Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.24915

177 (2020) 363–373
February

Scrutinizing the simultaneous impact of drought on irrigated agriculture and groundwater resources

Ahmad Haseeb Payab[a,c], Mohammad Ebrahim Banihabib[b], Umut Türker[c,*]

[a]*USAID, Strengthening Watershed and Irrigation Management Project, AECOM, Afghanistan, email: haseeb.payab@swimafg.com*
[b]*Department of Irrigation and Drainage Engineering, College of Abouraihan, University of Tehran, Tehran, Iran, email: banihabib@ut.ac.ir*
[c]*Civil Engineering Department, Eastern Mediterranean University, Famagusta, North Cyprus, Mersin 10, Turkey, email: umut.turker@emu.edu.tr*

Received 10 July 2019; Accepted 16 September 2019

ABSTRACT

This study investigated and quantified the temporal and spatial effects of drought on selected irrigated crops and groundwater of a coastal aquifer (Güzelyurt/Morphou aquifer) in North Cyprus. Coupled reconnaissance drought index (RDI) and crop water and irrigation requirements program of Food Agricultural Organization (CROPWAT) simulation model is employed to quantitatively evaluate the impact of drought on irrigation water requirement (IWR) of citrus and pomegranate in different regions based on moderate, severe and extreme drought categories. The response of groundwater to drought effect is investigated by analyzing the historical groundwater level (GWL) data series with the standardized precipitation index (SPI) and RDI severity values and the trend is examined using parametric and non-parametric statistical tests. During moderate, severe, and extreme drought it is found that the increase in IWR of irrigated crops is 8%, 11%, and 16%, respectively. Overall, the mean increase in IWR during dry years of drought is approximately 12%. In general, the temporal rise and fall of GWLs of Güzelyurt/Morphou aquifer are closely related to the positive and negative values of SPI and RDI with a mean correlation coefficient of 0.173 and 0.170, respectively. These findings can be effective in strategizing sustainable plans against climate change for integrated management of irrigated agriculture and groundwater resources.

Keywords: Drought; Groundwater; Irrigated agriculture; North Cyprus; RDI; SPI

---

1. Introduction

According to the Intergovernmental Panel on Climate Change, the world's climate is changing at an unprecedented rate that contributes to the frequency and magnitude of extreme events such as floods and droughts [1]. Drought is highly dependent on precipitation and its effect on agriculture is both on rainfed and irrigated agriculture in terms of reduced yield of crops and increased water demand for irrigation. Although irrigated agriculture is a major consumer of global freshwater resources, it plays an important role in agricultural production in maintaining global food safety and availability [2]. The precipitation in the Mediterranean region is subjected to high inter-annual and seasonal variability with frequent occurrence of extreme flood and drought [3]. Recent accelerated climate change in the Mediterranean has worsened existing environmental problems interrelated with food security and agriculture, increasing risks for the coming decades [4,5]. Based on [6], in the twenty-first century, as mean global temperature increases, in the Mediterranean region, precipitation will decrease at a rate of around 4% and temperature will warm 20% more than the global average, increasing the dependency on climate-sensitive agriculture.

Direct and indirect impacts of climate change on the quality and the number of groundwater resources, can no

---

[*] Corresponding author.

Presented at the 2nd International Conference on Water Problems in the Mediterranean Countries (WPMC-2019), 6–10 May 2019, Nicosia, North Cyprus

longer be hidden [7]. Groundwater is an essential source of fresh water around the globe. It is a substantial economic and strategic resource that provides water for domestic, agriculture and industrial use. Groundwater depends upon the natural recharge process which in turn among other factors, heavily relies on the distribution, timing, and quantity of temperature, precipitation, and evapotranspiration [8]. Therefore, a shift in precipitation, temperature and evapotranspiration regimes, causes a profound negative impact on the recharge rate, the depth of groundwater level (GWL) and consequently the amount of the groundwater [9]. As a consequence of this direct effect on natural processes of the hydrological cycle, climate change and variability indirectly affect the groundwater system through substantial change in human activities [10]. The indirect effect leads to increased abstraction and utilization of groundwater resources especially in areas where economic activities like irrigated agriculture heavily depend on groundwater [11].

Understanding that frequency of extreme events of climate change and variability, estimating and quantifying the direct and indirect effect of drought on groundwater is essential for sustainable management of this non-renewable resource. Therefore, the main aim of this study is 1) to assess and quantify the effect of drought on irrigation water requirement (IWR) of irrigated crops by using process-based crop simulation model and 2) to investigate the temporal and spatial variability of GWL to drought by examining GWL time series data of different observation wells. The drought and non-drought years in the study area under consideration are identified using the standardized precipitation index (SPI) and reconnaissance drought index (RDI).

2. Material and methods

2.1. Study area

The North Cyprus that lies at the Eastern part of the Mediterranean Sea has a semi-arid climate with mild and wet winter and hot and dry summer. It has an average annual rainfall of about 518 mm with 60% of rainfall taking place during winter. Similarly, depending on the location, the annual potential evapotranspiration varies between 1,541 and 2,296 mm. It is estimated that on average about 85% of total annual rainfall is lost to evaporation, leaving out only 15% of the rainfall to contribute to total water budget [12].

In the past few decades due to intensified inter-annual variations in precipitation, drought occurrence in the study area has increased both in magnitude and frequency and because of climate change, it is expected to increase further in the future [13].

The study area is divided into five main agricultural regions namely, Lefkoşa, G.Magusa, Girne, Güzelyurt, and İskele. Among these regions, the Güzelyurt region is the main hub of agriculture production as well as a huge consumer of irrigation water. The detailed map of the studied region is given in Fig. 1.

Water resources in North Cyprus are very scarce with groundwater constituting the major part of the water resources [14]. The estimated annual abstraction from the aquifers is approximately 98.6 million m^3 that fulfills more than 95% of total annual water demand out of which 63.1 million m^3 is utilized for irrigation purposes. There are twenty-three separate aquifers in the North Cyprus where the three main aquifers are Kyrenia mountain aquifer, Güzelyurt/

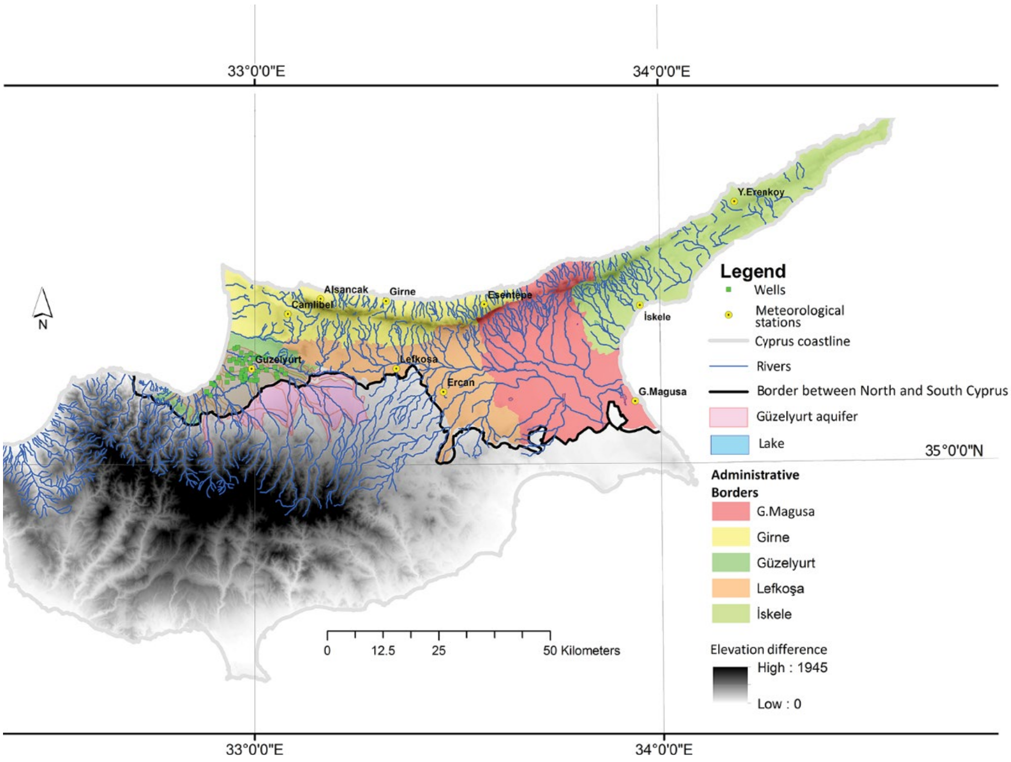

Fig. 1. Detailed map of the study area.

Morphou aquifer, and G.Magusa/Famagusta aquifer [15]. The Güzelyurt/Morphou aquifer is currently one of the most important aquifers as it supplies domestic and irrigation water to two-third of the country. It is located on the west coast near Morphou Bay and has an area of approximately 265 km^2. The aquifer is unconfined which makes it very vulnerable to climate change. The thickness of the aquifer varies between 45 and 100 m and is generally located on the impermeable clay layer, 100–120 m below the sea level [12,16]. The aquifer is mainly recharged by direct infiltration of precipitations. Due to over-abstraction, the salinity of the groundwater has increased and the saltwater intrusion has now reached up to 4 km inland [16]. As such, the aquifer is now seriously endangered by the over-abstraction, saltwater intrusion, mismanagement and extreme events of climate change such as drought.

2.2. SPI and RDI analysis

To quantify the impact of drought on irrigated agriculture water requirement and groundwater resources, it's essential to choose suitable drought indices. There exist more than 150 drought indices that can be used for drought monitoring of meteorological, agriculture, hydrological and socio-economic drought but each has its weakness and strength [17]. In this study, SPI and RDI are used as both have been widely implemented in several studies and tested worldwide under climate change and variability for drought characterization and monitoring, agriculture drought and groundwater drought [18,19]. SPI is developed by McKee et al. [20] and RDI is developed by Tsakiris and Vangelis [21]. The solution methodology of SPI uses mean monthly precipitation while RDI uses mean monthly precipitation and temperature as the main input variable. The amount of potential evapotranspiration in the study area, required as an input for the RDI method, was calculated using the empirical Thornthwaite method. The climatological data, monthly records of precipitation and temperature of nine meteorological stations situated in the five regions, are acquired from the State Meteorological Department from 1977 to 2013. In this study, the 12-month time scale is adopted for impact evaluation of drought by considering the hydrological year rather than the natural calendar. Other time scales were also analyzed but were not utilized. After the completion of drought analysis, keeping into consideration the aim of the study for agriculture drought only, moderate, severe and extreme drought years are determined from RDI severity values for each station and each year. Based on this categorization, the corresponding rainfall values for those specific years that fall under these three drought categories are identified and used as one of the inputs for crop modeling. Similarly, a good wet year is also identified as the reference year and its corresponding rainfall value is used in crop modeling. The reference year considered is 2012–2013.

2.3. Crop modelling

The IWR of citrus and pomegranate under different severity levels of drought is computed using the crop water and irrigation requirements program of Food Agricultural Organization (CROPWAT) 8.0 software. CROPWAT was developed by FAO [22]. It reliably and efficiently simulates crop water use and crop yield response to water stress under various scenarios of climate, crop, and soil [23,24]. Crop parameters, meteorological and climatic parameters, and soil parameters are the inputs of CROPWAT. The outputs are crop water requirement, irrigation requirement, actual crop evapotranspiration, effective rainfall, daily soil moisture deficit, and estimated yield. The necessary input data to perform the simulation in this study is acquired from different sources. The climatological data required for building the model were wind speed, mean maximum and minimum daily temperature, mean humidity, sun hours, and monthly records of precipitation. They were retrieved from the database of the State Meteorological Department and CLIMWAT [25] from 1977 to 2013. The historical production, cultivated area and yield data of pomegranate and citrus between 1995 and 2012 are obtained from the Ministry of Agriculture and Natural Resources. The crop parameters, crop coefficient values (K_c) and yield response factor (K_y) for initial, mid-season and late crop growth stages, duration of crop growing stages, planting and harvesting dates, crop development periods are obtained from Food Agriculture Organization (FAO) [26]. The total available soil moisture of six dominant and associated soils, covering the five regions was obtained from a harmonized world soil database [27] and soil maps of North Cyprus. Since in each region, soil characteristic was mainly associated with total available soil moistures of 150, 130, and 100, therefore these are used for the simulation purposes.

2.4. Evaluating the impact of drought on irrigated crops

The number of cases generated using the CROPWAT model amounts to 354. To quantitatively assess the impact of drought on IWR of citrus and pomegranate for the drought categories under the consideration in each region, the increase in IWR rate is calculated. In crop modeling, three different total available soil moistures were used for each station and drought category. Similarly, some agriculture regions had more than one station. To obtain the output values based on drought categories in each region, the mean values of the crop model output are calculated. The increase in the IWR rate is identified by the difference between IWR of the reference year and the IWR under different categories of drought. The increase in IWR rate is expressed as:

$$\text{Increase in IWR rate}_{i,d,c} = -\left(\frac{\text{IWR}_{i,c,\text{Ref}} - \text{IWR}_{i,d,c}}{\text{IWR}_{i,c,\text{Ref}}}\right) \times 100\% \quad (1)$$

where the increase in IWR rate$_{i,d,c}$ is the percentage change of IWR at region *i*, drought category *d* and for crop *c*. IWR$_{i,c,\text{Ref}}$ is the reference IWR at region *i* and for crop *c* while, IWR$_{i,d,c}$ is the IWR at region *i*, drought category *d* and crop *c*. The negative sign is placed to make the rate positive demonstrating an increase in IWR.

2.5. Evaluation of the drought impact on groundwater resources

The temporal-spatial impact of drought on groundwater is investigated and quantified by analyzing and computing the historical groundwater data series with the SPI and RDI severity values and examining the trend. The SPI and RDI severity values of the 12-month time scale are obtained from SPI and RDI analysis. Güzelyurt aquifer is used as the case study area since it is the main irrigation water supplying source in North Cyprus. They monitored water level data of 160 different wells belonging to the different parts of the aquifer that are acquired as raw data from the Water Works Department. The water table levels in terms of the monitoring period for each well included different periods ranging from 1977 to 2009. Out of 160 wells examined, 44 wells are selected that had more than 20 years of data and less than 10% of the records are missing. The linear regression model was used to estimate the expected value of the missing water level recordings in the wells. Most correlated neighboring well data were included in the regression model for reliable results. To enable comparison and correlation with the SPI and RDI and perform trend analysis based on different locations or the aquifer itself rather than each well, it is essential to transform the GWL series into a standardized anomaly or non-dimensional standardized anomaly. This removes the effect of water level height and does not distort the trend. The absolute GWLs are converted to groundwater level anomalies (GWLA) by following the procedure given by [28] and [29]. The GWLA is obtained by the following expression:

$$\text{GWLA}_{i,j} = -\left(\text{GWL}_{i,j} - \text{GWL}_{j,\text{mean}}\right) \tag{2}$$

where $\text{GWLA}_{i,j}$ is the GWLA of well i in year j, $\text{GWL}_{i,j}$ is the GWL of well i at year j and $\text{GWL}_{j,\text{mean}}$ is the mean GWL of well j. The negative sign indicates whether the GWL is below or above the average value. Utilizing the same concept of GWLA, the rate of change of groundwater level anomalies (CGWLA) can also be calculated. Its expressed as:

$$\text{CGWLA}_{i,j} = \left(\frac{\text{GWL}_{j,\text{mean}} - \text{GWL}_{i,j}}{\text{GWL}_{j,\text{mean}}}\right) \tag{3}$$

where $\text{CGWLA}_{i,j}$ is the change in GWLA of well i in year j, $\text{GWL}_{i,j}$ is the GWL of well i at year j and $\text{GWL}_{j,\text{mean}}$ is the mean GWL of well j. Averaging the GWLA help to examine and obtain the GWL trends at every location under consideration. The trend analysis through the non-parametric Mann-Kendall trend test was at a significance level of 5%. The non-parametric Sen's slope estimator and the linear regression method were effective to calculate the slope of the trend indicating the rate of change in GWL in m/y.

3. Result and discussion

3.1. Impact of drought on irrigated crops

Drought occurrence has a negative influence on not only water resources but also on the water requirement of irrigated crops. By coupled application of RDI and CROPWAT model, IWR and rate of increase in IWR for pomegranate and citrus fruits under different categories of drought are estimated in this study. In the study area, for the two crops under consideration, during the wet year the mean annual IWR in Girne that receives abundant rainfall is estimated to be approximately 625 mm while for Lefkoşa that receives less rainfall, the estimated mean annual IWR is approximately 790 mm. In other regions that have more or less similar precipitation trend, the IWR is estimated to be 750 mm. On the other hand, during drought years by considering moderate to extreme drought events, the mean annual IWR in Girne and Lefkoşa is estimated to be approximately 720 and 905 mm, respectively. In other regions, this IWR is estimated to be approximately 820 mm.

The spatial variation in the increase of IWR rate due to drought and its different severity levels for both pomegranate and citrus is shown in Figs. 2 and 3. At the regional level, the rate of increase in IWR for both pomegranate and citrus was high in Girne and Lefkoşa while İskele showed the least increase. For citrus during moderate to extreme drought, the increase in IWR rate in Lefkoşa, G.Magusa, Girne, Güzelyurt and İskele is estimated at 18%, 13%, 19%, 14%, and 12%, respectively. For pomegranate in the same regions, the rate was 11%, 6%, 13%, 7%, and 5%, respectively.

At the national level, for citrus during moderate, severe and extreme drought events, the increase in the rate of IWR is estimated as 10%, 16%, and 20%, respectively. For the same drought categories, the rate of increase for pomegranate was 5%, 7%, 12%, respectively. Overall, the mean increase in IWR rate during moderate, severe, and extreme drought is calculated as 8%, 11%, and 16%. As can be seen, though the IWR of pomegranate is slightly higher than citrus, the increase in the IWR rate of pomegranate is slow as compared to citrus. This can be due to the fact that pomegranate is more resistant to drought conditions, whereas, citrus is more sensitive and less resistant to a dry climate.

The rate of increase in IWR estimated in this study during dry years of drought is in line and in good agreement with the ones estimated or predicted by other authors. In this study, the mean increase in the IWR rate during moderate to extreme drought is computed as 12%. The research by [30] had predicted an increase in net IWR between 6% and 9% for Europe due to climate change by considering 1961–1990 climates as the baseline. Similarly, on a global basis, [30] calculated the increase in net IWR between 3%–8%. In another similar study, [31] estimated that regions with average net irrigation requirement of above 900 mm/year, the increase in net irrigation requirement would be less than 10% while regions having average net irrigation requirement between 300–600 mm/year, the increase would be between 10%–30%. This suggests that evaluating the increase in IWR of irrigated crops using drought indices (RDI) and crop simulation model (CROPWAT) can be informative and productive in simulating the impact of extreme events of climate change and variability such as drought on irrigated agriculture crops.

3.2. Impact of drought on groundwater

3.2.1. Trend of GWL

The temporal variability of GWLs due to the direct or indirect effect of climate extremes is assessed and quantified using the Mann-Kendall trend test, Sen's slop estimator and linear regression method. Table 1 shows the obtained results of these statistical tests in different locations of Güzelyurt aquifer and the aquifer itself for the studied time period. According to the results obtained, the water level

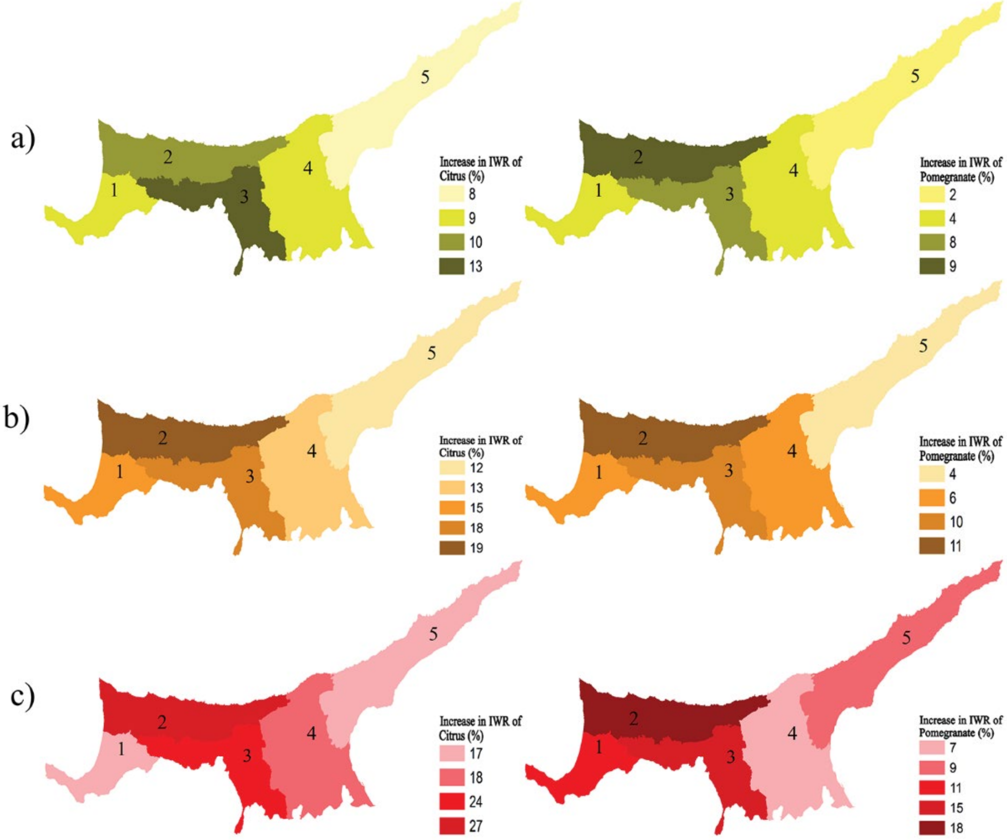

Fig. 2. Rate of increase in IWR based on drought categories: (a) moderate drought, (b) severe drought, and (c) extreme drought. The name of each region is given in numbers, (1) Güzelyurt, (2) Girne, (3) Lefkoşa, (4) G.Magusa, and (5) İskele.

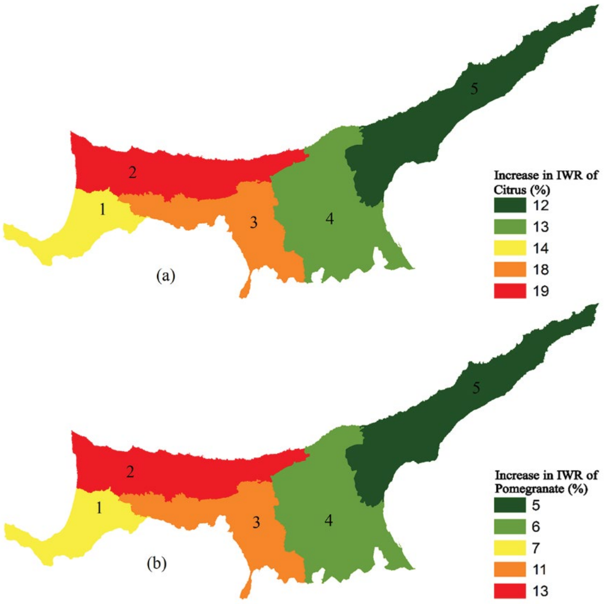

Fig. 3. Mean rate of increase in IWR during drought events: (a) citrus and (b) pomegranate. The name of each region is given in numbers, (1) Güzelyurt, (2) Girne, (3) Lefkoşa, (4) G.Magusa, and (5) İskele.

at the aquifer was not stable and declined at a substantial rate indicating severe groundwater depletion. The obtained slope of GWL indicated that the depletion rate at the aquifer was approximately 0.11 m/y. The depletion of groundwater can be possibly referred to as a decrease in mean precipitation amount, increase in a number of dry years because of the frequent occurrence of drought events and extensive withdrawal for irrigation purposes. Güzelyurt/Morphou aquifer and its surroundings are shown in Fig. 4. The trend tests revealed that the decline in water level in different locations of aquifer varied considerably from one location to another. In Yuvacık ($Z_S = -2.84$) and Zümrütköy ($Z_S = -3.22$), the groundwater depletion is identified to be severe which is reflected by a significantly high decreasing trend. The estimated slope in these two locations indicated a decline rate of 0.25 and 0.65 m/y, respectively. On the other hand, in areas including Güzelyurt, Bostancı, Yeşilyurt, Şahinler, Aydınköy, Akçay, and Mevlevi the result demonstrated a significantly low negative trend with the maximum declining rate of 0.36 m/y in Mevlevi. Locations with the negative trend and high declining rate demonstrate the fact that besides the effect of climate change and variability in the basin, the aquifer in these areas is heavily exploited for socioeconomic activities especially by irrigated agriculture. This also demonstrates that these areas are the main groundwater discharge areas. However, in Kumköy, Gaziveren and

Güneşköy significant weaker positive trend are detected possibly due to poor quality of water in these locations and intrusion of seawater. Overall, the difference in GWL declining rate among the wells located at different regions of the aquifer can be the result of heterogeneous soil and aquifer characteristics and heterogeneous patterns of groundwater utilization. Furthermore, the indication of an insignificant positive and negative trend in different locations signifies the fact that the effect of reduced precipitation and groundwater discharge does not exceed the groundwater storage.

Table 1
Trend analysis of GWLA in different locations of Güzelyurt aquifer

Locations	Z_S	Q_{med} (m/year)	b (m/year)
Güzelyurt	–1.31	–0.09	–0.06
Bostancı	–1.44	–0.14	–0.14
Yeşilyurt	–0.50	–0.03	–0.02
Yuvacık	–2.84	–0.25	–0.26
Şahinler	–1.48	–0.17	–0.15
Kumköy	0.34	0.01	0.00
Aydınköy	–1.31	–0.13	–0.15
Akçay	–1.22	–0.23	–0.21
Gaziveren	0.54	0.01	0.00
Güneşköy	0.77	0.16	0.17
Mevlevi	–1.30	–0.36	–0.29
Zümrütköy	–3.22	–0.65	–0.62
Güzelyurt aquifer	–1.70	–0.11	–0.10

Z_S: Mann-Kendall test;
Q_{med}: Sen's slope estimator;
b: The slope of linear regression.

3.2.2. Correlation analysis of CGWLA and SPI and RDI

Correlation analysis is performed to determine the strength in the relationship of the GWL time series and SPI & RDI. Its conduct in the same time period with no lag (lag-0) and with a lapse of time of one year (lag-1). As shown in Table 2, the correlation coefficient values in different locations between GWL and SPI and GWL and RDI are extremely close to each other indicating that both SPI and RDI behave in a similar manner in revealing the influence of the direct or indirect effect of drought on groundwater. The analysis also revealed two unique characteristics of the wells in relation to drought. Among the different locations, GWL in Kumköy, Akçay, and Mevlevi showed relatively good correlation to both SPI and RDI at the current year with no lag. This indicates that the influence of rainfall deficit during the dry years is significant in these locations. On the other hand, this also reflects the fact that these locations can be the potential recharge areas of the aquifer. In these areas, however, with a one year lag, the correlation reduces, indicating that the influence of drought diminishes as time passes. In contrast, at lag-0 the GWL in other locations revealed the least and very low correlation with both SPI and RDI. This weaker correlation can be possibly due to the complex nature of the groundwater system and aquifer hydrology, saltwater intrusion, management practices and over-exploitation of the aquifer. Conversely, with the passage of time for these locations, the correlation improves particularly after a lag

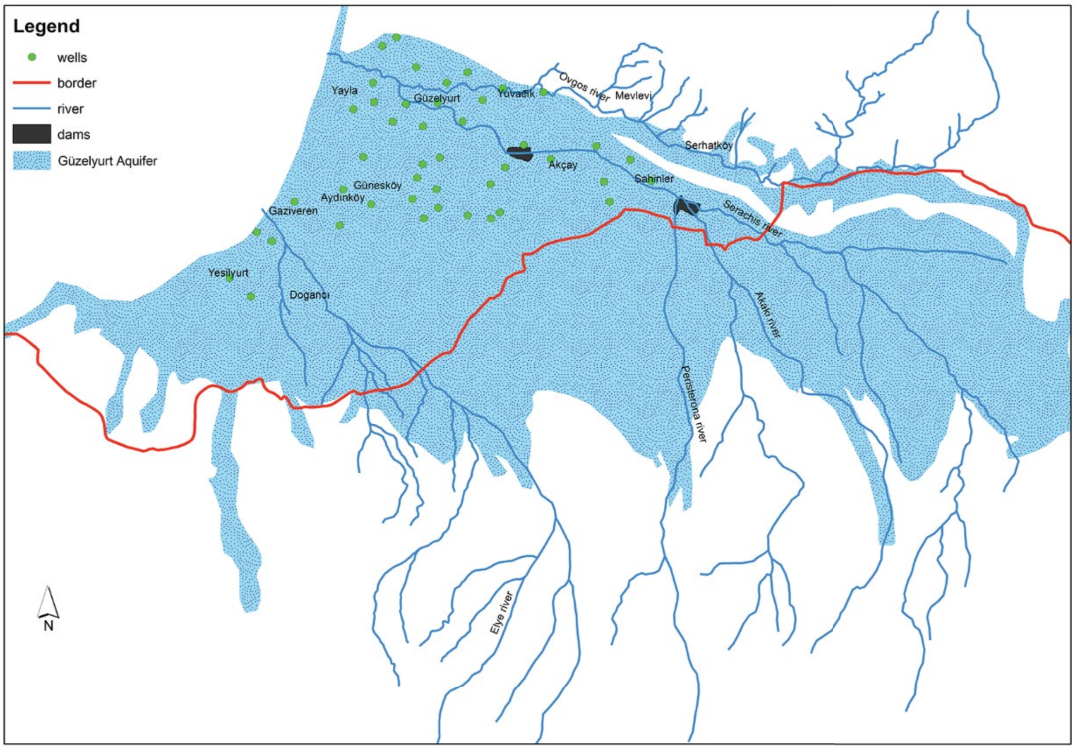

Fig. 4. Detailed map of the Güzelyurt aquifer and its surroundings.

Table 2
The overall correlation coefficient of CGWLA and SPI & RDI at lag-0 and lag-1 in different locations of Güzelyurt aquifer

Locations	Lag-0		Lag-1	
	SPI	RDI	SPI	RDI
Güzelyurt	0.114	0.116	0.198	0.209
Bostancı	0.166	0.137	0.189	0.192
Yeşilyurt	0.192	0.198	0.205	0.213
Yuvacık	0.065	0.056	0.117	0.114
Şahinler	0.117	0.123	0.222	0.241
Kumköy	0.332	0.339	–0.116	–0.107
Aydınköy	0.081	0.068	0.072	0.057
Akçay	0.295	0.295	0.316	0.328
Gaziveren	0.194	0.205	0.052	0.059
Güneşköy	0.016	0.047	0.288	0.315
Mevlevi	0.257	0.270	0.117	0.141
Zümrütköy	0.079	0.065	0.261	0.267
Güzelyurt aquifer	0.172	0.170	–0.130	–0.147

of one year. This demonstrates that in these types of wells the effect of drought slowly propagates through the system and gets visible after a year's time. Overall, the mean correlation coefficient of GWL in Güzelyurt aquifer to both SPI and RDI during the drought year is estimated at 0.173 and 0.170, respectively. The analysis showed that in general, there exists a positive relationship between GWL and SPI & RDI which indicates that drought is associated with the decline in GWL.

3.2.3. Temporal response of aquifer to drought events

The comparison between the GWL quantified by the rate of CGWLA and SPI & RDI is depicted by the hydrograph shown in Fig. 5. The hydrograph demonstrated important features of the response of aquifer in terms of temporal water level fluctuation to extreme events of climate change and variability. The result indicated that the positive and negative values of the CGWLA representing the rise and fall in GWL with respect to the long term mean. During wet years the CGWLA is mostly positive while during dry years it's mostly negative. The exception to this pattern exists in a few years where the CGWLA is positive and SPI & RDI values are negative or vice versa. Though the fluctuation in the CGWLA follows the same pattern generally, the rate and magnitude of the CGWLA are not homogeneous in space and time. Another important feature observed is the upward movement of the CGWLA after any drop-down during any drought event. This indicates the recovery of the GWL to pre-drought condition. However, the rate of recovery after each drought event depending upon different factors is not always the same and constant. Observing the hydrograph, the water table in an aquifer is more sensitive to the duration of the drought rather than its severity. The longer the duration of the drought even with low severity, the higher would be the impact.

The resemblance and close relationship between the fluctuation of the CGWLA and the SPI & RDI can also differentiate the effect of climate extremes on water table within the aquifer and the effect of other natural processes and anthropogenic activities. In this respect, four separate conditions depending upon the rate and magnitude of the fluctuation due to the effect of drought, in this case, can be drawn from the hydrograph. The first condition is where the CGWLA is approximately equal to the negative SPI & RDI values. This represents the sole direct effect of drought on the water table of the aquifer. During the drought event of 1985–86, 1991–92, 1997–98 and 1986–87 in Güzelyurt, Bostancı, Yeşilyurt, and Yuvacık, respectively, the CGWLA and SPI & RDI values coincide with each other. The second condition is where the CGWLA is smaller than the SPI & RDI negative values, possibly signifying the combined direct effect of drought and management actions such as implementing adaptation measures like limiting the withdrawal to a certain threshold during the drought event. This is the case in Şahinler, Kumköy, Aydınköy, and Akçay during the drought event of 2007–08, 1990–91, 1994–95 and 1978–79, respectively. The third condition is where the CGWLA is greater than the SPI & RDI negative values, demonstrating the combined direct effect of drought and the indirect effect of heavy extraction from the groundwater for irrigated agriculture. In this case, the indirect effect of withdrawal due to drought outweigh the direct effect of drought on the aquifer. This is the situation during the drought event of 2000–01, 1986–87, 1986–87 and 1991–92 in Gaziveren, Güneşköy, Mevlevi and Zümrütköy, respectively. The fourth condition is where both CGWLA and SPI & RDI values move in the opposite direction. This is the case where SPI & RDI values are negative and has a downward slope and the CGWLA is positive and have an upward slope or vice versa. In this situation, the effect during any drought event can be possibly due to the combined effect of drought and other natural processes such as heavy saltwater intrusion into the aquifer or combined effect of drought and management actions like completely stopping the water extraction from the aquifer. In these cases, the effect of management actions or natural processes is much more dominant than the effect of drought due to the reduced recharge of the aquifer. The behavior of CGWLA and the SPI & RDI values based on this condition is visible in Güzelyurt, Yuvacık, Aydınköy, and Mevlevi during the drought event of 2004–05, 1994–95, 1983–1984 and 1994–95, respectively.

4. Conclusions

Quantifying the spatial and temporal effect of drought on irrigated agriculture and groundwater resources is essential for food security and availability and sustainable management and utilization of non-renewable groundwater resources under changing the climate. Within this context, in this study, RDI coupled with a process-based crop simulation model (CROPWAT) is employed to determine the effect of drought on irrigated agriculture in terms of an increase in IWR based on moderate, severe and extreme drought categories. On the other hand, SPI and RDI are combined with GWL time series data to produce the required hydrographs to investigate and assess the response of groundwater resources to the temporal and spatial effects of drought. For in-depth, understanding, non-parametric Mann-Kendall trend test and Sen's slope estimator and the linear regression method is used to quantify the temporal changes and behavior of aquifer.

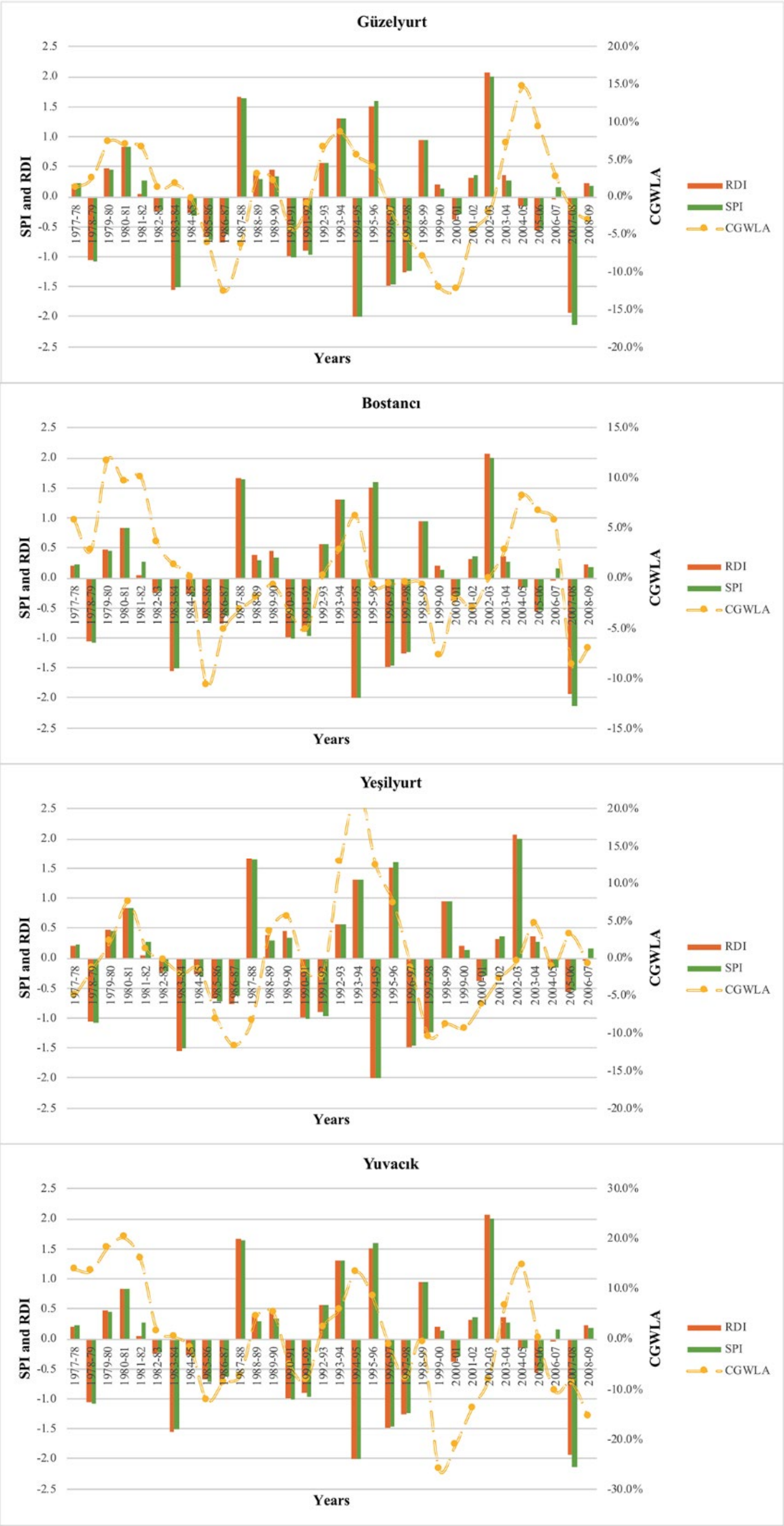

Fig. 5. Continued

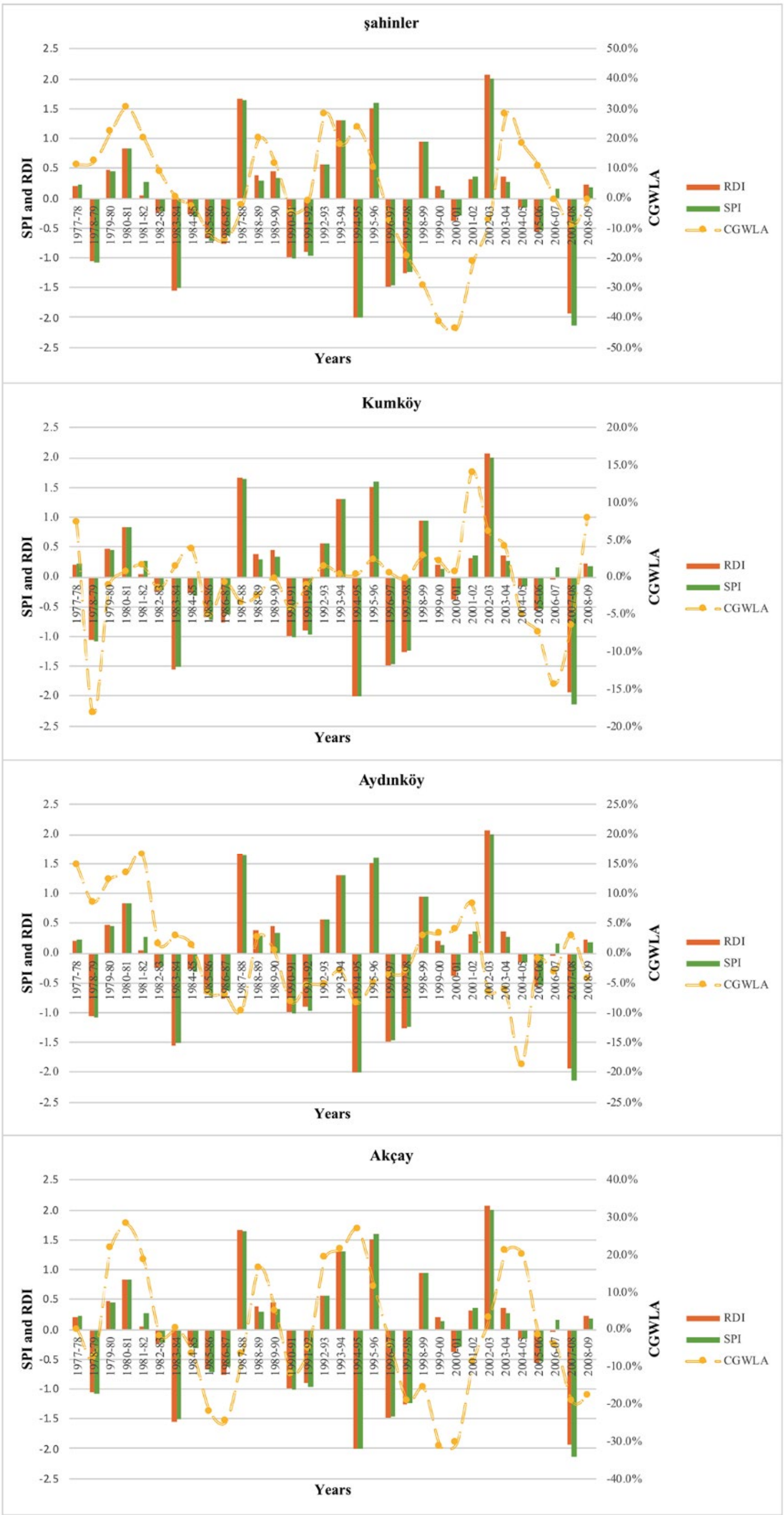

Fig. 5. Continued

Fig. 5. Spatio-temporal comparison of CGWLA and SPI & RDI in different locations of Güzelyurt aquifer.

The analysis revealed that during moderate, severe, and extreme drought the increase in IWR of irrigated crops is 8%, 11%, and 16%, respectively. Overall, the mean increase in IWR during dry years of drought is estimated at 12% which is in line with the findings of other authors.

The temporal fluctuation in GWL generally resembled the positive and negative values of SPI and RDI. In this regard, the mean correlation coefficient of GWL in Güzelyurt aquifer to both SPI and RDI is estimated at 0.173 and 0.170, respectively. The GWL trend signified that the water in Güzelyurt aquifer due to variability in precipitation, an increase in the frequency of dry years and anthropogenic activities is declining at a mean rate of 0.11 m/y. However, depending upon spatial heterogeneity of climate, soil and hydrogeological conditions and pattern of usage the rate varies. Location with the highest declining rate can be the potential discharge areas while in those areas where the groundwater is stabilized are the potential recharge areas.

The result of this study provides preliminary information for sustainable and strategic planning and management of irrigated agriculture and groundwater resources in the face of climate change. More research is required to better understand the hydrological and meteorological processes. Moreover, to better understand the influence of different factors affecting the aquifer it is also recommended to estimate the variation in pumping rate and/or drought-induced pumping under different climatic scenarios and conditions as well as assess the effect of land use and management.

References

[1] IPCC, Technical Paper on Climate Change and Water, IPCC Secretariat, Geneva, Switzerland, 2008.

[2] R. Schaldach, J. Koch, T. Aus der Beek, E. Kynast, M. Flörke, Current and future irrigation water requirements in pan-Europe: an integrated analysis of socio-economic and climate scenarios, Global Planet. Change, 94–95 (2012) 33–45.

[3] C. Gamvroudis, Z. Dokou, N.P. Nikolaidis, G.P. Karatzas, Impacts of surface and groundwater variability response to future climate change scenarios in a large Mediterranean watershed, Environ. Earth Sci., 76 (2017) 385.

[4] W. Cramer, J. Guiot, M. Fader, J. Garrabou, J.-P. Gattuso, A. Iglesias, M.A. Lange, P. Lionello, M.C. Llasat, S. Paz, J. Peñuelas, M. Snoussi, A. Toreti, M.N. Tsimplis, E. Xoplaki, Climate change and interconnected risks to sustainable development in the Mediterranean, Nat. Clim. Change, 8 (2018) 972–980.

[5] A.H. Payab, U. Türker, Comparison of standardized meteorological indices for drought monitoring at northern part of Cyprus, Environ. Earth Sci., 78 (2019) 309.

[6] P. Lionello, S. Luca, The relation between climate change in the Mediterranean region and global warming, Reg. Environ. Change, 18, (2018) 1481–1493.

[7] R.A. Aslam, S. Shrestha, V.P. Pandey, Groundwater vulnerability to climate change: a review of the assessment methodology, Sci. Total Environ., 612 (2018) 853–875.

[8] T. Garamhegyi, J. Kovács, R. Pongrácz, P. Tanos, I.G. Hatvani, Investigation of the climate-driven periodicity of shallow groundwater level fluctuations in a Central-Eastern European agricultural region, Hydrogeol. J., 26 (2018) 677–688.

[9] B. Kløve, P. Ala-Aho, G. Bertrand, J.J. Gurdak, H. Kupfersberger, J. Kværner, T. Muotka, H. Mykrä, E. Preda, P. Rossi, C.B. Uvo, E. Velasco, M. Pulido-Velazquez, Climate change impacts on groundwater and dependent ecosystems, J. Hydrol., 518 (2014) 250–266.

[10] T. Cui, M. Raiber, D. Pagendam, M. Gilfedder, D. Rassam, Response of groundwater level and surface-water/groundwater interaction to climate variability: Clarence-Moreton Basin, Australia, Hydrogeol. J., 26 (2018) 593–614.

[11] H. Treidel, J.L. Martin-Bordes, J.J. Gurdak, Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations, International Association of Hydrogeologists (IAH) – International Contributions to Hydrogeology, Taylor & Francis, London, UK, 2011, 414 p.

[12] H. Gökcekuş, A. Iravanian, U. Türker, G. Oğuz, S. Sözen, D. Orhon, Massive fresh water transport: a new dimension for integrated water-wastewater management in North Cyprus, Desal. Wat. Treat., 132 (2018) 215–225.

[13] A.H. Payab, U. Türker, Analyzing temporal–spatial characteristics of drought events in the northern part of Cyprus, Environ. Dev. Sustainability, 20 (2018) 1553–1574.

[14] U. Türker, B.S. Alsalabi, T. Rızza, Water table fluctuation analyses and associated empirical approach to predict spatial distribution of water table at Yeşilköy/AgiosAndronikos aquifer, Environ. Earth Sci., 69 (2013) 63–75.

[15] A.A.A. Jamal, U. Türker, Assessment of the regional water balance of the limestone subaquifers of Cyprus, J. Earth Syst. Sci., 124 (2015) 541–551.

[16] H. Gökçekuş, Hydrogeological and Hydrogeochemical Evaluation of the Güzelyurt Groundwater Basin, Unpublished Ph.D. Thesis, METU, Turkey, 1990.

[17] A.K. Mishra, V.P. Singh, A review of drought concepts, J. Hydrol., 391 (2010) 202–216.

[18] J. Lorenzo-Lacruz, C. Garcia, E. Morán-Tejeda, Groundwater level responses to precipitation variability in Mediterranean insular aquifers, J. Hydrol., 552 (2017) 516–531.

[19] L. Tian, S.S. Yuan, M.Q. Steven, Evaluation of six indices for monitoring agricultural drought in the south-central United States, Agric. For. Meteorol., 249 (2018) 107–119.

[20] T.B. McKee, N.J. Doesken, J. Kleist, The Relationship of Drought Frequency and Duration to Time Scales, Proceedings of the 8th Conference on Applied Climatology, 17–22 January, Anaheim, California, USA, 1993, pp. 179–184.

[21] G. Tsakiris, H. Vangelis, Establishing a drought index incorporating evapotranspiration, Eur. Water, 9 (2005) 3–11.

[22] FAO (Food and Agriculture Organization), CROPWAT Software, Food and Agriculture Organization, Land and Water Division, Rome, Italy, 2009.

[23] S. Chowdhury, M. Al-Zahrani, A. Abbas, Implications of climate change on crop water requirements in arid region: an example of Al-Jouf, Saudi Arabia, J. King Saud Univ. Eng. Sci., 28 (2016) 21–31.

[24] P. Paredes, D. D'Agostino, M. Assif, M. Todorovic, L.S. Pereira, Assessing potato transpiration, yield and water productivity under various water regimes and planting dates using the FAO dual K_c approach, Agric. Water Manage, 195 (2018) 11–24.

[25] FAO (Food and Agriculture Organization), CLIMWAT - A Climatic Database for Irrigation Planning and Management, FAO, Rome, Italy, 2012.

[26] FAO (Food and Agriculture Organization), Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements - FAO Irrigation and Drainage Paper No. 56, Food and Agricultural Organization of the United Nations, Rome, 1998.

[27] FAO/IIASA/ISRIC/ISSCAS/JRC, Harmonized World Soil Database (Version 1.1), FAO, Rome, Italy and IIASA, Laxenburg, Austria, 2009.

[28] S.N. Bhanja, M. Rodell, B.L. Li, D.P. Saha, A. Mukherjee, Spatio-temporal variability of groundwater storage in India, J. Hydrol., 544 (2017) 428–437.

[29] X.L. Hu, L.S. Shi, J.C. Zeng, J.Z. Yang, Y.Y. Zha, Y.J. Yao, G.L. Cao, Estimation of actual irrigation amount and its impact on groundwater depletion: a case study in the Hebei Plain, China, J. Hydrol., 543 (2016) 433–449.

[30] P. Döll, Impact of climate change and variability on irrigation requirements: a global perspective, Clim. Change, 54 (2002) 269–293.

[31] P. Döll, S. Siebert, Global modeling of irrigation water requirements, Water Resour. Res., 38 (2002) 1037.