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Determining the Relationship of Evapotranspiration with Precipitation and Temperature Over Turkey

Mustafa KUZAY[a*], **Mustafa TUNA**[b], **Mustafa TOMBUL**[c]

[a]*Eskişehir Osmangazi University, Department of Civil Engineering, 26040, Odunpazarı, ESKİSEHİR*

[b]*Ankara University, Faculty of Applied Sciences, Real Estate Development and Management Department, ANKARA*

[c]*Eskişehir Technical University, Department of Civil Engineering, 26555, Tepebaşı, ESKİSEHİR*

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Corresponding Author: Mustafa KUZAY, E-mail: kuzaymustafa@hotmail.com
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ABSTRACT

Evapotranspiration (ET), which is a combination of the words evaporation and transpiration, is expressed as the sum of water due to water consumption and evaporation in plants. In this study, the NASA Drought Early Warning Systems Network Land Data Assimilation System model (FLDAS NOAH) was used to determine evapotranspiration data for the 2018-2019 water years (October 2017-September 2019) on Turkey. In addition, NASA Global Land Data Assimilation System (GLDAS NOAH) was used for temperature data. Total precipitation data with corrected error rates are taken from MERRA-2 Model M2TMNXFLX. The relationship between the determined monthly total average evapotranspiration values and the monthly average precipitation and monthly average temperature values was determined by ArcGIS. It is important to examine the local evaporation and transpiration conditions in more detail in the regions where water resources planning will be made. The importance of water holding capacity in plants in determining agricultural and hydrological drought can be explained by evapotranspiration.

Keywords: *Drought, Hydrology, Climate Change, LDAS, FLDAS NOAH, GLDAS NOAH*

1. Introduction

One of the important hydrological processes in the planning of water resources is evaporation. Evaporation is defined as the transition of water from liquid to gas at temperatures below the boiling point of water, according to the World Meteorological Dictionary (WMO 2012). Evapotranspiration is one of the most important factors in understanding global hydrological budgets and is crucial to understanding accurate estimated water balance and developing efficient water resource management plans (Park & Choi 2015).

Water losses with the transformation into water vapor from the water surface are called evaporation, the loss of water from plants is called transpiration, and the loss of water from plants and the soil-water surface is called evapotranspiration. According to the studies conducted, approximately 90% of the water vapor in the atmosphere is due to evaporation and the remaining 10% is caused by the transpiration of plants (USGS 2019). Every water surface on earth is the source of water vapor in the atmosphere. Continuous evaporation occurs on almost all surfaces. Since the water cycle in the atmosphere is constant, the amount of water evaporating and the amount of water returning to the earth are approximately equal. However, this water cycle is not the same everywhere. On land surfaces, precipitation is more than evaporation, while on ocean surfaces, evaporation is more than precipitation (MGM 2019). However, in evaporation; meteorological factors (solar radiation, air vapor pressure, wind, temperature and pressure), geographical factors (latitude, altitude, aspect) and the quality and environment of the water are very important factors (MGM 2019).

Climate change is defined as "changes in the mean state and/or variability of the climate over a period of decades or more, regardless of the cause" (MGM 2019). The effects of climate change show not only with the increase in temperature, but also with consequences such as floods, drought, severe floods, increases in ocean and sea levels, increase in acidity in the oceans, which can develop suddenly and have great damage. For this reason, a detailed evaluation with a proactive method (long-term measurements, data analysis, trend analysis, spatial data analysis, etc.) is required. Evapotranspiration, precipitation, flow and temperature conditions are very important in the impact of climate change on the water cycle.

As an example of previous studies on this subject; remote sensing and spatial data has been performed for the evapotranspiration estimation and the result has been reached by correlating the experimental methods with the predicted values. Distributed hydrological model is used in the study. The process had a significant impact not only on the water table, but also on soil moisture and saturated water redistribution. This demonstrated the importance of modeling hydrological processes in mapping evapotranspiration. Drought indices based on thermal remote sensing of evapotranspiration have been evaluated. Drought indices based on remotely sensed evapotranspiration were determined by PALMER and SPI methods and a comparison was made between drought classifications reported in USDM from 2000 to 2009. As a result, it has been determined that potential evaporation can achieve clearer results in drought determination (Chen et al. 2005; Anderson et al. 2011).

Vegetation index and land surface temperature value were used to reflect these values measured at a measurement point where evapotranspiration and potential evapotranspiration are continuously measured at 10% error value to large areas. Between evapotranspiration and Vegetation Index, high accuracy has been determined in agricultural areas and natural ecosystems. In addition, modeling was supported by observations. It has been shown that this could be an achievable target if ground observations for measuring ET continue to improve. On the basis of the Priestley-Taylor equation combined with the time series and NDVI field, the surface temperature-Normalized Difference Vegetation Index feature area, MODIS (Medium Resolution Imaging Spectroradiometer) products and GLDAS (Global Land Data Assimilation System) were used to determine meteorological data. It was calculated using Tekesi River Basin as a pilot area. In addition, heat flow and Bowen Ratio were used for comparison between measurements. All these inputs were used to calculate ET and to identify anomalies. In addition, it has been determined that the effect of cloud formation during the day is very important for calculating ET (Glenn et al.2007). GLDAS data gave very successful results in areas where ET could not be determined by measurements (Du & Sun 2012).

Large-scale changes in continental water storage from satellite gravity data from the Gravity Recovery and Climate Experiment (GRACE) project were combined with river discharge data to obtain regionally average P-ET estimates. Additionally, the GRACE model has been compared and validated with the GLDAS. The GRACE model was compared seasonally and monthly to verify the model outputs (Swenson & Wahr 2006).

In this study, evapotranspiration losses due to precipitation and temperature were tried to be determined with spatial data and evaluations were made in certain periods in terms of hydrological and agricultural drought in Turkey.

2. Material and Methods

2.1. Study area

Turkey (36˚-42˚ N, 26˚-45˚ E) was chosen as the study area. More than half of the surface area of Turkey composed of a high area exceeding 1000 meters above sea level. Turkey elevation map was prepared using ArcGIS (Figure 1). Approximately thirty percent are covered with medium-high plains, plateaus and mountains, and ten percent with low areas. High and mountainous areas are mostly in the east of the country. The peak of Mount Ağrı, reaching 5137 meters, is the highest point in the country. The main wide plains are Konya Plain, Çukurova and Harran Plain. Kızılırmak, with a length of 1355 kilometers, is the longest river within the borders of the country. Covering an area of 3713 km², Lake Van is the largest natural lake in the country. Spreading over an area of 817 km², Atatürk Dam Lake is the largest artificial lake in the country. The total area of land masks is 770 760 km², and the total area of water areas is 9 820 km² (Cografya 2019).

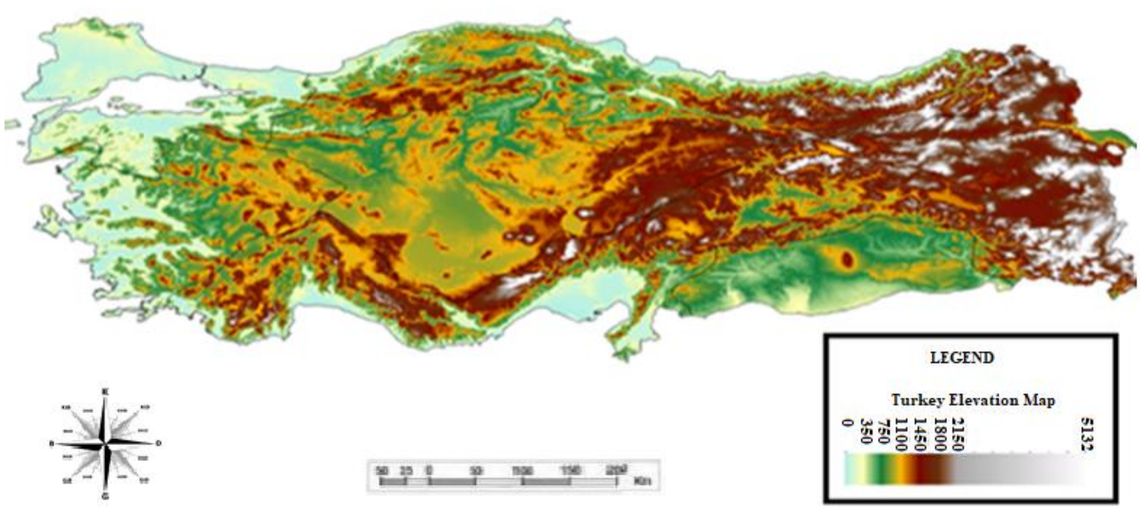

Figure 1- Elevation map of Turkey (SRTM DEM)

2.2. Spatial data

In this study, all data for the 2018-2019 water year period were obtained with Giovanni software (v 4.32), which is an environment in the NASA Earth Data system and where the resource (data line) is easily accessible. Giovanni provides an online environment for the display and analysis of geophysical parameters (GSFC 2019).

The NASA Geosciences Data and Information Services Center (GES DISC) provides access to LDAS datasets using multiple methods and the ability to sub-cluster spatial, temporal and variable. These datasets can also be accessed via Giovanni v4.32. Giovanni is an online application developed by GES DISC that allows researchers to quickly explore data so that spatial-temporal variability, anomalous conditions and patterns of interest can be analyzed online, optionally before downloading the data. Supported download formats include NetCDF, GeoTIFF and KMZ (Rodell et al. 2004).

Monthly Average Evapotranspiration was determined by FLDAS NOAH Model, monthly average surface temperature was determined by GLDAS NOAH Model and total precipitation with error rates corrected was determined by MERRA-2 M2TMNXFLX Model. Time-averaged maps of these three models were drawn every month in the 2018-2019 water years and compared. The FLDAS Model for ET (0.1 degree × 0.1 degree spatial resolution) was also compared with the GLDAS Model (0.25 degree × 0.25 degree spatial resolution) at specified times.

Evapotranspiration data, temperature data and precipitation data were determined with Giovanni software (v 4.32). Monthly Average Evapotranspiration was determined by FLDAS NOAH Model, monthly average surface temperature was determined by GLDAS NOAH Model and total precipitation with error rates corrected was determined by MERRA-2 M2TMNXFLX Model.

FLDAS is the Drought Early Warning Systems Network (FEWS NET) Land Data Assimilation System. FLDAS is a specific example of the NASA Land Information System (LIS) adapted to work with domains, data streams and monitoring. The aim of the FLDAS project is designed to enable more efficient use of limited available hydro-climatic observations and adopt them for routine use in FEWS NET decision support. The evapotranspiration unit in FLDAS is kg/m^{2}s. However, with the operations in the GIS software, the evapotranspiration unit was converted to mm. The FLDAS model used in the study was taken as monthly data and it has a spatial scale of 0.1 degrees. FLDAS model has a data set for each latitude and longitude in global spatial scope from January 1981 until today. Data sets obtained from satellite measurements and atmospheric analyses are created in the model, and height description information is provided via SRTM. The definition of the ground is explained by the model defined by Reynolds, Jackson and Rawls in 1999. In addition, the land mask was defined with MODIS and land surface models were defined according to NOAH 3.6.1. (Loeser et al. 2020).

The purpose of the GLDAS is to obtain satellite and ground-based observational data products using advanced terrain surface modeling and data assimilation techniques to produce optimal areas of land surface states and fluxes. GLDAS processes terrain surface models, combines large amounts of observation-based data, operates globally at high resolutions and is capable of generating results in near real time. Simulations of NOAH, CLM, VIC, MOSAIC (spatial data models) and basin surface models have been supported by surface meteorological data and parameter maps that have been modelled and observed since 1948. In the GLDAS model, the evapotranspiration unit is kg/m^{2}s. However, with the operations in the GIS software, the evapotranspiration unit was converted to mm. In addition, for the monthly average surface temperature used in the study, the GLDAS Model was used and Celsius was determined as the unit. The GLDAS model used in the study was taken as monthly data and has a spatial scale of 0.25 degrees. In the model, multiple data sets obtained from satellite measurements and atmospheric analyzes are provided since January 1948 at each latitude and longitude in all areas up to 60 degrees north. The height definition is explained by the GTOPO30 model, for the ground definition the model defined by Reynolds, Jackson and Rawls in 2000 is used. Land surface models are provided by Mosaic, CLM2, NOAH, VIC and Catchment LIS, and GRIB, NetCDF, ASCII and GDS are used as output format (Fang et al. 2009). GLDAS and FLDAS offer spatial data all over the world (Fang et al. 2009; Loeser et al. 2020).

Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA-2) is an atmospheric re-analysis using GEOS-5 as a result of combining Atmospheric Data Assimilation System (ADAS) and Goddard Earth Observation System Model. The MERRA project focuses on historical analysis for time scales of a wide variety of weather and climate events. It gives effective results all over the world with data assimilation. With this model (0.625 degree×0.5 degree), monthly average precipitation was obtained in mm (Reichle et al. 2017).

The average value for whole of Turkey is calculated as follows:

$$\overline{ET} = \frac{\sum ET_A \times A_{SR}}{A_T} \tag{1}$$

$$\bar{P} = \frac{\sum P_A \times A_{SR}}{A_T} \tag{2}$$

$$\bar{T} = \frac{\sum T_A \times A_{SR}}{A_T} \tag{3}$$

Where; $\overline{ET}$: average monthly evapotranspiration, ET_A: monthly evapotranspiration value, A_{SR}: spatial resolution area, A_T: total area, $\bar{P}$: average monthly precipitation, P_A: monthly precipitation value, $\bar{T}$: average monthly temperature, T_A: monthly temperature value.

3. Results and Discussion

Monthly average surface temperatures determined according to the GLDAS NOAH Model (spatial resolution of 0.25 degree×0.25 degree) between the water years 2018-2019 are given in Figure 2. The temperature scale is between -20 ºC and 40 ºC. The lowest temperature was seen in January and February, while the highest temperature was seen in August. The lowest temperature values were seen in January and February. The highest temperatures were seen in July and August (spatially).

Monthly average precipitation data were taken from the MERRA-2 (spatial resolution of 0.625 degree×0.5 degree) Model between the water years 2018-2019 and these data are given in Figure 3. The precipitation scale is between 0 and 455 mm. 455 mm/month value was seen in January 2019.

Monthly average evapotranspiration values determined according to the FLDAS NOAH Model (spatial resolution of 0.1 degree×0.1 degree) between the water years 2018-2019 are given in Figure 4. Evapotranspiration scale is between 0 and 225 mm. Evapotranspiration values started to increase in May and reached its highest value in July.

In addition to all these, a comparison was made between the two models in order to determine the evapotranspiration correctly with GIS software (FLDAS 0.1 degree and GLDAS 0.25 degree). A comparison was made according to average values from May to October in 2018. No significant difference was observed in the outcome, but it is clear that FLDAS NOAH with the higher spatial resolution gives accurate results at the areal scale.

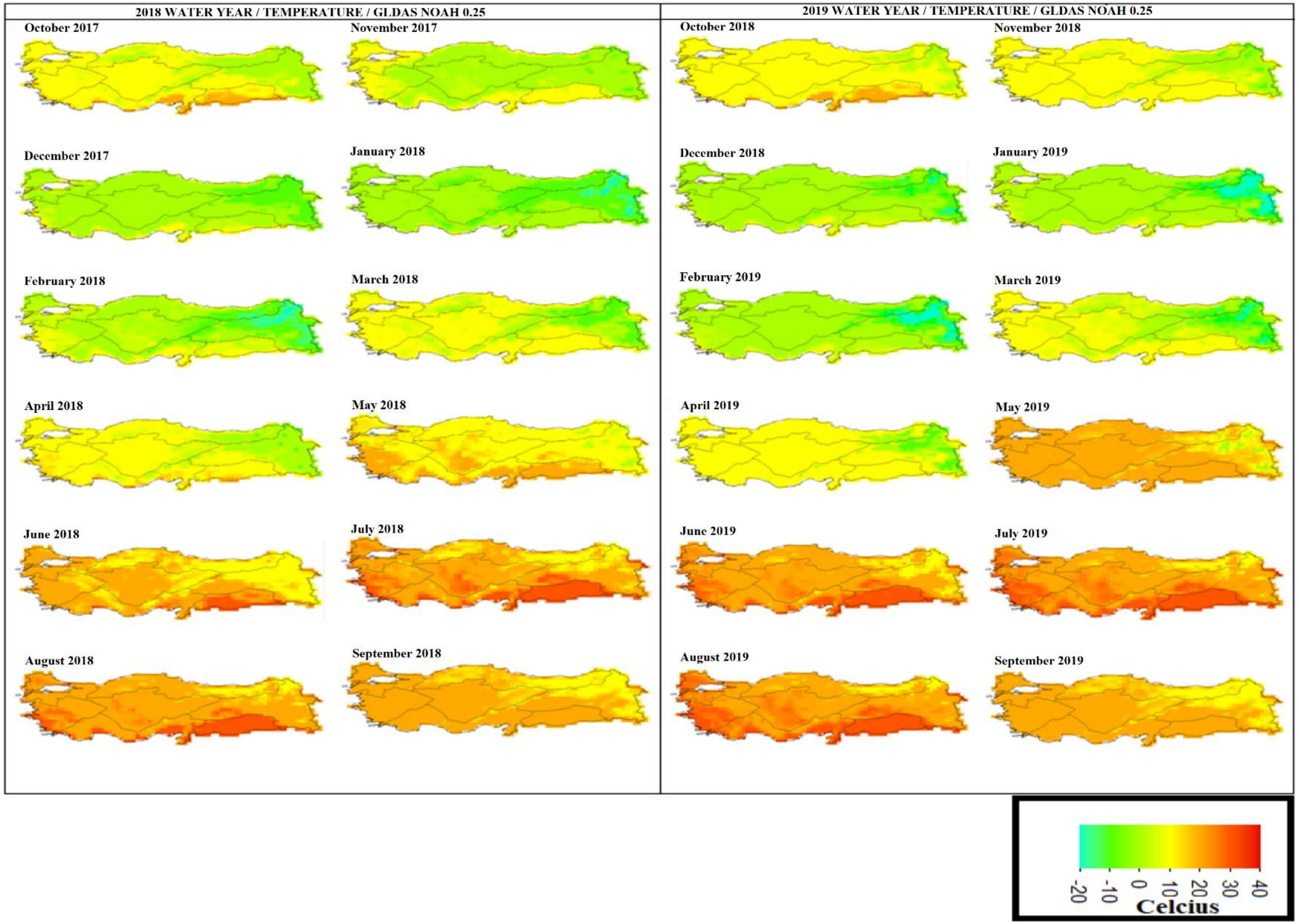

Figure 2- GLDAS NOAH Model monthly average surface temperature (ºC)

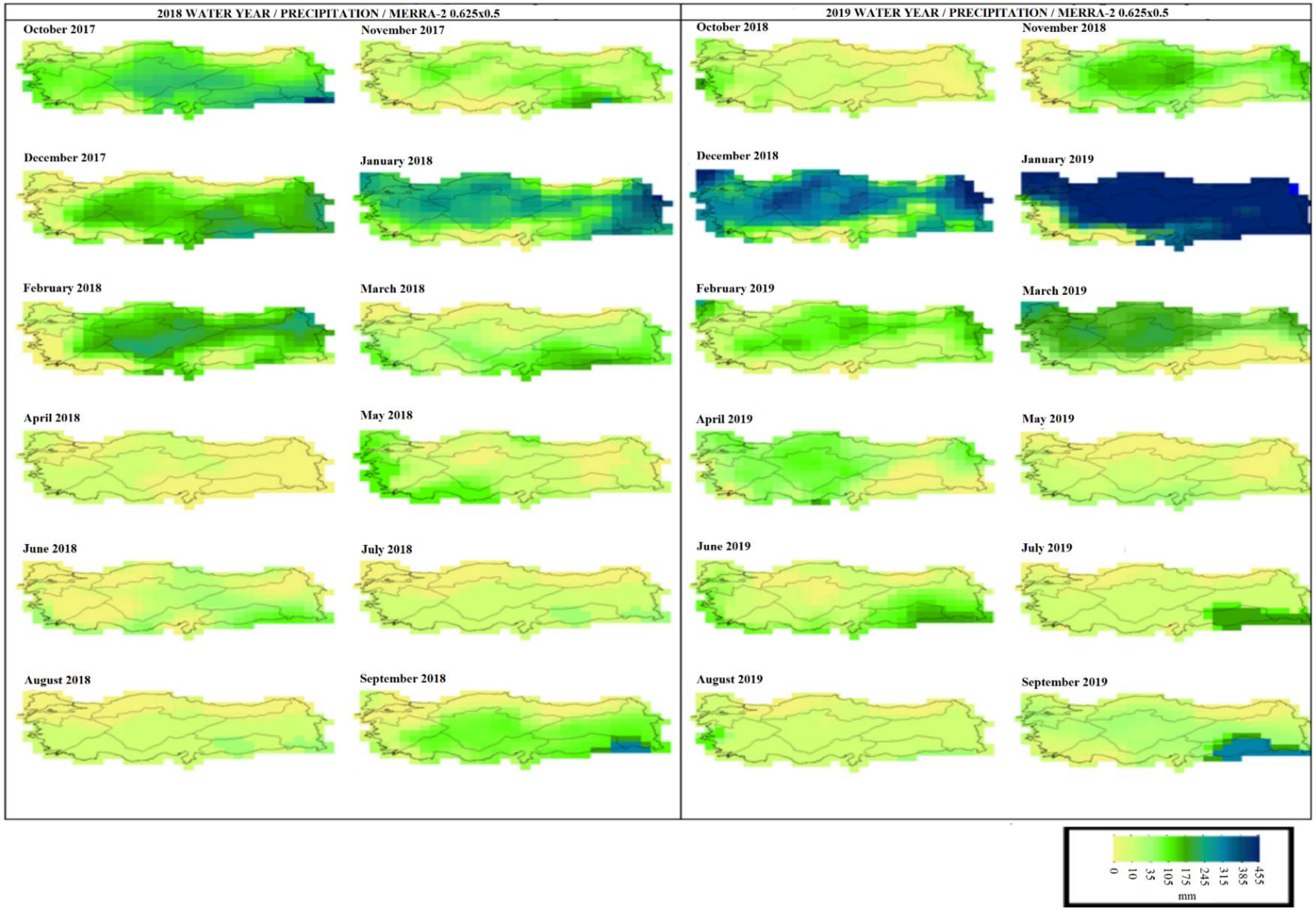

Figure 3- MERRA-2 Model monthly average precipitation (mm)

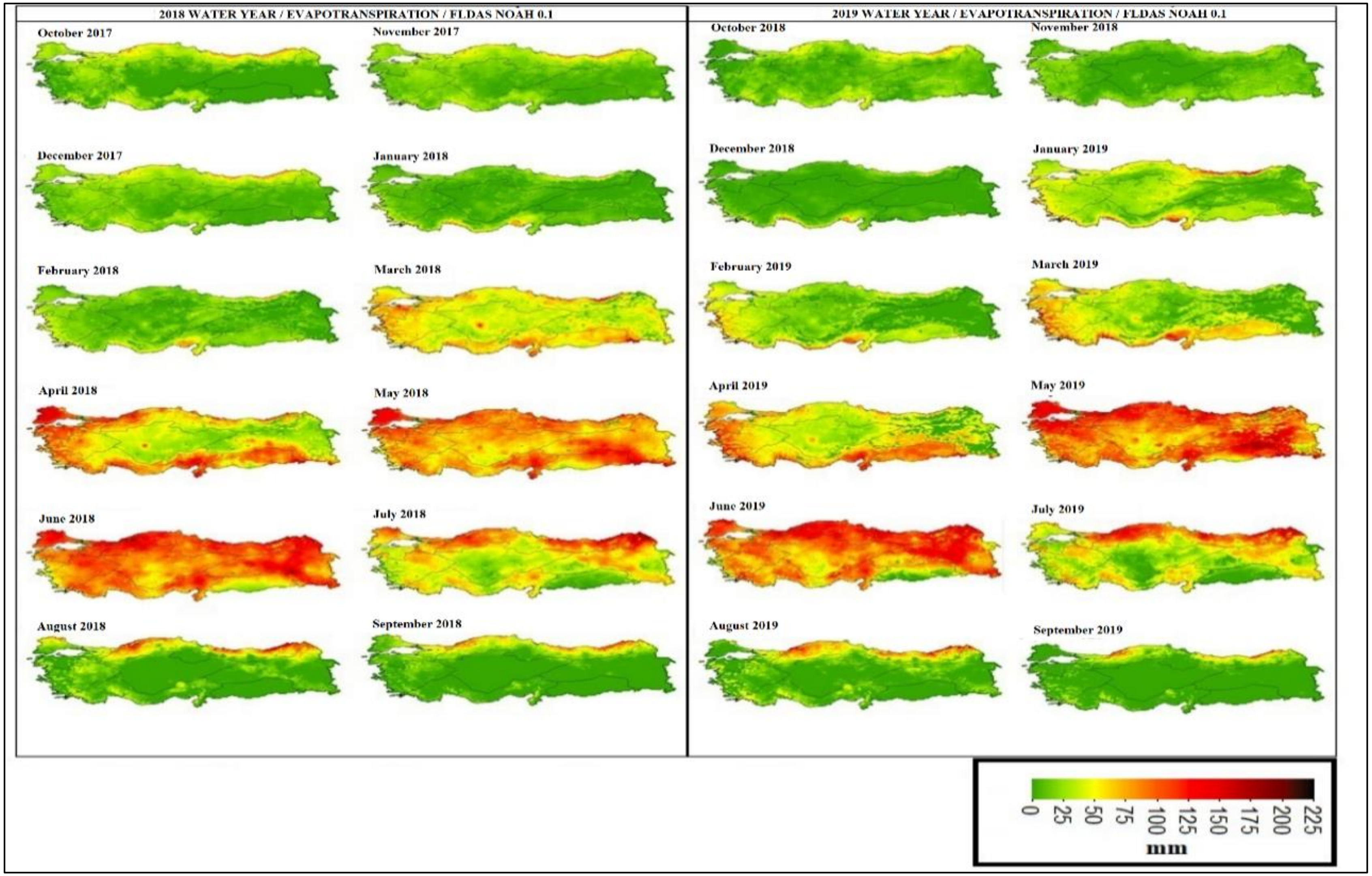

Figure 4- FLDAS NOAH Model monthly average evapotranspiration (mm)

The average value for whole of Turkey is calculated as follows:

$$\overline{ET} = \frac{\sum ET_A \times A_{SR}}{A_T} \quad (1)$$

$$\bar{P} = \frac{\sum P_A \times A_{SR}}{A_T} \quad (2)$$

$$\bar{T} = \frac{\sum T_A \times A_{SR}}{A_T} \quad (3)$$

Where; $\overline{ET}$: average monthly evapotranspiration, ET_A: monthly evapotranspiration value, A_{SR}: spatial resolution area, A_T: total area, $\bar{P}$: average monthly precipitation, P_A: monthly precipitation value, $\bar{T}$: average monthly temperature, T_A: monthly temperature value.

The findings obtained in the study, unit transformations and coloring of the maps were made with ArcGIS. Evapotranspiration values, temperature values and precipitation values calculated with spatial data from October 2017 to September 2019 are given in Table 1.

Table 1- Calculation of monthly averages using satellite images in Turkey

Water Year	*Month*	*Temperature (°C)*	*Precipitation (mm)*	*Evapotranspiration (mm)*
2018	October	16.37	72	35
	November	11.09	70	47
	December	6.88	65	45
	January	4.71	55	43
	February	6.53	60	61
	March	8.87	62	79
	April	14.67	33	108
	May	20.03	48	126
	June	23.99	39	160
	July	25.84	27	134
	August	27.21	28	113
	September	21.73	58	88
2019	October	16.98	60	71
	November	12.35	59	44
	December	6.63	82	53
	January	4.74	113	67
	February	6.32	62	71
	March	7.71	63	94
	April	13.12	46	112
	May	18.62	36	149
	June	23.85	35	163
	July	25.09	33	152
	August	26.22	41	91
	September	22.1	62	77

It is seen that there is a positive correlation between temperature and evapotranspiration in 2018-2019 water years (Figure 5). In addition, Figure 6 shows the inverse relationship between precipitation and evapotranspiration.

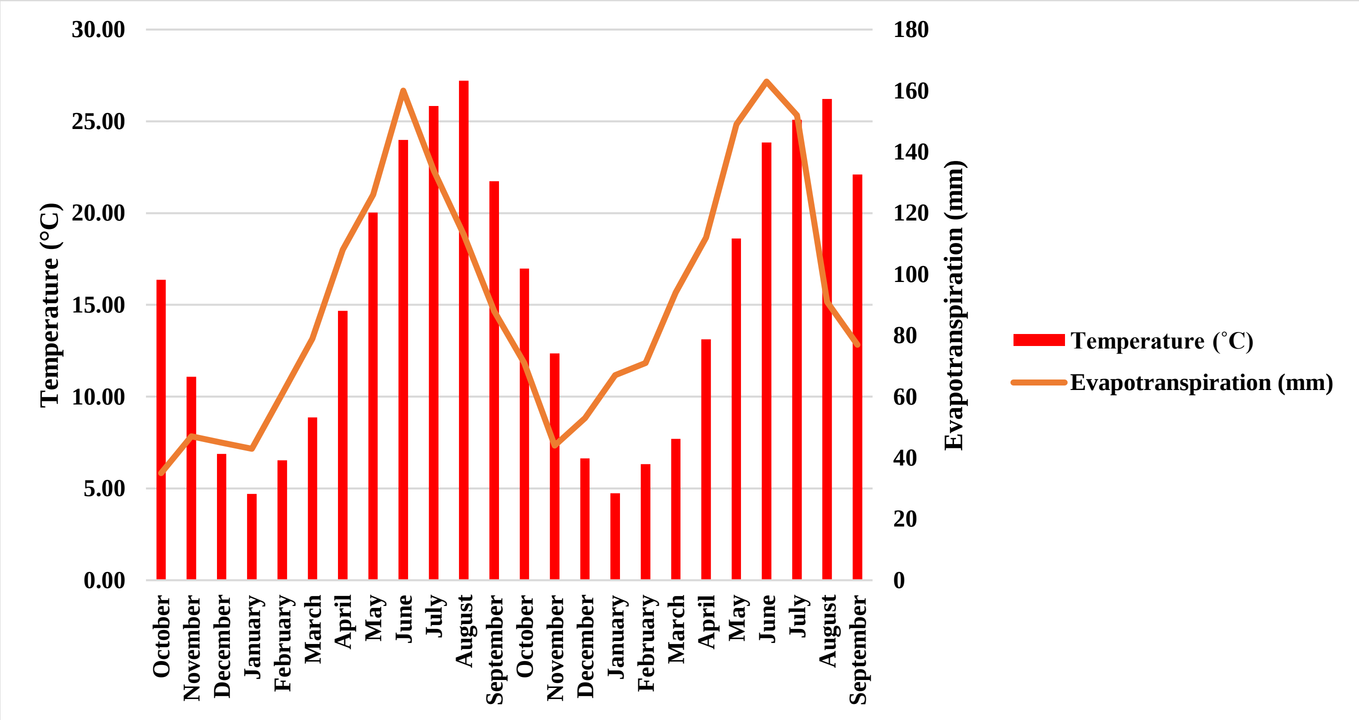

Figure 5- Relationship between evapotranspiration (FLDAS NOAH 0.1 degree) and temperature (GLDAS NOAH 0.25 degree) in 2018-2019 water years

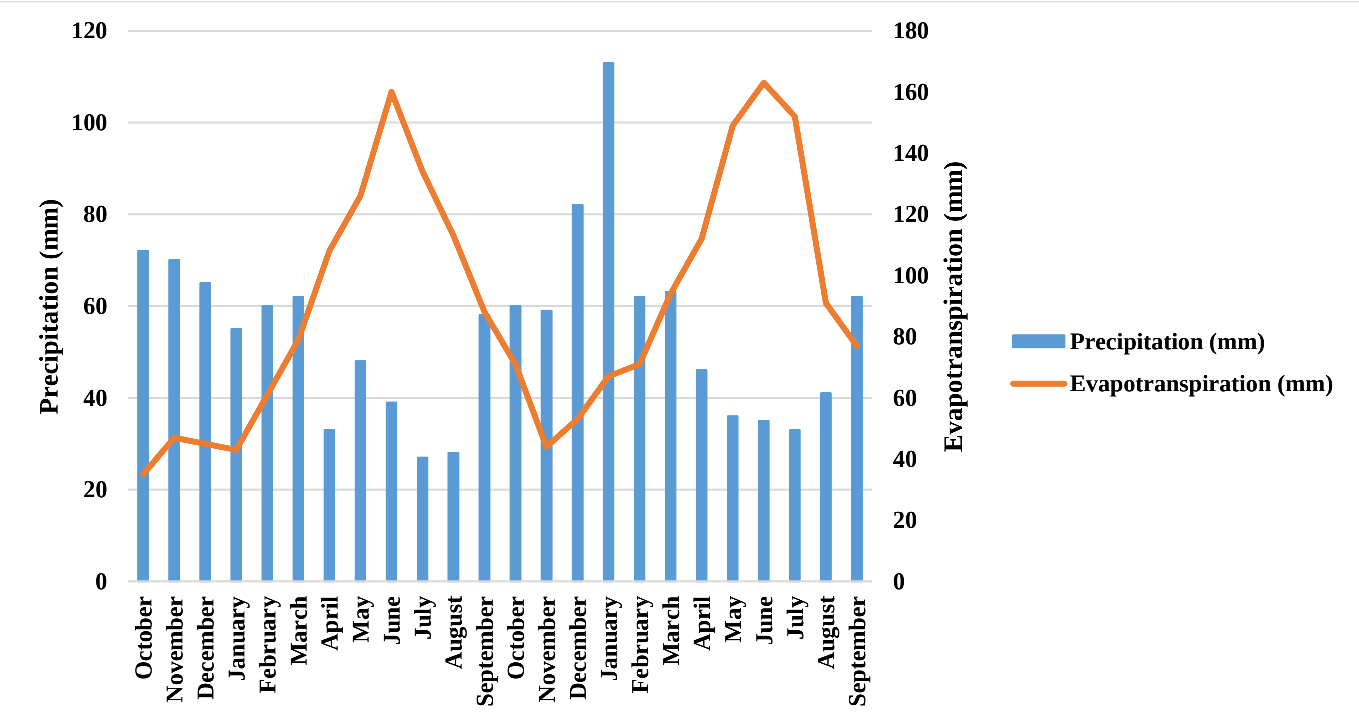

Figure 6- Relationship between evapotranspiration (FLDAS NOAH 0.1 degree) and precipitation (MERRA-2) in 2018-2019 water years

Values related to evapotranspiration on the land mask increase when the amount of precipitation on the surface flows and the temperature rises. In the 2018 water year, monthly average evapotranspiration reached a maximum level of 191 mm/month in July. Also, in the 2019 water year, the monthly average maximum value in July was determined as 175 mm/month. These maximum values are seen in northern Turkey. The reason for this is that the amount of flow increases, and the temperature rises significantly. However, when looking at the overall situation in Turkey in June, the average maximum evapotranspiration (163 mm/month) is reached. For this reason, the months of June and July can be considered critical according to the regions. In addition, it is clearly evident that the temperature increased by 7-8 ˚C during these periods compared to the previous months. From May flow caused by rainfall and snowmelt is increasing in Turkey, and it is inevitable that the high value of evapotranspiration in June.

4. Conclusions

The change in the amount of evapotranspiration determined between 2018-2019 water years in the study is directly dependent on temperature, precipitation, and flow. For this reason, in addition to long or short-term heavy rains and temperature increases, which are seen as a result of climate change, the sudden change of evapotranspiration can be mentioned.

Considering all these results it can be said that temperature and evapotranspiration are directly proportional, and that evapotranspiration increases during the beginning of flow. In addition, evapotranspiration is as important as precipitation, flow, and temperature in determining the effects of climate change and water resources management.

Evapotranspiration (evaporation and transpiration) is very important in the hydrological cycle. It is inevitable to see the effects of climate change with evapotranspiration analysis based on long-term data. It is possible to reach clearer results by using regional analysis and quality spatial resolution satellite images when necessary. In addition, the reservoir evaporation conditions in dams, ponds, lakes or other structures to be supplied with water should be carefully examined. However, since this reservoir evaporation is open surface evaporation, it should never be confused with evapotranspiration. In addition, long-term satellite images, measurements and spatial data should be used for forecasting. In addition, this is a preliminary study. Datasets of 30-40 years (long term) are required to develop the scope of the study.

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