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ORIGINAL PAPER

Drought hazard, vulnerability, and risk assessment in Turkey

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Abstract

Drought has multiple impacts on socioeconomic sectors, and it is expected to increase in the coming years due to non-stationary nature of climate change and variability. Drought hazard and vulnerability are investigated based on hydro-meteorological and actual socioeconomic data for provinces of Turkey. Drought vulnerability and risk assessment are essential parts of drought phenomenon; however, lack of proper integrated drought risk assessment in Turkey (and elsewhere) might lead to higher socioeconomic impacts. Drought Hazard Index (DHI) is derived based on the probability of drought occurrences using Standardized Precipitation Index (SPI). Besides, Drought Vulnerability Index (DVI) is calculated by utilizing four socioeconomic indicators to quantify drought impact on society. Finally, Drought Risk Index (DRI) is obtained by multiplying DHI and DVI for provinces of Turkey to highlight the relative importance of hazard and vulnerability assessment for drought risk management. A set of drought hazard, vulnerability, and composite risk map is prepared for further interpretations. The analyses reveal that among 81 administrative provinces, 73 are exposed to low drought risk ($0 < DRI < 0.25$), 6 provinces to moderate drought risk ($0.25 < DRI < 0.50$), and 1 province (Konya) to high drought risk ($0.50 < DRI < 0.75$). These maps can assist stakeholders to identify the regional drought vulnerability to help mitigation strategy developments and for effective water resource management.

Keywords Risk mapping · Kriging · Standard precipitation index · Socioeconomic assessment

Introduction

Drought is concerned with recurring climate phenomena because of water deficit over a certain period. Extreme drought conditions are known to influence agriculture, environment, and health activities leading to severe socioeconomic repercussions (Rahman and Lateh 2016; Mishra and Singh 2010; Dai 2013). The global water demand is set to increase due to rapid population growth as well as globalization (Zhang et al. 2011). However, global climate model projections show that increase in drought occurrence result from either decreased precipitation and/or increased evaporation (Dai 2011; Trenberth 2011).

Being in a sensitive climate change hotspot, the Mediterranean region is not immune to global changes (Diffenbaugh and Giorgi 2012). Studies have indicated an increase in frequency (Venkataraman et al. 2016) and severity (Gampe et al. 2016) of Mediterranean droughts. In Turkey, the drought occurrence and severity follow the Mediterranean patterns. Several studies are concerned with diverse drought characteristics, which are specific to Turkey including quantification of drought intensity, severity, and duration by various drought indes utilizations (Şen 2015).

Models of drought propagation and occurrences are proposed to assist drought planning and mitigation (Tosunoglu and Can 2016) in addition to establishment of teleconnections for major climate oscillations by spatiotemporal frequency analysis (Dogan et al. 2012). Researches related to drought risk assessment in a socioeconomic context are still in their blooming stages. Socioeconomic drought vulnerability assessment is essential to plan the future policy actions to reduce the potential for possible damages (Rajsekhar et al. 2015). Along this direction, Sönmez et al. (2005) reveal that droughts

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pose significant risk to agriculture in the southeastern Anatolia region of Turkey. Kahraman and Kaya (2009) estimated the drought risks on Istanbul dams using several processes based on few indices. Şen et al. (2012) studied the drought risk associated with crop productivity for future projections. Gumus and Algin (2017) investigated meteorological and hydrological drought in Seyhan Basin using SPI (Standard Precipitation Index) and SDI (Streamflow Drought Index). Also, drought characteristics of Turkey are employed comparing SPI and modified SPI results by Türkeş and Tatlı (2009). In this study, although some reasonable differences are investigated between classical SPI and modified SPI, general results do not illustrate big difference with respect to classical SPI. Recently, Dabanlı et al. (2017) assessed spatiotemporal variability of droughts including (SO) Southern Oscillation effects in Turkey.

The socioeconomic drought impact (risk) for Turkey has not been investigated, although the previous studies provide basic information. Socioeconomic aspects usually involve factors like damage lost, population density, agricultural land, access to domestic water, etc. It is expected that a drought with high socioeconomic value might result in more loss than the other hazards (Mishra and Singh 2010). Over the past 30 years, Turkey has experienced a tremendous growth in urbanization fueled by its open economic policies and industrialization (World Bank Report 2015). Water demand enhances based on increasing population progressively. Finally, changes on land use especially changes in irrigated land areas are increased based on different politics. These changes make the Turkey more vulnerable to droughts. It is, therefore, necessary to have a comprehensive understanding of drought implications on socioeconomic sectors in terms of hazard, vulnerability, and risk assessments.

Globally, many studies have emphasized that a suitable way to assess the drought risk is by combining the socioeconomic hazard and vulnerability of a region (Shahid and Behrawan 2008; Verdon-Kidd and Kiem 2010; Lin et al. 2011; Belal et al. 2012; Weng et al. 2015, Rajsekhar et al. 2015, Jia and Wang 2016; Pei et al. 2016). Definition of vulnerability and risk changes is based on a different perspective. Wisner et al. (1994) defined risk as a product of hazard and vulnerability. In the case of drought too, several studies have used similar definitions for drought risk pattern identification. Although multiple studies evaluated drought risk assessment, only few of them considered both hazard and vulnerability factors joint incorporation (Rajsekhar et al. 2015) to investigate the socioeconomic ability of the region to cope with the drought event (Shahid and Behrawan 2008).

Application of some of the drought studies based on socioeconomic information include potential drought-related impact by environmental and socioeconomic factor consideration (Knutson et al. 1998), integration of stakeholder's information in drought vulnerability assessment (Fontaine and Steinemann 2009), and system-based agricultural drought vulnerability assessment (Wilhelmi and Wilhite 2002).

Because of complexity of droughts, the standardized indices are generally preferred for drought studies, for example, Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI). The SPI is a commonly used indicator due to its simple structure (Dutra et al. 2014). Türkeş and Tatlı (2009) developed modified SPI by comparing results to classical SPI. Furthermore, Reconnaissance Drought Index (RDI) based on the ratio of cumulative precipitation to potential evapotranspiration was developed by Tsakiris et al. (2007). The standardized precipitation evapotranspiration index (SPEI) is used based upon the difference between potential evapotranspiration and cumulative precipitation (Vicente-Serrano et al. 2010). Among the dozens of drought index, multivariate drought index (MDI) (Rajsekhar et al. 2014), multivariate standardized drought index (MSDI) (Hao and AghaKouchak 2013), and triple drought indicator (TDI) (Şen 2015) are the frequently seen recent studies.

Based on the literature background, a simple methodology is followed for drought risk assessment identifying vulnerability levels of provinces in Turkey. For this purpose, rainfall data are used to calculate SPI leading to drought hazard calculation by assigning weights and ratings to SPI probability distribution (Kim et al. 2015). Regional vulnerability to droughts is then identified by integrating four socioeconomic indicators like population density, total agricultural areas, irrigated land areas, and municipal water.

Study area and data

Turkey is an intercontinental (Europe and Asia) country located between 26 and 45 E and 36–42 N longitudes and latitudes, respectively. Homogeneously distributed precipitation data are available from 250 rain gauges scattered over 81 administrative provinces of Turkey (Fig. 1). Monthly precipitation data are obtained from Turkish State Meteorological Service (TSMS), (http://www.mgm.gov.tr) between 1971 and 2010. The north part of Turkey can be regarded as rainfall-intense regions in comparison to other parts especially in winter and spring seasons. Summer droughts are prolonged towards the south and west sides of the country. Agricultural sector and urban populations are settled on these regions due to favorable geographical features and climatic conditions.

The spatial pattern of annual rainfall is presented in Fig. 2. It can be observed that annual rainfall increases towards the northeastern Black Sea coast of Turkey and the magnitude varies from 24 to 228 cm. The driest regions are in the middle and southeastern parts of Turkey, whereas the wettest pattern is observed in the northeastern parts with limited spatial extent.

The socioeconomic data, which include population density, municipal water supply, total agricultural and irrigated land,

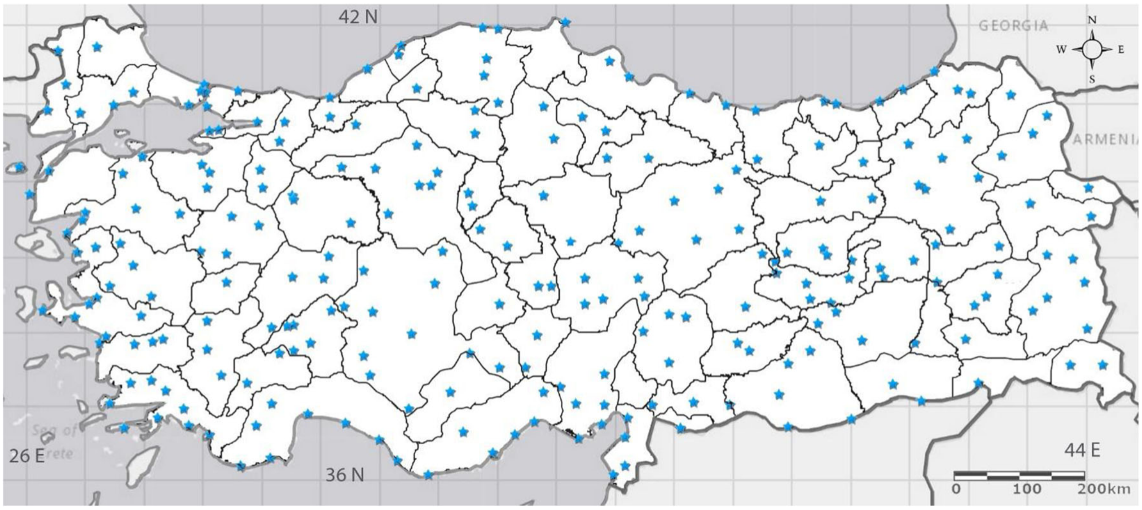

Fig. 1 Spatial map showing administrative provinces and selected rain gauges in Turkey (number of administrative provinces 81; number of rain gauges 250)

are obtained from Turkish Statistical Institute (http://www.tuik.gov.tr). The percentage distribution of socioeconomic data (based on total aggregation) for provinces is illustrated in Fig. 3. Population density is highly correlated with municipal water demand except in few provinces (e.g., Muğla, Antalya, Hatay, and Diyarbakır). On the other hand, total agricultural and irrigation lands are not strongly correlated in few provinces. For example, although total agricultural land of Ankara is classified in (4–6) % interval, the irrigation land is scored within (0–2) %. Similarly, total agricultural lands of several provinces are rather extensive, but irrigated lands are not equally extensive. It is expected that severity of drought hazard could be more hazardous especially in non-irrigated land areas.

Methodology

The SPI methodology provides a proxy to quantify drought. Risk assessment of an extreme event can be carried out using hazard, vulnerability, and risk (Rajsekhar et al. 2015).

Standardized precipitation index

The Standardized Precipitation Index (SPI) is used to quantify drought due to its simple procedure and standardization. SPI ensures that drought quantification at any location and on any time is consistent. The computational procedure for deriving SPI involves the following steps.

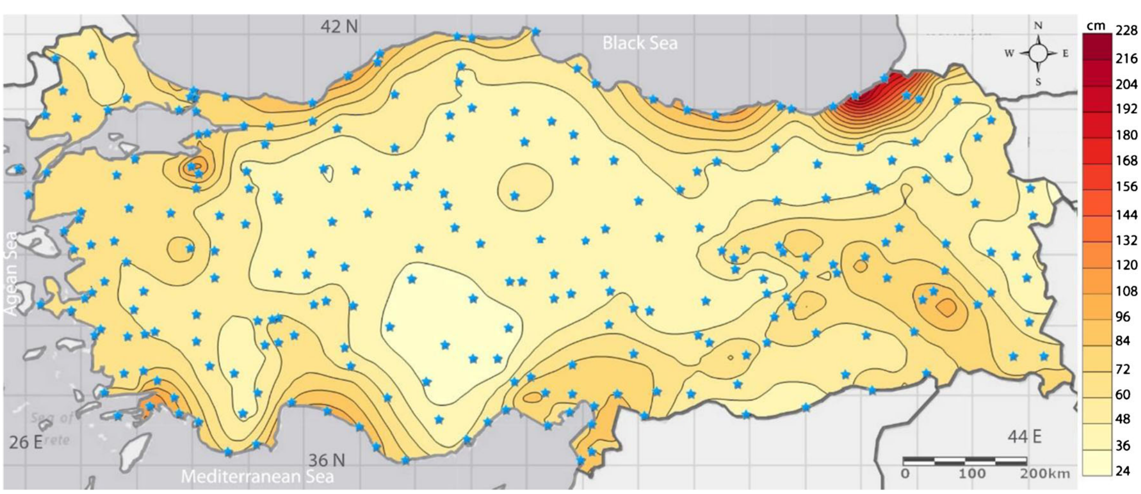

Fig. 2 Contour plot for annual rainfall from 250 homogeneously distributed gauges in Turkey

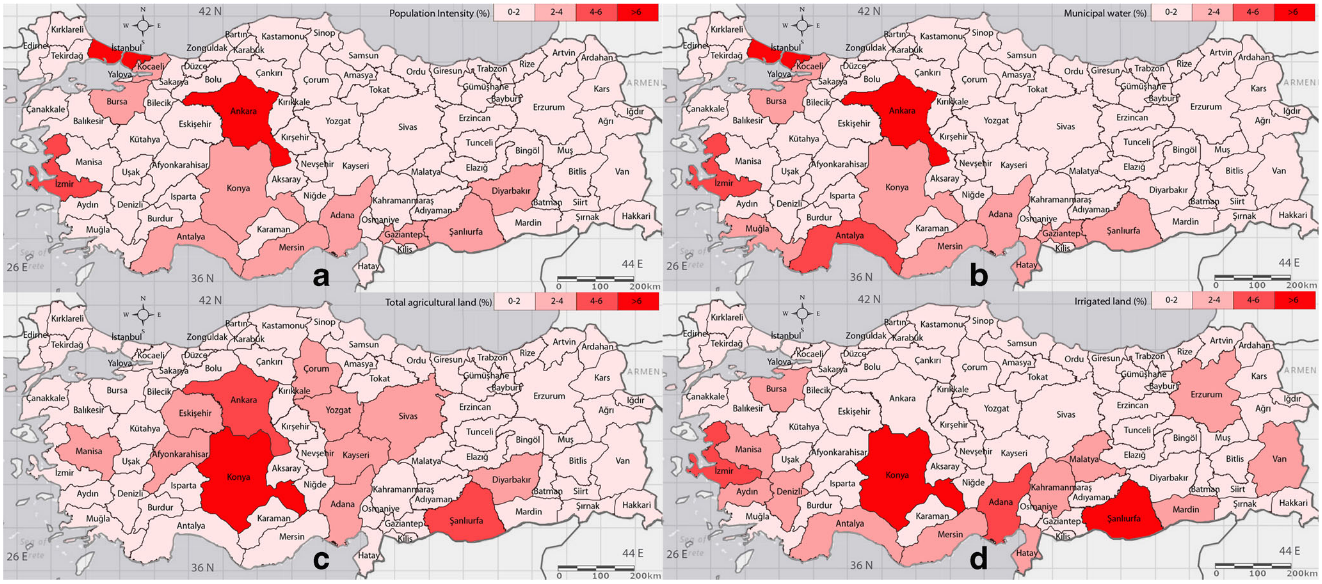

Fig. 3 Socioeconomic data for provinces of Turkey. **a** Population intensity (%). **b** Municipal water demand (%). **c** Total agricultural land areas (%). **d** Irrigated land areas (%)

1. First, an appropriate probability density function (PDF) is fitted to the precipitation aggregated over the time scale of interest
2. Each PDF is then transformed into a standardized normal probability distribution

The detailed mathematical procedure for calculation of SPI can be found in McKee et al. (1993), Guttman (1999), Mishra and Singh (2010), and Şen (2015). Considering that drought and its socioeconomic impact evolve at a longer temporal scale (window), SPI-12 is adapted in this paper to quantify drought hazard, vulnerability, and risk. SPI-based drought classification is presented in Table 1.

Drought hazard index

In general, hazard quantifies a potentially damaging phenomenon probability of occurrence, which ranges between 0 and 1. It is measured as the product of magnitude and the associated frequency of drought event occurrence.

Table 1 Drought classifications based on SPI

Probability (%)	SPI	Drought category
2.30	SPI ≥ 2.00	Extreme wet
4.40	2.00 > SPI ≥ 1.50	Very wet
9.20	1.50 > SPI ≥ 1.00	Moderate wet
68.20	1.00 > SPI ≥ −1.00	Normal
9.20	− 1.00 ≥ SPI > −1.50	Moderate drought
4.40	− 1.50 ≥ SPI > −2.00	Severe drought
2.30	− 2.00 ≥ SPI	Extreme drought

Using a weighting system based on the cumulative distribution function (Fig. 4), weight (W) and rating (R) scores are assigned based on the normal cumulative probability function for drought hazard assessment associated with severity and occurrence probabilities. Weight scores are determined from the SPI intervals, such that weight is equal to 1, 2, 3, and 4 for normal (ND), moderate (MD), severe (SD), and extreme (ED) droughts, respectively. On the other hand, weights for SPI > 0 are equal to zero. Similarly, rating scores are assigned from 1 to 4 in increasing order by dividing the interval of cumulative probabilities in each drought range.

Weight and rating scores are assigned based on the intervals, which are illustrated in Fig. 4. Multiplication of weight and rating scores generates drought hazard score (DHS), which is calculated for each SPI values between 1971 and 2010. The aggregated DHS is obtained by the following expression:

$$(\mathrm{DHS})_i = \sum_{i=1}^{N_{\mathrm{SPI}}} W_i x R_i \tag{1}$$

where N_{SPI} refers to number of SPI values for selected time interval. After obtaining DHSs for 250 gauges, drought hazard contour map (Fig. 6) is generated by using Kriging methodology. To obtain DHI for provinces, contour map percentage area A (%) and corresponding DHS are aggregated within province boundary according to

$$(\mathrm{DHI})_i = \sum_{i=1}^{n} A(\%)_i x(\mathrm{DHS})_i \tag{2}$$

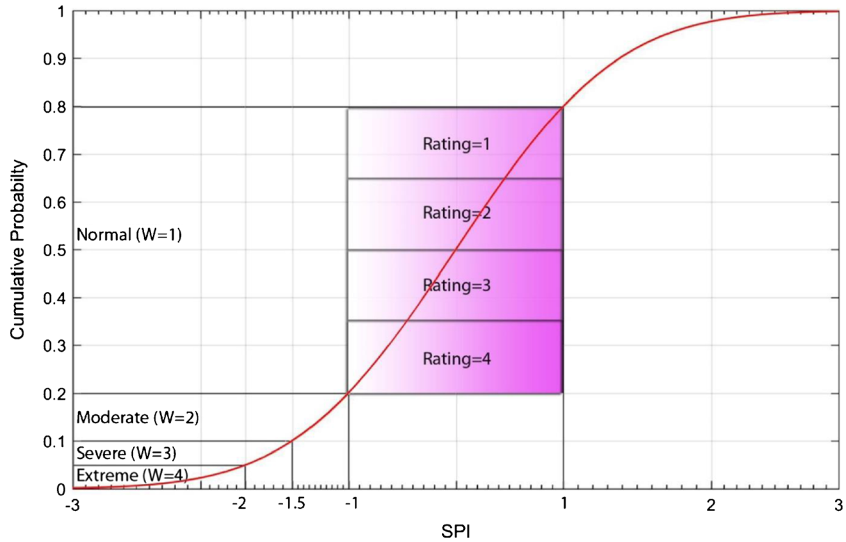

Fig. 4 Weight and rating scores based on normal cumulative probability distribution of SPI

This methodology is more appropriate in comparison to Thiessen polygon methodology for DHI calculations for each province. Boundaries of Thiessen polygons are generated by sharp lines; however, in this methodology, hazard region transition boundaries are smooth. Therefore, this approach can generate more realistic hazard scores in province scale.

Drought vulnerability index

Vulnerability is a relative measure, and it indicates the degree to which a system is susceptible to damage (harm) due to the occurrence of an event (Smit et al. 1999). Vulnerability is closely related to the socioeconomic conditions of a region and a potential indicator to measure maximum loss or harm during the event. Several studies conducted vulnerability assessment related to the effect of climate changes on water resources (Metzger et al. 2005). They may not adequately reflect drought scenarios especially at the local level and may not be relevant across multiple sectors (Fontaine and Steinemann 2009). The selection of vulnerability indicators or variables varies based on local study context and purposes.

Four socioeconomic indicators are selected in this study, which includes irrigated land (IL), total agricultural land (TAL), population density (PD), and municipal water (MW) for Drought Vulnerability Index (DVI) calculations with the following equation:

$$\mathrm{DVI} = \frac{\mathrm{IL}_n + \mathrm{TAL}_n + \mathrm{PD}_n + \mathrm{MW}_n}{4} \qquad (3)$$

where IL_n, TAL_n, PD_n, and MW_n are normalized values assigned to irrigated land, total agricultural land, population density, and municipal water, respectively. Each indicator is normalized within its own range and common distribution interval is adjusted for all indicators to overcome the different unit effects. The DVI is re-scaled into four classes, namely, low vulnerability ($0 < \mathrm{DVI} < 0.25$), moderate ($0.25 < \mathrm{DVI} < 0.50$), high ($0.5 < \mathrm{DVI} < 0.75$), and very high ($0.75 < \mathrm{DVI} < 1.0$).

Drought risk index

Drought risk assessment is investigated by incorporating the hazard and vulnerability indexes. Typically, the drought risk index (DRI) is calculated as multiplication of DHI with DVI. There will be no risk when either DVI or DHI is 0, but higher value of either DVI or DHI will result in risk increment. To quantify drought risk, both hazard and vulnerability information are essential. The quantitative assessments of drought risk are vital for coping with drought hazard consequences. Drought risk index is calculated by using a conceptual model presented in Fig. 5 using DHI and DVI.

Fig. 5 Conceptual model procedure of drought risk assessment

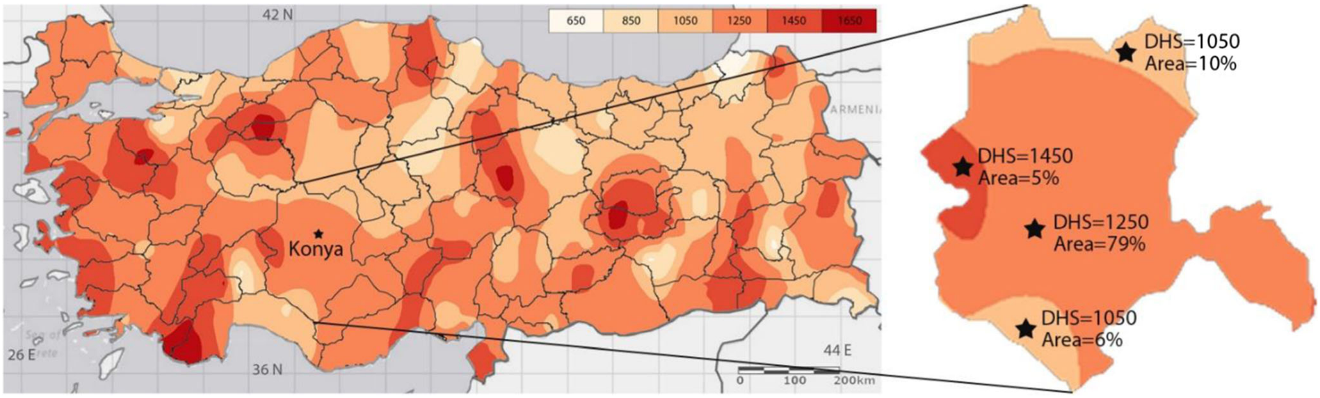

Fig. 6 Drought hazard assessment contour maps and sample illustration DHS and corresponding areas of Konya for DHI calculation

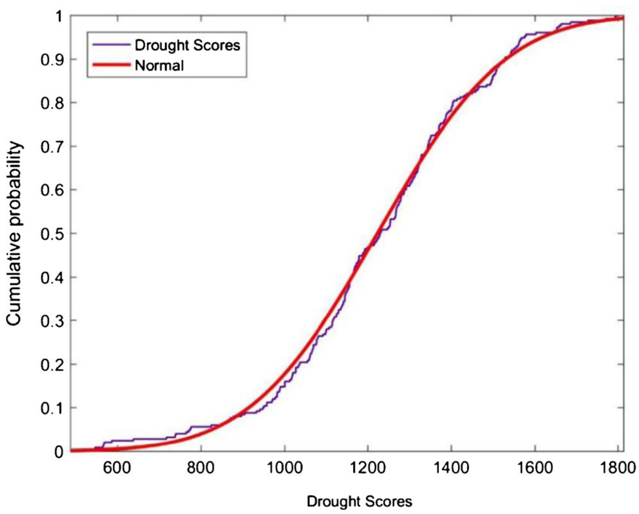

Fig. 7 The CDF of total drought scores in average of 250 stations between 1971 and 2010

Results and discussion

Drought hazard assessment

After obtaining DHSs for 250 gauges, drought hazard contour map is generated by using Kriging methodology as in Fig. 6. Cumulative sum of DHS values between 1971 and 2010 can be directly related to drought hazard. Accordingly, Fig. 6 proves consistency with higher drought scores over the southern and western parts of Turkey. Magnitude of precipitation is lower in the southern and western parts of Turkey.

The cumulative distributions of DHS for rain gauges are fitted by normal CDF as in Fig. 7. The fitted normal CDF is validated by Kolmogorov-Smirnov test for 95% confidence interval. It is expected that SPI and DHS distributions should be similar to each other. This coherence of normal probability distribution makes DHS calculation well directed.

To obtain province-scale DHI, contour map percentage area A (%) and corresponding DHS are aggregated within

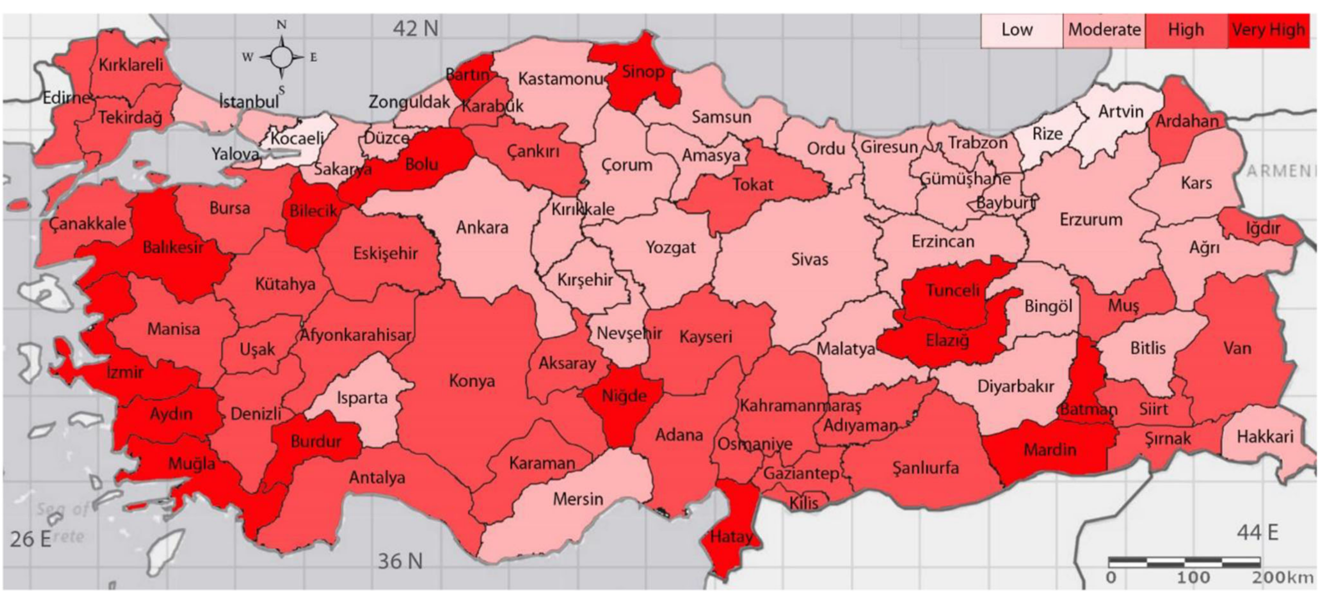

Fig. 8 Drought hazard map for Turkey based on DHI

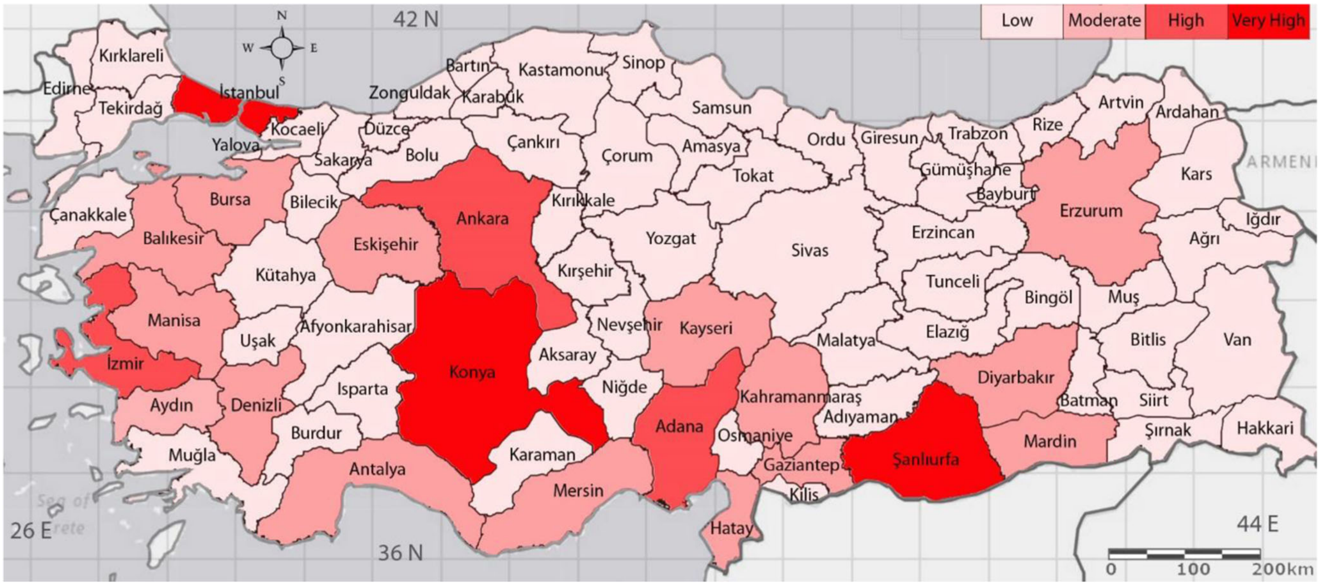

Fig. 9 Drought vulnerability map for Turkey based on DVI

province boundary by using Eq. 2. In Fig. 6, DHS and corresponding area percentages are presented for Konya province, which is the largest in Turkey to illustrate the DHI calculation procedures.

Drought hazard scores (DHS) and drought severity percentages are calculated leading to DHI calculations as 1229 ($1229 = 1250 \times 0.79 + 1450 \times 0.05 + 1050 \times 0.16$) from Eq. 2. The similar calculation procedure is applied for other provinces in Turkey. The DHI scores are normalized through rescaling between 0 and 1. The provinces are classified based on the DHI into four classes such as "low" between 0 and 0.25, "moderate" between 0.25 and 0.50, "high" between 0.5 and 0.75, and "very high" between 0.75 and 1.0. After obtaining four drought hazard classes, drought hazard map is generated as shown in Fig. 8. The DHI map shows more severity on the south and the west provinces of Turkey. This is due to that the south and west part altitudes of the Turkey are lower with respect to the east and north. This feature makes these provinces warmer due to the warm weather movement effects.

Drought vulnerability assessment

Generally, vulnerability is known as an indicator of sensibility or resilience to cope with the consequences of natural disasters (Wilhelmi and Wilhite 2002). Several studies investigated the link between climate change impacts on water resources and

Fig. 10 Drought risk map for Turkey based on DRI

Table 2 DHI, DVI, and DRI scores for 81 provinces in Turkey

No.	Province	DHI		DVI		DRI	
		Score	Class	Score	Class	Score	Class
1	Adana	0.59	High	0.52	High	0.30	Moderate
2	Adıyaman	0.73	High	0.14	Low	0.10	Low
3	Afyonkarahisar	0.67	High	0.21	Low	0.14	Low
4	Ağrı	0.46	Moderate	0.20	Low	0.09	Low
5	Amasya	0.34	Moderate	0.13	Low	0.05	Low
6	Ankara	0.46	Moderate	0.67	High	0.31	Moderate
7	Antalya	0.61	High	0.37	Moderate	0.23	Low
8	Artvin	0.00	No	0.04	Low	0.00	No
9	Aydın	0.82	Very high	0.33	Moderate	0.27	Moderate
10	Balıkesir	0.87	Very high	0.25	Moderate	0.22	Low
11	Bilecik	0.75	Very high	0.04	Low	0.03	Low
12	Bingöl	0.32	Moderate	0.06	Low	0.02	Low
13	Bitlis	0.48	Moderate	0.08	Low	0.04	Low
14	Bolu	0.82	Very high	0.05	Low	0.04	Low
15	Burdur	0.87	Very high	0.10	Low	0.08	Low
16	Bursa	0.63	High	0.32	Moderate	0.20	Low
17	Çanakkale	0.72	High	0.17	Low	0.12	Low
18	Çankırı	0.63	High	0.08	Low	0.05	Low
19	Çorum	0.34	Moderate	0.20	Low	0.07	Low
20	Denizli	0.73	High	0.30	Moderate	0.22	Low
21	Diyarbakır	0.39	Moderate	0.29	Moderate	0.11	Low
22	Edirne	0.65	High	0.14	Low	0.09	Low
23	Elazığ	0.95	Very high	0.14	Low	0.14	Low
24	Erzincan	0.42	Moderate	0.10	Low	0.04	Low
25	Erzurum	0.37	Moderate	0.31	Moderate	0.11	Low
26	Eskişehir	0.57	High	0.28	Moderate	0.16	Low
27	Gaziantep	0.62	High	0.28	Moderate	0.18	Low
28	Giresun	0.26	Moderate	0.07	Low	0.02	Low
29	Gümüşhane	0.31	Moderate	0.04	Low	0.01	Low
30	Hakkari	0.27	Moderate	0.05	Low	0.01	Low
31	Hatay	0.82	Very high	0.30	Moderate	0.25	Low
32	Isparta	0.47	Moderate	0.12	Low	0.06	Low
33	Mersin	0.39	Moderate	0.35	Moderate	0.13	Low
34	İstanbul	0.29	Moderate	0.90	Very high	0.26	Moderate
35	İzmir	0.91	Very high	0.54	High	0.49	Moderate
36	Kars	0.40	Moderate	0.08	Low	0.03	Low
37	Kastamonu	0.43	Moderate	0.08	Low	0.04	Low
38	Kayseri	0.66	High	0.27	Moderate	0.18	Low
39	Kırklareli	0.62	High	0.09	Low	0.05	Low
40	Kırşehir	0.29	Moderate	0.13	Low	0.04	Low
41	Kocaeli	0.14	Low	0.15	Low	0.02	Low
42	Konya	0.62	High	1.00	Very high	0.62	High
43	Kütahya	0.72	High	0.12	Low	0.09	Low
44	Malatya	0.45	Moderate	0.23	Low	0.10	Low
45	Manisa	0.66	High	0.36	Moderate	0.24	Low
46	Kahramanmaraş	0.50	High	0.36	Moderate	0.18	Low
47	Mardin	0.76	Very high	0.28	Moderate	0.21	Low

Table 2 (continued)

		DHI		DVI		DRI	
No.	Province	Score	Class	Score	Class	Score	Class
48	Muğla	0.88	Very high	0.19	Low	0.17	Low
49	Muş	0.58	High	0.13	Low	0.07	Low
50	Nevşehir	0.44	Moderate	0.14	Low	0.06	Low
51	Niğde	0.84	Very high	0.15	Low	0.13	Low
52	Ordu	0.31	Moderate	0.11	Low	0.03	Low
53	Rize	0.18	Low	0.03	Low	0.01	Low
54	Sakarya	0.47	Moderate	0.15	Low	0.07	Low
55	Samsun	0.31	Moderate	0.24	Low	0.07	Low
56	Siirt	0.63	High	0.06	Low	0.04	Low
57	Sinop	0.84	Very high	0.05	Low	0.04	Low
58	Sivas	0.50	Moderate	0.26	Moderate	0.13	Low
59	Tekirdağ	0.64	High	0.14	Low	0.09	Low
60	Tokat	0.67	High	0.16	Low	0.11	Low
61	Trabzon	0.31	Moderate	0.08	Low	0.02	Low
62	Tunceli	0.89	Very high	0.04	Low	0.03	Low
63	Şanlıurfa	0.61	High	0.75	Very high	0.46	Moderate
64	Uşak	0.65	High	0.07	Low	0.05	Low
65	Van	0.63	High	0.26	Moderate	0.16	Low
66	Yozgat	0.26	Moderate	0.20	Low	0.05	Low
67	Zonguldak	0.42	Moderate	0.05	Low	0.02	Low
68	Aksaray	0.53	High	0.16	Low	0.08	Low
69	Bayburt	0.31	Moderate	0.05	Low	0.02	Low
70	Karaman	0.65	High	0.14	Low	0.09	Low
71	Kırıkkale	0.31	Moderate	0.09	Low	0.03	Low
72	Batman	0.77	Very high	0.08	Low	0.06	Low
73	Şırnak	0.66	High	0.07	Low	0.05	Low
74	Bartın	1.00	Very high	0.02	Low	0.02	Low
75	Ardahan	0.62	High	0.02	Low	0.01	Low
76	Iğdır	0.65	High	0.08	Low	0.05	Low
77	Yalova	0.40	Moderate	0.03	Low	0.01	Low
78	Karabük	0.65	High	0.03	Low	0.02	Low
79	Kilis	0.60	High	0.04	Low	0.02	Low
80	Osmaniye	0.65	High	0.11	Low	0.07	Low
81	Düzce	0.44	Moderate	0.05	Low	0.02	Low

drought vulnerability (Eakin and Conley 2002; Metzger et al. 2005; Brooks et al. 2005; Kim et al. 2015), but the objective assessment of vulnerability often neglects socioeconomic variables. Herein, several socioeconomic local variables are presented to assess drought vulnerability to fill these kinds of regional gaps.

Prolonged drought event has a direct impact on socioeconomic sectors. For example, the rate of evapotranspiration increases during drought period leading to depletion in soil moisture, which is directly linked to the agricultural activity and food productions. Similarly, the reductions in stream flow and reservoir storage cause agricultural and municipal water supply deficits. Thus, drought is directly associated with municipal and agricultural water shortages, which severely affect irrigated agricultural areas and population. In this paper, depending on the availability of reliable socioeconomic data, four indicators are selected, such as irrigated land (IL), total agricultural land (TAL), population density (PD), and municipal water (MW). The drought vulnerability is calculated by substitution of four socioeconomic indicator parameters into Eq. 3. The vulnerability map based on DVI is presented as in Fig. 9. It is observed that Konya and Şanlıurfa provinces have

Table 3 DHI, DVI, and DRI percentages for 81 provinces in Turkey

Level	DHI		DVI		DRI	
	Count	Percentage (%)	Count	Percentage (%)	Count	Percentage (%)
No	1	1.23	–	0.00	1	1.23
Low	2	2.47	58	71.60	73	90.12
Moderate	31	38.27	17	20.99	6	7.41
High	32	39.51	3	3.70	1	1.23
Very high	15	18.52	3	3.70	–	0.00
Total	81	100	81	100	81	100

very high vulnerability, because of their extensive agricultural lands, whereas Istanbul province has very high vulnerability, because of its population density. Similarly, Adana, Ankara and Izmir are identified as high vulnerability provinces, because of their dense population and large agricultural land. Likewise, many interpretations can be extracted from this vulnerability map to understand existing circumstances of each province. The common feature for moderate vulnerability regions that consist of 15 provinces can be attributed to agriculture and population density. In these 15 provinces, the ratio of IL, TAL, PD, and MW are calculated as 36, 26, 27, and 29%, respectively. Furthermore, the northern Turkey vulnerability is low due to the relatively lower population and agricultural land. Most of the provinces in the northern and eastern side of Turkey are located at higher altitudes with mountainous areas, and it may be possible to say that lower vulnerability pattern may be correlated with elevation of Turkey in these regions.

Drought risk index assessment

The DRI is generated based on meteorological and socioeconomic information by multiplying DHI with DVI. The drought risk map is generated based on DRI as in Fig. 10. Each province is categorized into four groups like DHI and DVI class intervals.

If one of DVI or DHI is equal to “0,” then the DRI score becomes “0,” which means that there is no drought risk as in the Artvin province as in Fig. 10. Similarly, if one of DVI or DHI is higher, then the DRI becomes higher. In other words, DVI and DHI have essential contributions on DRI assessment. This drought risk assessment method can help to identify and compare drought risk among provinces to reduce and mitigate the adverse drought hazard results. The generated maps for drought hazard, vulnerability, and risk help to identify spatial distribution of drought risk indicators. Based on the DHI map (Fig. 8), Sinop, Bartın, Bolu, Bilecik, Balıkesir, Izmir, Aydın, Muğla, Burdur, Niğde, Hatay, Mardin, Batman, Elazığ, and Tunceli are classified in the highest level of drought hazard. On the other hand, depending on the DVI maps in Fig. 9, three major provinces (Istanbul, Konya, and Şanlıurfa) have very high degree of vulnerability. Hence, considering both the DHI and the DVI, the DRI map (Fig. 10) indicates Konya province poses a highest drought risk in Turkey. Also, Istanbul, Ankara, Izmir, Adana, Şanlıurfa, and Aydın have moderate drought risks based on DRI scores. The results of DHI, DVI, and DRI are summarized in Table 2 to identify drought risk for different provinces.

According to this table, among 81 provinces, 73 are exposed to the low drought risk ($0 < DRI < 0.25$), 6 to the moderate drought risk ($0.25 < DRI < 0.50$), only Konya province to the high drought risk ($0.50 < DRI < 0.75$), and only Artvin has no drought risk ($DRI = 0.00$). The district of Konya has extensive agricultural and irrigated land, which leads to the high drought vulnerability and risk. Arvin has relatively zero DHI, which has no drought risk due to its highest amount of annual rainfall regime. Among the moderate-risk-scored provinces, highest population density is sensible for Istanbul. Other provinces in moderate level (Ankara, Adana, İzmir, Aydın, and Şanlıurfa) can be explained by both agricultural land and population density with respect to low-score provinces. Corresponding percentages of occurrence from generated maps are presented in Table 3 for DHI, DVI, and DRI.

Based on literature review, previous studies did not assess drought risk based on DVI and DHI for provinces of Turkey. This approach can provide meaningful information for drought management studies in Turkey. High-risk provinces can mitigate drought risk through local but effective water resource managements. For this purpose, the policy makers should develop appropriate measures to protect existing water supplies in risky provinces.

Conclusion

In this paper, spatial drought risk pattern is quantified by incorporating hazard and vulnerability for provinces in Turkey. The drought hazard index is identified by using SPI weight and rating scores between 1971 and 2010. The drought vulnerability analysis is conducted using four socioeconomic indicators related to water demand and supply. Drought risk is assessed by using DHI and DVI for the administrative districts of Turkey. Drought hazard, vulnerability, and risk maps are generated based on DHI, DVI, and DRI for investigating spatial variability of droughts. It was observed that 73 cities are exposed to the low, 6 cities to the moderate, 1 city (Konya) to the high, and finally only 1 city (Artvin) to the no drought risk. Furthermore, the conceptual drought risk model depending on actual socioeconomic variables can help to minimize drought impacts in Turkey. This information can be used to identify provinces that are most vulnerable to drought with relative assessment among the provinces. The socioeconomic indicators can be further included to generate drought risk maps for vulnerability analysis and to develop strategies to minimize socioeconomic impacts.

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