Desalination and Water Treatment
www.deswater.com

26 (2011) 14–23
February

doi: 10/5004/dwt.2011.2105

Meteorological drought analysis case study: Central Anatolia

Ülker Güner Bacanli[a,*], Fatih Dikbaş[a], Türkay Baran[b]

[a]*Faculty of Engineering, Civil Engineering Department, Pamukkale University, Kınıklı Campus, Denizli/Turkey*
Tel. +90 258 2963403; email: ugbacanli@pau.edu.tr
[b]*Faculty of Engineering, Civil Engineering Department, Dokuz Eylul University, Kaynaklar Campus, İzmir/Turkey*

Received 25 November 2009; Accepted 22 March 2010

ABSTRACT

Drought is one of the major disasters which might have consequences like hunger and poverty. The droughts depend on many factors including climatic and regional properties, soil type, population increase and environmental degradation. The complex character of drought makes it difficult to define. Hence, various specific criteria must be defined and used for the evaluated basin, region or territory to determine drought. In this study, several drought analysis methods are performed on the Central Anatolian Region in Turkey where has survived a severe drought. In comparative analysis, Palmer Drought Severity Index (PDSI), Erinc and De Martonne methods were used. The evaluated data consist of the observed monthly mean precipitation and temperature data of 13 selected meteorology stations in the region. The observed data in between 1965–2006 periods were evaluated for all stations. Thus, the distribution of dry and wet periods is investigated at monthly time scale. The comparative results show that PDSI index indicates more humid conditions than Erinc and De Martonne indices. Nevertheless, the results verify that the region is still in danger of severe drought.

Keywords: De Martonne method; Drought; Erinc method; Palmer drought severity index

1. Introduction

Drought is the one of the most important and pervasive natural disasters influencing human life. Drought is a complex phenomenon, which is difficult to define. It might have many social and economical consequences like low agricultural production and famine. The term is used to refer to deficiency in rainfall, soil moisture, vegetation greenness, ecological conditions or socioeconomic conditions, and different drought types can be inferred [1]. Nevertheless, drought is multifaceted and complex hydrological phenomenon, a consequence of an abnormal decrease of precipitation [1,2]. Drought characteristics are often represented by the drought indices to indicate the actual hydrological conditions in a single number.

The researchers use different type of drought indices. For example, the widely used Palmer Drought Severity Index (PDSI) has four different forms. The Palmer drought indices are used [PDSI, the Palmer Hydrological Drought Index (PHDI), the Palmer Moisture Anomaly Z-Index (Palmer Z-index) and the Modified Palmer Drought Severity Index (Weighted PDSI)] to monitor hydrological droughts [3]. In this study, the results of the drought analysis for the Central Anatolian Region in Turkey are presented. This region is defined under dry sub-humid climatic conditions [4]. To define the drought, Palmer Drought Severity Index (PDSI), Erinc and De Martonne methods were used.

2. Materials and methods

2.1. Drought indexes

2.1.1. Necessity of drought indexes

Drought indexes created to provide a concise overall picture of droughts are often derived from massive

*Corresponding author.

Presented at the International workshop on urbanisation, land use, land degradation and environment (ULE 2009), 28 September – 1 October 2009, Denizli, Turkey

amounts of hydro-climatic data and are used for decision making on water resources management and water allocations for mitigating the impact of droughts. Although various drought indexes have been used in water resources management studies, the indexes measure the climatic and hydrologic trends and fluctuations in principal.

In consequence of climate change, drought studies have received special attention in recent years [5]. In this context, the development of drought monitoring plans has become the first priority in one hand [6,7]. On the other hand, some researchers have analyzed the atmospheric causes of droughts [8,9] in order to improve drought prediction [10–12]. Therewith for using diverse variables for drought quantification, numerous drought indices were developed during the 20th century [13–15]. Although temperatures or evapotranspiration are generally included in drought index calculation, precipitation is the most important parameter as available water [16,17].

One of the most important water management problems is to define the spatial patterns of drought risk in order to assist agricultural or environmental management. Some researchers focused on these problems [18–20], but these efforts have focused mainly on the development of drought indexes, to identify and quantify drought's magnitude, duration, intensity and spatial extent, and to improve techniques for drought early warning and management [21].

A drought index integrates various hydrological and meteorological parameters like rainfall, evapotranspiration, runoff and other water supply indicators into a single number and gives a comprehensive picture for decision making. Among various drought indexes, the Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), De Martonne, Erinc methods are used extensively for water resources management, agricultural drought monitoring and forecasting. Each of these drought indexes, their strengths and limitations are explained briefly in the following section.

2.1.2. Palmer drought severity index

The PDSI, developed by Palmer [22], is based on the supply and demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of this index was to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between mons.

These departures are converted into indices of moisture anomaly as

$$Z = K(j) \times D \tag{1}$$

where K(j) is a weighting factor, also accounting for spatial variability of the departures (D). The Z-index time series are analyzed to develop the criteria for the beginning and ending of drought periods and an empirical formula for determining drought severity, such as:

$$X_j = 0.897 * X_{j-1} + \frac{Z_j}{3} \tag{2}$$

where Z_j is the moisture anomaly index and X_j is the PDSI for the j-th mon. Dry and wet periods can be classified according to determined PDSI values (Table 1).

2.1.3. Erinc method

Erinc index is used by many researchers to assess the drought problem of Turkey and to determine the dry/wet areas and periods. Erinc proposed the following precipitation efficiency or namely drought index relationship using precipitation and maximum temperature causing water loss via evaporation [24].

$$I_m = \frac{P}{T_{om}} \tag{3}$$

In this equation, I_m is the precipitation efficiency, P is the total annual precipitation amount (mm) and T_{om}

Table 1
Classification of dry and wet periods according to PDSI [23]

PDSI	Class	PDSI	Class
≥4.00	Extremely wet (W3)	(–1.50) ~ (–2.99)	Moderate drought (D1)
3.00 ~ 3.99	Very wet (W2)	(–3.00) ~ (–3.99)	Severe drought (D2)
1.50 ~ 2.99	Moderately wet (W1)	≤(–4.00)	Extreme drought (D3)
(–1.49) ~ 1.49	Near normal (N)		

is the annual maximum mean temperature (°C). The drought classification according to the Erinc Index values is presented in Table 2.

2.1.4. De Martonne method

The classification according to De Martonne formula includes both the temperature and precipitation and also the parameters like relative moisture, sunshine duration and evaporation [25]. The annual drought or aridity index formula is given as:

$$I_a = \frac{P}{2\left[(T+10) + 12\dfrac{p}{(t+10)}\right]} \tag{4}$$

In this equation, P is the mean of long years total precipitation (mm); T is the long years mean temperature (°C), p is the total precipitation of the driest mon (mm) and t is the mean temperature of the driest mon (°C). The number 10 is the constant value which is used to make t positive in places where the temperature is below zero.

De Martonne has used the aridity index to study irrigation demands [26]. The classification according to De Martonne aridity index is presented in Table 3.

Table 2
Classification of drought according to Erinc index [24]

Class	Index value	Vegetation
Completely dry	<8	Desert
Dry	8–15	Desert, steppe
Semi-dry	15–23	Steppe
Semi-wet	23–40	Park like forest
Wet	40–55	Wet forest
Extremely wet	55<	Very wet forest

Table 3
Classification of drought according to De Martonne Aridity index

Index	Class	Index	Class
<8	Dry	21–28	Semi-humid
8–10	Semi-dry	29–55	Humid
11–20	Steppe–Semi-wet	55<	Very humid

2.2. The study area and available data

The study area is the Central Anatolian Region (Fig. 1) which consists of three major river basins: Kızılırmak basin, Sakarya basin and Konya closed basins. The agriculture has a major importance for the region, especially the Plain of Konya which is called "the granary of Turkey".

Climate of Central Anatolia has the following properties: The weather in the summer is a little hot and winters are cold. The severity of cold weather increases towards the eastern parts of Central Anatolia. Natural flora consists of steppes in the lower regions and dry forests in the higher regions because of summer droughts. Mean temperature of January, the coldest mon, is 0.7 °C and it is 22 °C in July, the hottest mon. Annual mean temperature is 10.8 °C. Mean annual precipitation is 413.8 mm and most of the precipitation occurs in winter and spring seasons. The percent of summer rains among the annual total is 14.7%. The annual mean proportional moisture in the region is 63.7% [27].

In drought analysis, the meteorological stations are evaluated to define meteorological drought. At the first step, the operational meteorological stations which are managed by DMI (State Meteorological Service) and DSI (State Hydraulic Works) are pre-evaluated for available long term precipitation and temperature data. Hence, the drought analyses have been performed on Aksaray, Ankara, Çankırı, Eskişehir, Karaman, Kayseri, Konya, Kırıkkale, Kırşehir, Nevşehir, Niğde, Sivas and Yozgat meteorological stations which are located in major city centers of the Central Anatolian Region. The evaluated records are observed in the 1965–2006 period.

The study area is mainly divided into three major basins, but not entirely. The Upper Sakarya, the Upper and the Middle Kızılırmak, and the entire Konya closed basins are located in the study area. The characteristics of the watersheds and the considered meteorological stations for these sub regions are presented in Table 4. The main characteristics of the meteorological stations and the observed maximum, minimum and the long term mean for the observed values are presented in Table 5.

3. Results

According to the defined formulas in Chapter 2, the PDSI, Erinc and De Mortonne indices were calculated for the Central Anatolian Region.

The PDSI results are presented in relative frequency form for each meteorological station, classified by the inclusive watershed (Figs. 2a–d).

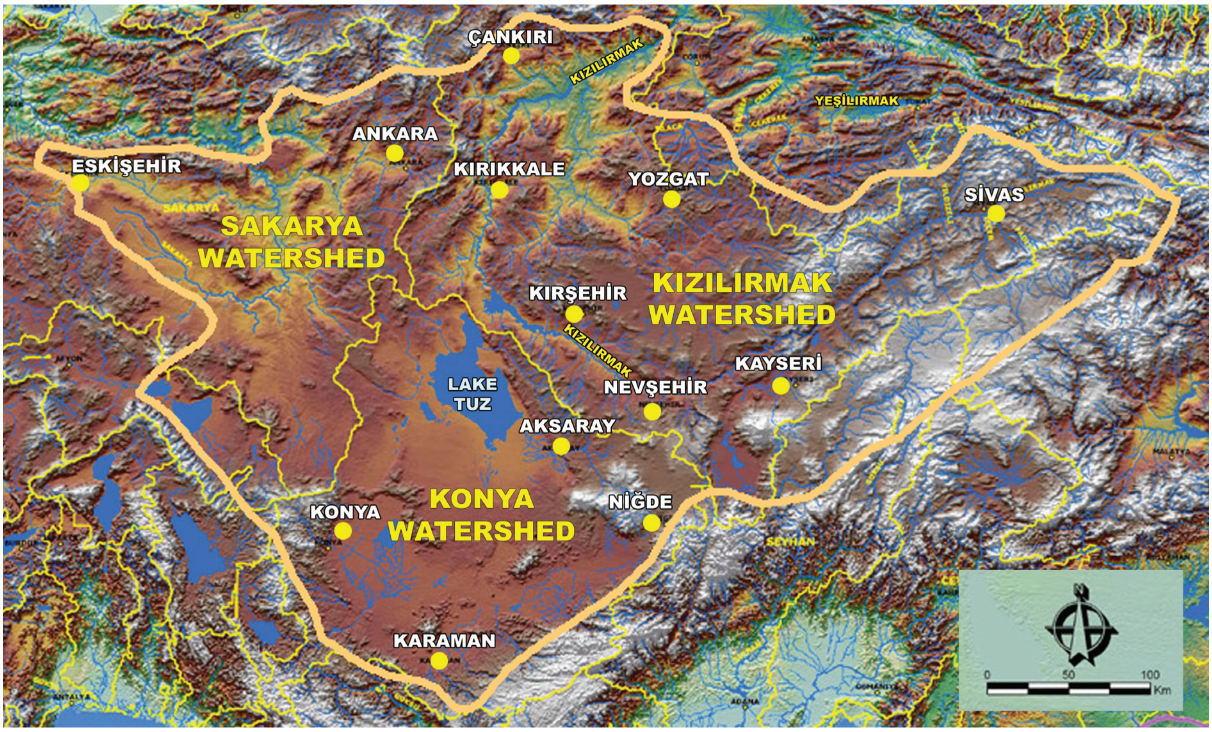

Fig. 1. Central Anatolian region.

Table 4
The major characteristics of the study area

Watershed	Meteorological stations	Meteorological station number	Longitude	Latitude	Watershed area (km²)	Mean elevation (m)	Mean annual precipitation (mm)
Upper Sakarya	Eskişehir	17124	30° 35′	39° 47′	33,847	839	400
	Ankara	17130	32° 53′	39° 57′			
	Çankırı	17080	33° 37′	40° 37′			
Konya	Konya	17244	32° 33′	37° 59′	53,850	1005	344
	Aksaray	17192	34° 03′	38° 23′			
	Karaman	17246	33° 13′	37° 12′			
Upper Kızılırmak	Sivas	17090	37° 01′	39° 45′	6,607	1285	444
Middle Kızılırmak	Kayseri	17196	35° 29′	38° 45′	78,180	1103	414
	Nevşehir	17193	34° 42′	38° 37′			
	Niğde	17250	34° 41′	37° 58′			
	Kırşehir	17160	34° 09′	39° 10′			
	Kırıkkale	17135	33° 31′	39° 51′			
	Yozgat	17140	34° 48′	39° 49′			

The relative frequencies of PDSI values have shown that the Central Anatolian Region can be defined as "normal" in general. The PDSI results show that the severe and extreme drought periods mostly appear in Niğde, Nevşehir and Sivas which are located in Kızılırmak basin.

The Upper Sakarya basin which includes Ankara, Eskişehir and Çankırı stations has moderate (D1) drought nearly 20% of the time (Fig. 2a). The drought period approaches to 30%, by addition of severe (D2) and extreme (D3) drought periods.

Table 5
Main characteristics of the meteorological stations

Meteorological stations	Elevation (m)	In observation period (1965–2006)					
		Mean annual precipitation (mm)	Annual precipitation (mm)		Mean annual temperature (°C)	Annual temperature (°C)	
			Max	Min		Max	Min
Aksaray	961	340.6	506.2	228.8	11.8	13.8	10.0
Ankara	891	401.9	571.2	242.0	11.8	13.5	10.3
Çankırı	751	403.9	554.0	229.8	11.1	12.6	9.9
Eskişehir	786	345.4	458.8	227.1	10.5	11.8	9.1
Karaman	1023	333.2	513.4	212.6	11.7	13.2	9.4
Kayseri	1093	383.1	614.1	257.9	10.3	12.6	8.4
Konya	1031	323.8	544.9	176.1	11.4	13.2	9.2
Kırıkkale	751	373.8	610.1	207.3	12.4	14.4	11.2
Kırşehir	1007	383.4	541.9	254.2	11.2	13.0	9.4
Nevşehir	1260	409.8	589.0	293.8	10.4	12.3	8.4
Niğde	1211	325.7	454.8	192.9	10.9	12.8	8.6
Sivas	1285	436.9	567.8	284.8	8.9	10.9	6.6
Yozgat	1298	587.8	858.2	391.0	8.8	10.6	7.0

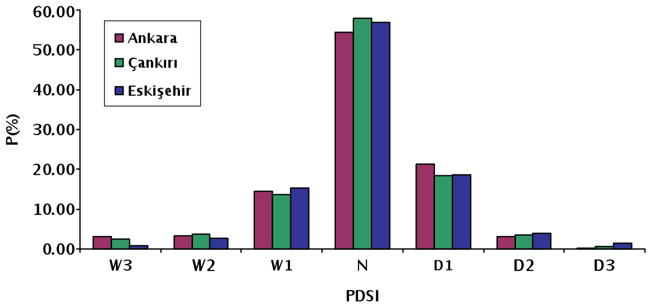

Fig. 2a. The relative frequencies of PDSI for the Upper Sakarya basin.

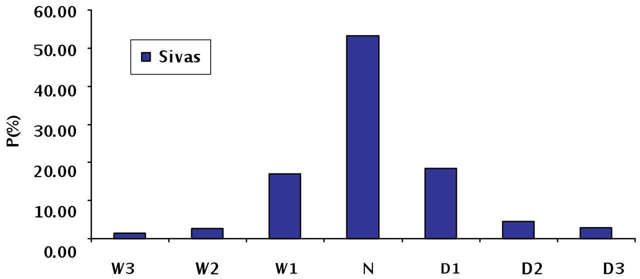

Fig. 2c. The relative frequencies of PDSI for the Upper Kızılırmak basin.

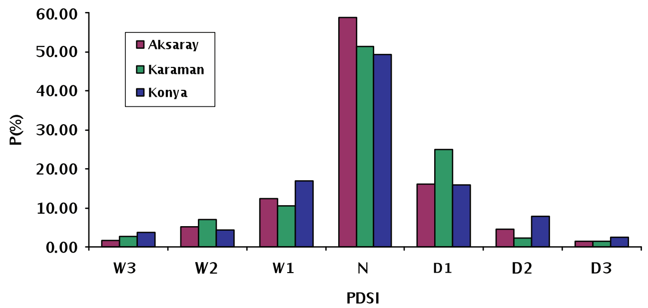

Fig. 2b. The relative frequencies of PDSI for the Konya closed basin.

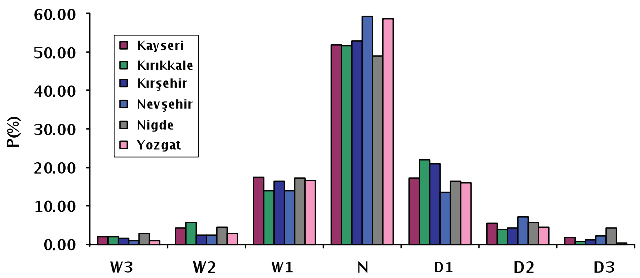

Fig. 2d. The relative frequencies of PDSI for the Middle Kızılırmak basin.

The Konya closed basin which is represented by Konya, Aksaray and Karaman stations have moderate (D1) drought nearly 20% of the time (Fig. 2b). The drought period approaches to 30%, by addition of severe (D2) and extreme (D3) drought periods for this basin. The moderate drought is over 30% in Aksaray, where the Lake Tuz is located. It is reported that the Lake Tuz (meaning Salt Lake) derogated 85% since 1915 [28]. Hence, the Lake Tuz has become the third largest lake in Turkey after the Beyşehir Lake since 2005.

The Upper Kızılırmak basin which is only represented by Sivas station have moderate (D1) drought about 20% of the time (Fig. 2c). The drought period approaches to 30%, by addition of severe (D2) and extreme (D3) drought periods for this basin.

The Middle Kızılırmak basin is represented by six stations, namely Kayseri, Nevşehir, Niğde, Kırşehir, Kırıkkale and Yozgat. The basin has moderate (D1) drought approximately 20% of the time (Fig. 2d). The drought period approaches to 30%, by addition of severe (D2) and extreme (D3) drought periods for this basin, if Yozgat station is excluded.

The drought classification results of PDSI are shown in Fig. 3. As it is stated before, the PDSI results show that the Central Anatolian Region can be defined as "normal" in general.

The drought classification results of De Martonne method are shown in Fig. 4. According to De Martonne aridity index, the Central Anatolian Region is classified under three sub-regions:

- Group I (Semi-dry region): Aksaray, Ankara, Çankırı, Eskişehir, Kayseri, Kırşehir, Nevşehir, Kırıkkale, Sivas.
- Group II (Dry region): Karaman, Konya, Niğde.
- Group III (Semi-wet region): Yozgat.

The results of De Martonne method indicated the following classifications according to the watersheds:

- Upper Sakarya basin is classified as semi-dry.
- Konya Closed basin is classified as dry.
- Upper Kızılırmak basin is classified as semi-dry.
- Middle Kızılırmak basin has no monotype classification. Some sub-regions are classified as dry or semi-dry and one of them is classified as semi-wet.

The summary of the relative frequency values of Erinc Index are presented in Table 6. According to the Erinc method, the driest period was experienced in

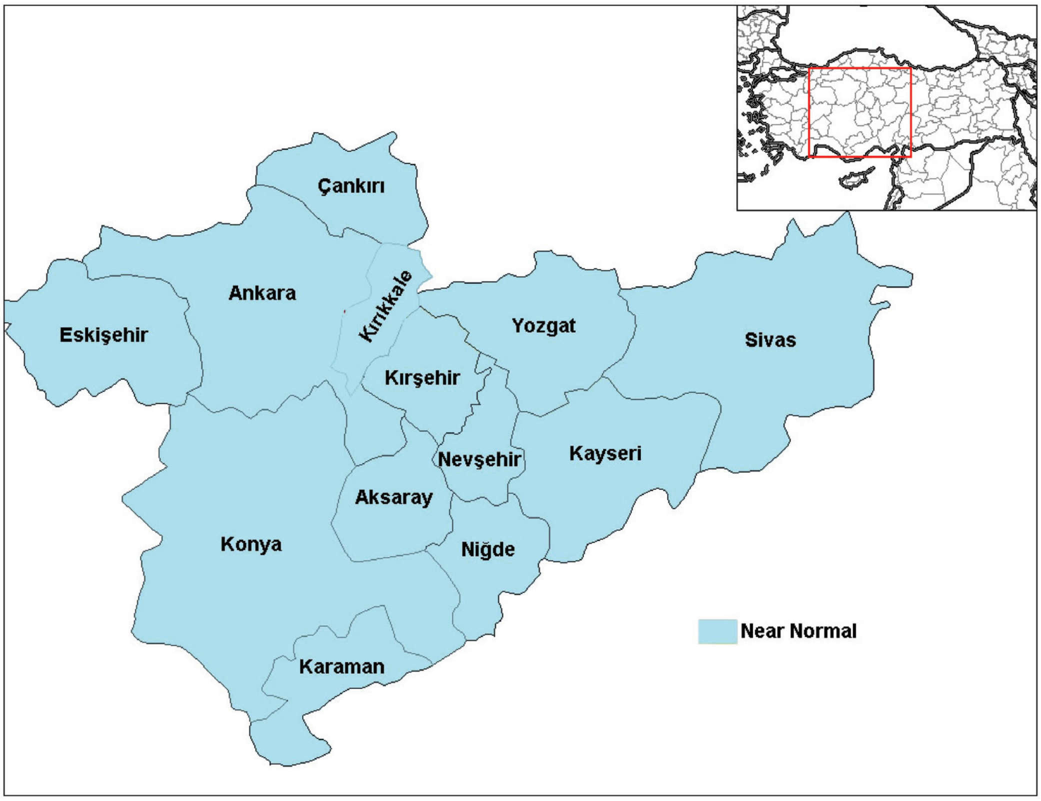

Fig. 3. PDSI monthly drought classification for modal frequencies.

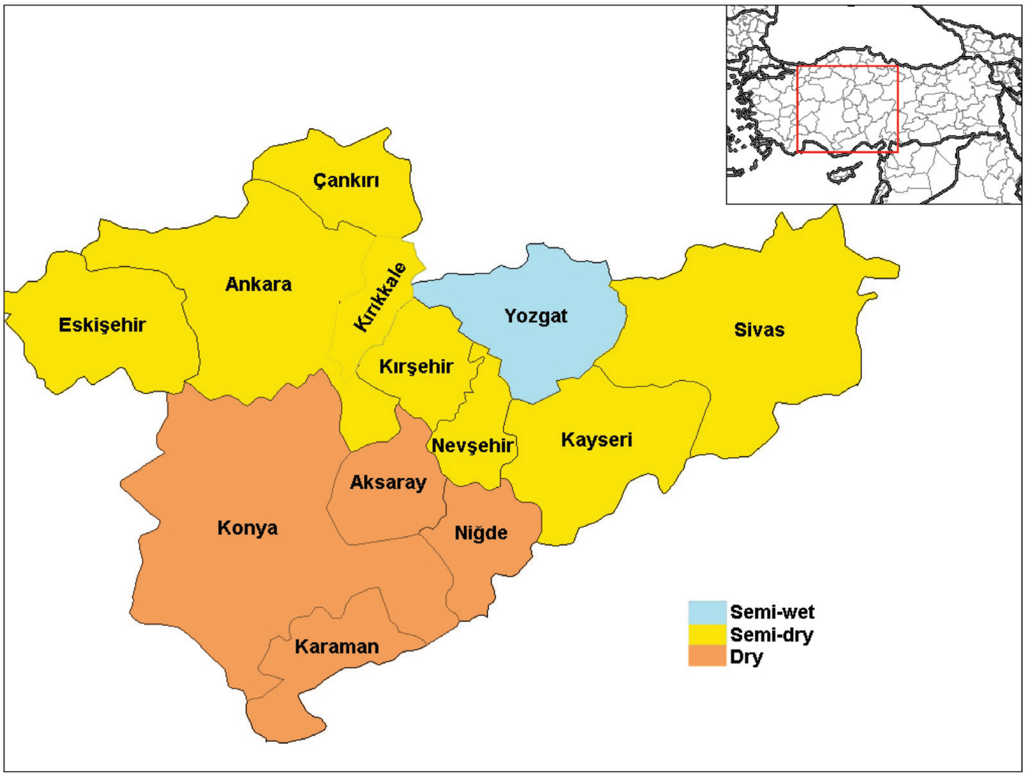

Fig. 4. De Martonne aridity index classification in Central Anatolian Region.

Table 6
The relative frequencies of Erinc indexes of the stations in Central Anatolia

	Comp. dry	Dry	Semi-dry	Semi-wet	Wet	Very wet
Aksaray	0.00	0.62	0.38	0.00	0.00	0.00
Ankara	0.00	0.31	0.64	0.05	0.00	0.00
Çankırı	0.00	0.24	0.74	0.02	0.00	0.00
skişehir	0.00	0.28	0.70	0.02	0.00	0.00
Karaman	0.00	0.64	0.36	0.00	0.00	0.00
Kayseri	0.00	0.26	0.69	0.05	0.00	0.00
Kırıkkale	0.03	0.62	0.33	0.02	0.00	0.00
Kırşehir	0.00	0.40	0.58	0.02	0.00	0.00
Konya	0.02	0.70	0.26	0.02	0.00	0.00
Nevşehir	0.00	0.19	0.69	0.12	0.00	0.00
Niğde	0.00	0.52	0.48	0.00	0.00	0.00
Sivas	0.00	0.05	0.62	0.33	0.00	0.00
Yozgat	0.00	0.00	0.10	0.86	0.05	0.00

Konya with 70% and semi-dry periods were experienced in Çankırı with 74% and in Eskişehir with 70%. The mean rate of semi-dry period was observed in Upper Sakarya watershed with 67%, Konya watershed 35%, Upper Kızılırmak watershed with 62%, and Middle Kızılırmak watershed with 51% (Fig. 5).

In Fig. 6, the non-exceedence probabilities of semi-dry classification for Erinc index are presented. This figure shows the importance of the drought for the Central Anatolian Region. It is clear that the drought risk threatens the whole region except Yozgat, located in Middle Kızılırmak sub-basin.

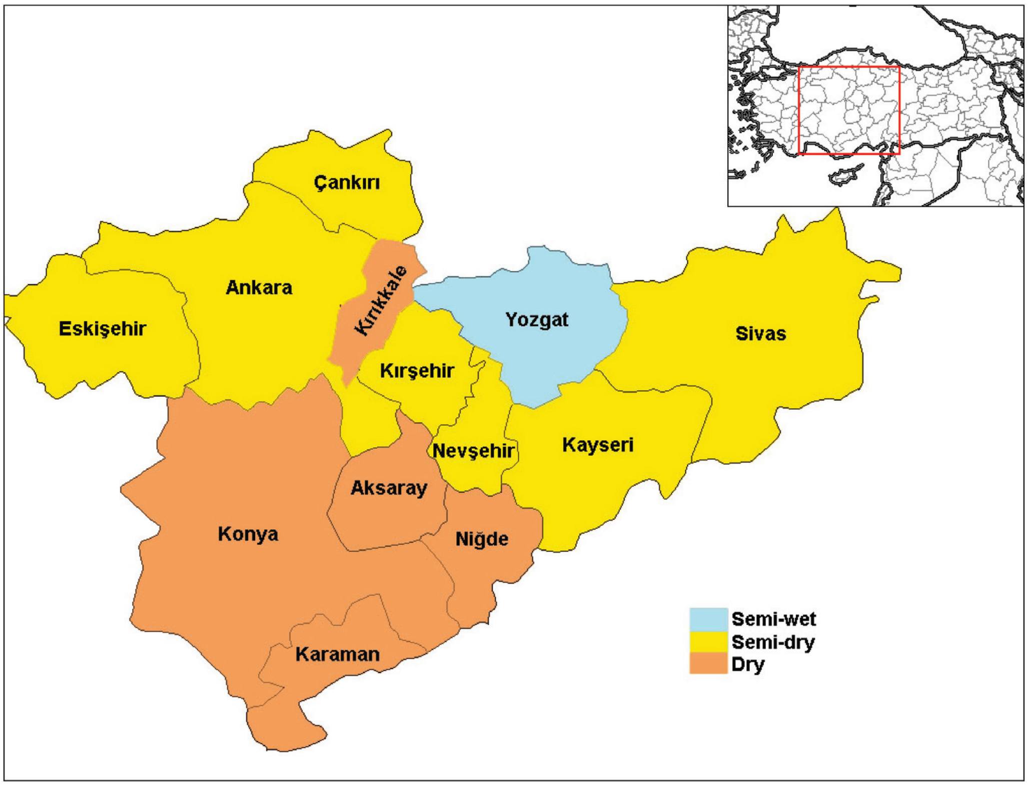

Fig. 5. Erinc index drought classification for modal frequencies.

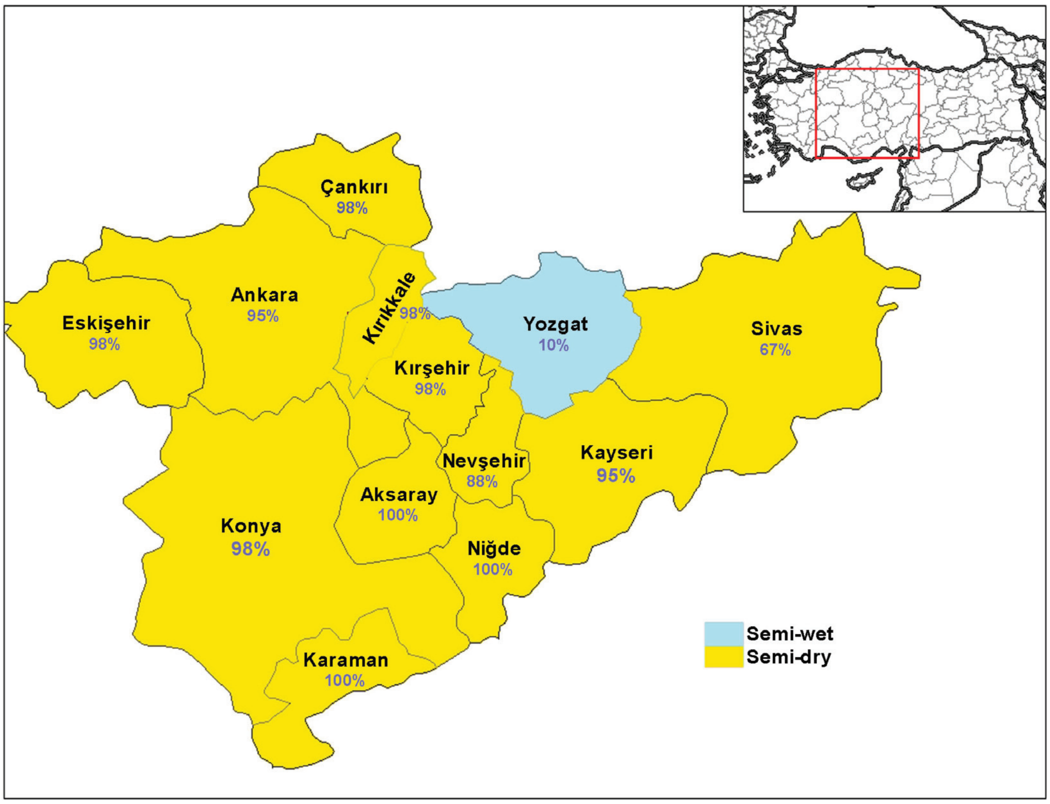

Fig. 6. Erinc index annual semi-dry drought classification for non-exceedence probability.

4. Conclusion

The results of the PDSI method were not realistic for the investigated region. De Martonne method shows small inconsistencies in the evaluations inside the watersheds. The Erinc Index is generally consistent in the evaluation of the watersheds. The comparative results show that PDSI index indicates more humid conditions than Erinc and De Martonne indices. On the other hand, the results indicate that the region is still in danger of severe drought.

With the results of the Erinc method, it can be stated that the project area is generally in a drought period in the recent years. The results of De Martonne aridity and Erinc index confirm that the persistence of drought risk is still continued for the Central Anatolian Region. The results show that Konya Closed basin, "the granary of Turkey", needs urgent drought management plans. It can be said that the drought risks might turn into desertification risk for this basin (Figs. 5 and 6).

On the other hand, the Upper Sakarya basin which is highly important not only for agriculture but also the water supply project for the Capital Ankara and Eskişehir metropolis, is under the risk of drought. Similarly, the Middle Kızılırmak basin especially Niğde, Aksaray and Kırıkkale regions, where the karst is the dominant geographical formations, is under the risk of drought. Hence, it is necessary to arrange the integrated drought risk management plan for the Central Anatolian Region.

The severe drought indicators for the region should be taken into consideration and the drought management plans should urgently be prepared for the region which is agriculturally important. It is needed to establish a drought center with researchers from different disciplines for decreasing the drought influences, taking precautions and continuous monitoring. The investigation of drought in the basin scale will have important contribution in the determination of the priorities for planning, design and construction of water structures.

Acknowledgements

The authors would like to thank the anonymous reviewers and the editors for their helpful comments, which improved the quality of the final manuscript. The authors would also thank to TÜBİTAK for their valuable support via the project numbered 107Y348.

Symbols

Z	—	Moisture anomaly index
$K(j)$	—	Weighting factor
D	—	Spatial variability of the departures
X_j	—	Palmer Drought Severity Index for the j-th month
I_m	—	Precipitation efficiency
P	—	Total annual precipitation amount
T_{om}	—	Annual maximum mean temperature
I_a	—	De martonne annual drought index
T	—	Long years mean temperature
p	—	Total precipitation of the driest month
t	—	Mean temperature of the driest month

References

[1] N.S. Grigg, Water Resources Management: Principles, regulations and cases. New York, Mc Graw-Hill (1996).

[2] M.A. Beran and J.A. Rodier (Rapporteurs), Hydrological Aspects of Drought, UNESCO/WMO, Paris (1985).

[3] L. Vasiliades and A. Loukas, Hydrological response to meteorological drought using the Palmer drought indices in Thessaly, Greece. Desalination, 237 (2009) 3–21.

[4] M. Türkeş, Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. Tr J. Eng. Env. Sci., 23 (1999) 363–380.

[5] H.R. Byun and D.A. Wilhite, Objective quantification of drought severity and duration, J. Climate, 12 (1999) 2747–2756.

[6] M. Svoboda, D. LeCompte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, R. Tinker, M. Palecki, D. Stooksbury, D. Miskus and S. Stephens, The drought monitor, B. Am. Meteorol. Soc., 83 (2002) 1181–1190.

[7] D.A. Wilhite, The Role of Disaster Preparedness in National Planning with Specific Reference to Drought. In:M.K.V. Sivakumar, R.P. Motha and H. Das (eds.) Natural Disasters and Extreme Events in Agriculture, Springer, Berlin (2005) 23–37.

[8] J. Namias, Some causes of United States drought, J. Clim. Appl. Meteorol., 22 (1983) 30–39.

[9] C.F. Ropelewski and M.S. Halpert, Precipitation patterns associated with the high phase of the Southern Oscillation, J. Climate., 2 (1989) 268–284.

[10] I. Cordery and M. McCall, A model for forecasting drought from teleconections, Water Resour. Res., 36 (2000) 763–768.

[11] B. Lloyd-Hughes and M.A. Saunders, Seasonal Prediction of European Spring Precipitation From El Ni˜No-Southern Oscillation and Local Sea-Surface Temperatures, Int. J. Climatol., 22 (2002) 1–14.

[12] D.A. Wilhite, M.V.K. Sivakumar and D.A. Wood (eds.), Early Warning Systems for Drought Preparedness and Drought Management. Proceedings of an Expert Group Meeting. Lisbon, Portugal, September 5–7. World Meteorological Organization, Geneva, Switzerland (2000).

[13] E.O. Oladipo, A comparative performance analysis of three meteorological drought indices, J. Climate., 5 (1985) 655–664.

[14] C.G. Du Pisani, H.J. Fouch´e and J.C. Venter, Assessing Rangeland Drought in South Africa, Agr. Syst., 57 (1998) 367–380.

[15] R.R. Heim, A Review of Twentieth-Century Drought Indices Used in the United States, B. Am. Meteorol. Soc., 83 (2002) 1149–1165.

[16] N.B. Guttmann, Comparing the Palmer Drought Index and the Standardized Precipitation Index, J. Am. Water Res. Assoc., 34 (1998) 113–121.

[17] J. Keyantash and J. Dracup, The quantification of drought: An evaluation of drought indices, B. Am. Meteorol. Soc., 83 (2002) 1167–1180.

[18] J.A. Dracup, K.S. Lee and E.G. Paulson, On the Statistical Characteristics of Drought Events, Water Resour. Res., 16 (1980) 289–296.

[19] X. Lana and A. Burgueño, Probabilities of Repeated Long Dry Episodes Based on The Poisson Distribution. An Example for Catalonia (NE Spain), Theor. Appl. Climatol., 60 (1998) 111–120.

[20] S.M. Vicente-Serrano and S. Beguería, Estimating Extreme Dry-Spell Risk in the Middle Ebro Valley (Northeastern Spain): A Comparative Analysis of Partial Duration Series With a General Pareto Distribution and Annual Maxima Series with a Gumbel Distribution, Int. J. Climatol., 23 (2003) 1103–1118.

[21] D.A. Wilhite, Drought monitoring and early warning: concepts, progress and future challenges, World Meteorological Organization, Geneva, Switzerland (2006).
[22] W.C. Palmer, Meteorological Drought. Research paper No 45, U.S. Weather Bureau (1965).
[23] T.R. Karl, The Sensitivity of the Palmer Drought Severity Index and Palmer's Z-Index to their Calibration Coefficients Including Potential Evapotranspiration, J. Climate. Appl. Meteorol., 25 (1986).
[24] S. Erinc, Climatology and its Methods. Istanbul University, Institute of Geography Press, Istanbul: Turkey (in Turkish) (1969).
[25] E de Martonne, Une nouvelle fanction climatologique: l'indice d'aridité. La Météorologie 2: (1926) 449–458.
[26] World Meteorological Organization (WMO), Drought and agriculture. WMO Note 138, Publ WMO-392, Geneva (1975).
[27] DMI (State Meteorological Service) http://www.dmi.gov.tr/files/en-US/climateof turkey.pdf, Last Access: November (2009).
[28] C. Ormeci and S. Ekercin. An assessment of water reserve change in the Salt Lake, Turkey through multitemporal Landsat imagery and real-time ground surveys. Hydrol. Process., 21, 1424–1435, DOI: 10.1002/hyp.6355 (2007).