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Hydrological Droughts and Runoff Trends of the Demirköprü Dam Reservoir Basin on Gediz River, Turkey

Gediz Nehri Demirköprü Baraj Havzasının Hidrolojik Kuraklıkları ve Eğilimleri

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Abstract

In recent years, the impacts of climate change on water resources are much more noticeable. In terms of sustainable management of water resources, it is important to identify drought occurrences in river basins and to identify drought trends. For this purpose, many drought indices have been developed in order to define the droughts quantitatively and Streamflow Drought Index (SDI) method is frequently used to determine the hydrological droughts among them. In this study, hydrological droughst of on Acısu, Selendi, Deliiniş, Demirci sub-basins and incoming total runoff to Demirköprü Dam reservoir on the Gediz River were analyzed in monthly, quarterly, six-month and annual time-scales. The total inflows of Demirköprü Dam reseroir trends were investigated at same time scales.As a result of the study, it was determined that the all sub-basins runoff and incoming total runoff to Demirköprü Dam reservoir were affected from hydrological droughts for long periods and trends of incoming runoff to Demirköprü Dam reservoir were towards the dry periods.

Keywords: *SDI; hydrological drought; trend analysis; Demirköprü Dam; Gediz basin*

Öz

Son yıllarda, iklim değişikliğinin su kaynakları üzerindeki etkileri çok daha belirgin bir biçimde ortaya çıkmaktadır. Su kaynaklarının sürdürülebilir yönetimi açısından, nehir havzalarındaki kuraklık olaylarını ve kuraklık eğilimlerini tanımlamak büyük önem taşımaktadır. Bu amaçla, kuraklıkları niceliksel olarak tanımlamak için birçok kuraklık endeksi geliştirilmiştir ve bilhassa hidrolojik kuraklıkları belirlemek amacıyla Streamflow Drought Index (SDI) yöntemi sıkça kullanılmaktadır. Bu çalışmada Gediz Nehri'ndeki Acısu, Selendi, Deliiniş, Demirci havzaları ve Demirköprü Baraj rezervuarındaki hidrolojik kuraklık ve eğilimleri aylık, üç aylık, altı aylık ve yıllık zaman ölçeklerinde incelenmiştir. Çalışma sonucunda, Demirköprü Barajı havzası girişlerinin uzun süre hidrolojik kuraklıklardan etkilendiği ve kuraklık analizlerinin kurak dönemleri işaret ettği tespit edilmiştir.

Keywords: *SDI; Hidrolojik kuraklık; eğilim analizi; Demirköprü barajı; Gediz havzası*

1. Introduction

Droughts, often caused by deforestation, urbanization and similar factors, related to changing climate conditions and population growth [1, 2]. The meteorological drought, which is defined as the lack of the precipitation over the long-term averages, will lead to decreases in the stream runoff as a result of the continuation of a certain period of time, and hydrological drought will occur. In other words, hydrological drought can be defined as decreases in runoff in surface and groundwater forms [3]. Hydrological droughts have a significant negative impact on socio-economic life as given rise to restrictions especially on agricultural irrigation, decreasing energy production and water supply [4]. Characterization of hydrological droughts occurring in the basin is important for reducing these impacts and sustainable water resources management [5]. Hydrological drought indices have been developed in order to determine duration and magnitude intensity of droughts in basin runoff such as, Streamflow Drought Index (SDI), Surface Water Supply Index (SWSI), Reclamation Drought Index (RCDI) and Nonlinear Multivariate Drought Index (NMDI) [6, 7, 8, 9]. The SDI method examines droughts based on different time scales and requires only monthly runoff data; therefore, reduces computational difficulties and data requirements and gives powerful assessing at basin-drought [6, 10, 13].

Many studies have been carried out worldwide due to the fact that the SDI method can be applied to hydrological droughts at different time periods (1, 3, 6, 9, 12 and 24 months) [10, 11]. The hydrologic droughts occuring in the Sefid-Rud basin have been determined by SDI during the seasonal, 6-months and annual periods between 1984 and 2013 water years [12]. The hydrological droughts of Seyhan-Ceyhan rivers have been investigated on between the years 1970-2005 in 3, 6 and 12 months periods using with SDI. As a result of the study, severe hydrological droughts occurred in the basins in 2001 [13].

The water scarcity significantly will occur in Gediz River Basin on supplying of irrigation water. Approximately 90% of the Gediz basin irrigation area is covered by the Demirköprü Dam reservoir located on the Gediz River, Turkey. Therefore, the hydrological droughts occurring in the basin streams feeding the Demirköprü dam reservoir significantly affects supply of Gediz Basin irrigation water requirements. This study covers the determination of the hydrological drought and trend analyses incoming total runoff to Demirköprü Dam reservoir between 1970-2007 water years. Hydrological droughts and trends of incoming runoff to Demirköprü Dam reservoir were examined on monthly, quarterly, semi-annual and annual timescales using the SDI method and Mann-Kendall test, respectively.

2. Materials and Methods

2.1. Study area and data

The Gediz Basin lies between northern latitudes of $38^0$04’–$39^0$13’ and southern longitudes of $26^0$42’–$29^0$45’ in Aegean Region, western Turkey (Figure 1). The basin covers an area of 17500 km², which is equal to 2.2% of the total area of Turkey and the total irrigation area is 110000 ha. The Gediz River, is 275-kilometer long. The Demirköprü Dam was built on the Gediz River in Manisa Province of Turkey between 1954 and 1960, in an effort to enhance irrigation, power generation, and flood control activities. The height of this embankment dam from the streambed is 75.00 m. The hydroelectric power plant built in the dam generates 193 GWh electric power annually with a capacity of 69 MW. Lying between 28° 18' – 28° 28' eastern longitudes and 38° 36' – 38° 45' northern latitudes, the Demirköprü Dam reservoir also provides water for the irrigation of 99.220 hectares. With the reservoir catchment that covers an area of 5520 km², that constitutes 32% of all Gediz basin. Demirköprü Dam reservoir is fed by Acısu, Selendi, Deliiniş and Demirci tributaries of the Gediz River (Figure 1) and the number of runoff gauge stations on these tributaries are 523, 514, 515, 522, respectively. Among these, Acısu Tributary has the biggest catchment area with 3272 km². The smallest catchment area, however, belongs to Selendi Tributary with 689.6 km² hectares [18].

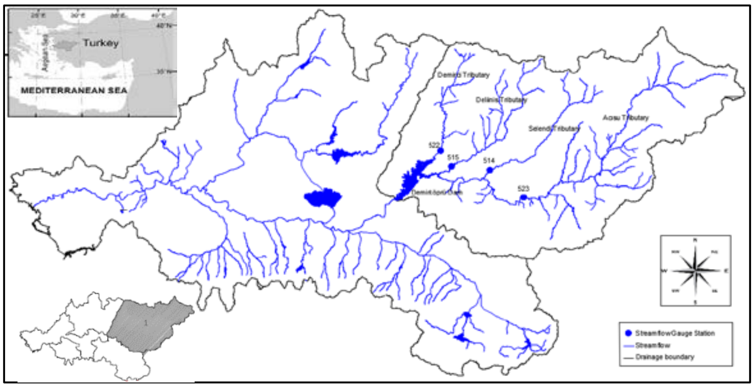


Fig. 1. Gediz River Basin and the Demirköprü Dam Reservoir

2.2. Streamflow Drought Index (SDI)

Periodical drought indices of the streams in question were measured using the SDI developed by Nalbantis [6]. The SDI indices are calculated by Eq.1 in consideration of total monthly streamflow values.

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V_k}}{S_k} \qquad (1)$$

where, "i" is equal to the water year, "k" refers to the period (monthly, quarterly, semiannual and annual), $V_{i,k}$ total monthly flow volume (m^3/month), $\overline{V_k}$ is the mean and S_k is the standard deviation of the total streamflow of the kth period.

If cumulative streamflow data corresponds to a distribution such as log-normal distribution, the SDI values are calculated by taking the natural logarithms of the cumulative streamflow data [6]. Suitable probability functions for the runoff data are investigated using several goodness-of-fit test and thereby the Normal distribution is chosen as the best one among the successful distributions in this study. The hydrological droughts of all sub-basins runoff and incoming total runoff to Demirköprü Dam reservoir were invetigated at month monthly (SDI1), quarterly (SDI3), 6-month (SDI6) and annual (SDI12) time scales in the study.

Table 1. The claasification of droughts for SDI

Drought Classes	SDI
Extreme wet (EW)	SDI > 2
Severe wet (SW)	1.5 < SDI ≤ 2
Moderate wet (MoW)	1.0 < SDI ≤ 1.5
Mild wet (MW)	0 < SDI ≤ 1
Mild drought (MD)	-1 < SDI ≤ 0
Moderate drought (MoD)	-1.5 < SDI ≤-1
Severe drought (SD)	-2 < SDI ≤-1.5
Extreme drought (ED)	-2 ≤ SDI

2.3 Mann-Kendall Test

In the study, The Mann-Kendall test was used for defining the trends for total incoming runoff to Demirköprü Dam reservoir. The Mann-Kendall test has a non-parametric nature. This test is applied to x_i and x_j data sets, ordered as i=1,2,..., N-1 and j=i+1,...,N, respectively. Each ordered x_i figure is taken as a point of reference and figures are compared with the x_j data set using Eq.2.

$$sgn(x_j - x_i) = \begin{cases} 1 & ; \quad x_j > x_i \\ 0 & ; \quad x_j = x_i \\ -1 & ; \quad x_j < x_i \end{cases} \qquad (2)$$

The Mann-Kendall test (S) statistics are calculated using Eq.3., with the help of the results to be obtained through Eq.3.

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i) \tag{3}$$

For N≥8, S shows normal distribution with an average (E[S]) and variance (Var(S)) same as those calculated with Eq.4 and Eq.5. However, if N≥30, z test value will be closer to t test [15].

$$\boldsymbol{E[S] = 0} \tag{4}$$

$$\boldsymbol{Var(S) = \frac{N(N-1)(2N+5) - \sum_{i=1}^{P} t_i(t_i-1)(2t_i+5)}{18}} \tag{5}$$

where, the number of relative groups in P data set refers to an observation in the i series. The term "total" in Eq.5 is only used if a relative observation exists within the data set. The standardized Mann-Kendall statistics (z) are calculated by Eq.6.

$$z = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} & ; \quad S > 0 \\ 0 & ; \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}} & ; \quad S < 0 \end{cases} \tag{6}$$

A significance level α is used for testing either an upward or downward trend. An absolute value of z is higher than $z_{\alpha/2}$ at α significant level also indicates a trend. A negative z value means that the trend is downward, while a positive (+) one refers to an upward trend. Significant trends of total incoming runoff at different timescales were determined at 0.05 level of α.

3. Results and Discussion

In the study, hydrological droughts for all sub-basins runoff and incoming total runoff to Demirköprü Dam reservoir and the trends of total incoming runoff were discovered at different time scales in the period between the 1970 to 2007 water years. The distributions of SDI for only monthly timescale for investigated period are given in Figure 2. Quarterly, semiannual and annual SDI time series between 1970 and 2007 water years are shown in Figure 3.

Considering the SDI1, SDI3, SDI6 and SDI12 of the sub-basins runoff and incoming total runoff to Demirköprü Dam reservoir, the drought events occurred more frequently in period of 1985 and thereafter especially between 1985-1995 water years. The variation of SDI values for all examined timescales demonstrate that the extreme wet event is happened, but the extreme drought event is not seen between 1970-2007 water years. The highest severe drought events for incoming total runoff of dam reservoir were occurred May 1989 and June 2001 for SDI1, in April-June 1984 for SDI3, in April-September 1984 for SDI6 and in 1989 water year for SDI12 (Fig.2 ,Fig. 3). The durations of drought period and significant trends of incoming total runoff to dam reservoir are shown in Table 2. The longest drought duration is observed in November between 1985-2009 water years for SDI1, in October-December between 1985-1997 water years for SDI3, in October-March between 1988-1997 and in April-September between 1985-1994 for SDI6 and between 1988-1997 water years for SDI12. The trends of the incoming total runoff to dam reservoir have downward trends in October, November, January, June, July, August and September and the other months of SDI1 have shown no trend. When trends in SDI3 periods total runoff are examined, it is seen that there are downward trends in October-December and July-September periods and no trend in other periods. The incoming total runoff trends are identified in SDI6 as a downward trend for both semi-annual periods, in SDI12 has a downward trend

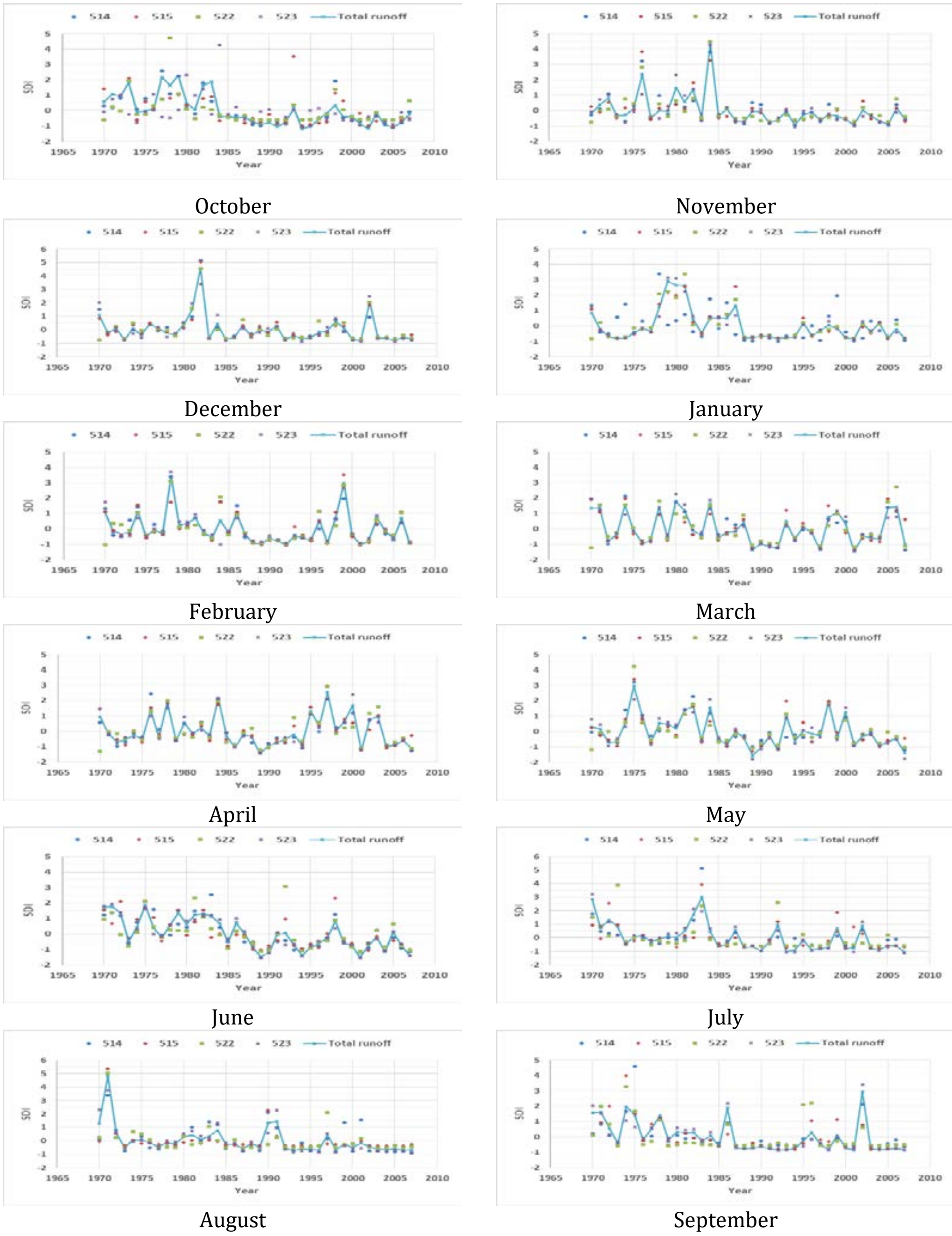
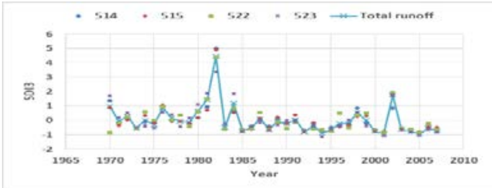
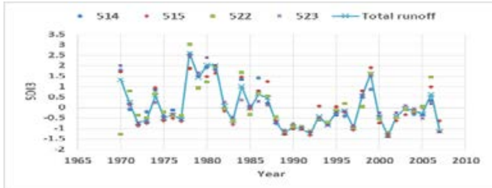


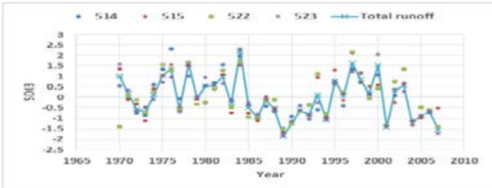
Fig.2. Monthly SDIs time series between 1970 and 2007 water years for 514, 515, 522, 523 and total runoff of Demirköprü Dam Reservoir



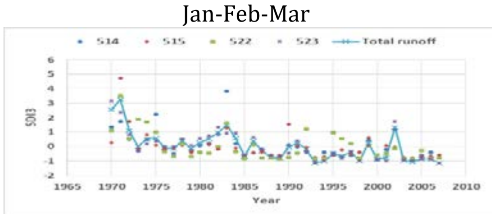
Oct-Nov-Dec



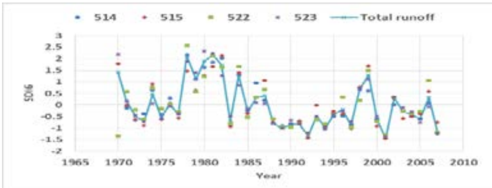
Jan-Feb-Mar



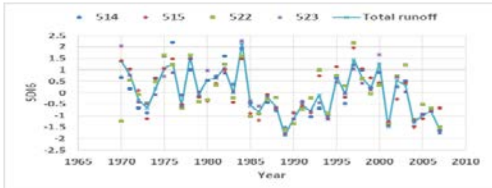
Apr-May-Jun



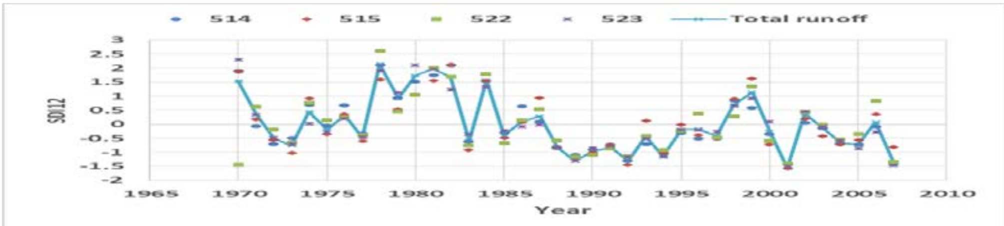
Jul-Aug-Sep



O-N-D-J-F-M



A-M-J-J-A-S



O-N-D-J-F-M- A-M-J-J-A-S

Fig.3. Quarterly, semiannual and annual SDI time series between 1970 and 2007 water years for the stations 514, 515, 522, 523 and total runoff of Demirköprü Dam Reservoir

Table 2.Monthly, quarterly, semi-annual and annual timescales drought periods and trends of the incoming total runoff to Demirköprü Dam Reservoir

Months	SDI1						SDI3		SDI6	SDI12
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Oct. – Dec.	Jan. – Mar.	Oct..- Mar.	Oct.- Sep.r
Drought	1999-2007	1985-2005	1992-1997	1971-1977 1988-1994	1987-1995	1989-1992 2001-2004	1985-1997	1988-1997	1988-1997	1988-1997
Max Length	9 years	19 years	6 years	7 years	9 years	4 years	13 years	10 years	10 years	10 years

Trend (α=0.05)	↓	↓	↓	→	↓	→	↓	→	↓	↓
Months	Apr.	May	June	July	Aug.	Sep.	Apr.-June	July-Sep.	Apr.-Sep.	
Drought	1985-1994	1985-1992	1987-1997	1993-1998	1998-2007	1987-1995	1985-1992	1992-1998	1985-1994	
Max Length	10 years	8 years	11 years	6 years	10 years	9 years	8 years	7 years	10 years	
Trend (α=0.05)	→	→	↓	↓	↓	↓	→	↓	↓	

Figure 4 shows that the wet and drought events frequencies of incoming total runoff to Demirköprü Dam reservoir between 1970-2007 water years. The highest drought frequency level is observed to be 68%, 66%, 58%, 58% for SDI1-November, SDI3 October-December, SDI6 October-March and SDI12, respectively. The drought events are much more happened than the wet events according to the all examined timescales.

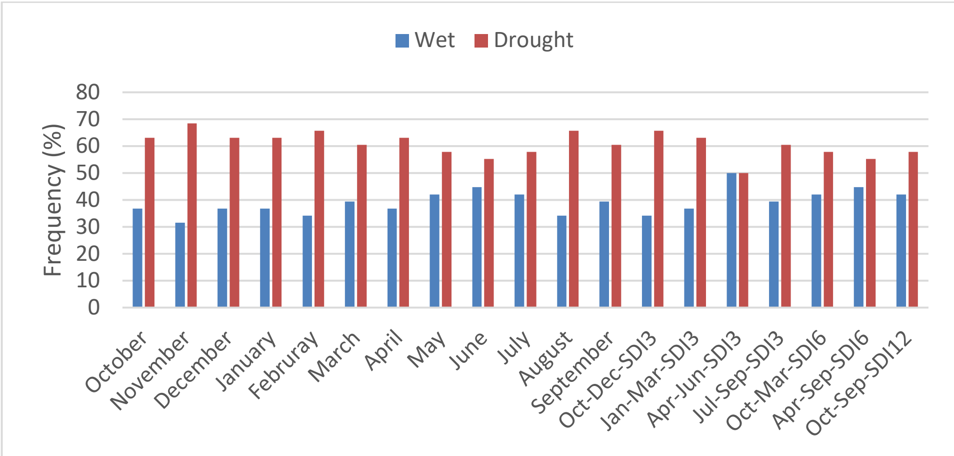


Fig. 4. The frequency of wet and drought events of incoming total runoff to Demirköprü Dam Reservoir for SDI1, SDI3, SDI6 and SDI12 timescales

When the results obtained in the SDI1, SDI3, SDI6 and SDI12 timescales are evaluated together, it is seen that there are significant drought periods especially at between 1988-1997 water years and downward trends in the the incoming total runoff to the Demirköprü dam reservoir basin. Hydrologic drought, which started in 1985 on a monthly timescale in Demirköprü dam basin runoff, were occured in the 3-month, 6-month and annual timescale droughts in 1988 and continued until 1997. The impact of this drought caused the changes in the operating plans of the dam to restricted irrigation of the 99000 ha area that supplied water from the Demirköprü dam reservoir [16, 17].

4. Conclusion

In this study, hydrological droughts for all runoff, with by SDI method, and the trends of incoming total runoff to Demirköprü Dam reservoir are found out at 1, 3, 6 and 12 month time scales in period between 1970 to 2013 water years for the Demirköprü Dam reservoir basin runoff, Turkey.

According to the 1, 3 6 and 12 months timescales SDI indices hydrological drought seasons are more prevalent, and incoming runoff to Demirköprü Dam reservoir trends show a trend to the dry periods within the investigated period. All these data and information about the runoff feeding important reservoirs for both irrigation and power generation indicate an alarming situation in sustainable management of these facilities. The frequent hydrological drought seasons that have occurred within the past years may decrease the level of waters in reservoirs used for irrigation and power generation, therefore affect the variety and quality of agricultural products. As a result, this kind of studies should be furthered as they may provide significant guidance to the partners involved in decision and policy-making processes about reservoirs and water management measures.

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