ACCORDING TO THE SPEI DROUGHT INDEX, THE DROUGHT TREND PROJECTION IN TURKEY FOR THE NEXT CENTURY

Gülten ÇAMALAN[1], A.Serap AKGÜNDÜZ[1], Hanifi AYVACI[1], S.ÇETİN[1], H.ARABACI[1], M.ÇOŞKUN[1]

General Directorate of Meteorology-Ankara

gcamalan@mgm.gov.tr[1]; sakgunduz@mgm.gov.tr[1]; hayvaci@mgm.gov.tr[1]; harabaci@mgm.gov.tr[1]; mustafacoskun@mgm.gov.tr[1]

Bu çalışmada Türkiye'den seçilen 123 meteoroloji gözlem istasyonunun 1971-2015 aylık ortalama sıcaklık ve aylık toplam yağış gözlem verileri ile küresel iklim modellerinden HadGEM2-ES modelinin RCP4.5 senaryosunun 2016 – 2098 periyodu bölgesel iklim projeksiyon çıktıları kullanılarak SPEI kuraklık şiddet indisi 1, 3 ve 12 aylık zaman ölçeklerinde hesaplanmış ve SPEI indisi kuraklık sınıflarına göre olasılıkları (oluşum sıklıkları) elde edilmiştir. Yapılan çalışmayla kuraklığın oluşum sıklığının zamansal ve mekansal değişimleri 12 aylik zaman ölçeğinde incelenmiş ve geçmiş dönemlerdeki klimatolojisi referans alınarak gelecekte de var olabilecek kuraklaşma eğiliminin klimatolojik açıdan değerlendirmesi amaçlanmıştır. Bu şekilde, tarım, hayvancılık, özellikle toprağa bağlı üretim ve çevre açısından; yöneticilere, araştırmacılara, kamu kurumları ve tüm ilgililere, ileriye yönelik planlama çalışmalarında bilimsel destek sunacağı için projeksiyon modellerinin kuraklık yönetiminde faydalı bir araç olarak kullanılması hedeflenmiştir.

Anahtar Kelimeler: SPEI, Kuraklık, HadGEM2-ES

ABSTRACT

In this study, the monthly average temperature and monthly total rainfall data of the 1971-2015 period of the 123 meteorology observation stations with different climate characteristics selected from Turkey, and the regional climate projection data of the RCP 4.5 scenario of HADGEM2-ES model for 2016-2098 period were used. SPEI drought severity indices were calculated at 1, 3 and 12 month time scales with this data and the frequency of occurrence according to drought classes was obtained. The temporal and spatial changes of the frequency of occurrence of drought with the calculated SPEI values were examined and it was aimed to evaluate the climatic tendency which may exist in the future with reference to the climatology in the past periods. In this way, it is aimed to use projection models as a useful tool in the management of drought in order to provide scientific support for managers, researchers, public institutions and all interested parties, especially for agriculture, animal husbandry, agricultural production and environment.

Keywords: SPEI, Drought, HadGEM2-ES

INTRODUCTION

Disasters have very important role in human life for a long time. One of the most important disasters is drought which is affecting widespread human populations. Although drought is a disaster which starts and develops slowly, it is the most difficult climatologic phenomenon to forecast. It is also continuous with its adverse effects by accumulating long time periods.

Drought could be defined as natural phenomena which causes degradation on hydrological balance and adverse effect over terrain and water resources as a result of significant decreasing of recorded normal levels of precipitation [1]. As well as many types of drought in literature, there are 4 significant type of drought which are meteorological drought, agricultural drought, hydrological drought and social-economical drought. [2]

All drought types begin firstly as a meteorological drought which means insufficient precipitation. Agricultural droughts follow this situation with decreasing soil moisture and decreasing evapotranspiration levels. Hydrological drought follows that by decreasing levels of river and dam water and this situation finally results in socio-economic droughts.

Drought is an important reason for agricultural, economic and environmental damages. Since the effects of drought have been slowly appear after a long time with lack of rainfall, it is difficult to determine beginning, content and end of drought. For this reason, it is hard to measure objectively period of droughts with regard to scope of density, magnitude, duration and areal. It has been made an effort for developing techniques about drought analysis and monitoring. Definition of quantative indexes is the most widespread approach among this, however subjectivity in definition of drought has made difficult to generate unique and universal drought index definition.

Many of studies about drought analysis and monitoring systems has been planned for two approaches:

1. Palmer Drought Severity Index (PDSI) which based on soil water balance equation [3]
2. Standardized Precipitation Index. (SPI) [4],

Drought indices are acknowledged as an efficient approach and method for monitoring and measuring of droughts, because the indexes provide to understanding of complicate interactions between climatic variables and climate related processes by summarizing.

The use of drought indices permits quantitative assessment of climatic anomalies in terms of severity, geographical spread and frequency of occurrence, as well as exchange of information on both the decision makers and between society and citizens about the drought conditions [5].

Standard Precipitation Index (SPI), that will be used to characterize meteorological drought by national meteorological and hydrological services, has been accepted by World Meteorological Organization (WMO). Besides, SPI only depends on precipitation data, which doesn'ttake into account other meteorological variables determining temperature, relative humidity, evaporation, winds speed etc...However some studies show that the precipitation is the main factor for determining the intensity of drought, period of drought and end of drought.

As a result of increasing global temperatures at last 150 years, significant temperature increase has foreseen at 21st century by climate change models. The trends of increasing global temperatures show that the possibility of dramatic results on drought conditions. Increasing greenhouse gas levels such as CO_2 at Earth since the industrial revolution is a triggering factor for global warming. To slow this increases at global warming there are taken precautions for decreasing carbon emissions. On the other hand, severity of the drought and effects of drought are tried to predict by using statistical and amprical approaches. Usage of drought indices which include temperature data such as Palmer Drought Index (PDSI) are particularly prefered for applications that inculde climate scenarios. However PDSI is insufficient neither evaluating of drought that is related to different hydrological systems nor multi-scalar criterias which is neccesary to distinguish different types of drought. Therefore Normalized Precipitation-Evaporation İndex (SPEI) are formuleted that based on the precipitation and PET. SPI could not determine the role of increasing temperature values at drought conditions and the role of temperature variables and warm air currents independently of global warming scenarios, in response to this SPEI could explain the possible effects of temperature variability and extreme temperatures with the difference of global warming. SPEI has sensibility of PDSI against the fluctuations of latent heat and natural spatial distribution of SPI. The index had been developed by Vincente-Serrano at al. [6].

SPI is especially effective at determination and monitoring of drought and also explaining the results of global warming at drought conditions. [7;8;9]

The calculation and identification of the probabilities of various drought index classes (briefly drought) in drought determination, evaluation and monitoring studies to be carried out within the framework of a comprehensive and large-scale Drought Management Plan is very important in terms of the success of the management plan.

The primary purpose for evaluation of drought quality is determining and evaluating time of drought events and severity of droughts which occurs probabilistic terms in a particular location, region or basin. Thus, such a scientific assessment is very useful for describing droughts that have a certain time of return (frequency of occurrence) in terms of solving the former drought events that have occurred in those areas in the past according to the existing evidence.

METHODS and DATA

In this study, that has been examined observation data which belongs to 123 Meteorological Observation Station in between 1971-2015 years by using SPEI method. In addition, it has been examined spatial variations in the frequency of occurrence of drought at 1,3,12 month scale and time dependent variations of SPEI values by using regional climate projection data at 2016-2098 years of HadGEM2-ES RCP4.5 scenario which is a global climate model. (Time-dependent variations could not be showed this paper due to the page limitation).

Climate projections for 2016-2098 years (monthly mean temperature and monthly total precipitation) has been produced by adding 1971-2000 period anomalies which is an observation reference period of stations that is used when the models runned to the anomaly values of the nearest grid points to the stations. The time interval of projections has been examined in terms of three periods (2016-2040, 2041-2070, and 2071-2098).

Application data for each period has been runned with observation data. The aim of this is to procure continuous for drought analysis. Although the future data hasn't got any effect at examined working period, initial data is important. However, series for calculating SPEI drought indices has been runned and examined in terms of three different period which is 1971-2040 period for 2016-2040 period, 1971-2070 period for 2041-2070 period and at 1971-2098 period for 2071-2098 period just in case future predictions could affect observation data.

After calculating the SPEI drought severity indices, the occurrence of frequency of drought categories (frequency possibilities) has been determined and possible tendency of drought in the future has been evaluated by referencing historical climatology of drought.

SPEI is based on climatic water balance (precipitation and evaporation) and it has been advised for determination of drought periods. 3 parameter log logistic distribution has been used by taking into consideration excess of negative values. Evaporation has been calculated by Thorntwaite Method [10]. Analysis of SPEI has been calculated according to distribution of Pearson Type III. The parameters of α, β and γ which belongs to this distribution has also been obtained by using L-Moment Method. L-Moments is a linear combination of probability weighted moments given by Greenwood [11] and that has been obtained by increasing or decreasing the observations

The simplest approach in PET calculations is the Thorntwaite method. The formula of the method, which uses average monthly temperature only, is like the following.

$$i = \left(\frac{t}{5}\right)^{1.514}$$

where i is the monthly temperature index and t is the average monthly temperature. The sum of "i" values for 12 months gives the annual temperature coefficient of I.

A= 6.75*10-7 *I3 -7.71*10-5 *I2 + 1.79*10-2 *I +0.492 multiplied by sunshine durations by the latitude of the stations for PET.

$$PET = 16 * K * \left[\frac{10 * T(I)}{I}\right]^{A}$$

K= correction coefficient calculated for the latitudes of the stations and months.

The difference between PET values for a given month and precipitation provides the amount of excess or deficiency of water.

$$Di = Pi - PETi$$

Tsakiris et al. (2007) showed that the P/PET ratio (the ratio of total monthly precipitation to potential monthly evapotranspiration) is also a suitable parameter to obtain a drought index which takes the process of global warming into account. However, considering the P/PET ratios, especially in winter months, the cases with PET values of "0" were undefined. The Di values can be calculated in different time scales (such as monthly, for 3, 6, 12, 18, 24 months). For example, the January 3-month Di value of a given year is the sum of the values of previous year's November and December, and that year's January.

While 2-parameter gamma distribution is used in SPI calculations, SPEI calculations use 3-parameter distribution. The L-moment method was used in parameter estimations of 3-parameter distributions.

L-moments of the Di series were obtained from probability weighted moments.

Probability weighted moments are obtained using the following formula;

$$w_s = \frac{1}{N} \sum_{i=1}^{N} (1 - F_i)^s * D_i$$

$\lambda 1 = w0$; $\lambda 2 = w0 - 2w1$; $\lambda 3 = w0 - 6w1 + 6w2$; $\lambda 4 = w0 - 12w1 + 30w2 - 20w3$

$$F_i = \frac{i-0.35}{N}$$ (Hosking 1990).

Fi → Frequency estimator

i → Order numbers given by ordering D_i values in a way to obtain an increasing sequence

N→ Number of observations

3-parameter log-logistic distribution was used to standardize the Di = (Pi – PETi) series of 12 stations in the study area. The probability density function of the 3-parameter log-logistic distribution;

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2}$$

In this distribution function, α is the scale, β is the shape and γ is the position parameter (γ >Di < α)

The parameters of the log-logistic distribution can be obtained in various ways. However, the l-moment method is the simplest approach (Ahmad et al. 1998).

The parameters of Pearson type III distribution are obtained after calculating the l-moments.

$$\beta = \frac{2w_1-w_0}{6w_1-w_0-6w_2}\ ; \qquad \alpha = \frac{(w_0-2w_1)*\beta}{\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right)}\ ; \quad \gamma = w_0 - \alpha\,\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right)$$

Here, Γ(β) is the gamma function of beta.

Log-logistic distribution represents the Di series very well in all time scales.

The probability distribution function of the Di series based on log-logistic distribution;

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1}$$

while with F(x), SPEI is calculated as the standardized variable of F(x) like the following;

$$\mathrm{SPEI} = w - \frac{C_0+C_1w+C_2w^2}{1+d_1w+d_2w^2+d_3w^3}$$

where $w = \sqrt{-2\ ln(P)}$ → for P≤0.5

While P is the probability of exceeding a certain D value, P= 1-F(x).

If P>0.5, then P is replaced by 1-p and the sign of SPEI is reversed. In this formulation, the constants are;

C0 = 2.515517; C1 = 0.802853; C2 = 0.010328

d1 = 1.432788; d2 = 0.189269; d3 = 0.01308

SPEI’s mean is 0 and standard deviation is 1. As SPEI is a standardized variable, it is related to other SPEI variables in the area time dimension.

After the calculation of SPEI drought index, frequency probabilities has been calculated for each station according to drought classes. Probablities have been obtained by rating each drought class over total occurance of droughts [12].

$\mathrm{P(A)} = \lim_{n\to\infty}\frac{n_a}{n}$ P(A): Relative probability (probability of frequency), n_a :Number of occurrence desired event , n:number of all events.

In fact, normal drought class shows the sum of moderately wet drought and moderately dry. For this reason this class interval has been regulated Figure 1, in accordance with the purpose of this study.

Table:1 *SPEI category of drought intervals*

SPEI	Class of Drought
≥ 2.00	Extremely wet
1.50 –1.99	Severely wet
1.00 – 1.49	Moderately wet
0.99-(-0.99)	Normal wet
(-1.00) – (-1.49)	Moderately drought
(-1.50) – (-1.99)	Severely drought
(-2.00) ≥	Extremely drought

Table:2 *Fixed SPEI category of drought intervals*

SPEI	Class of Drought
≥ 2.00	Extremely wet
1.50 –1.99	Severely wet
1.00 – 1.49	Moderately wet
0.0 – 0.99	Lightly wet
0.0 – (-0.99)	Lightly drought
(-1.00) – (-1.49)	Moderately drought
(-1.50) – (-1.99)	Severely drought
(-2.00) ≥	Extremely drought

RESULTS AND DISCUSSION

The analyses show that if the period of time increases the frequency of drought is less but it is also long-acting effective. In the period of 1-3 months, drought gets more frequent but the duration of its effect shortens; however, as the time period enlarges, the duration of drought effect increases, while its occurrence frequency decreases in especially the period of 12 months.

Although the issues that has been faced on short term severe drought periods are same with the issues which is long duration drought, the damages that occurs in droughts which last longer periods will be more effective. Therefore, precautions which will take for drought, should be generated by taking into account the severity of drought events, areal consistency of drought and duration of drought.

On the basis of 12-months-scale, it is estimated that SPEI drought severity frequency possibilities that concentrate on Damp Dry part of normal class have the tendency [13] to slip through a higher drought class as being lightly drought (Figure: 1-3) at 2016-2040 and 2071-2098 periods and as being drought at medium level at 2041-2070 period regarding the drought severity classes with the increase on heat and decrease on rain for 2041-2070 period at HadGEM2-ES RCP4.5 model projection climate data according to the existing observations all around Turkey (Figure: 2).

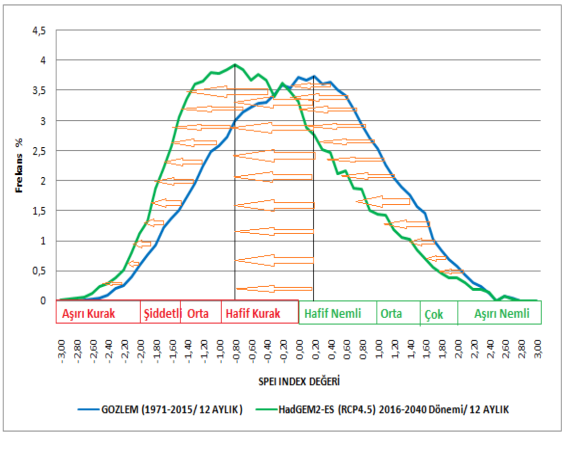

Figure-1 *Turkey-Wide Observation (1971-2015) and SPEI Frequency Possibility Change at HadGEM2-ES RCP4.5(2016-2040)Period on 12-Months Basis*

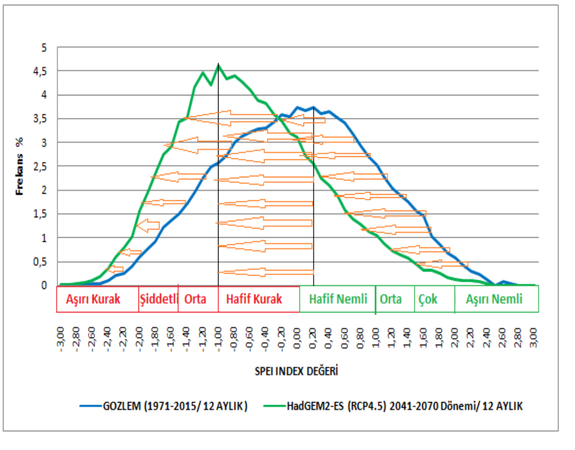

Figure-2 *Turkey-Wide Observation (1971-2015) and SPEI Frequency Possibility Change at HadGEM2-ES RCP4.5(2041-2070)Period on 12-Months Basis*

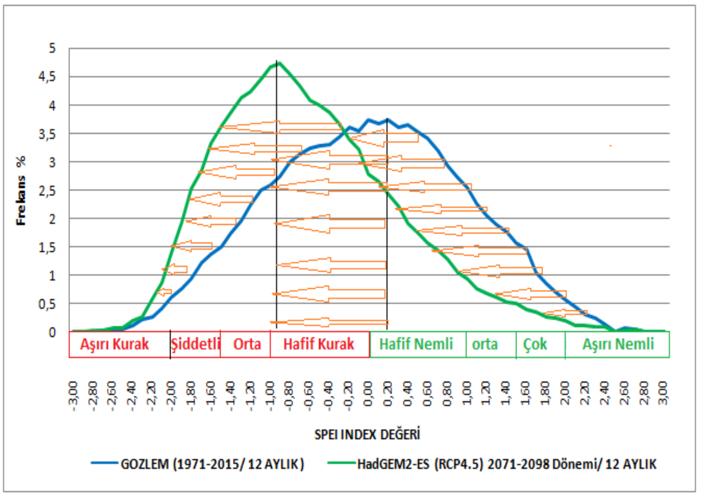

Figure-3 *Turkey-Wide Observation (1971-2015) and SPEI Frequency Possibility Change at HadGEM2-ES RCP4.5(2071-2098)Period on 12-Months Basis*

The current evaluations and predictions of drought periods are been given in the following Figures based on 12 months and on spatial distribution.

The distributions of the increases and decreases has also been examined by adding the difference maps of HagGEM2-ES 4.5 scenario from the observations with the observation data's and model predictions.

The possibilities of frequency at normal class which includes lightly drought and lightly wet class have been mostly seen in Turkey. As it is expected that the extreme drought frequency possibilities, which range on 0-4% scale within observations (Figure: 4a), increase (5-9%) at 2016-2040 period of projection, in around Central Black Sea, the eastern part of Aegean Region, the western part of Central Anatolia, West Thrace, Eastern Mediterranean and in Igdir, Gumushane, Batman and Siirt it is also expected to protect the current situation in around Mugla and Mersin and to have a decrease in Erzurum (Figure: 4b-e).

Northern Marmara, Western Black Sea and Central Black Sea shores are foreseen to keep their current situation on observations at 2041-2070 period while regions other than those are predicted to have an increase as the highest increase is envisaged to be in Artvin, Ardahan and Kars (9%). (Figure: 4c-f). It is foreseen that a decrease at 2071-2098 period in Central Anatolia and Central Black Sea shores and interiors is expected while other places are expected to have an increase. (1-6%) (Figure: 4d-g).

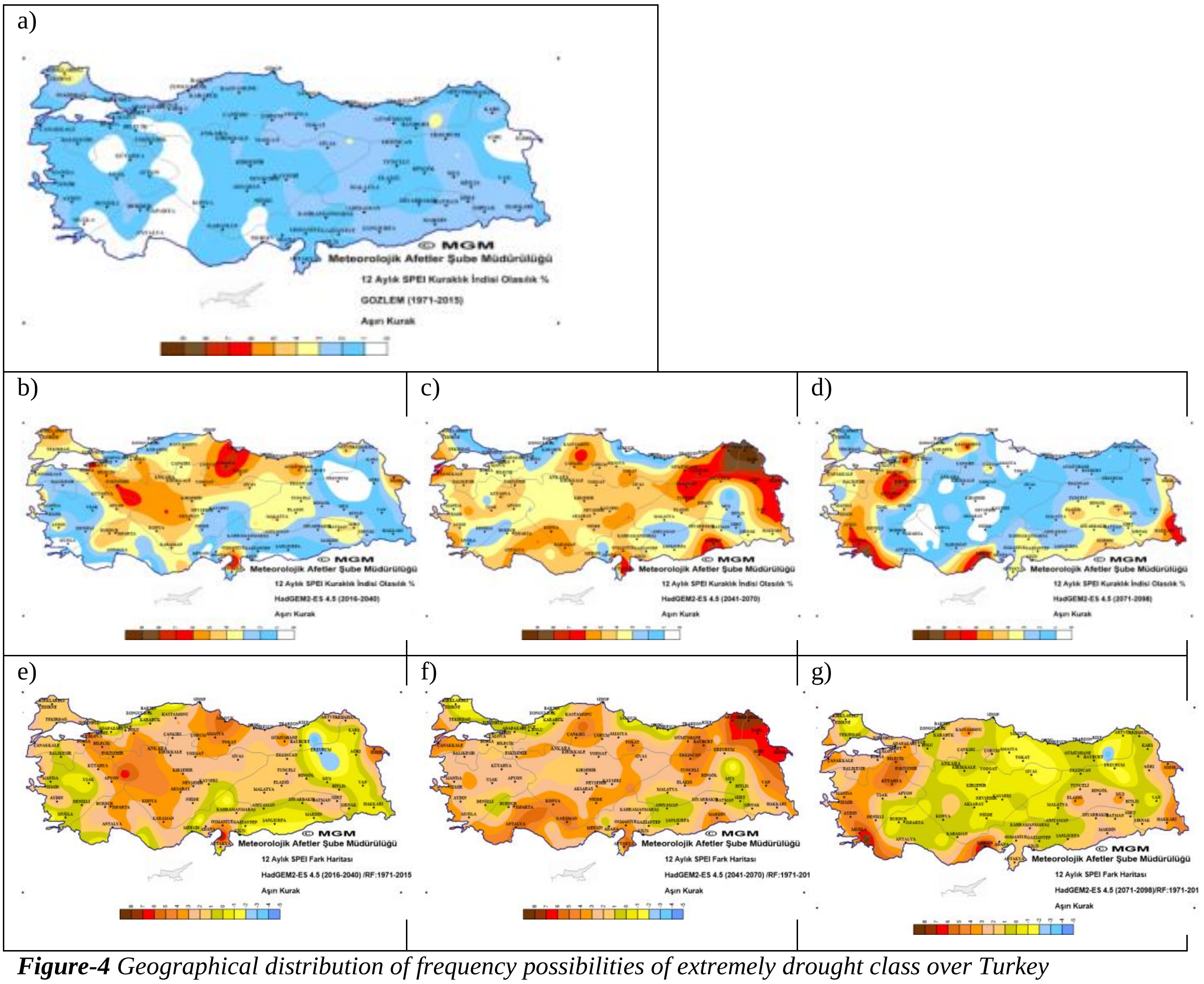

Figure-4 *Geographical distribution of frequency possibilities of extremely drought class over Turkey*

a. Observation
b. HagGEM2-ES 4.5 (2016-2040)
c. HagGEM2-ES 4.5 (2041-2070)
d. HagGEM2-ES 4.5 (2071-2098)
e. HagGEM2-ES 4.5 (2016-2040)/(RF: 1971-2015) The Difference Map
f. HagGEM2-ES 4.5 (2041-2070)/(RF: 1971-2015) The Difference Map
g. HagGEM2-ES 4.5 (2071-2098)/(RF: 1971-2015) The Difference Map

Severity drought probability frequencies has been reached the highest values for observations at Southern Marmara, Inner Aegean Region, West and East Mediterranean Region, Eastern part of Central Anatolia, Eastern part of Southeastern Anatolia Region, middle part of Eastern Anatolia Region and around the Igdir (Figure 5a). During the period of 2016-2040 of projection, coastal regions of Thrace, West and East Black Sea and coastal regions of Western and Eastern Black Sea in 2041-2070 / 2071-2098 periods are predicted to protect the situation in the observations. It is predicted that other places outside these regions will show an increase in the period of 2016-2040 and the highest increase will be around Şanlıurfa, Uşak and Giresun (Figure 5b-e). In the period of 2041-2070, an increasing trend is predicted, with the Central Black Sea (Samsun), Göller Region (Burdur), Niğde, Kahramanmaraş, Malatya and Batman circles being higher. (%18-20) (Şekil:5c-f). It is predicted that increases in the period of 2071-2098 will be continued in Göller Region (Isparta, Burdur) (22%) (Figure: 5d-g).

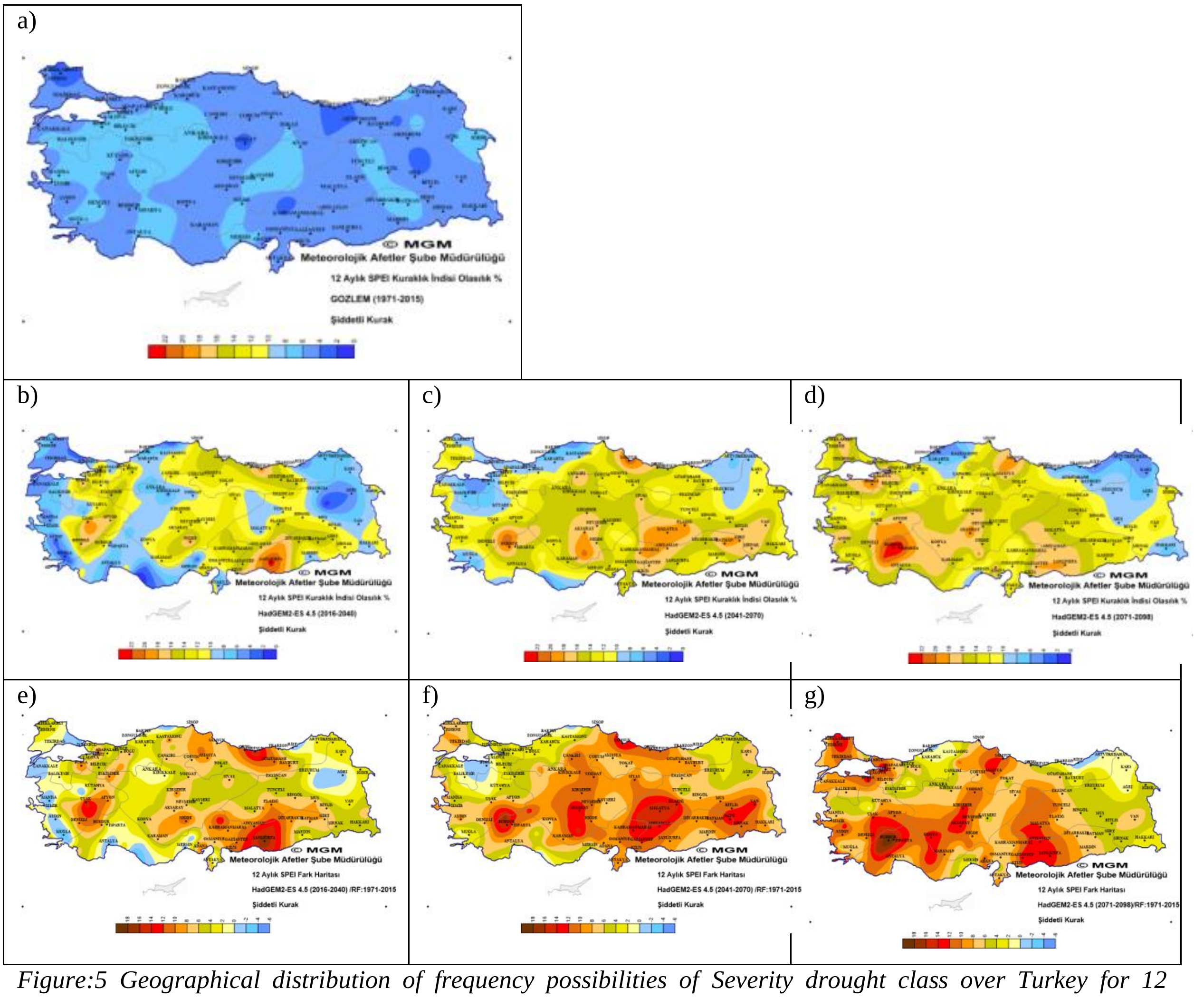

Figure:5 Geographical distribution of frequency possibilities of Severity drought class over Turkey for 12 months

a. Observation
b. HagGEM2-ES 4.5 (2016-2040)
c. HagGEM2-ES 4.5 (2041-2070)
d. HagGEM2-ES 4.5 (2071-2098)
e. HagGEM2-ES 4.5 (2016-2040)/(RF: 1971-2015) The Difference Map
f. HagGEM2-ES 4.5 (2041-2070)/(RF: 1971-2015) The Difference Map
g. HagGEM2-ES 4.5 (2071-2098)/(RF: 1971-2015) The Difference Map

Moderately dry frequency probabilities for observations are higher in the Aegean coastal areas, coastal and inland parts of the Central and Eastern Black Sea, Mediterranean, Southeastern Anatolia and around Ağrı, and lower in other places (6-14%) (Şekil:6a) . In the 2016-2040 period of the projection, while the Southern Marmara region is expected to protect the situation, in the western observations, Turkey shows an increase trend in other regions (12-34%), higher in Ankara and its vicinity (Figure: 6b-e). It is also expected this increasing trend will continue in 2041-2070 period and it will be more pronounced in Southeastern Anatolia (12-36%) (Şekil:6c-f). Similarly, in the 2071-2098 period, higher increasing trend is expected to continue especially in Southeastern Region of Turkey (%12-30) (Figure:6d-g).

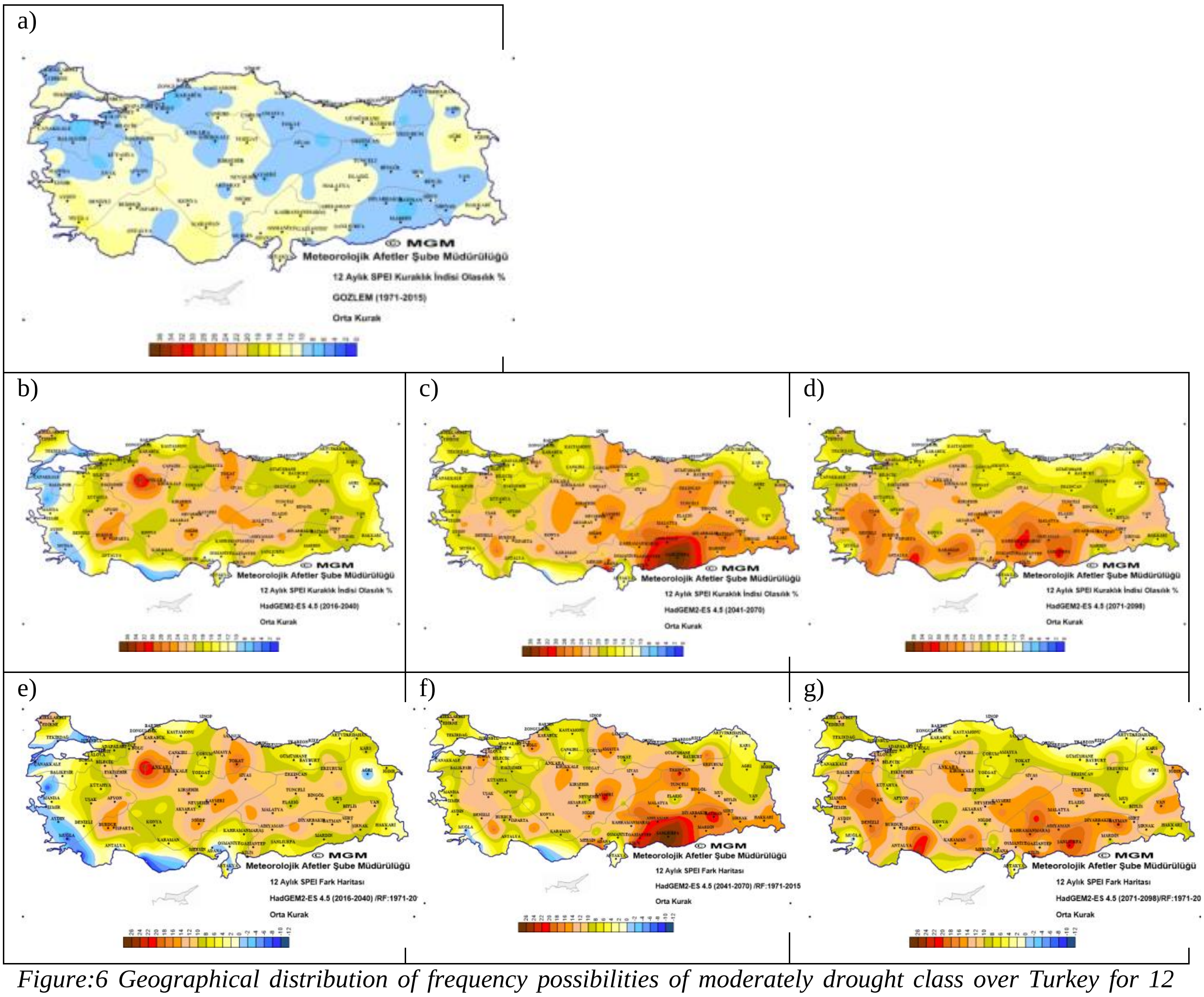

Figure:6 Geographical distribution of frequency possibilities of moderately drought class over Turkey for 12 months

- *a.* *Observation*
- *b.* *HagGEM2-ES 4.5 (2016-2040)*
- *c.* *HagGEM2-ES 4.5 (2041-2070)*
- *d.* *HagGEM2-ES 4.5 (2071-2098)*
- *e.* *HagGEM2-ES 4.5 (2016-2040)/(RF: 1971-2015) The Difference Map*
- *f.* *HagGEM2-ES 4.5 (2041-2070)/(RF: 1971-2015) The Difference Map*
- *g.* *HagGEM2-ES 4.5 (2071-2098)/(RF: 1971-2015) The Difference Map*

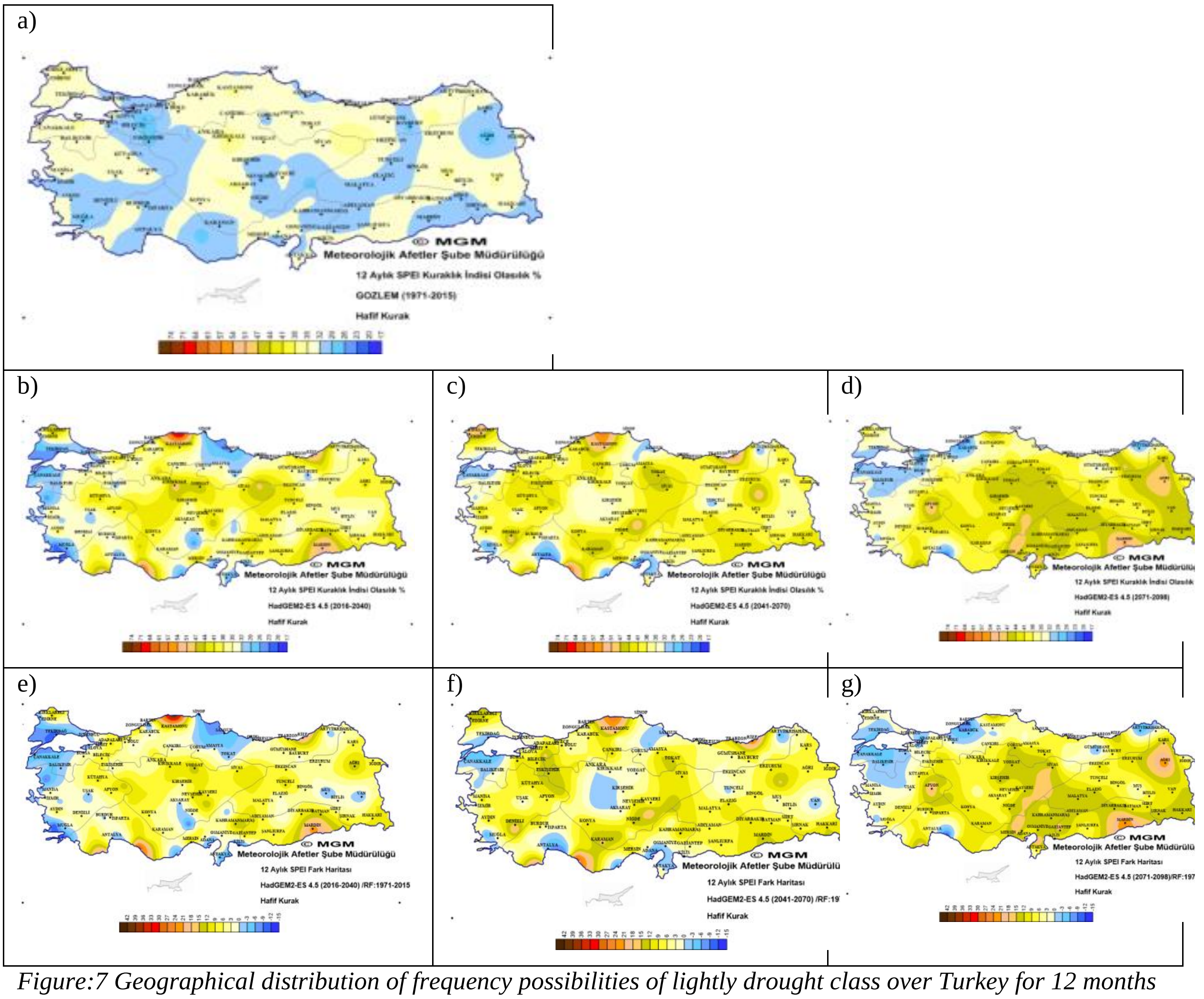

Figure:7 Geographical distribution of frequency possibilities of lightly drought class over Turkey for 12 months

- *a. Observation*
- *b. HagGEM2-ES 4.5 (2016-2040)*
- *c. HagGEM2-ES 4.5 (2041-2070)*
- *d. HagGEM2-ES 4.5 (2071-2098)*
- *e. HagGEM2-ES 4.5 (2016-2040)/(RF: 1971-2015) The Difference Map*
- *f. HagGEM2-ES 4.5 (2041-2070)/(RF: 1971-2015) The Difference Map*
- *g. HagGEM2-ES 4.5 (2071-2098)/(RF: 1971-2015) The Difference Map*

Moderately drought frequency probabilities are approximately 23-38 % (Figure:7a). In the 2016-2040 period of the projection, observations are expected to protect their situation for the coastal and inland parts of the Central Black Sea and the northern part of the Marmara region and western part of Istanbul and Tekirdağ and the west part of Southern Marmara region. It is also predicted that all regions will show an increase trend with the coastal side of Western Black Sea being higher (%32-74) (Şekil:7b-e). This values which belongs to 2016-2040 period of the projection, will be expected to decrease in the 2041-2070 period of the projection (%32-54) (Şekil:7c-f). In the period of 2071-2098, it is foreseen that while the increase will be seen in Central Anatolia, Inner Aegean, Eastern and Southeastern Anatolia Regions, there is an expected lower tendency than the situation for the Western Black Sea, Southern Marmara Region and Thrace regions show a lower tendency than observed situation (Figure: 7d-g).

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