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Climate Change Impacts on Potential Groundwater Recharge in the Palas Basin, Turkey

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Abstract

Climate change poses a major threat for sustainability of groundwater resources. In this study, we aimed to determine how climate change can affect groundwater recharge potential in the Palas Basin. Palas Basin is a semi-arid closed basin located in Kayseri, in the central Anatolia region of Turkey. Agriculture is the major economic activity in the region and groundwater is used extensively for irrigation purposes. In this study, we estimated potential groundwater recharge for the Palas Basin under two representative concentration pathway (RCP) scenarios (RCP4.5 and RCP8.5) projected by the HadGEM2-ES, MPI-ESM-MR, GFDL-ESM2M global climate models. All models projected a decrease in mean annual potential groundwater recharge under the RCP8.5 scenario. Under the RCP4.5 scenario, the trends in annual potential groundwater recharge were downward according to the HadGEM2-ES and MPI-ESM-MR models but slightly positive according to the GFDL-ESM2M model. For the sustainability of groundwater system and agricultural activities in the basin, climate change adaptation strategies should be developed for the agricultural sector.

Key words

Climate Change, Groundwater Recharge Potential, Palas Basin

1. INTRODUCTION

Water resources sector is among the major sectors to be affected by climate change. Changes in climatic conditions can affect hydrologic characteristics of both surface waters and groundwater [1;2]. These changes, in turn, cause other effects such as the reduction of biological diversity, water quality changes, etc.

The effects of climate change on groundwater recharge have been investigated in a number of studies [3]. Net recharge and potential recharge were estimated based on climate projections. These studies showed that precipitation changes were mostly responsible for decreases or increases in groundwater recharge. Majority of the studies predicted a decrease in groundwater recharge [4;5;6;7]. Some other studies examined the effects of changes in evapotranspiration and land cover [7]. Increases in evapotranspiration and land cover changes, which increased impervious areas, also projected to cause decreases in groundwater recharge.

Turkey is among the countries, expected to be adversely affected by climatic changes. Turkey has diverse climatic conditions, changing from Mediterranean along the coasts to continental in central regions. Regions with different climatic characteristics can respond differently to climatic changes [8]. In coastal areas, changes in precipitation patterns can cause changes in frequency flood events [9;10]. In central regions, where continental climate prevails, decreases in precipitation can increase the frequency of droughts [10;11;12]. Previous studies showed that downward trends in precipitation have already been detected in central regions and these trends are expected to continue in the future [13]. The decreases in precipitation can affect the groundwater recharge [14]. The reductions in groundwater recharge, in turn, can have negative impacts on the agricultural sector and on groundwater-dependent ecosystems [9;10].

In this study, we examined the changes in potential groundwater recharge due to climate change in the Palas Basin, Kayseri, Turkey. We estimated potential groundwater recharge by considering hydrogeological characteristics of the Palas Basin and precipitation projections for the future. Precipitation projections developed with three global circulation models (HadGEM2-ES, MPI-ESM-MR, GFDL-ESM2M) under RCP4.5 and RCP8.5 scenarios were used in the analyses. This study can show the sensitivity of groundwater to climate change in the Palas Basin and in other semi-arid regions.

2. 2. METHODS

2.1. Study Area

This study was conducted in the Palas Basin, located in Kayseri, Turkey (Figure 1). The basin is a closed basin where the elevation changes between 1131 and 2120 m above sea level [15]. The average altitude of the basin is 1336 meters and it covers an area of approximately 100 km^2 [15].

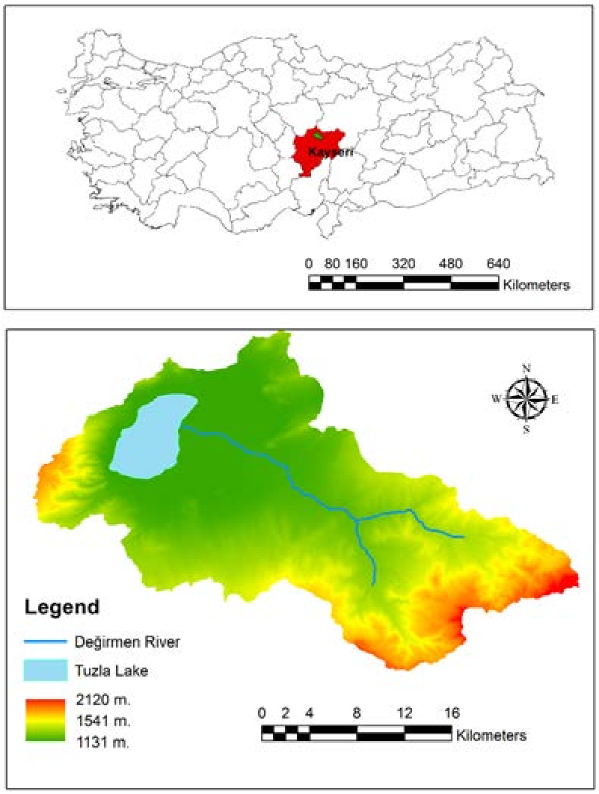

Figure 1: Location and physical and topographical characteristics of the Palas Basin

Figure 2 shows the geological characteristics of the Palas Basin. Mesozoic ophiolitic complex, sedimentary rocks, Mesozoic aged magmatic rocks, Eocene and Neogene aged sediments, Plio Quaternary clayey silty fine-grained sediments, Quaternary slope accumulation and alluviums can be identified in the basin. In general, geological formations in the Palas Basin can be divided into three main groups. These are Quaternary alluviums in the lake and its immediate surroundings, Tertiary aged formations spread over a wide area in the east of the basin and Mesozoic formations located in a narrow area in the southwest of the basin.

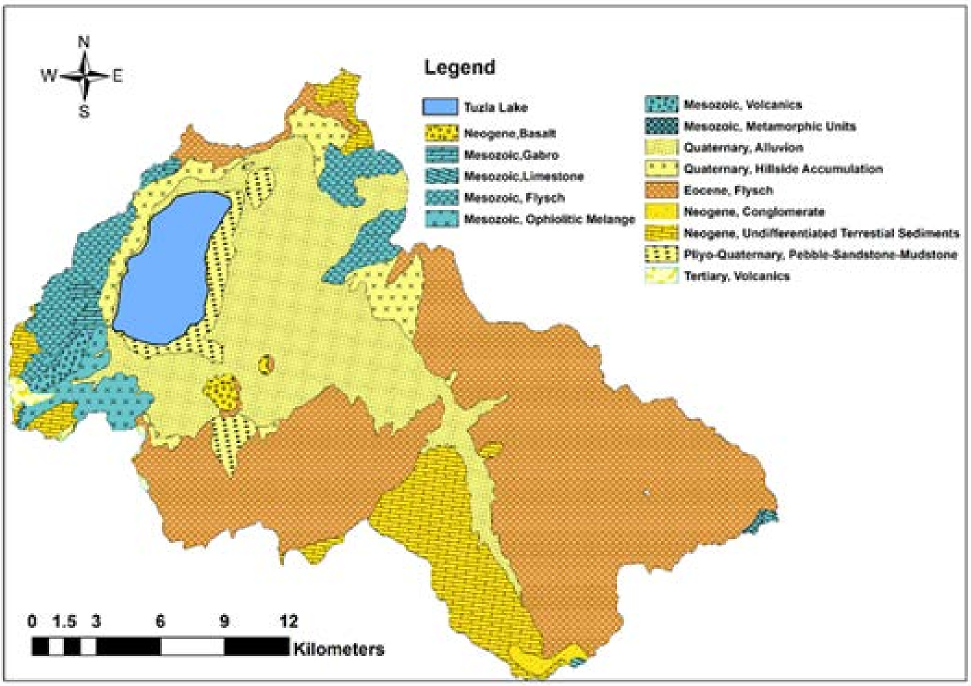

Figure 2: Geological characteristics of the Palas Basin [16]

The climate is semi-arid with an annual average temperature of about 11°C and the annual precipitation of 400 mm. Surface water resources are scarce in the basin. There is a small stream, Değirmen River, flows from southeast to northwest and discharges into Tuzla (Palas) Lake, located to the west of the basin. In summer months, the stream becomes completely dry and is lost before reaching the lake. Tuzla Lake is a saline playa lake, fed by rainfall and surface and groundwater flows. It is the second largest saline lake in Turkey and is a nature conservation area due to its ecological characteristics.

Agriculture is the major economic activity in the region and other economic activities are animal husbandry and salt extraction. Groundwater is the major water source used for irrigation activities. In irrigated areas, maize, sugar beets and vegetables are cultivated. Cereals are common in unirrigated areas.

2.2. Estimating Potential Groundwater Recharge

Potential groundwater recharge was estimated according to Equation 1, based on lithological classes and precipitation.

$$R=\sum_{i=1}^{n} P A_i I_i \qquad (1)$$

In Equation 1, R is expressed as the potential recharge (m^3/year), A is the area of each lithological unit (I) (m^2), P is the annual precipitation (m/year), n is the total number of lithological units. I represents the percolation coefficient for each lithological unit. The area of each lithological unit was estimated from the geological map given in Figure 1. The percolation coefficients for each lithological unit was estimated as given in Table 1 [16].

Table 1: Lithological units, their areal coverages and percolation coefficients [16]

Lithological Class	**Area (km^2)**	**Lithological Percolation**
Quaternary, Alluvium	105.18	0.15
Quaternary, Hillside Accumulation	9.15	0.05
Pliyo-Quaternary, Pebble, Sandstone, Mudstone	5.62	0.10
Neogene, Basalt	2.27	0.10
Neogene, Unconsolidated Terrestrial Sediments	15.99	0.05
Eocene, Flysch	59.64	0
Mesozoic, Flysch	5.80	0
Mesozoic, Ophiolitic Melange	0.13	0

2.3. Climate Projections

We obtained precipitation projections in daily timescale from the Turkish State Meteorological Service (MGM). MGM produced downscaled precipitation data by using input from three Global Circulation Models, GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR, for two representative concentration pathways (RCPs): RCP 4.5 and RCP 8.5. The data were downscaled with the RegCM4.3.4 Regional Model by MGM based on the 1971-2000 reference period [17]. GFDL-ESM2M model is produced by Geophysical Fluid Dynamics Laboratory (United States) with a resolution of 2.5° × 2.0°. HadGEM2-ES model is produced by Met Office Hadley Centre (United Kingdom). It has resolution of 1.875° × 1.250°. MPI-ESM-MR is run by Max Plank Institute (Germany) with 1.865◦×1.875◦ resolution. The RCP 4.5 assumes that greenhouse gas concentration will peak around 2040, then decline from the mid-century, while the RCP8.5 assumes that greenhouse gas concentration increasing until the 21st century. The projections for the 2021-2098 period were used in the analyses.

3. RESULTS

In this study, potential groundwater recharge was calculated for the 2021-2098 period based on RCP4.5 and RCP8.5 scenarios from the HadGEM2-ES, MPI-ESM-MR, GFDL-ESM2M models. RCP4.5 was the scenario with lower carbon emissions on a global scale and it is the scenario, targeted globally. RCP8.5, on the other hand, is the scenario with higher carbon emissions and is farther from the target point.

Below, we first present projected precipitation changes under RCP4.5 and RCP8.5 scenarios with HadGEM2-ES, MPI-ESM-MR, GFDL-ESM2M models. Then, we discuss projected changes in potential groundwater recharge.

3.1. Changes in Precipitation from 2021 to 2098

Annual precipitation data estimated based on RCP4.5 and RCP8.5 scenarios from 2021 to 2098 with HadGEM2-ES, MPI-ESM-MR, GFDL-ESM2M models were shown in Figure 3.

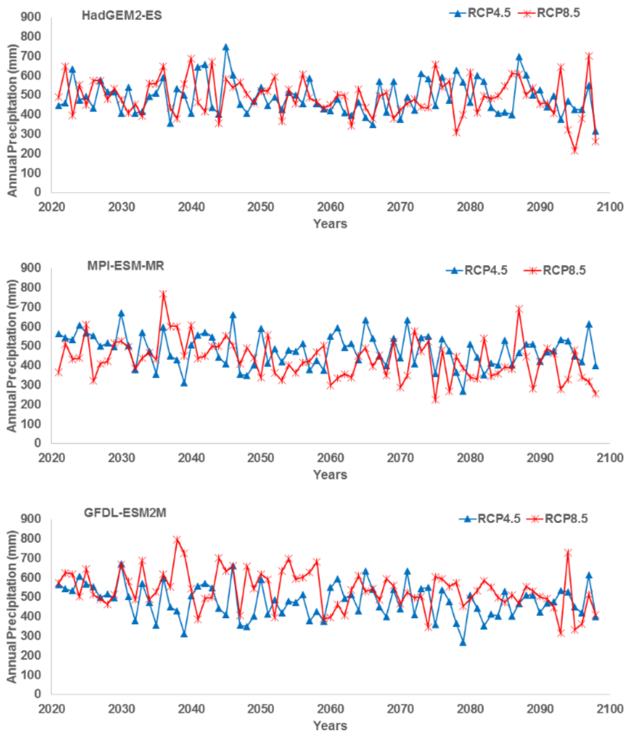

Figure 3: Projected annual precipitation from 2021 to 2098

We estimated the trends in precipitation series using the linear regression method. According to the HadGEM2-ES and MPI-ESM-ER models, downward trends were detected under both RCP4.5 and RCP8.5 scenarios. GFDL-ESM2M model estimated a slightly positive trend under the RCP4.5 scenario but downward trend under the RCP8.5 scenario. The trends detected for RCP8.5 scenarios with GFDL-ESM2M and MPI-ESM-ER models were statistically significant at the 0.01 level.

Table 2: Trends in precipitation series and their statistical significance

Precipitation	RCP4.5		RCP8.5	
	Trend (mm/year)	P Value	Trend (mm/year)	P Value
HadGEM2-ES	-0.26	0.558	-0.75	0.126
MPI-ESM-ER	-0.80	0.062	-1.55	0.002
GFDL-ESM2M	0.11	0.851	-1.51	0.002

We also analyzed precipitation data for the 2021-2040 (near future), 2041-2070 (medium future) and 2071-2098 (distant future) periods. Compared to the 2021-2040 period, mean annual precipitation is predicted to decrease by 46.9 mm (%8.67) (GFDL-ESM2M), 1.7 mm (%0.35) (HadGEM2-ES), and 25.3 mm (%5.01) (MPI-ESM-ER) during the 2041-2070 period according to the RCP4.5 scenario. The decrease would be 0.1 mm (%0.02) (GFDL-ESM2M) and 42.3 mm (%9.11) (MPI-ESM-ER) from the 2021-2040 to the 2071-2098 period. HadGEM2-ES estimated a slight increase of 12.3 mm (%2.54) in the 2071-2098 period compared to the 2021-2040 period.

According to the RCP8.5 scenario, mean annual precipitation during the 2041-2070 period would decrease by 33.8 mm (%5.80) (GFDL-ESM2M), 29.6 mm (%5.80) (HadGEM2-ES), and 66.1 mm (%13.50) (MPI-ESM-ER) compared to the 2021-2040 period. GFDL-ESM2M, HadGEM2-ES and MPI-ESM-ER models predicted that the annual precipitation would be 82.17 mm (%14.20), 32.86 mm (%6.4), 89.9 mm (%18.40) lower from 2021-2040 to the 2071-2098 period. As can be seen from these results, precipitation predicted with RCP8.5 scenarios are lower than those predicted by RCP 4.5 scenarios.

3.2. Changes in Potential Groundwater Recharge from 2021 to 2098

Precipitation values produced by three models, GFDL-ESM2M, HadGEM2-ES and MPI-ESM-ER, were used as input for estimating potential groundwater recharge under the RCP4.5 and RCP8.5 scenarios. Changes in potential groundwater recharge from 2021 to 2098 are shown in Figure 4.

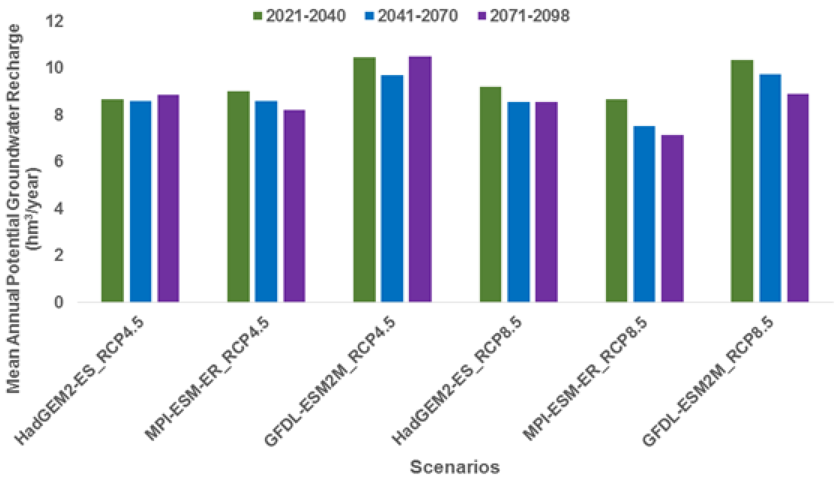

Figure 4: Potential groundwater recharge under the RCP4.5 and RCP8.5 scenarios

Compared to the 2021-2040 period, mean annual potential groundwater recharge is predicted to decrease by 0.78 hm^3 (%7.42) (GFDL-ESM2M), 0.09 hm^3 (%1.02) (HadGEM2-ES), and 0.44 hm^3 (%4.87) (MPI-ESM-ER) during the 2041-2070 period according to the RCP4.5 scenario. The increase would be 0.02 hm^3 (%0.23) (GFDL-ESM2M), 0.18 hm^3 (%2.13) (HadGEM2-ES) while we expect a decrease of 0.80 hm^3 (decrease %8.87) with MPI-ESM-ER from the 2021-2040 to the 2071-2098 period.

According to the RCP8.5 scenario, from the 2021-2040 to the 2041-2070 period, the average annual potential groundwater recharge decrease would be 0.61 hm^3 (5.90%) (GFDL-ESM2M), 0.62 hm^3 (6.70%) (HadGEM2-ES), and 1.11 hm^3 (12.80%) (MPI-ESM-ER). In the RCP 8.5 scenario, the decrease from 2021-2040 to 2071-2098 is 1.47 hm^3 (14.20%) (GFDL-ESM2M), 0.65 hm^3 (7.10%) (HadGEM2-ES), 1.50 hm^3 (17.40%) (MPI-ESM-ER). Figure 4 shows that potential groundwater recharge values in the RCP4.5 scenario in GFDL-ESM2M and MPI-ESM-ER projections are higher than those in the RCP8.5 scenario.

We estimated the trends in annual potential groundwater recharge using the linear regression method. According to the data obtained from the HadGEM2-ES and MPI-ESM-ER models, downward trends were detected both under the RCP4.5 and RCP8.5 scenarios. GFDL-ESM2M model estimated a slightly positive trend under the RCP4.5 scenario but downward trend under the RCP8.5 scenario. The trends detected for the RCP8.5 scenario with GFDL-ESM2M and MPI-ESM-ER models were statistically significant at the 0.01 level.

Table 3: Trends in annual potential groundwater recharge series and their statistical significance

Potential Recharge	RCP4.5		RCP8.5	
	Trend (m^3/year)	P Value	Trend (m^3/year)	P Value
HadGEM2-ES	-4063	0.572	-14767	0.087
MPI-ESM-ER	-13901	0.092	-25580	0.002
GFDL-ESM2M	2999	0.784	-26828	0.002

4. CONCLUSIONS

In this study, we used precipitation projections from three different global circulation models – GFDL-ESM2M, HadGEM2-ES and MPI-ESM-ER, to understand how potential groundwater recharge can change in a semi-arid agricultural basin from 2021 to 2098. The analyses were based on two RCP scenarios; RCP4.5 and RCP8.5. RCP4.5 scenario can be defined as a scenario where the factors triggering global warming are more under control. Two models HadGEM2-ES and MPI-ESM-ER projected a downward trend in potential groundwater recharge values from 2021 to 2098 under the RCP4.5 scenario. Only GFDL-ESM2M model projected a slight upward trend under the RCP4.5 scenario. RCP8.5 scenario assumes a situation where the factors triggering global warming are more intense. Under the RCP8.5 scenario, the annual potential groundwater recharge values went down from 2021 to 2098 and the downward trends were much stronger than the ones detected with the RCP4.5 scenario.

As a result, potential groundwater recharge is expected to decrease in the Palas Basin. A reduction in potential groundwater recharge means that groundwater to be used for agricultural purposes will become more limited. This situation can have social and economic consequences for the region. Groundwater is also important for the Tuzla Lake ecosystem. A decrease in precipitation and groundwater recharge can have adverse effects on the hydrological and ecological characteristics of Tuzla Lake ecosystem.

In order to maintain the hydrological balance in the region under changing climatic conditions, measures should be taken to reduce water use in irrigation. This can be achieved by changing irrigation technologies and crop types or using different irrigation scheduling and water saving technologies. The results obtained in this study can be helpful for more comprehensive studies such as net recharge calculation, surface water modeling, socio-economic modeling.

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