Temporal and Spatial Evaluation of Drought in Agricultural Stability Zones in Syria between 1992 and 2018 by Using SPI Index

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Abstract

This study used data of 165 rain stations for mapping SPI index for winter season at the base of 7 months period (from November to next April). For compensating the lost measurements in stations, we used the Kriging method in ArcGIS10.1 for producing precipitation maps for each period of the year. We used a simple equation for calculating SPI_7, and modeled the process by using Model Maker tool within the ERDAS 2014. The application of this model over the period from 1992 to 2018 produced twenty-seven annual maps of the SPI_7 in Syria. By plotting the general trend of precipitation changes according to this index, we observed that the entire study area is stable on a normal climatic state close to the annual average during the most of years. By analyzing precipitation and SPI maps using statistical zonal methods, based on agricultural stabilization zones, we found different behaviors of drought in every zone and between these zones.

Key Words: Syria, SPI, drought, rain stabilization zones.

1   Introduction

Drought is one of the most important natural phenomena that negatively affects the value and the quality of agricultural production. It is difficult to estimate the direct and indirect losses resulting from its occurrence. Therefore, it is necessary to examine, monitor and evaluate the drought in detail in order to avoid its negative economic and social impacts by adopting the suitable procedures. Hagman (1984) noted that drought was considered by many scientists as one of the most complicated phenomena and difficult to be understood comparing with any other phenomenon. In general, drought gives an impression of water scarcity resulted due to insufficient precipitation, high evapotranspiration, and over-exploitation of water resources or combination of these parameters (Bhuiyan, 2004; Bhuiyan *et al.*, 2006). World Meteorological Organization (WMO) defined drought as a natural hazard based on the notion that precipitation deficit leads to a water shortage and subsequent negative impact on an activity, group or environmental process. (Howard *et al.*, 2018). This temporary phenomenon affects sustainability

of agriculture and may results environmental degradation, which is one of the contributing factors to the vulnerability of agriculture (Dalezios et al., 2014). It is important to differentiate aridity, which is a permanent feature, from drought, which is temporary phenomena difficult to detect and can present a range of diverse aspects in different regions (Jeyaseelan, 2005; Morid, 2007).

Researchers tried to develop variety of methods and indicators to study this complex phenomenon. These indicators reflect multiple types or manifestations of drought such as climate, hydrological, agricultural and socio-economic drought (Layelmam, 2008). These methods and indexes measure different drought-causative and drought-responsive parameters such as precipitation, soil moisture, evaporation, vegetation growth and groundwater and surface water levels (Bhuiyan et al., 2006). Climate indexes use historical records for a long period of precipitation and temperature as well as evaporation, measured by ground weather stations, to compare current condition to the general trend (Layelmam, 2008). Hydrological indexes are function of changes in groundwater, water bodies and watercourses from their current level (Bhuiyan, 2004). For the indicators of agricultural growth intensity, studies often measure the biological and phenological properties of plants as well as the physical and chemical properties of the soil (Layelmam, 2008).

SPI is a drought index first developed by T. B. McKee, N.J. Doesken, and J. Kleist in 1993 (McKee et al. 1993). It is the most used indices in many countries of the world for understanding the severity and persistence of climate drought. Usually scientists use SPI index to evaluate the intensity and spatial distribution of drought in a given area as it provides quick assistance by a simple approach requiring less data (Komuscu, 1999). The SPI is probability based and designed to be a spatially invariant indicator of drought that recognizes the importance of time scales in the analysis of water availability and water use (Guttman, 1999). Ideally, one needs at least 20-30 years of monthly values, with 50-60 years (or more) being optimal and preferred (Guttman, 1994, 1999; WMO, 2012). The SPI is computed by dividing the difference between the normalized seasonal precipitation (X_{ij} at the ith rain-gauge station and j^{th} observation) and its long-term seasonal mean (X_{im}) by the standard deviation (σ) (Bhuiyan et al., 2006). Thus, SPI=$(X_{ij} - X_{im})/\sigma$. Since precipitation data are nosily skewed, in order to compute SPI, precipitation data are normalized by fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station (Edwards and Mckee, 1997; Bhuiyan *et al*, 2006; Jungang and Roswintiarti, 2008).

The increasing of drought frequency in Syria will affect the national agricultural policy built up on the presence of five distinct zones identified by their annual precipitation average. This

present study aims to experiment SPI index for measuring the homogeneity response of each agricultural stability zone in Syria to climate change, represented by the spatiotemporal variation in precipitation between 1992 and 2018.

2   Study area

The total area of the Syrian Arab Republic is about 185,000 square kilometers, divided into 14 governorates. The climate of Syria is Mediterranean where summer is dry and winter is rainy. About 85% of Syria is either arid or semi-arid area where annual precipitation average is below 350 mm.

The first agricultural stability zone covers 15% of the Syria and has annual Rainfall between 350 and 1500 mm. This zone includes two sub-regions. The rate of the first is more than 600 mm and of the second is between 350 and 600 mm. The second zone covers 13% with annual rate ranging between 250-350 mm. The third zone represent only 7% of the country where annual rate exceeds 250 mm in more than half of the seasons. The fourth area covers ten percent of the country and receives annual average precipitation between 200 and 250 mm in more than half of the seasons. The fifth region, the largest, covers more than half of the country (55%) with annual rate less than 200 mm in more than half the seasons.
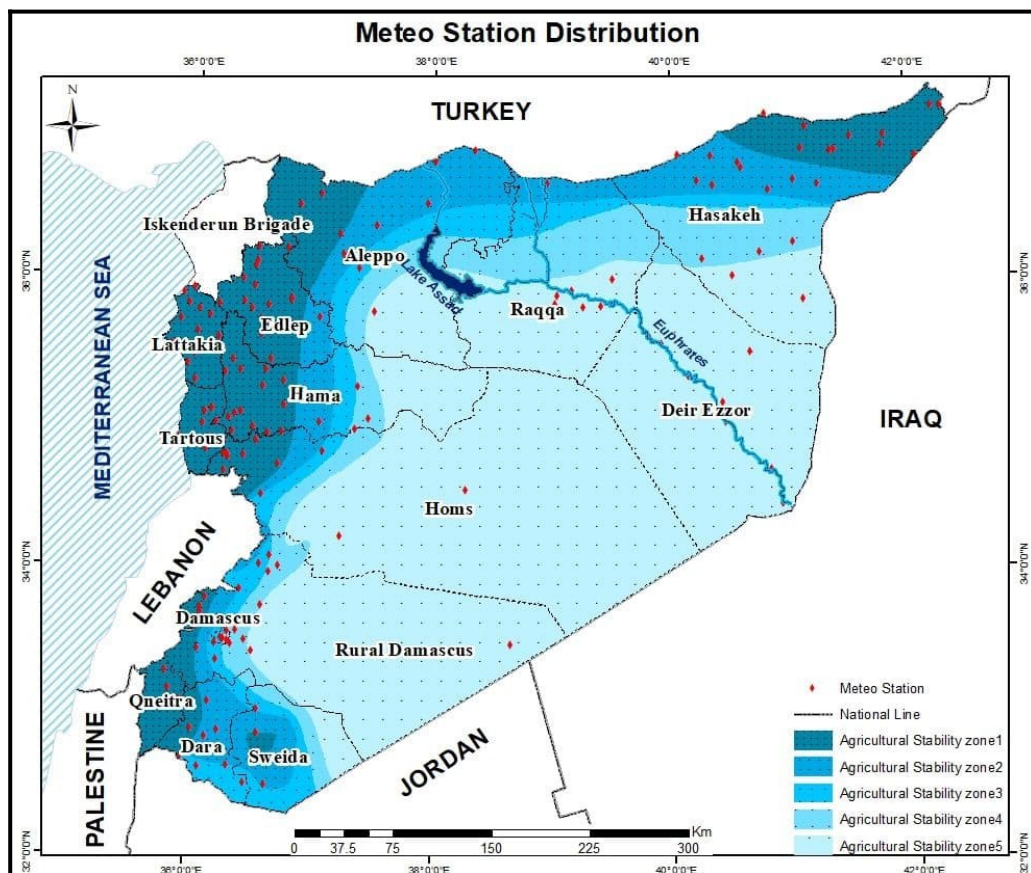

Figure 1: Ground rain stations distribution within the agricultural stabilization Zones in Syria (Source: Ministry of Agriculture).

3   Methodology

In Syria, the rainy period that affects directly the equilibrium of the ecosystems and the main agricultural production starts in November and finishes in next May. Therefore, we calculated the SPI_7 (at the base of 7 months' time scale) between 1992 and 2018, which allows us to assess the probability that the periodical precipitation for each location in Syria will deviate from its periodical rate all along the time of the study. Ministry of Agriculture in Syria installed about 165- ground rain stations; most of them located in the first and second zones (figure 1). Some of these stations record precipitation values since 1991 (about 93 stations). In some years, there are more than 150 stations in operation but some of them have rainfall data for less than 20 years. For this reason, the actual study used the spatial interpolation of the precipitation of each rainy season for filling the historical gap in data in each station. The employed method for this purpose is the Kriging. These produced maps are the inputs of the algorithm designed for mapping the SPI_7, and modeled by using "Model Maker" tool within the ERDAS 2014. After producing rainfall maps, each site (pixel of 1 km^2) in the study area had 27 values. Therefore, the algorithm used the simple equation mentioned in the introduction. The actual research used the standards of the European Drought Observatory (EDO) to classify the drought maps into seven category according to the SPI_7 values as shown in Table (1).

SPI Classification		
SPI <= MAX > 2.0	Extremely wet	Class 1
SPI <= 2.0 > 1.5	Very wet	Class 2
SPI <= 1.5 > 1.0	Moderately wet	Class 3
SPI <= 1.0 > 1.0-	Normal precipitation	Class 4
SPI <= -1.0 > 1.5-	Moderately dry	Class 5
SPI <= -1.5 > 2.0-	Very dry	Class 6
MIN <= SPI <= -2.0	Extremely dry	Class 7

Table1: Classification of the SPI by EDO (http://edo.jrc.ec.europa.eu/, 2018).

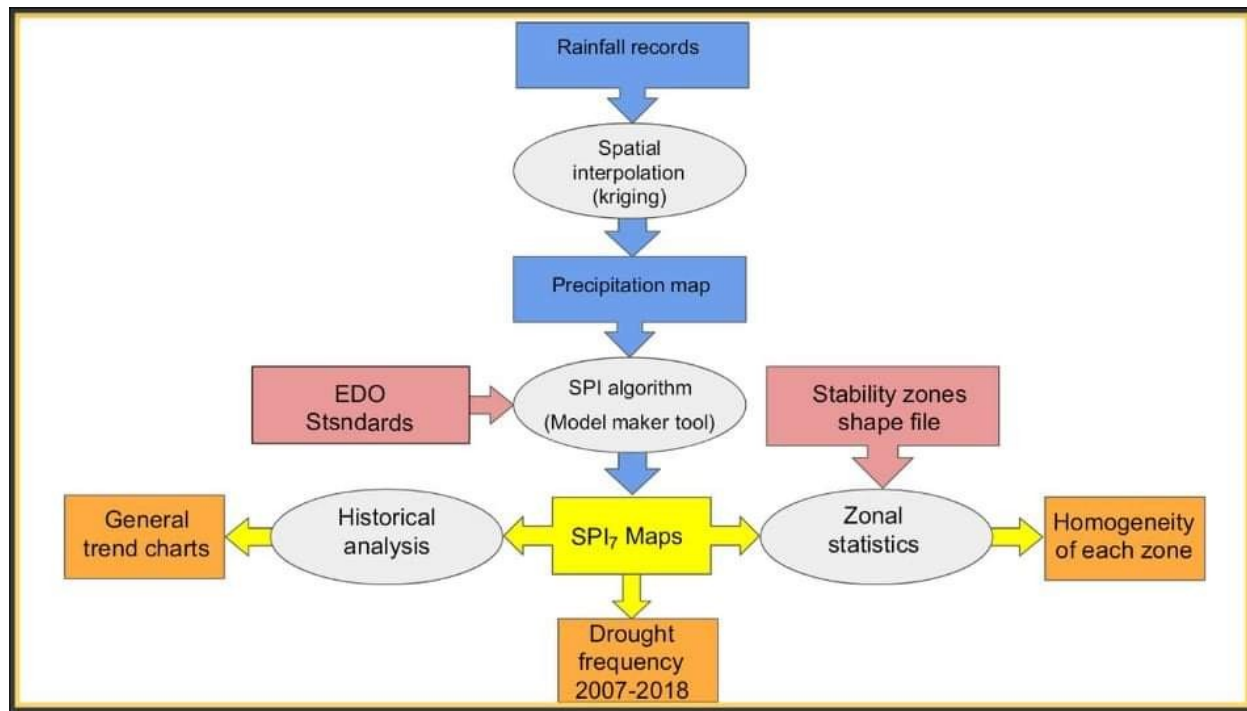The following diagram (Figure 2) presents the different steps of the methodology.

Figure 2: Methodology chart

4   Results and discussion

Following the processing steps mentioned in the previous paragraph, we mapped the "SPI₇" inside the Syrian boundaries for each year between 1992 and 2018. The general trend of the "SPI₇" index variation shows, in the most of the study years (22 years), that only less than 20% of the Country suffered of drought (Figure 3). From the last figure, we identified the first appearance of drought in 1999, where more than 35% of the country was very dry and little less than 30% of it suffered moderate drought. In addition, we consider 2013 very dry because more than 55% of the country is very dry and more than 15% of it is extremely dry. In 2008 and 2010, precipitation average decreased moderately in more than 60% of Syrian soil (61% and 67% successively).

Figure 3: Percentage of areas exposed to droughts across the Syrian Arab Republic.

In general, we noticed an increase in the drought frequency and in its spatial extent since 2008; nevertheless, the tendency is not the same in each of five Agricultural zones during the drought years. In 1999, the most affected zone were the fifth (about 83% of it) and the third (about 60% of it), while in 2008 less than 30% of the first zone exposed to drought compared to more than 70% in the other zones. Two years later, in 2010, 80% of the first zone exposed to drought where about 30% of this zone was very dry, while the other zones were moderately dry. In 2013 and 2014, drought dominated the first and second zones where more than 30% of their area was very or extremely dry. The rainfall in 2013 was much less than the average in more than 60% of the three other zones. In 2014, the climate was similar to last year, except for the fifth zone where the precipitation was mostly normal. Exceptionally, in 2016, the dry climate dominated more than 65% of the wet zone, the first; by contrast, the precipitation in the other zones was normal. (See figures 4, 5, 6, 7, 8 and 9).
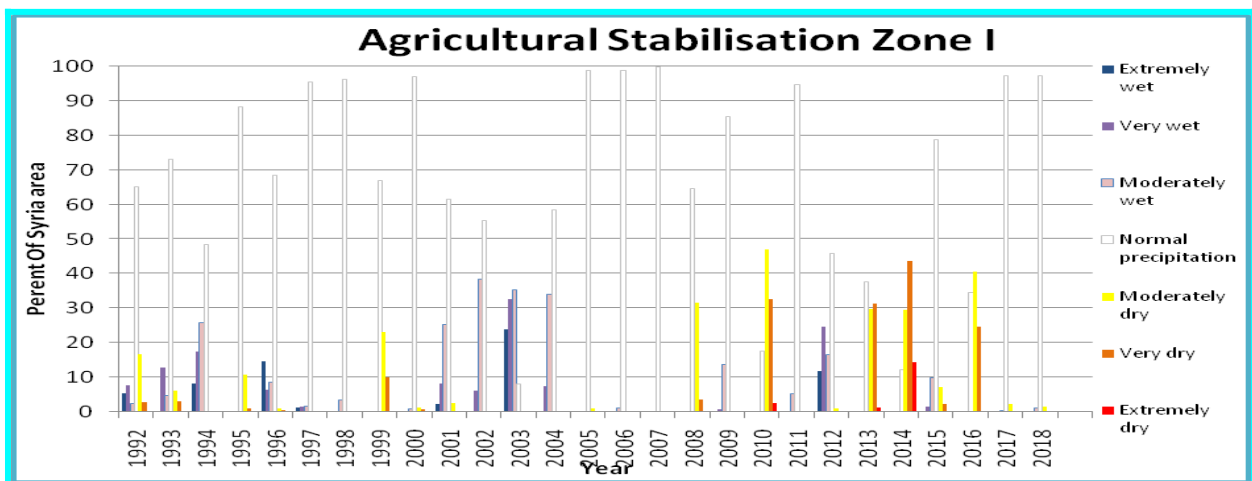

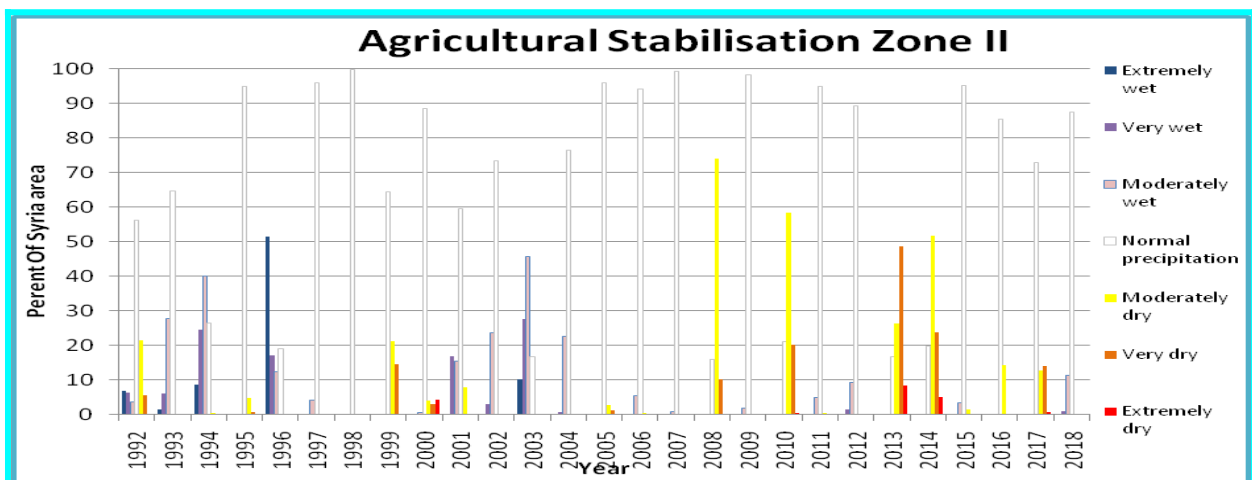Figure 4: Percentage of areas exposed to droughts across the agricultural stabilization zone I.

Figure 5: Percentage of areas exposed to droughts across the agricultural stabilization zone II.
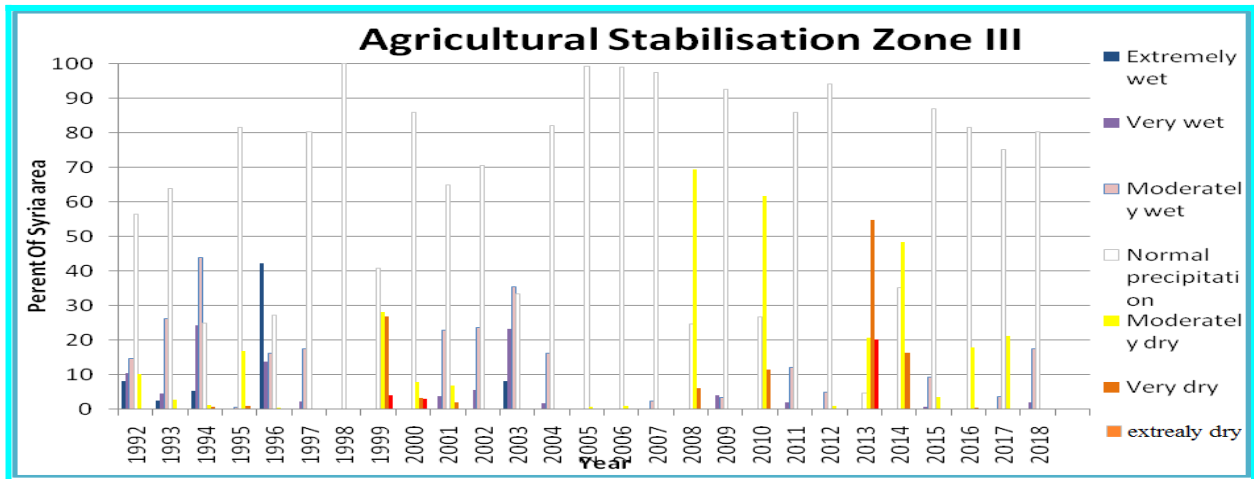
Figure6: Percentage of areas exposed to droughts across the agricultural stabilization zone III.
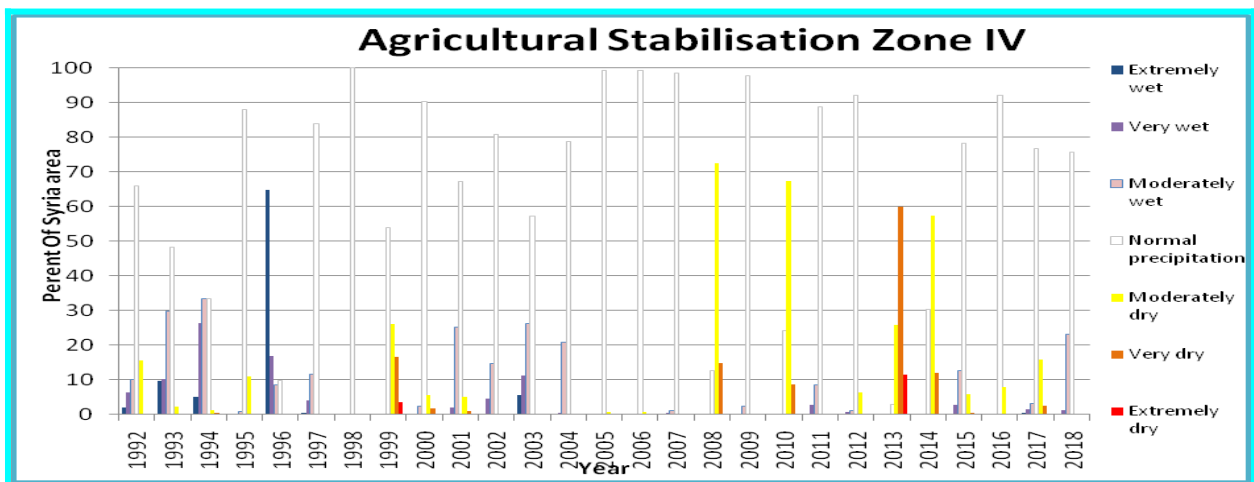

Figure 7: Percentage of areas exposed to droughts across the agricultural stabilization zone IV.
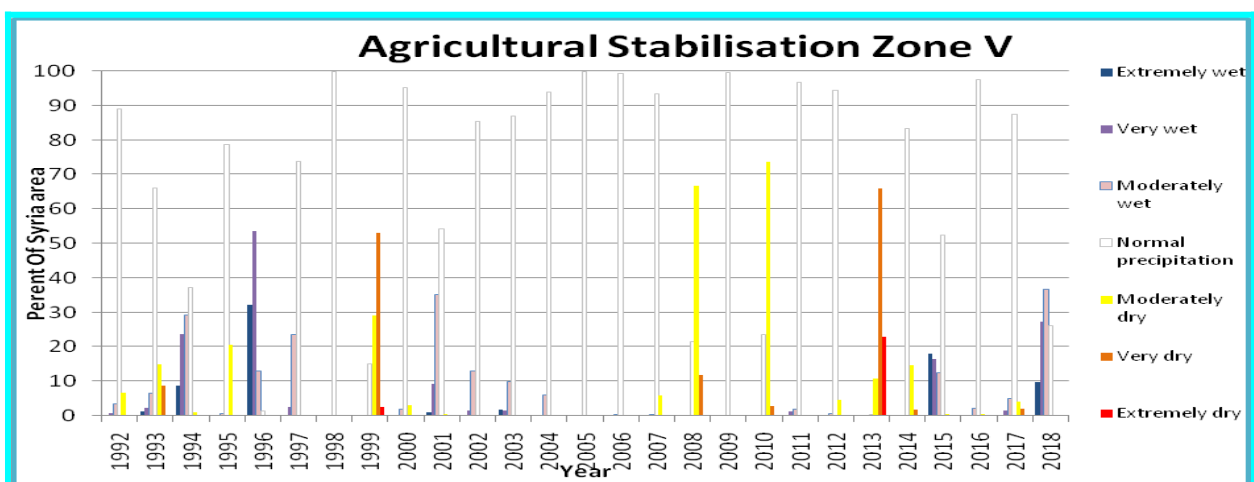

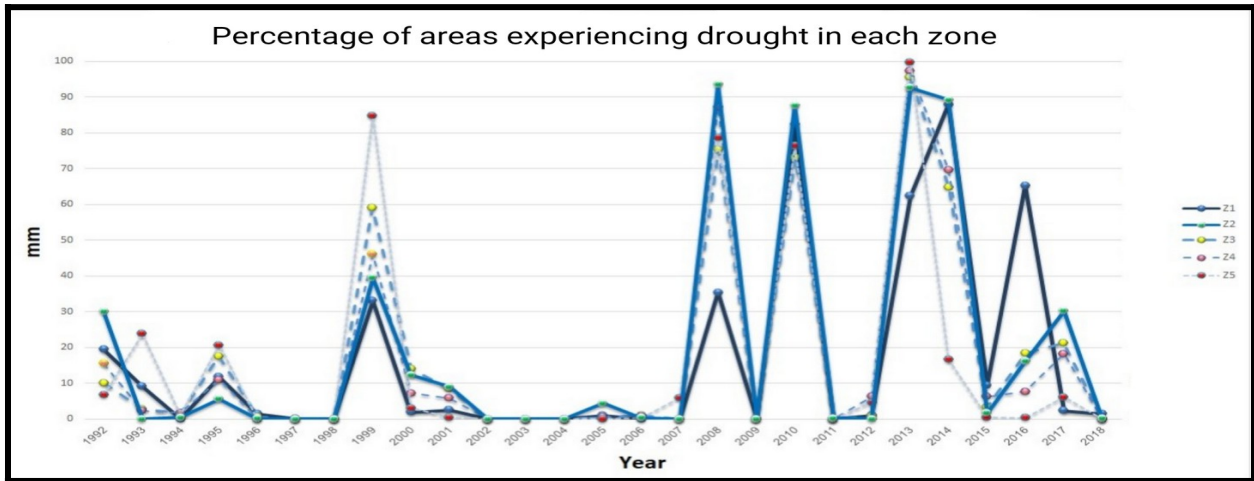**Figure 8: Percentage of areas exposed to droughts across the agricultural stabilization Zone V.**

Figure 9: Percentage of stabilization zones areas that experienced drought (moderate, very dry, extreme dry).

Figure (9) shows the spatial evolution of drought in each agricultural stability zone between 1992 and 2018. Between 1992 and 1996, less than 30% of each zone was dry, compared to less than 10% of those between 2000 and 2007. After 2007, the drought became more frequent and the climate tends towards aridity.

The geographical extension of each stability zone is wide and include varied morphologies and land covers, thus, it is important to quantify the spatial distribution of drought in every area throughout the study period. Therefore, we used "Zonal Statistic" tool, available in in ArcGIS, to apply tow spatial statistics, mean and standard deviation, on the 27 seasonal precipitation maps. Figures (10, 11) present the results.
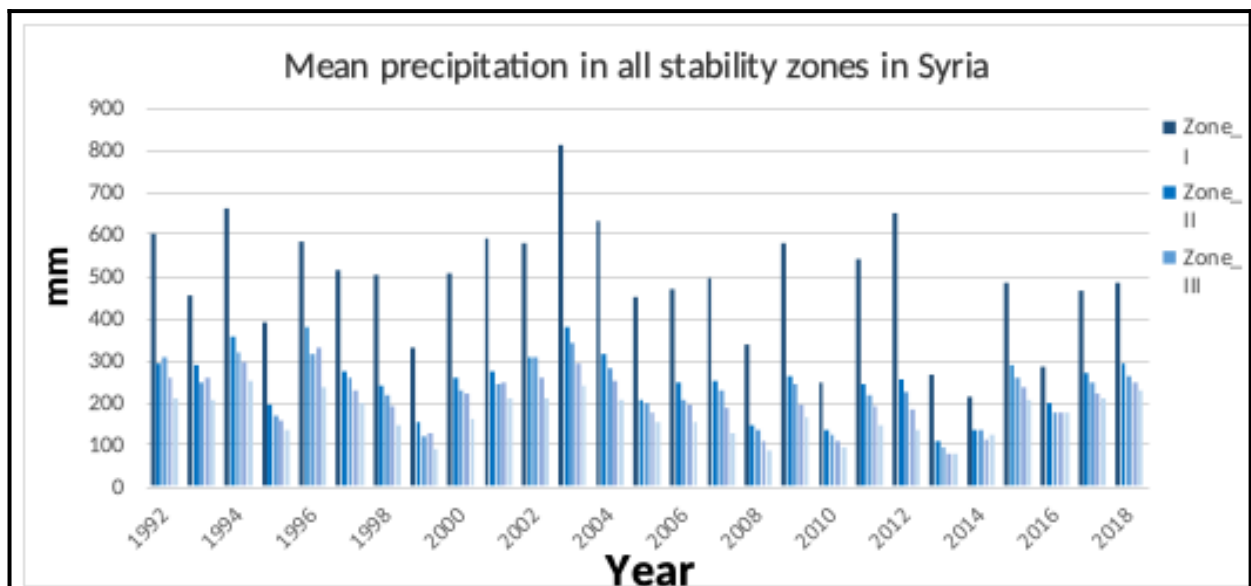

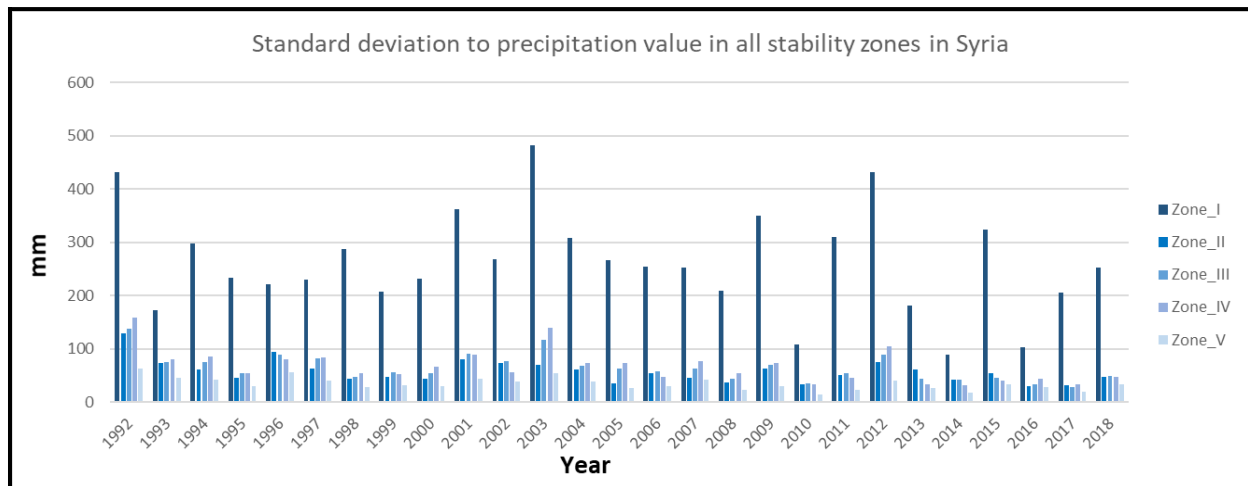Figure 10: Mean precipitation in all stability zones in Syria

8

Figure 11: Standard deviation to precipitation value in all stability zones in Syria

The evolution of spatial mean of precipitation in each zone (figure 10) shows the deterioration of its climates since 1992 through the decrease of rainfall average. In general, the amount of precipitation decreased significantly after 2004. In 24 seasons of the study years, the spatial rate of precipitation in the first zone was less than 600 mm and the spatial SD was more than 200 mm.. After 2012, the rate decreased under 500 mm with spatial SD less than usual.

The precipitation rate in the other four zones is close as it varies between 168 mm in the fourth and 248 mm in the second. Any observer distinguish easily the aridity encroachment to the second and third stability zones where the spatial mean of rainfall is less than 250 mm in 12 and 20 years, successively, since 1992. However, in same time, the spatial distribution of rainfall in the second, third and fourth zones is more homogenous as the spatial SD is less than 100 mm in almost all years. The fifth zone witnessed a close spatial SD, but we consider it too large in relation to the value of rainfall in it. Thus, this explains the important spatial variation in this zone especially since 2007.

As the SPI index expresses better the temporal variation of climate, the figure 9 showed the extreme trend of drought after 2006. Therefore, we produced the map of drought repetition in Syria since 2007 (figure 12). This map, which represents the spatial variation in drought frequency within each stability zone, displays a stable climate, around the normal, in southwest against drought more frequent in the northeast of the country. The drought characterized the most of northern half of Syria, which belong to five zones, at least 4 years since 2007. We recognize the same in the majority of coastal region.
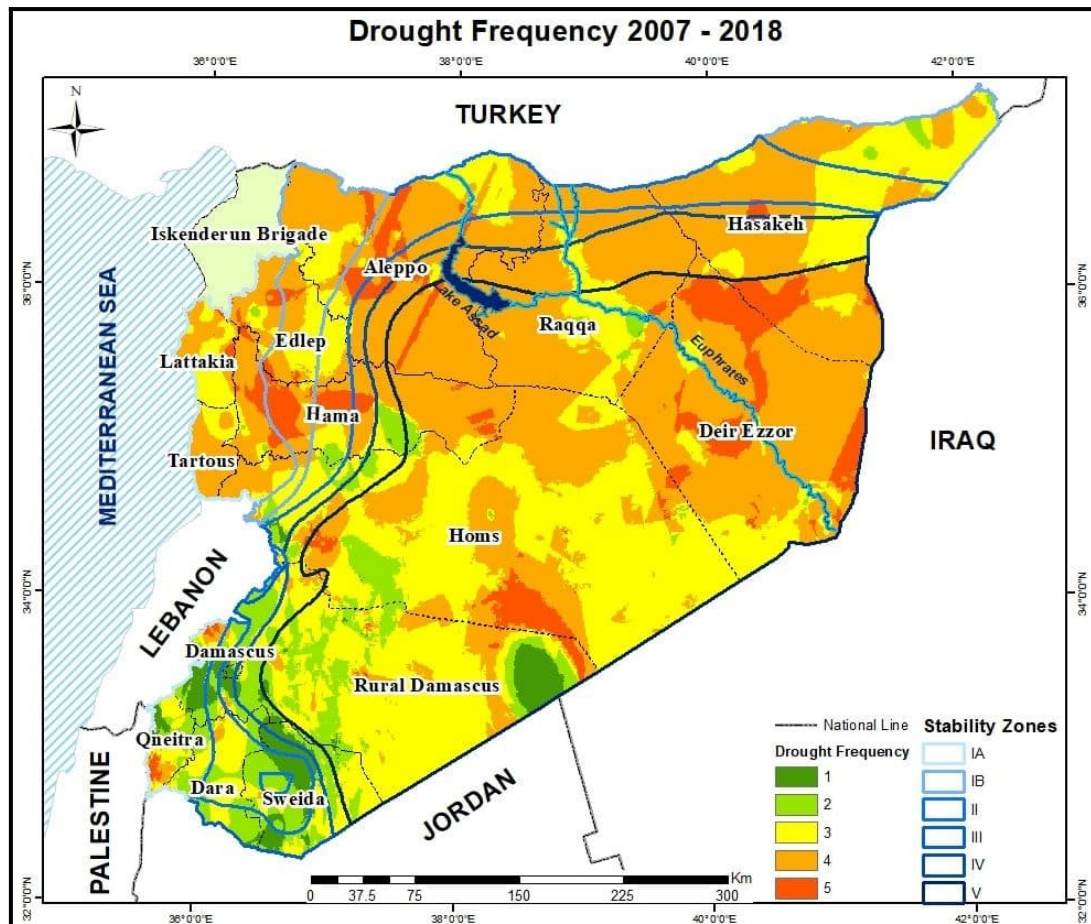
Figure 12: Drought frequency 2007_2018 in Syria

5   Conclusion

In this research, we tried to evaluate the stability of five agricultural zones response in relation to the new climatic conditions of drought in Syria by using SPI indicator. We worked to link the variation of surfaces exposed to drought in every zone to the spatial statistic expressing the temporal and spatial distribution of precipitation in it. Both the graphs of the percentages of areas exposed to drought, as well as the map of repetition of drought since 2007 showed that each of the five zones is heterogeneous in terms of the distribution of rainfall in it, especially in the last decade. In addition, this study remarked the aridity encroachment to the second and third stability zones. The local variation of the climate related to rain in every zone oblige detailed study with taking account of the global climate changes.

Knowing that the boundaries of stability zones was determined according to the rates approved from a long time, it is important to revise this boundaries with respect of new climate state taking in account local, regional and global changes and on focusing on other elements as temperature and vegetation response indexes.

10

Acknowledgments

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