLES

Table 1. Calibrated parameters of the model gathered from SWAT-CUP for the Susurluk Basin

FIGURE LEGENDS

Figure 1. a) Location b) Hydrogeological (map was adopted by IHME1500 v11) c) Corine Land-use d) Topographic map of Susurluk Basin.

Figure 2. Flowchart of study. The first process illustrates the settings of rainfall-runoff model. How data model obtained from regional climate was explained in second process. Third process demonstrates the comparison of interested parameters based on different reservoir scenarios.

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Figure 4. Boxplot comparisons of water resources under different scenario results (The stars at top of facet indicate the significance values of Mann-Whitney U test; ns: $p > 0.05$, *: $p <= 0.05$, **: $p <= 0.01$, ***: $p <= 0.001$ ****: $p <= 0.0001$).

Figure 5. a) Falkenmark indicator results based on climate and population scenarios (dashed lines indicate no scarcity or water stress), b) ratio of water (m^3) in runoff and reservoirs.

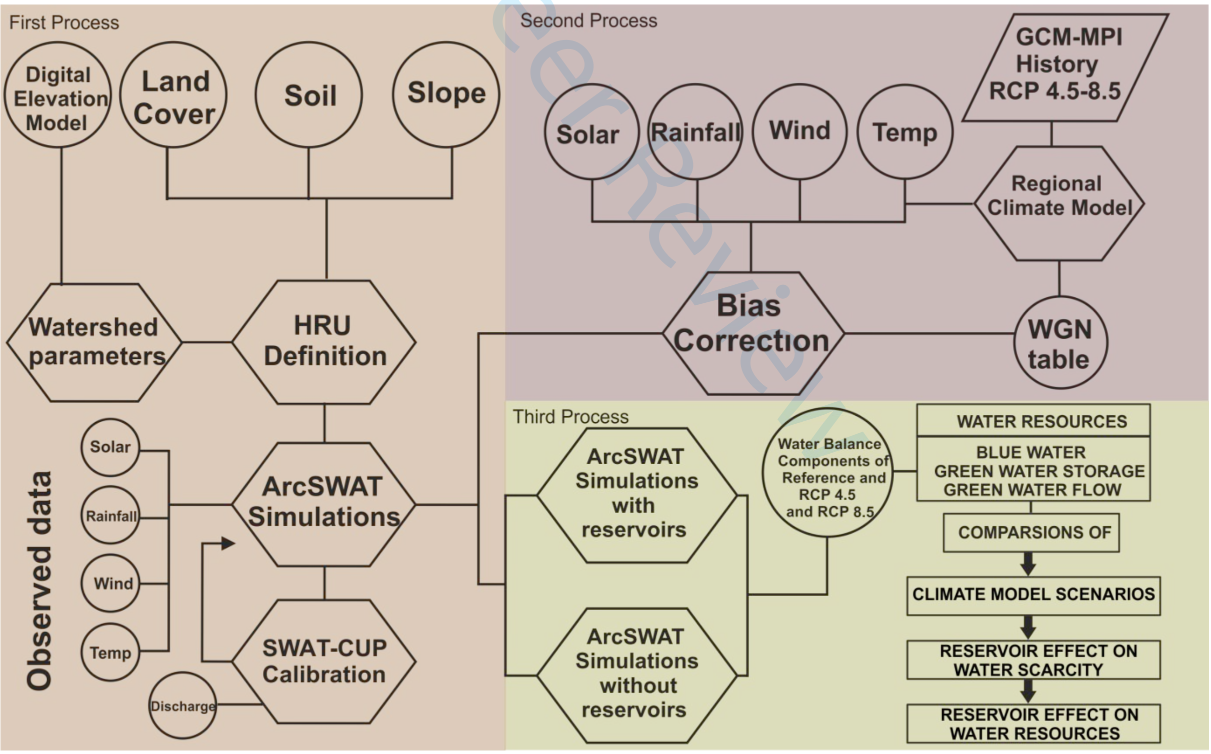
Figure 6. a) Histogram distributions of water resources of Susurluk Basin b) Error plots of water resources of Susurluk Basin based on reservoir and climate scenarios.

What about reservoirs? Questioning anthropogenic and climatic interferences on water availability

Abdullah Akbas*, Jim Freer, Hasan Ozdemir, Paul Bates, M. Tufan Turp

Finding

Nowadays, many studies only focus on climate change on water resources as part of hydrological studies. However, the role and cost of reservoirs on water resources has poorly investigated and quantified. In this study, we quantify the impact of these water infrastructures, as novelty, on water resources along with the impact of climate change under reservoir and climate scenarios



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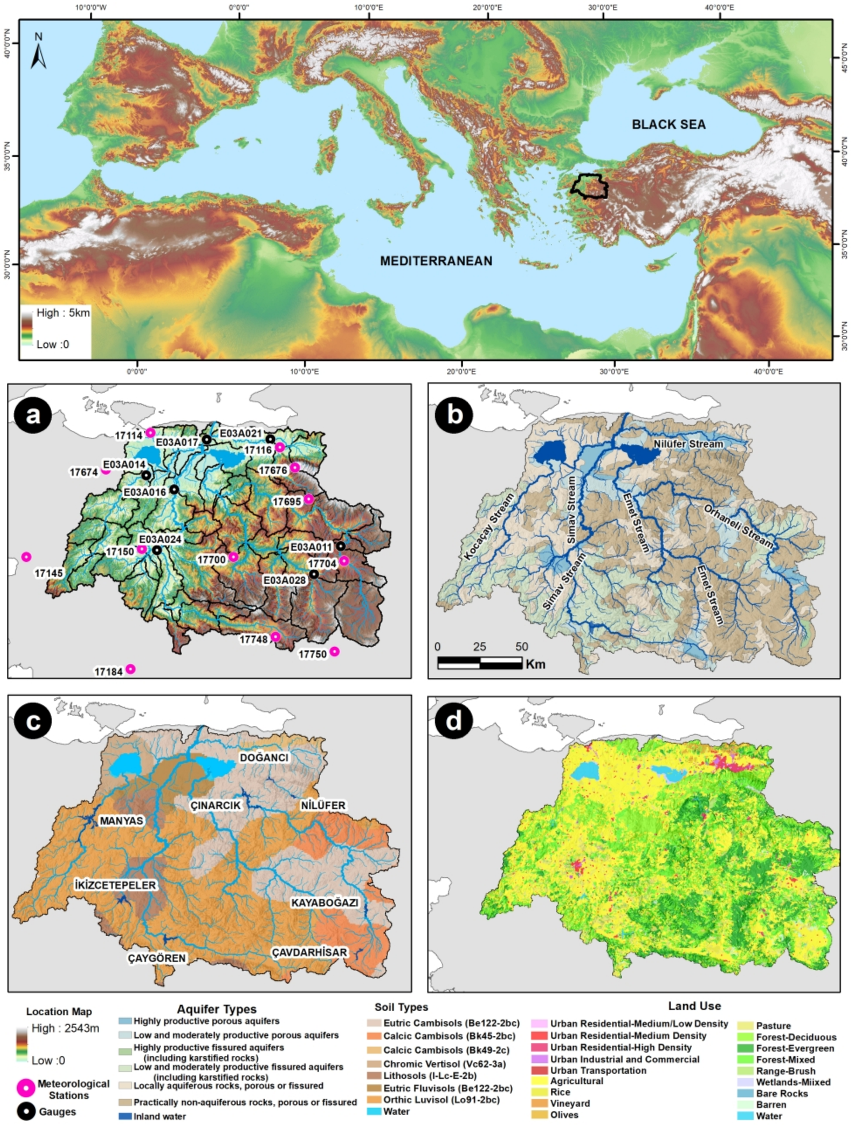

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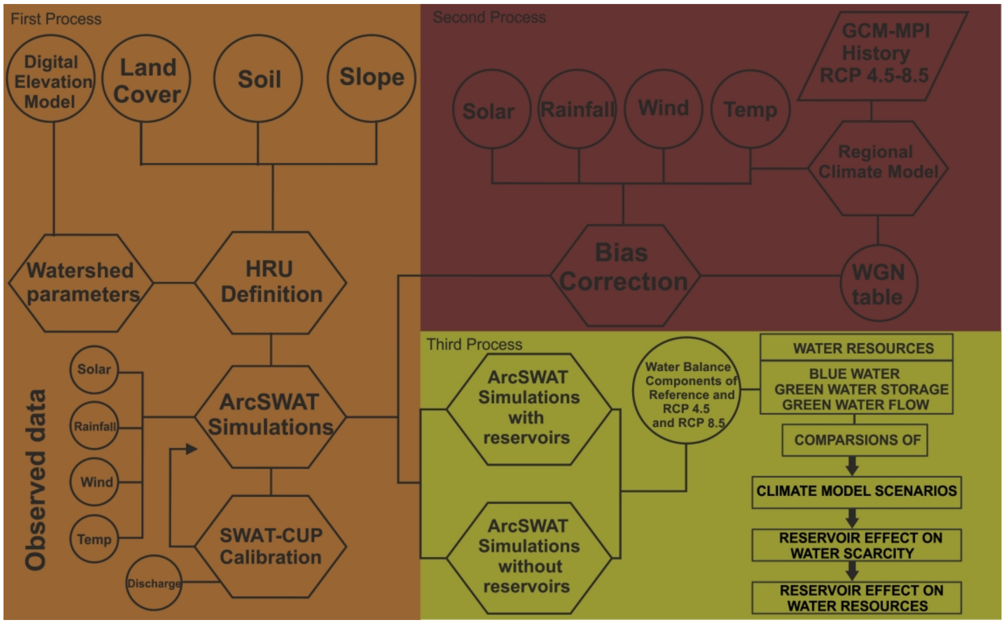

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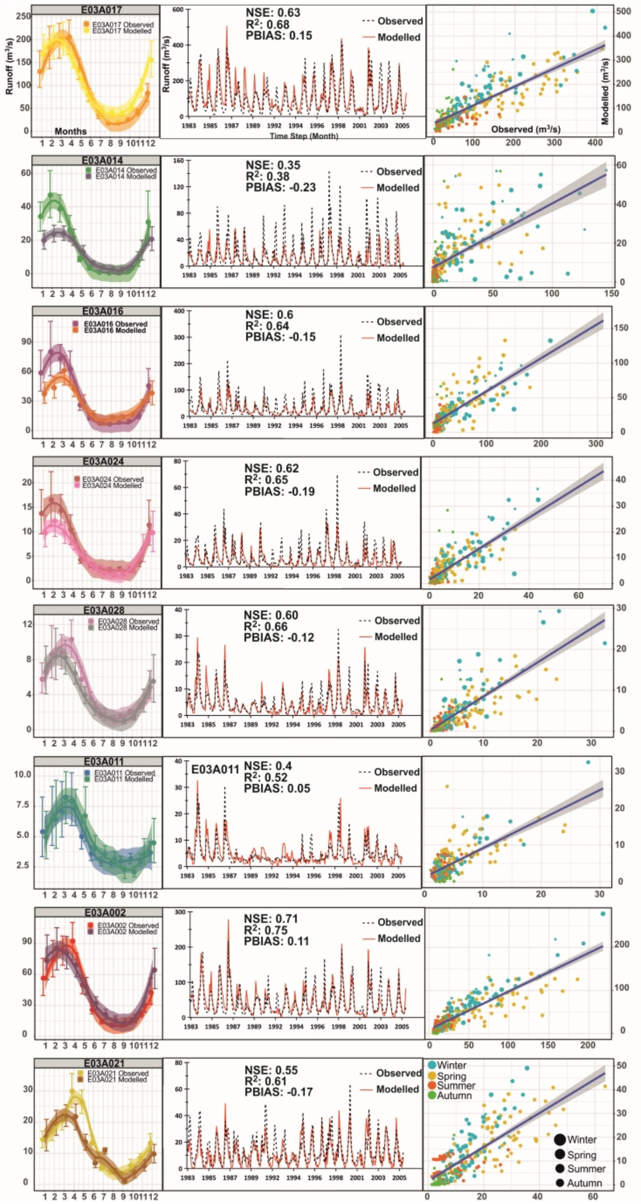

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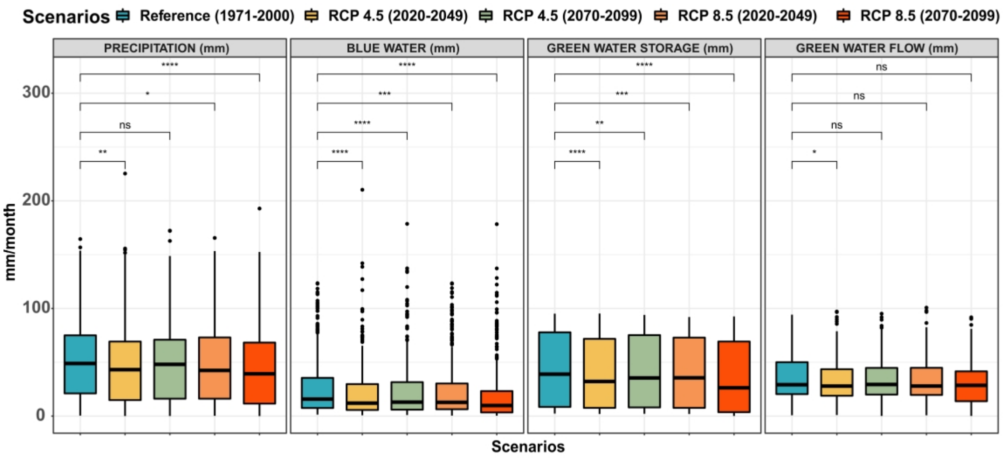

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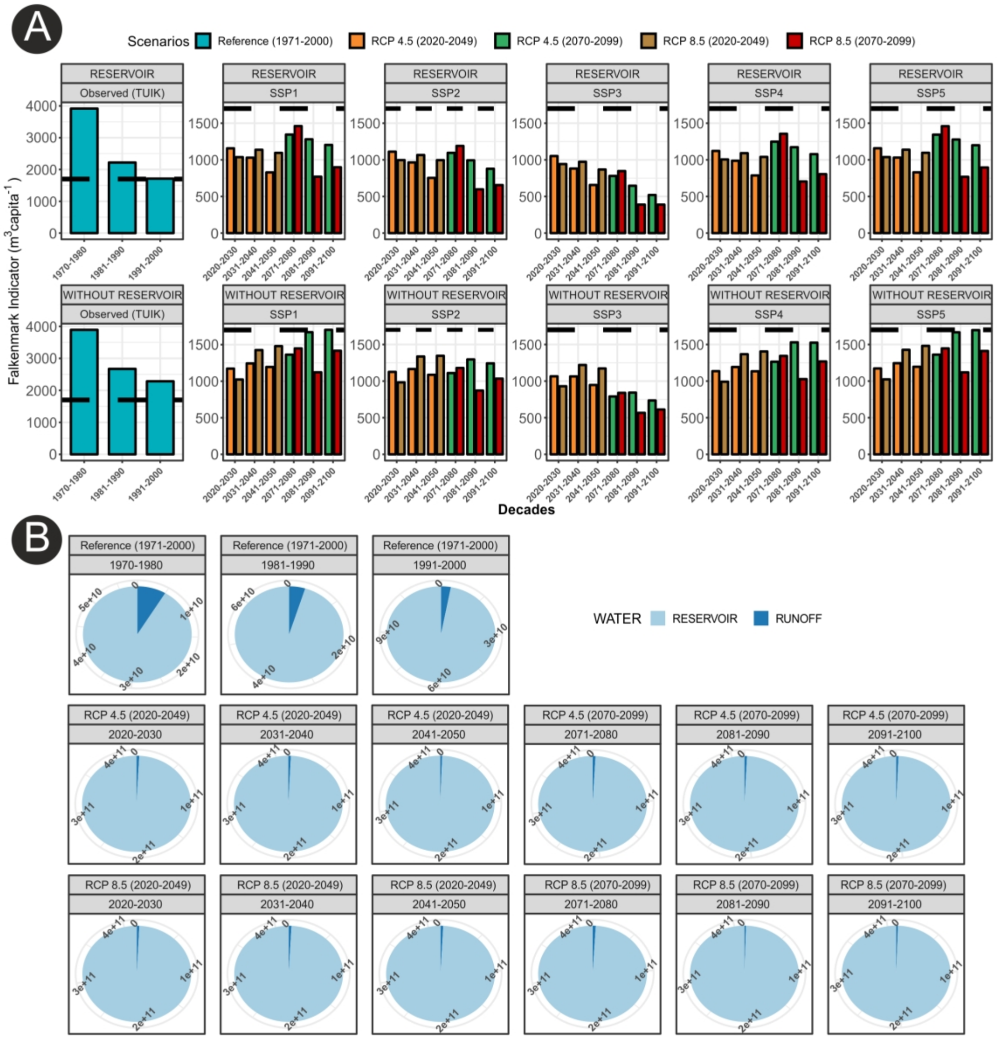

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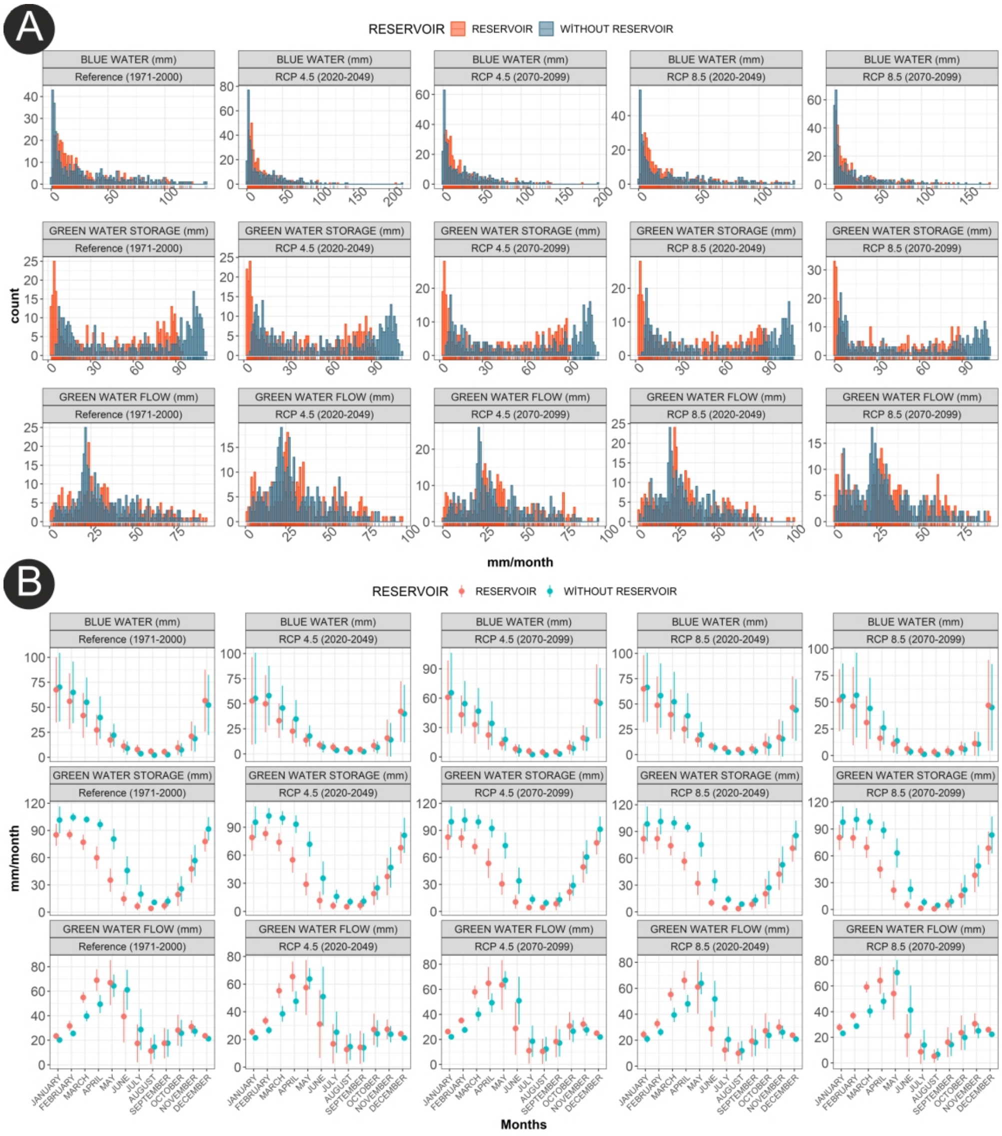

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Table 1. Calibrated parameters of the model gathered from SWAT-CUP for the Susurluk Basin

		Initial Ranges		Ultimate Ranges		Best Value
Name of Parameter	Method	Minimum Range	Maximum Range	Minimum Range	Maximum Range	
CN2.mgt	Relative	-0.2	0.2	-0.31	0.03	-0.14
ALPHA_BF.gw	Replace	0	1	0.27	0.81	0.54
GW_DELAY.gw	Replace	30	450	-53.04	282.44	114.70
GWQMN.gw	Replace	0	5000	-2063.57	2646.90	291.67
REVAPMN.gw	Replace	0	50	9.11	36.39	22.75
GW_REVAP.gw	Replace	0.02	0.2	-0.01	0.13	0.06
ESCO.hru	Replace	0	1	-0.21	0.60	0.19
SOL_AWC.sol	Relative	-0.2	0.2	-0.35	0.02	-0.16

Supplement for **"What about reservoirs? Questioning anthropogenic and climatic interferences on water availability"**

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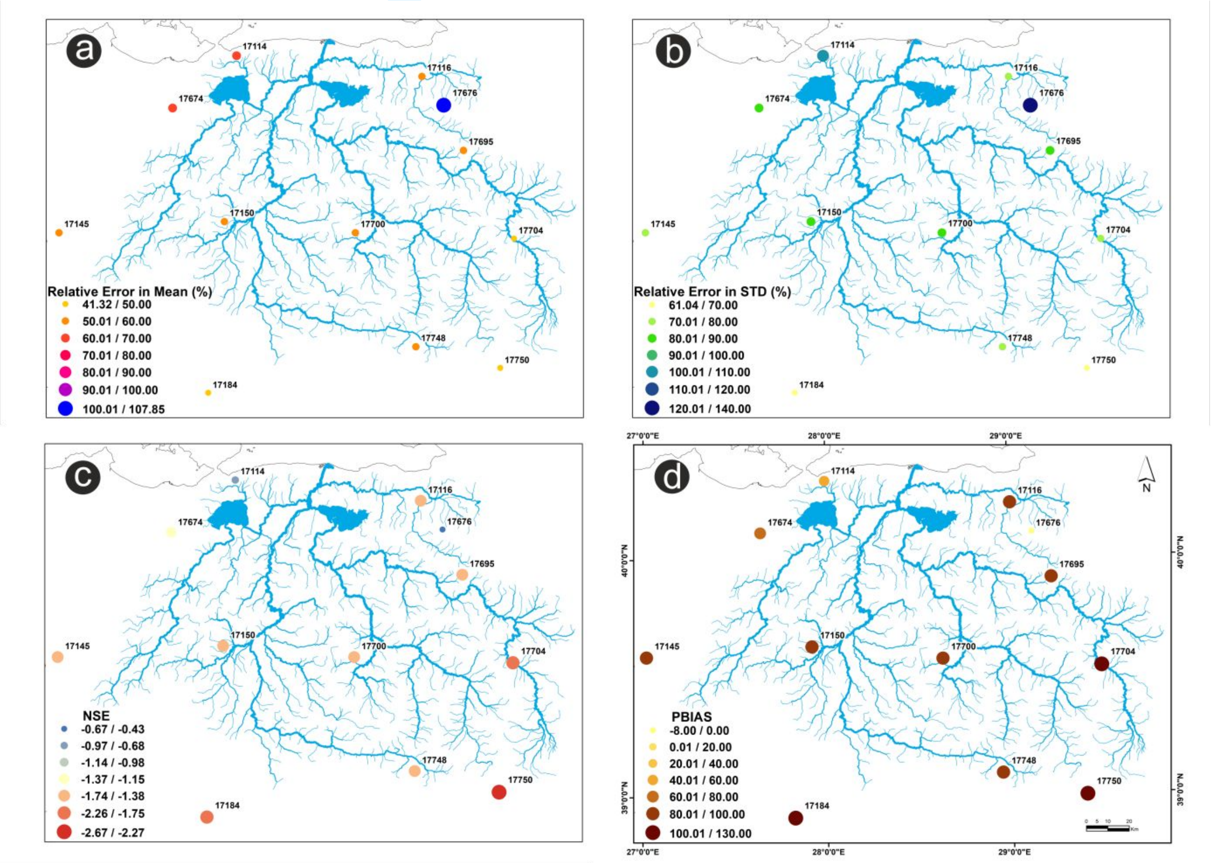
1. RegCM4.4 Regional Climate Model Description and Bias Correction

1.1. Model Description

The outputs of the MPI-ESM-MR global circulation model of the Max Planck Institute for Meteorology was selected and dynamically downscaled to 10-km horizontal resolution for Turkey via the regional climate model RegCM4.4 of the Abdus Salam International Centre for Theoretical Physics (ICTP). Afterwards, RCP4.5 and RCP8.5 scenarios have been selected as Representative Concentration Pathways (RCPs). These two pathways represent emission scenarios at different radiative forcing with 4.5 W/m² (middle case scenario) and 8.5 W/m² (worst case scenario or business-as-usual case) in the future (Van Vuuren et al., 2011). Reference (1971-2000) and future (2020-2049 and 2070-2099) periods were used to understand and compare the impact of climate change on water balance parameters in the Susurluk Basin. Here, the period of 2020-2049 was called mid-century and 2070-2099 was called late-century. All parameters that were applied in this study were daily scale. In order to get proper and reliable climate outputs for the domain, the regional climate model is parametrized using the options which are tested and suggested by previous studies (Almazroui, 2016; Almazroui, Islam, Al-Khalaf, & Saeed, 2015; Ozturk, Ceber, Türkeş, & Kurnaz, 2015; Turp, Ozturk, Türkeş, & Kurnaz, 2014). In this context, the regional climate model was run using the Fritsch-Chappell type closure (Fritsch & Chappell, 1980) of the Grell scheme (Grell, 1993) for convective (synoptic-scale dynamic or convective instability-induced rising air movements) cloud and precipitation formation mechanisms, and Holtslag parameterization (Holtslag, De Bruijn, & Pan, 1990) for the planetary boundary layer. Biosphere and Atmosphere Transfer Scheme (BATS) (Dickinson, Kennedy, & Henderson-Sellers, 1993) was also chosen as the land-surface scheme.

1.2. Bias Correction

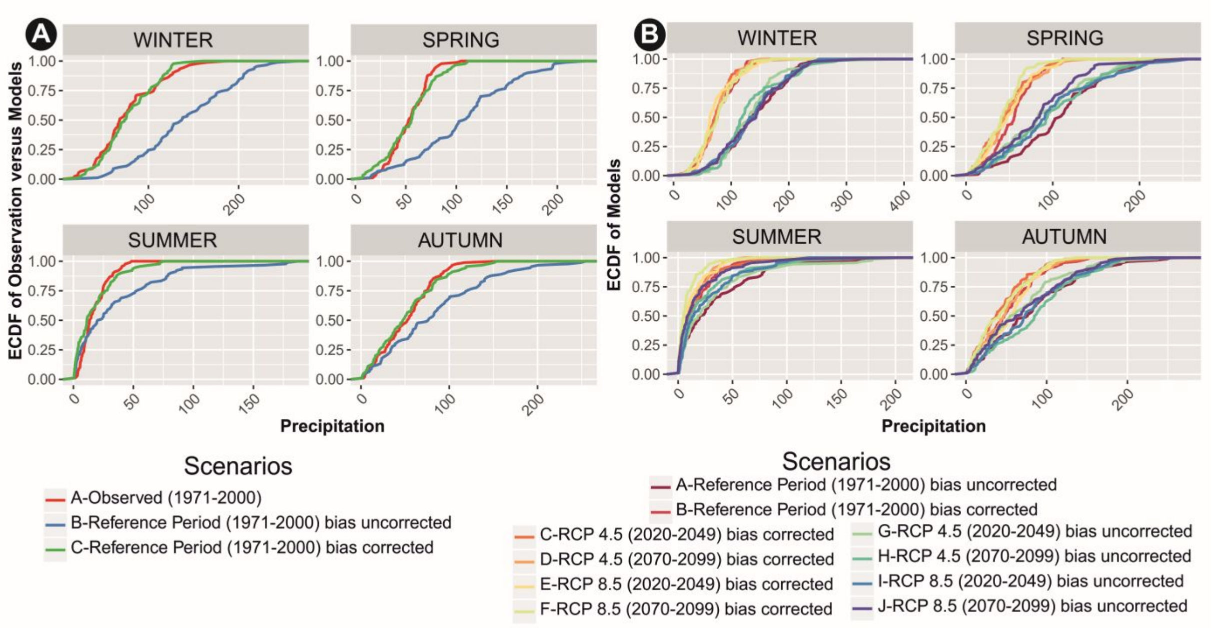
Bias correction for climate model outputs are another standout topic besides downscale problem due to uncertainty in outputs of climate model. Bias correction, which is especially important in impact studies, is still controversial, although various bias correction methods have been described in the literature for different variables and application areas (Ehret, Zehe, Wulfmeyer, Warrach-Sagi, & Liebert, 2012; Maraun, 2013; Maraun & Widmann, 2018; Teutschbein & Seibert, 2012). On the other hand, daily observed precipitation has been compared with projected precipitation from regional climate model in the Susurluk Basin to see the bias and it clearly demonstrates that all model results have overestimation or positive bias on precipitation values. The relative errors in mean for projected and observed precipitation indicate that model has enough capability to simulate mean values of precipitation for the basin. Similar circumstance has been obtained for standard deviations of precipitation (Figure S1).



FigureS1. The comparison of the projected precipitation from regional climate model and the observed precipitation data through a) Relative Error in Mean, b) Relative Error in Standard Deviation, c) NSE and d) PBIAS.

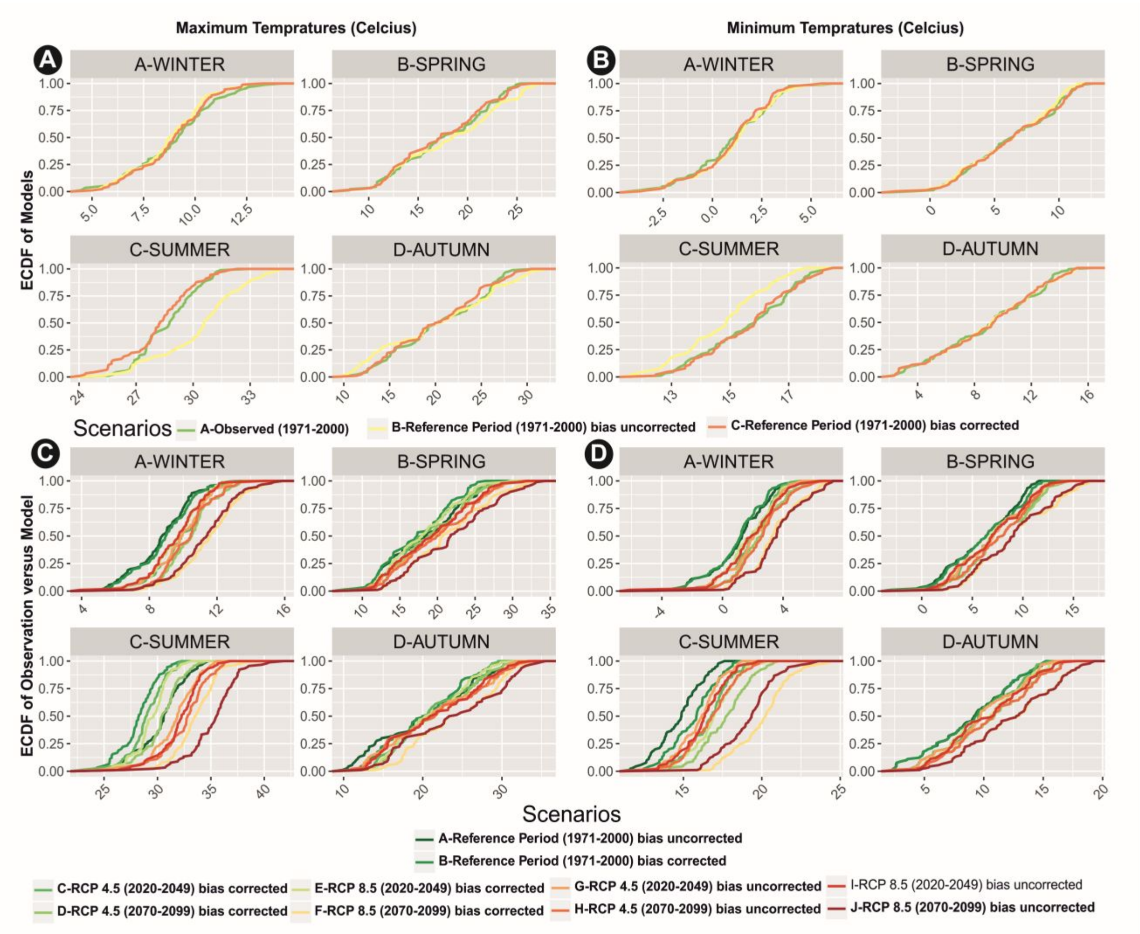
However, results of NSE and PBIAS for observed and projected precipitation in the basin have different characteristic than errors in mean and standard deviation, because time series has been compared in this method unlike relative error of mean and standard deviation. The results illustrate that projected values have significant positive bias around the basin except Uludağ station (17676) and coastal area. Generally, it can be said that the model excellently projects average conditions of precipitation in the basin, but whole time series of projected precipitation has positive bias apart from mountainous area where orographic processes are dominant differently from mid-latitude frontal systems.

Bias corrections have been performed according to the results of the comparisons of bias analysis on the rainfall and the maximum and minimum temperature values of the Susurluk Basin. Linear scaling factor (Lenderink, Buishand, & Deursen, 2007; Teutschbein & Seibert, 2012) was employed in order to eliminate over and under projection (bias) of the precipitation and temperature values of the Susurluk Basin by using the observed values, which was obtained from the meteorology stations of Turkish State Meteorological Service (TSMS). Based on observation, bias of precipitation and temperature was corrected for reference and future period. Both seasonal reference period and seasonal future with reference period of empirical cumulative distribution function (ECDF) was drawn to depict the corrections of precipitation and temperature values. ECDF graph of precipitation values has revealed that although summer and autumn has less bias than other seasons, precipitation values have positive bias in all seasons during the reference period. ECDF curve of bias corrected precipitation for reference period oscillates around of ECDF of observed precipitation after bias correction via linear scaling factor. ECDF curves of bias corrected and uncorrected RCP4.5 and RCP8.5 precipitations for future from only regional climate model has significantly shifted left side of uncorrected precipitation curves. Summer is the season that needs less bias correction because of less rain during this season (Figure S2).



FigureS2. The comparison of bias corrected and uncorrected precipitations a) for reference period and b) reference and future period of RCP4.5 and RCP8.5 scenarios.

Apart from precipitation, bias correction for minimum and maximum temperature of the Susurluk Basin was implemented and similar to precipitation, ECDF of bias corrected and uncorrected values minimum and maximum temperature were drawn as well. The results show that bias corrected minimum and maximum temperature in all seasons has no any significant change or shift after correction but summer, which is hottest and more drought season in the basin, for reference period. Therefore, regional climate model optimally projects the minimum and maximum temperature more than precipitation. RCP4.5 and RCP8.5 scenarios of minimum and maximum temperature feature similar behavior as reference period does. All future and reference scenarios of minimum and maximum temperature from regional climate model illustrate that climate model projection for this parameter has no significant change except summer as seen with observation. Apart from corrections, the results demonstrate that minimum and maximum temperature have moved right side of reference period even though they are corrected for bias. This can be indication of warming in basin according to results (Figure S3).



FigureS3. The comparison of bias corrected and uncorrected a) maximum b) minimum temperatures for reference period and bias corrected and uncorrected c) maximum d) minimum temperatures of reference and future period of RCP4.5 and RCP8.5 scenarios.

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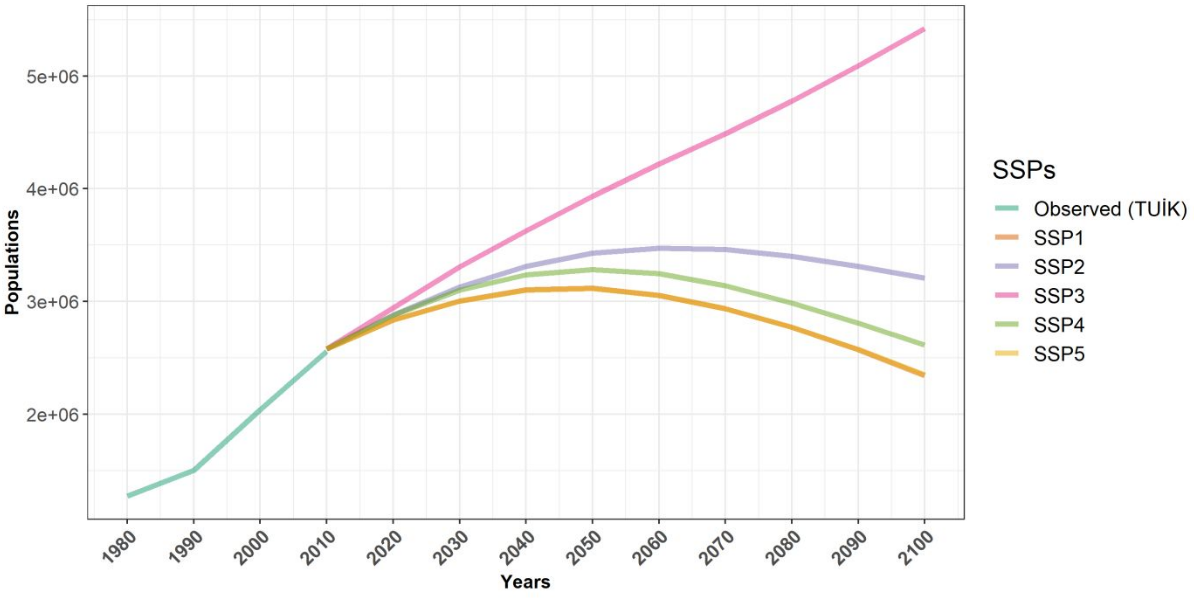
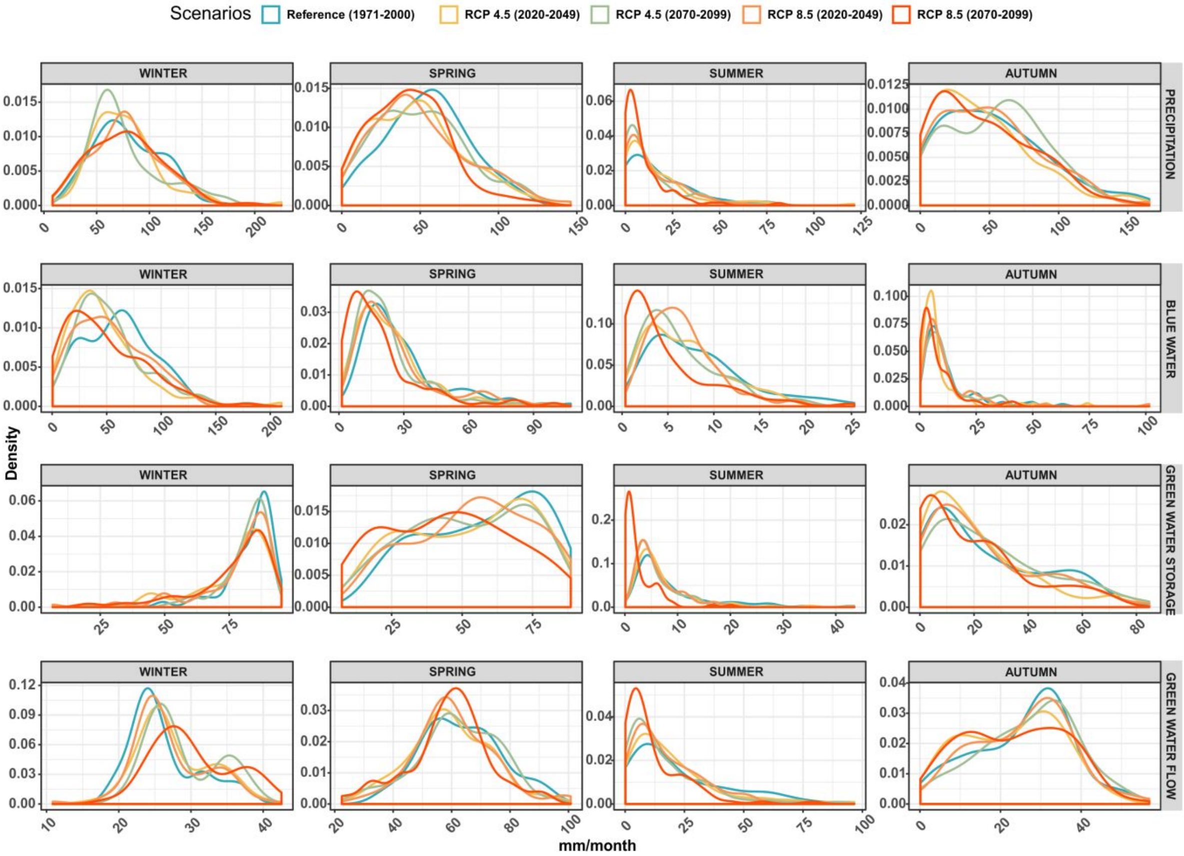


FigureS4. Projected population scenarios of Susurluk basin based on Shared Socioeconomic Pathways (SSPs).



FigureS5. Seasonal Kernel density function of water resources for the Susurluk Basin.