ASSESSMENT OF TEMPORAL VARIATIONS OF GROUNDWATER RECHARGE IN ERGENE BASIN (NORTHWESTERN TURKEY) IN TERMS OF CLIMATE CHANGE

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Abstract

Recharge of groundwater is important for the sustainability of this resource. Groundwater in Ergene Basin is used for domestic purposes, irrigation and industrial demand. In this study, it is aimed to determine the temporal variations of groundwater recharge in Ergene Basin. For this purpose, data of main meteorological stations located the basin in 1966 - 2014 were used. The study area is divided into two zones, eastern zone (EZ) and western zone (WZ). Groundwater recharge, which is calculated using hydrologic budget method, showed a decreasing trend in EZ while very slightly increasing trend in WZ consistent with the decreasing precipitation and increasing temperature trends. Increasing demand for groundwater and over pumping in EZ of the Basin caused significant groundwater declines with combined effect of climate change. According to Standardized Precipitation Index (SPI) values the study area also experienced moderate-mild draught during the study periods.

Key words: Groundwater Recharge, Ergene Basin, SPI index, Climate change

Ergene Havzası'nda (Kuzeybatı Türkiye) Yeraltısularının Beslenmesinin Zamansal Değişimlerinin İklim Değişikliği Açısından Değerlendirilmesi

Öz

Yeraltısularının sürdürülebilir olarak kullanımı için beslenme çok önemlidir. Ergene Havzasında yeraltısuları evsel kullanım, sulama ve sanayi ihtiyacı için kullanılmaktadır. Bu çalışmada, Ergene Havzası'ndaki yeraltısuyu beslenmesinin zamansal değişiminin belirlenmesi amaçlanmıştır. Bu amaçla havzada bulunan ana meteoroloji istasyonlarının 1966-2014 yıl aralığındaki verileri kullanılmıştır. Çalışma alanı çok büyük olduğu için Doğu ve Batı Bölge olmak üzere iki bölgeye ayrılmıştır. Hidrolojik bütçe yöntemi kullanılarak hesaplanan yeraltısuyu beslenmesi, yağış ve sıcaklık trendleri ile uyumlu olarak Batı Bölgesinde çok az bir artış eğilimi gösterirken Doğu Bölgesinde azalma eğilimi göstermiştir. Havzanın Doğu Bölgesinde ise artan su ihtiyacı, aşırı çekim ve iklim değişikliğinin birleşik etkisiyle önemli yeraltı suyu düşümleri meydana gelmiştir. Hesaplanan Standart Yağış İndeksi (SPİ) değerleri, çalışma alanında araştırma dönemleri boyunca orta-hafif kuraklık periyodu yaşandığını tespit edilmiştir.

Anahtar Kelimeler: Yeraltısuyu beslenmesi, Ergene Havzası, SPI indeksi, İklim değişikliği

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1. Introduction

Groundwater is an important resource all over the world for drinking, industry and irrigation. Approximately 50% of drinking water and 43% of irrigation water consumption is supplied from groundwater [1, 2]. The use of groundwater has led to significant social development and economic growth in all countries of the world, and at the same time increased food safety [3].

Future demand for groundwater is increasing. Despite its huge presence, groundwater resources are under threat due to over exploitation in many regions of the world [4- 7]. Another significant threat to groundwater resources is reduced recharge of aquifers and surface water bodies due to climate change. Many researchers specified that increase in temperature and change of rainfall patterns due to climate change will affect groundwater recharge notably [8, 9].

Although impacts of climate change on groundwater recharge is an urgent issue to be addressed, direct studies of the effects of climate change on groundwater recharge is limited [10]. Van Engelenburg et al., [5] assessed the projected impact of Climate Change on hydrology of Velewe area, Netherlands and stated that the impact strongly depend on local conditions. Green et al., [6] discussed the impacts of Climate Change on all components of groundwater and stated that potential impacts of Climate Change is largely unknown. Salem et al., [4] assessed the impacts of Climate Change on irrigation cost in a groundwater dependent region of Bangladesh and concluded that climate change induced fluctuations in groundwater level on crop production cost is significant where groundwater levels are declining fast. Ferguson & Gleeson, [11], discussed the vulnerability of coastal aquifers and stated that sea level rise due to climate change adversely impacts the coastal aquifers due to salt water intrusion. Döll [12] assessed the vulnerability of renewable groundwater resources to climate change in global-scale and suggested that groundwater recharge will be decreased by %10 until 2050 in global scale. Jyrkama, M. I., & Sykes, J. F. [13], used modified HELP3 to estimate both temporal and spatial effect of climate change on groundwater recharge in Ontario, Canada.

In the fourth evaluation report of the Intergovernmental Panel on Climate Change [14], according to the outputs of the Global Circulation Model (GCM) for different emission scenarios, significant decreases in precipitation will occur with the rise of temperatures towards the end of the twenty-first century in the Mediterranean Basin, including Turkey. This make the region will

be one of the most vulnerable to global climate change [15]. Projections reveal that Turkey will face an increase in the temperature in all seasons, this increase will be more in the summer, but remain limited in the winter months. However, especially in the south, precipitation will decrease and the Mediterranean Climate will be observed in the northern regions, which will result in a decline of the amount of useable water and reduction of water resources.

According to pessimistic scenario of IPCC (A2), model projections show that, water potential in Turkey in the year 2050 and 2075 will be reduced by 16% and 27% respectively. This decline in rainfall and increase in temperature will also increase the drought in Turkey [15].

Industry has developed rapidly in the Thrace region in recent years. Along with this, the increasing population and the need for irrigation in agriculture also increased.

For this reason, the groundwater in the basin is under pressure due to the increasing water demand. When impacts of climate change, such as decreasing or insufficient precipitation and high temperature, added to these pressures, the situation even gets worse and access to water for industry, irrigation and domestic use becomes more difficult.

As in many other aquifers in the world, aquifers in Turkey are also under the threat of depletion, due to climate change and demand brought by humans. It is important to understand the impact of climate change for ecosystems and society, especially in terms of complex changes that affect the sustainability and availability of both underground and surface water resources [16].

The aim of this study is to present, evaluate, discuss temporal variations and influences of human actions on groundwater recharge in Ergene Basin in terms of climate change western Turkey.

2. Study area

Ergene river basin is situated in the northwest of Turkey (Fig.1) covers a drainage area of 8928 km^2 at GS2 flow observation station. The basin is mainly flat and elongated in E-W direction, surrounded by low hills. In this study Ergene river basin is divided into two sub basins; namely "eastern sub basin" (ESB) and "western sub basin" (WSB) For the separation of these two zones, the drainage network from which the river flow rate gauging station GS1(Muratlı) received data determined as ESB, and then the drainage network area of GS1 (ESB) is extracted from drainage area of discharge rate gauging station GS2 (Uzunköprü) and the remainder area is determined as the WSB of the study area.
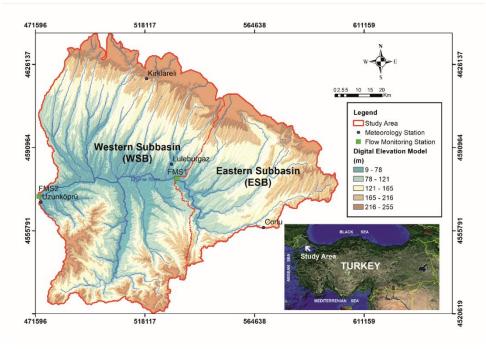
Figure 1. Study area (modified from Google Earth)

Ergene Basin is an important region in terms of its climate, topography and agriculture for Turkey. The main agricultural products of the region are paddy, canola, wheat and wine grapes. The study area supplies Turkey's, 12% of wheat, 46.3% of sunflower, 45.6% of the rice and 76% of Canola production. Industrial sites for, textile and machinery are mostly situated in the ESB.
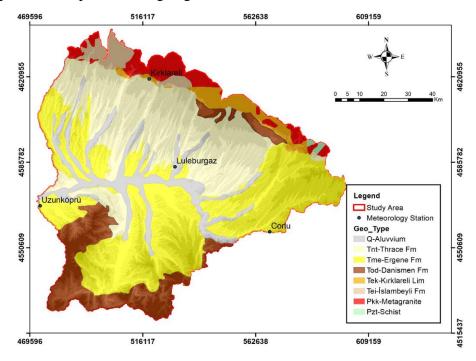
The study area is constituted of the drainage area of Ergene River and its tributaries, while annual average discharge rate of Ergene River is 5.6 m^3/s. In the study area summers are hot and dry while winters are cold and rainy. The average annual precipitation of the study area is 510 mm.
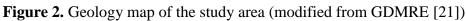
Metamorphic rock sequences of Istranca Massif composes the basement rocks of the Ergene Basin (Figure 2). These Metamorphic sequences are; gneisses, mica schists, granitic gneises, which mainly crop out in the north (Pkk-Pzt). Basement rocks are overlain unconformably in the north by Eocene aged clastics, İslambeyli Formation and Kırklareli Limestones, composed of sandstones and limestones (Tei, Tek).

At the center of the study area Oligecene aged Danismen Formation (Tod) composed of successive claystones and sandstones came over these units. These units are overlain by Miocene aged Ergene Formation (Tme) composed of gravelstones and sandstones. Neogene sedimentary sequencein the

study area is characterized by sandstone– mudstone successions, named as Trakya Formation (Tnt). Alluvial deposits are deposited along Ergene River and its tributaries in basin area.

Figure 2. Geology map of the study area (modified from GDMRE [21])

The geologic formations observed in the basin were divided into geohydraulic units due to their water-bearing potential [17]. According to this classification, basement rocks, gneisses and schists are attributed as impervious due to lack of fractures and low water storage properties. Oligocene units are defined as impervious-semi impervious due to water retention properties of claystones. All Miocene and alluvium units are referred as pervious due to high porosity and permeability features of conglomerates and sandstones. Groundwater in these units are under unconfined conditions. Since first impacts of climate change directly influences these type of aquifers [18-20] this aquifer is very susceptible to changes of climatic variables.

3. Methodology

Geological map of the study area is digitized with ArcMap software using previous maps prepared by General Directorate of Mineral Research and Exploration (GDMRE), these maps are available online from earth sciences portal of GDMRE [21]. Rainfall data of the study area is obtained from the stations operated by General Directorate of Meteorology (GDM). For this purpose, long term

(1966-2015) rainfall data of Lüleburgaz TİGEM, Çorlu, Kırklareli and Uzunköprü stations were used. Rainfall map of the study area is generated using proximity toolset for creating Thiessen polygon in ArcMap software. Evapotranspiration of the study area was determined by using Thornthwaite method [22] from the data obtained from GDM and all calculations were done using MS Excel. The flow of Ergene River is measured by gauging stations operated by state Hydraulic Works (SHW). For the base flow and flow parameters of Ergene River, data of Muratlı (GS1) and Uzunköprü (GS2) gauging stations provided by SHW were used.

4. Hydrometeorological evaluation

ESB covers an area of 2546 km^2 where dense population and organized industrial zones are located. The population of main districts of ESB is 502549 as of 2017. WSB of the study area covers an area of 6382 km^2, in contrast to its largeness, the population density is lesser and industrial facilities are also less in number and agricultural fields predominantly situated in this area. The population of main districts of western part is 311294 as of 2017.

Due to this different distribution in the population, industry and agricultural areas, the groundwater requirement in the ESB of the study area is expected to be higher than WSB.

4.1. Precipitation, P

Climate change has a direct impact on precipitation patterns in a basin. Understanding effects of climate change on long-term precipitation trends is important for groundwater management studies. The most important source of recharge in a basin is the infiltration from direct rainfall. Amount and duration of precipitation from rainfall effects the rate of recharge in the basin. One of the common methods used in calculating the amount of precipitation falling into the basin is Polygon (Thiessen) method [23]. In this method, each precipitation station is combined with other stations to form triangles.

Then, polygons are formed with vertical center studs that emerge from the middle of these triangles. In this way, there is only one rainfall value is attributed to each polygon. Using this value and the polygon area, the average rainfall value is calculated using the following equation by ArcMap software (Fig.3).

$$P_{av} = \frac{\sum_{i=1}^{n} P_i A_i}{A_t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(Eq. 1)}$$

In equation 1;

P_{av}: Average precipitation value in the basin

A_i: Polygon area

P_i: Precipitation value of each station in each polygon

A_t: Total area of the basin

Using this method mean rainfall calculated for east and west zone of the study area covering years from 1966 to 2015. From Kırklareli, Uzunköprü, Lüleburgaz and Çorlu stations of GDM. According to calculations from measurements, the maximum rainfall value for the ESB of the basin was 336 mm while the minimum rainfall value was 145mm and for the WSB maximum and minimum values are, 363 mm and 164 mm respectively.
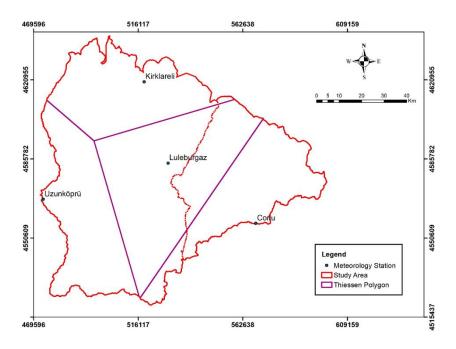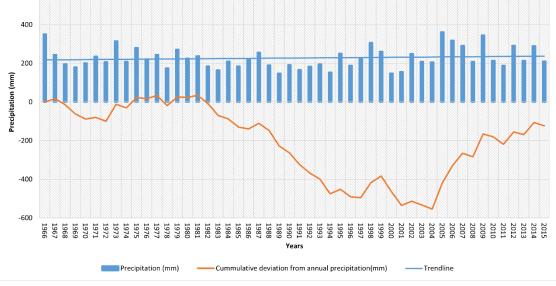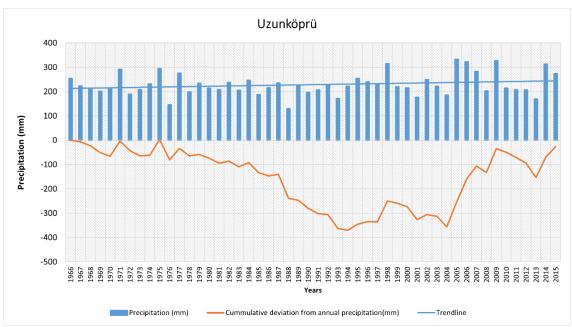

Figure 3. Thiessen Polygon map of meteorological stations

The annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend of the cumulative deviation from mean annual precipitation for these stations are given in Figures 4, 5, 6 and 7.

Figure 4. The annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend of Kırklareli meteorology station (1966-2015).
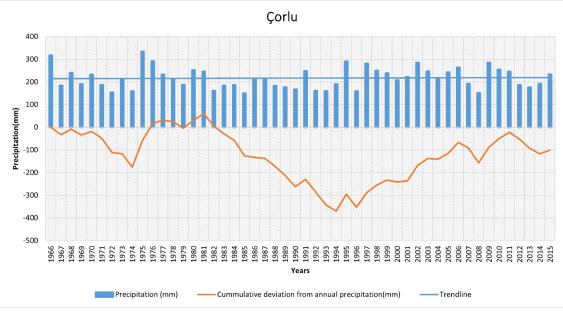

Figure 5. The annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend of Uzunköprü meteorology station (1966-2015).
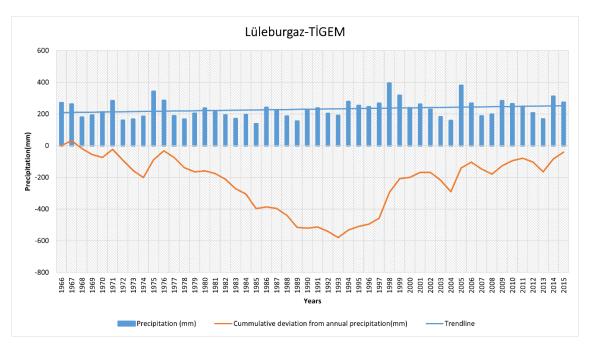
Figure 4 and Figure 5 show the data of two precipitation stations in the north (Kırklareli Station) and south (Uzunköprü Station) of the WSB of the study area. The two figures show similar rainfall

patterns, which indicates that the basin receives similar amounts of precipitation. WSB experienced a dry period between 1974 and 2004, and a wet period from 2006 until 2015. Long-term trend lines of both stations show a slightly increasing pattern in precipitation between 1966 and 2015.

Figure 6. The annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend of Çorlu meteorology station (1966-2015).

Figure 7. The annual precipitation, the cumulative deviation from mean annual precipitation and the long-term trend of Lüleburgaz-TİGEM meteorology station (1966-2015).

Figure 6 and 7 belongs to stations located in ESB of the study area and they also show a similar trend in precipitation as stations of WSB. Çorlu station experienced a dry period between 1966 and 1974, then a rainy period between 1974 and 1981.Then again, a dry period between 1981 and 1994 and again a rainy period from 1994 till 2015. Lüleburgaz-TİGEM station experienced a dry period beginning from 1967 until 1993, then a rainy period between 1993 and 2015. Long-term trend lines of both stations show a slightly increasing trend in precipitation between 1966 and 2015 same as WSB stations.

4.2. Temperature, T

Temperature is a basic measurement of the energy status of the environment and it powers weather and defines climate. Accurate long-term temperature records are important for understanding climate trends. The rate of temperature rise will affect the response time of climate change. According to the long-term data obtained from the meteorological stations of Kırklareli and Çorlu, a significant increase observed especially in the temperature values after 1994 (Figure 8 and Figure 9).
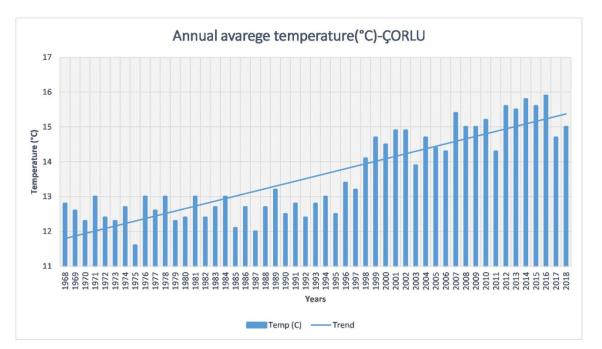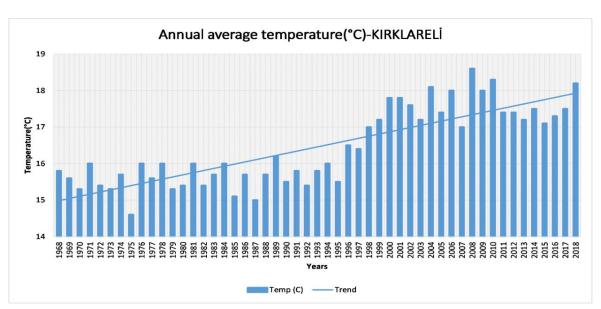

Figure 8. The annual average temperature variation of Çorlu meteorology station (1968-2018).
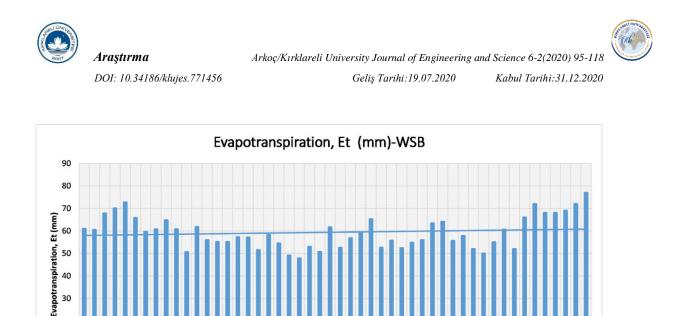
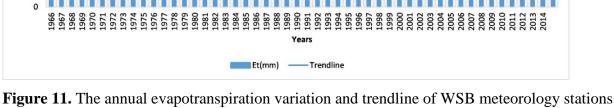**Figure 9.** The annual average temperature variation of Kırklareli meteorology station (1968-2018).

4.3. Evapotranspiration, Et

Evapotranspiration (Et) is the sum of evaporation from the land surface plus transpiration from plants to the atmosphere and it is the one of the most important water balance equation component [24].

Figure 10. The annual evapotranspiration variation and trendline of ESB meteorology stations (1966-2015).

Figure 11. The annual evapotranspiration variation and trendline of WSB meteorology stations (1966-2015).

According to the data obtained from the meteorological stations, the warmest month in the basin is August (highest temperature reaches to 38.4°C) and the coldest month is January (lowest temperature reaches to -13.5 °C). To calculate the evapotranspiration values in the study area, stations providing data for long-term evapotranspiration calculation are used. For this purpose in the ESB of the study area, Lüleburgaz-Tigem, Çorlu and Kırklareli meteorology stations data were used while the data of Uzunköprü, Lüleburgaz-Tigem and Kırklareli meteorology stations were used to calculate the evapotranspiration values in the WSB of the study area. According to these data, the average annual evapotranspiration value shows an increasing trend between 1966 and 2016 (Figure 10 and 11).

4.4. Gravimetric terrestrial water storage of the study area

The Gravity Recovery and Climate Experiment (GRACE) satellite mission is sponsored by National Aeronautics and Space Administration (NASA) and its partner German Aerospace Center (DLR). The mission had collected data from 2002 till 2017 [25]. The nominal data products of this mission are monthly Earth gravity fields [25].

In order to make worldwide estimation of total vertical water storage (TWS) these nominal data is being used. A few 100 km and larger spatial scaled data estimations are much more accurate (Wahr et al., 2004). Monthly released GRACE gravity field data (Monthly) is consisted of a set of spherical harmonic (Stokes) coefficients. This monthly GRACE gravity field is filtered using the method of Swenson and Wahr [26] and converted to mass in units of equivalent water thickness [25]. Then these monthly time series are used to track the trend of the TWS in the study area. These filtered time series of the study area are obtained from data portal for GRACE by the University of Colorado Boulder [27]. According to these data, the average TWS values shows an increasing trend between 2002 and 2016 (Figure 12).

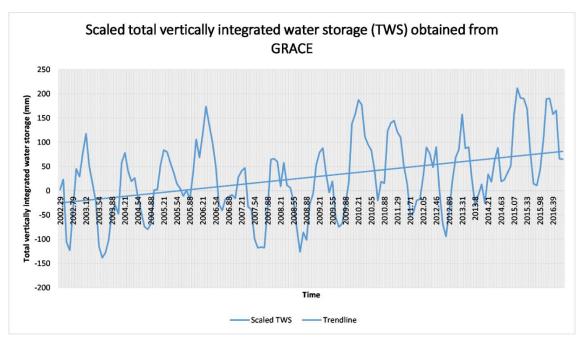**Figure12.** TWS variation of the study are data obtained from GRACE mission (2002-2016).

4.5. SPI index method

The Standardized Precipitation Index (SPI) is a commonly used index to characterize meteorological drought on a range of timescales. For short period of time, the SPI is tightly related to soil moisture, while for longer period of time, the SPI values could be related to groundwater and aquifer storage [28].

To calculate the SPI of any location, long-term precipitation data for a wanted period is required. The historic record is fitted to a probability distribution, which is then transformed into a normal distribution such that the mean SPI value for that location and period is zero. SPI values below 0 indicates rainfall deficits (droughts), on the other hand SPI values between greater than 0 indicates excess rainfall in the given location.

SPI value of the study area was evaluated by 12-month time scales. The Standardized Precipitation Index (SPI) is evaluated from the following equation:

$$SPI = \frac{x_i - x_{mean}}{S}$$ .... (Eq. 2)

where, X_i, is monthly rainfall data of the meteorological station, X_{mean} is rainfall mean and S is the standard deviation.

Drought is a harmful hazard of climate. It can have a substantial impact on the ecosystem and harm to the affected region's economy. Drought can be defined as prolonged shortage of water supply (precipitation, surface water groundwater), usually a season or more. Main factor that controls the drought is the precipitation. Using SPI drought can be defined as functional and quantitative for each time scale [28]. Different drought categories are defined according to the calculated SPI values (Table 2).

Table 2. SPI classification scale from [28]

SPI values	Drought category
0 to –0.99	Mild drought
–1.00 to –1.49	Moderate drought
–1.50 to –1.99	Severe drought
–2.00 or less	Extreme drought

Meteorological drought analysis was carried out in the Ergene River basin using the SPI method over a 12-month period. For the calculation of SPI index values of the study area, average precipitation values of Çerkezköy and Kırklareli meteorological stations were used (Fig.13).
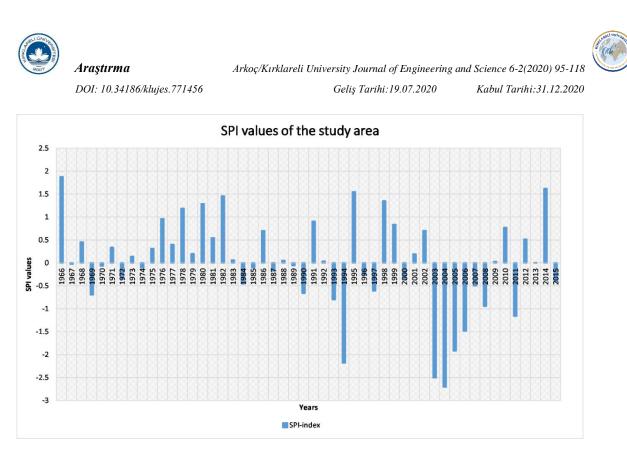
Figure 13. SPI values of the study area (1966-2015).

Calculated SPI values revealed that, extremely dry years were 1994, 2003 and 2004, severe dry year was 2005, moderate dry years were 2006 and 2011 and mild dry years were 1969,1970, 1972, 1974, 1984, 1987, 1990, 1993, 1996, 200, 2007, 2008 and 2015. In addition severe wet years were 1966 and 2014, moderate wet years were 1978, 1980, 1982, 1995 and 1998, and mild wet years were 1968, 1971, 1973, 1975, 1976, 1977, 1979, 1981, 1983, 1986, 1991, 1993, 2002, 2009, 2010 and 2012. On average, %55 of the SPI values of the years studied were wet period.

5. Groundwater recharge

Understanding groundwater recharge is necessary for the successful management of groundwater resources [29]. For the quantification of the impacts of climate change on groundwater resources, groundwater recharge estimation over time is as important as forecasting of changes in key climatic variables [13]. Groundwater recharge could be defined as the portion of precipitation infiltrating the soil surface and percolating through the unsaturated zone of the aquifer reaching the water table and adding to groundwater storage [30, 31]. In groundwater systems, groundwater recharge is the primary component in integrated water resources management studies since it is used for prediction of impacts of climate change in groundwater models [32]. Knowledge of aquifer recharge also

helps to identify the sustainable yield of a catchment and thus protecting the groundwater resources [33].

In this study, a hydrological simulation was carried out to determine the distribution of spatial and temporal changes of groundwater recharge from precipitation and surface run-off in to Ergene River Basin aquifer system. In this simulation method, rainfall reaching the ground surface infiltrates into soil. This infiltrating water supplies soil moisture deficit, part of the infiltrating water becomes direct runoff and other part becomes groundwater recharge. Under this supposition, groundwater recharge was calculated by the use of equation below;

$$P = Q + \mathrm{Et} + R + \triangle S$$

Where P= precipitation, Q= surface run-off, Et= evapotranspiration, R= groundwater recharge and $\triangle$S= change in soil moisture storage. In order to analyze the quantification of groundwater recharge,

in Ergene River basin for both EZ and WZ a 49-year period between 1966 and 2015 monthly precipitation and evapotranspiration data of Lüleburgaz-Tigem, Çorlu and Kırklareli, Uzunköprü meteorological stations are used to trace monthly changes in soil moisture. Results of this analyses are given in figures 14 and 15 for EZ and WZ, respectively.
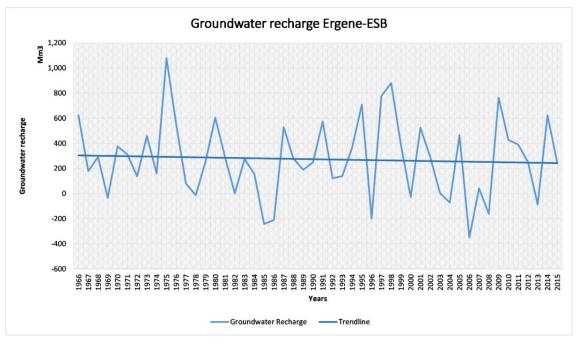

Figure 14. Calculated groundwater recharge variation with trendline in ESB (1966-2015).
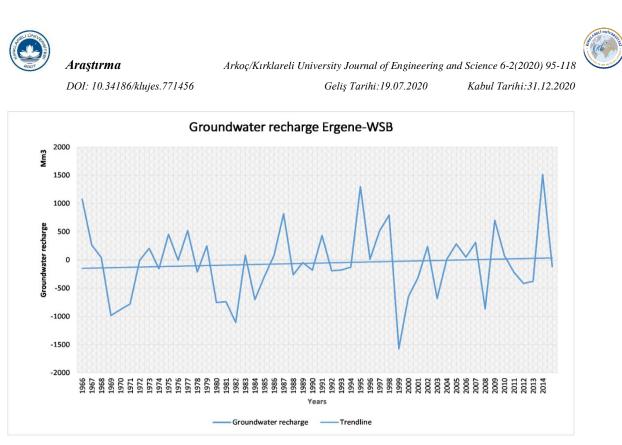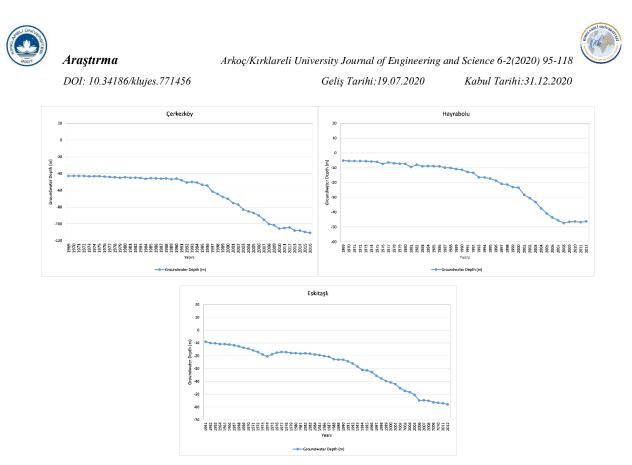
Figure 15. Calculated Groundwater recharge variation in trendline WSB (1966-2015).

In the WSB of the study area (Fig.14), groundwater recharge was observed to increase, albeit to a limited extent, while it was observed to decrease in the ESB. Although precipitation in both zones of the study area increased, impact of this increase on groundwater recharge is limited. This could be attributed to overexploitation of the aquifer system. As noted by State Hydraulic Works [34] overexploitation of the aquifer in the ESB began in early 1990s resulted in a

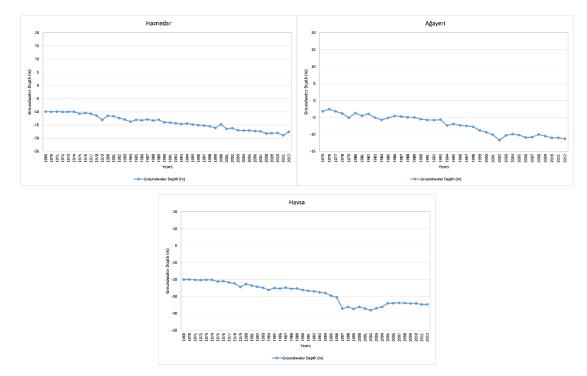**Figure 16.** Variation of groundwater depth in ESB observation wells Çerkezköy, Hayrabolu, Eskitaşlı

Figure 17. Variation of groundwater depth in WSB observation wells Haznedar, Ağayeri, Havsa

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significant decline in water table depth, this decline resulted in making deeper wells and deeper wells triggered more decline in water table depth. These declines in water table reached to 40m – 70m in the center of the EZ. Since climate in the study area gets drier, it is expected to have lower water tables in response to decreasing recharge (Figure16 and 17).

In the WSB of the study area this decline in groundwater levels is between 10 to 20 m which is limited compared to ESB (Fig. 17) and recharge of the aquifer is significantly much more than ESB (Figure 15) in correspondence with higher precipitation values (Fig. 4, 5, 6 and 7).

During the observation period groundwater recharge of the ESB showed a decreasing trend and trending groundwater recharge values were between 210 and 223 Mm^3, never reached negative values. But on the other hand, although groundwater recharge of the WSB showed an increasing trend, trending values were between -112 and 56 Mm^3.
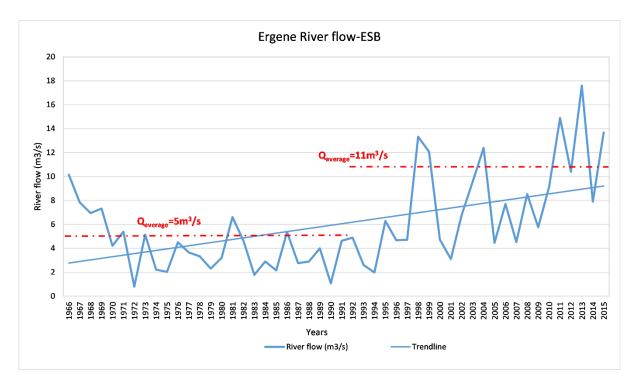

Figure 18. Annual flow variation of Ergene river with trendline (1966-2015).

Besides, flow of Ergene River in EZ of the study area significantly increased from 1990 from average of 5 m^3/sec to 11 m^3/sec, (Fig.15) this increase could be attributed to both increasing precipitation pattern in the area and discharge of process waters of some factories pumped from

groundwater and let to Ergene River. But nevertheless, no positive affect of this discharge process on groundwater recharge was observed.

6. Discussion and conclusion

In this study, temporal variations of groundwater recharge in terms of climate change in the Ergene Basin, in north-west Turkey between 1966 and 2015 were investigated based on precipitation, temperature and evaporation data. Precipitation, which is one of the main components of groundwater recharge, has shown a linear-slight increasing trend in both zones of the study area, also both temperature and evapotranspiration values has also revealed an increasing trend.

Scaled monthly GRACE gravity field data for TWS of the study area between 2008 and 2016 had also exhibited an increasing trend. In the light of this data, it should be expected that groundwater recharge will increase in the region. This GRACE data belongs to a noticeably short time interval, but it is observed that precipitation and groundwater recharge has also increased. In this context, it can be concluded that GRACE data for TWS and precipitation data are compatible in this time interval.

Groundwater tables of observation wells of both zones exhibited a decreasing trend in 1964-2015, which is much more evident in ESB than WSB. Due to both industrial and agricultural demands for water in the region, early 1990s overexploitation of the aquifer resulted in more rapid decline in groundwater table and decreasing recharge values. This caused a trend towards water scarcity in the ESB of the basin. Although the study area receives increasing precipitation, overexploitation of the aquifer might be one of the reasons for declining groundwater recharge. According to SPI values between1993, 1994 and 2003 - 2008, moderate - mild draught was also observed in the study area. This also had an impact in decreasing trend of recharge values of ESB. From the beginning of 1990s process waters of factories in the ESB, which are let to Ergene river, had great contribution to river flow but this contribution did not affect the groundwater recharge (Fig.14 and 15).

On the other hand, there are some factors that darkens the recharge estimation. Firstly, over exploitation of the aquifer makes it difficult to assess how groundwater recharge is affected, where pumping volume of the groundwater from the aquifer is unknown. Secondly the study area covers a large area and for more accurate assessment it has been divided in to two zones. But the

unconfined aquifer in the study area has an integrated distribution, not as two parts, so it is inevitable that there might be some errors in recharge estimation values of both zones.

But overall, findings of the study still emphasizes the impact of climate change on temporal variations of groundwater recharge in the study area which is observed as increase in temperature, evapotranspiration and decreasing trend in precipitation and declining groundwater recharge in the ESB and a slight increase in groundwater recharge in the WSB .

For ensuring sustainable groundwater management it is a requisite forecasting the impact of climate change and develop mitigation strategies. These strategies should include the local regulations and dominant users of groundwater resources. One of the important alternative mitigation strategies that could be applied to preserve and restore the natural conditions of groundwater recharge in the basin is artificial groundwater recharge. On the other hand, agricultural sector and industry are the main users of groundwater. For the water demands of both sectors, the amount of groundwater withdrawal from the aquifer should be optimized. Additionally, water resources managers and local administrators should also realize their essential role for groundwater resources in adapting and reducing the impacts of climate change along with human activity as well as meeting demands for domestic usage, irrigation, industry, and sustainable ecological systems. The agricultural sector in the basin is the main user of groundwater, therefore more efficient irrigation methods are recommended. Both for the water demands of the industry and the irrigation practices the amount of groundwater withdrawal from the aquifer should be optimized.

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