Drought Assessment Using GIS and Remote Sensing in Amman-Zarqa Basin, Jordan

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ABSTRACT

This study aims at assessing drought for Amman-Zarqa basin, north Jordan. This basin is one of the important basins in Jordan where most of the agricultural and hydrological activates are located. During the last decades, Amman-Zarqa basin had faced a high variability of the rainy season which starts every year in October and ends in April. The main objective of this research is to find out if this basin is currently facing drought conditions. Two different drought indices were used in this study; these are the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI) to evaluate drought using rainfall data and satellite images.

Geographical information systems (GIS) software were used in this study to; 1) Create spatial digital database to hold meteorological information for the study area, 2) Generate thematic layers representing spatial distribution of drought for both SPI and NDVI and 3) Delineate areas with high drought risk using SPI and NDVI and compare the results of both models .

The results obtained from this study show that Amman-Zarqa basin is currently facing drought conditions. Furthermore, it was concluded that the combination of various indices offer better understanding and better monitoring of drought conditions for semi-arid basins like Amman-Zarqa Basin.

Keywords: Drought Assessment, GIS, Remote Sensing, Amman-Zarqa Basin.

INTRODUCTION

Drought is a disastrous natural phenomenon that had multi-sever impacts on human and environment. The difficulty of studying such phenomena came from the fact that no one can recognize when the drought can be started or even when it is ended. In most cases, its impact persists even after ending of the drought event. Furthermore, the drought concept varies among regions of different climates (Dracuo et al., 1980).

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The area of Jordan is about 90,000 km^2 located between latitudes 20.5 and 30.5 degrees north and longitudes 35 and 39.5 degrees east. It lies within the semiarid climatic zone and has a typical Mediterranean short, rainy winter and long dry summer. Annual precipitation varies from 50 mm in the desert to 600 mm in the North West highlands (Figure 1). About 91.4% of Jordan's total area receives an average annual rainfall less than 200mm and only 3% of its area receive an annual rainfall greater than 300 mm. The consequences of this situation lead to a large imbalance between supply and demand, continued depletion of valuable aquifers beyond the points of ever being replenished, unequal water distribution by region and a tendency to concentrate investments on the development of new water resources (supply management) while neglecting demand management and water saving strategies.

The rainy season in Jordan extends from October to April; the peak is usually during December, January and February. The long-term average annual precipitation is 8,500 MCM of which an average of 92.5% is lost by evaporation (MWI, 2003). The high temperatures and low humidity in Jordan result in an extremely high evaporation rate. The long-term average evaporation rate is 92.5%; this ranges from 63% in the highlands to around 99% in the eastern desert (Table 1).

According to FAO report in the 3rd of June 1999, “Severe drought that cut rainfall in Jordan by up to 70 percent has left the country facing its worst cereal harvests in more than 40 years”. An FAO/WFP Crop and Food Supply Assessment mission that visited Jordan in April/May 1999 reported that “the unprecedented drought could not have come at a worse time”.

According to Dracup et al. (1980), the U. S. Weather Bureau defines drought as “Lack of rainfall so great as so long continued to affect injuriously the plant and animal life of a place and to deplete water supplies both for domestic purposes and the operation of power plants especially in these regions where rainfall is normally sufficient for such purposes”.

As this definition implies, drought is mainly and directly linked with lack of rainfall that causes consequences including agricultural and hydrological hazards associated with severity and duration of this lack (Dracup et al., 1980).

Many authors and researchers agree on the aforementioned definition of drought (Dracup et al., 1980; Wilhite, D.A., 2000a, 2000b). However, they prefer to adopt an operational definition that distinguishes between meteorological, agricultural and hydrological droughts (Chang, 1991) with respect to the parameter of prime interest which could be precipitation (meteorological drought), soil moisture (agriculture drought), stream flow (Cancelliere et al., 1995) or groundwater levels (hydrological drought).

Unlike other natural hazards, drought differs in several issues as (Wilhite, 2005): a) The drought often accumulates slowly over a considerable period of time, therefore, it is not easy to determine when a specific drought event had started or ended, b) There is no precise and widely accepted definition of drought; which means that drought conditions for a specific region might be considered as wet conditions for another region (i.e., it is a relative term) and c) The impact of specific drought event might extend for a period after the end of this event. This impact may vary by affected sector, thus making different definitions of drought relevant to specific affected groups .

The main objective of this study is to assess drought conditions prevailing in Amman-Zarqa basin, northern Jordan, using different drought indices using GIS and remote sensing techniques.

DESCRIPTION OF THE STUDY AREA

Amman Zerqa Basin is one of the important hydrological basins in Jordan. It is located in the north western part of Jordan and comprises a total area of 4,025 km^2. About ninety percent of this area is located in Jordan, and the rest in Syria (Figure 2). This basin is the most densely populated area in Jordan, it comprises around 65% of the country’s population, and 80% of its industries, in addition to intensive agricultural activities.

The climate of the basin is semiarid where rainfall precipitates mostly in the winter season while the summer season is extensively dry. The rainfalls in Jordan are produced due to the Eastern Europe and Western Mediterranean cold fronts. The amount of rainfall in the Amman-Zarqa Basin decreases towards the east through the basin.

The temperature in the basin varies in an east-west direction. Table (2) shows average monthly climatological parameters prevailed in the study area. The average annual minimum and maximum temperatures are 11.1 °C and 23.5 °C, respectively. The absolute maximum temperature (°C) is recorded in July 1978 and was 43 °C, while the absolute minimum (0 °C) is observed in January of 1993.

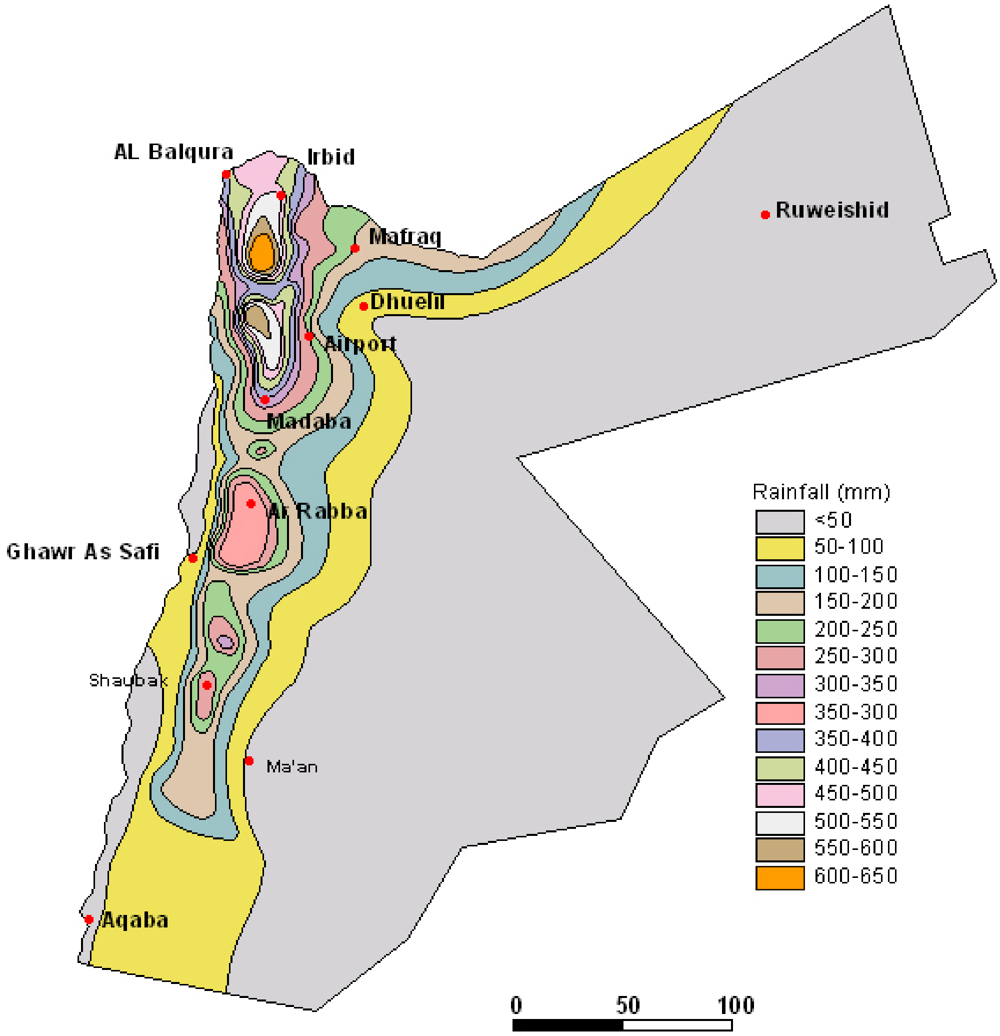

Figure (1): Long-term annual rainfall over Jordan from 1937-2000.

Table (1): Classification by Rainfall Distribution.

Classified Zone	Annual Rainfall (mm/yr)	Catchment Area (km^2)	Area Ratio %	Rainfall Volume (AD1937 – 2003) (MCM)
Semi-humid	500 – 600	620	0.7	425
Semi-arid	300 – 500	2,950	3.3	1,170
Marginal	200 – 300	2,030	2.2	530
Arid	100 – 200	20,050	22.3	2,950
Desert	< 100	64,350	71.5	3,425
Total		**90,000**	**100**	**8,500**

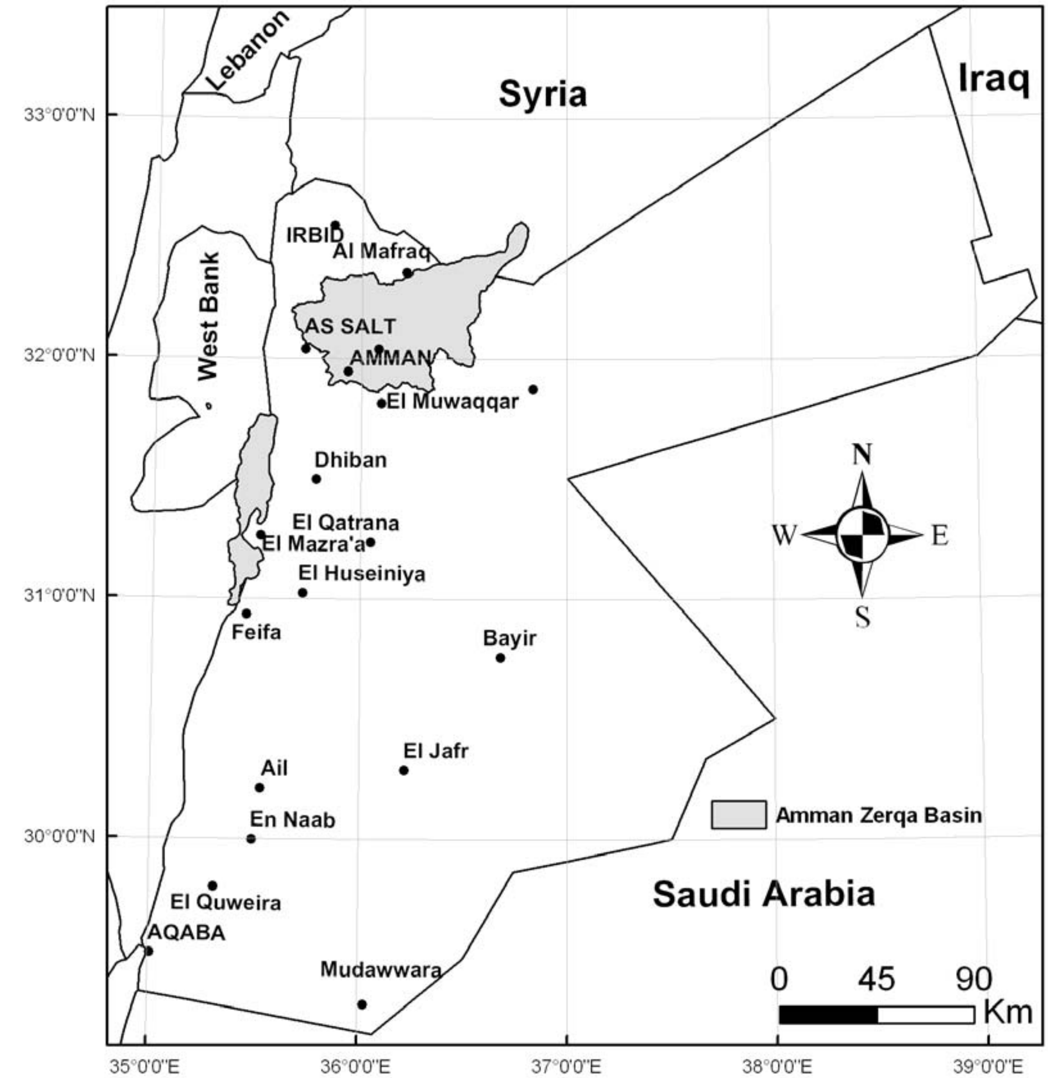

Figure (2): Location of Amman-Zarqa Basin.

The maximum sunshine duration occurs in July, with an absolute value of 14 hrs/d, which was observed in 1978.

METHODOLOGY

Drought assessment in this study was carried out using two different indices, these are:

1) Standardized Precipitation Index (SPI)

SPI was developed in Colorado by McKee et al. (1993) to quantify the precipitation scarcity for multiple time scales which reflect the impact of drought on the availability of the different water resources.

The SPI calculation is based on the long-term precipitation record for a time period. This long-term record is fitted to a probability distribution, which is transformed into a normal distribution where the mean SPI for the location and desired time period is zero (Edwards and McKee, 1997). The interpretation of positive SPI values indicate greater values than the median precipitation, while negative values indicate less values than the median precipitation. One of the advantages of SPI is its ability to monitor dry and wet climate as it's a normalized index. According to McKee et al. (1993), SPI values can be classified as shown in Table (3) to describe drought intensities.

Table (2): Average Monthly Climatic Parameters Representing the Study Area (1967 - 2002).

Climatic Parameters	Month											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Maximum Temperature (oC)	27.1	20.5	14.4	12.4	13.9	17.4	22.5	27.7	30.8	31.9	32.4	30.7
Minimum Temperature (oC)	13.6	9.3	5.1	3.5	4.2	6.1	9.3	13.3	16.4	18.2	18.3	16.3
Mean Temperature (oC)	20.3	14.8	9.8	8.0	9.1	11.7	15.9	20.5	23.6	25.1	25.4	23.4
Wind Speed (m/s)	2.3	2.45	2.9	3.25	3.7	3.8	3.85	3.65	4.1	4.3	3.7	2.8
Sunshine Duration (hrs/day)	9.5	7.8	6.2	6.3	7.0	7.9	9.4	11.0	12.8	12.9	12.2	11.0
Relative Humidity (%)	47	56	68	70	67	60	50	39	37	40	43	47
Rainfall (mm)	5.0	15.6	28.7	38.1	33.3	27.4	7.5	1.1	0	0	0	0
Class A Pan Evapotranspiration (mm/day)	6.9	4.5	2.8	2.8	3.6	4.8	7.0	9.6	11.6	12.0	10.9	9.1
Potential Evapotranspiration (mm/day)	4.9	3.2	1.9	1.8	2.5	3.5	5.0	7.0	8.3	8.5	7.1	6.2

McKee et al. (1993) had also considered the time scale for any drought event. The negative values indicate the occurrence of drought event. The SPI values would be less than -1. The drought event will finish when SPI values become positive. Therefore, each drought event has a duration limited by its beginning and end, and an intensity for each month in which the event continues. The accumulated magnitude of drought can also be the drought magnitude, and it is the positive sum of the SPI for all the months within a drought event (McKee et al., 1993).

SPI is a standardized index, therefore, it is possible to expect the percentage of specific drought event from normal distribution of SPI. For example, the percentage of "Extreme Drought" event would be 2.3% of the SPI values (Wilhite, 1995).

Table (3): Classification of SPI Values.

SPI range	Drought intensity class
2.0 +	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
0.99 to -0.99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2.0 and less	extremely dry

Table (4): Drought and Wet Periods for Rainfall Stations.

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2) ***Normal Difference Vegetation Index (NDVI)***

NDVI was first suggested by Tucker in 1979 as an index of vegetation health and density

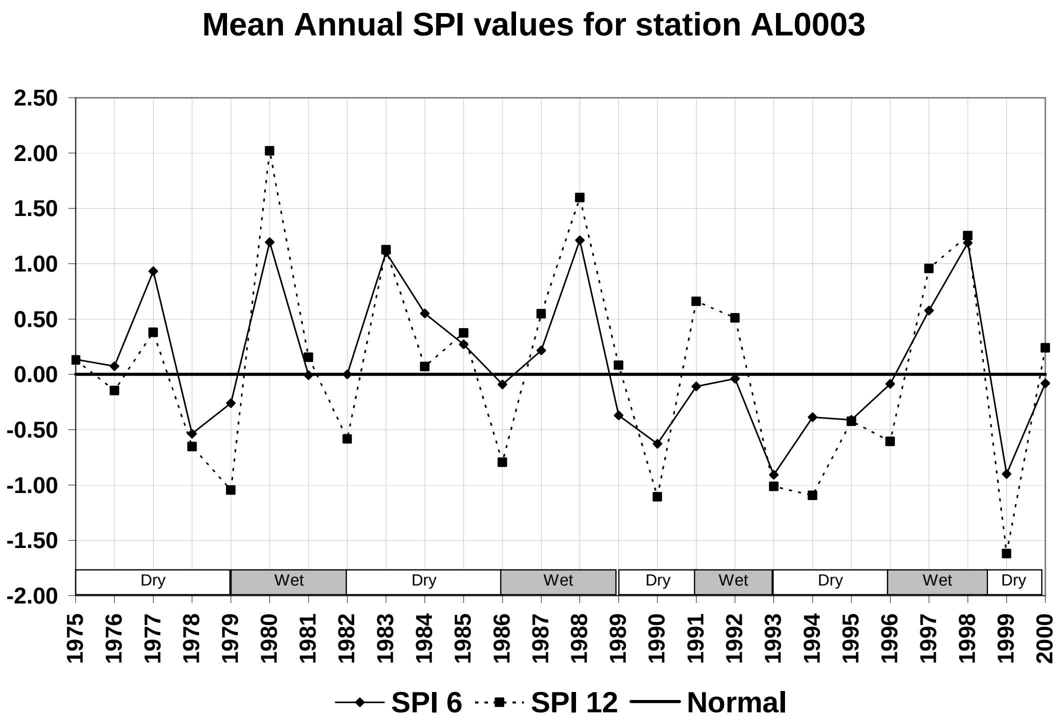
$$\mathbf{NDVI = (\lambda_{NIR} - \lambda_{RED}) / (\lambda_{NIR} + \lambda_{RED})}$$

where, λ_{NIR} and λ_{RED} are the reflectance in the near infrared (NIR) and red bands, respectively. NDVI reflects vegetation vigor, percent green cover, Leaf Area Index (LAI) and biomass. The NDVI is the most commonly used vegetation index. It varies in the range of -1 to + 1. However, NDVI a) uses only two bands and is not very sensitive to influences of soil background reflectance at low vegetation cover, and b) has a lagged response to drought because of a lagged vegetation response to developing rainfall deficit due to residual moisture stored in the soil (Jensen, 1996). Previous studies have shown that NDVI lags behind antecedent precipitation by up to 3 months. The lag time is dependent on whether the region is purely rainfed, fully irrigated or partially irrigated. The greater the dependence on rainfall is; the shorter is the lag time. NDVI itself does not reflect drought or non-drought conditions. But the severity of a drought (or the extent of wetness, on the other end of the spectrum) may be defined as the NDVI deviation from its long-term mean (DEV_{NDVI}).

This deviation is calculated as the difference between the NDVI for the current time step (e.g., January 1995) and a long-term mean NDVI for that month (e.g., an 18-year long mean NDVI of all Januaries from 1981 to 2003) for each Pixel:

$$\mathbf{DEV_{NDVI} = NDVI_i - NDVI_{mean,m}}$$

Where, $NDVI_i$ is the NDVI value for month i and $NDVI_{mean,m}$ is the long-term mean NDVI for the same month m (e.g., in a data record from 1981 to 2003, there are 23 monthly NDVI values for the same month, e.g., 23 Julys'), and 12 long-term NDVI means (one for each calendar month). When DEV_{NDVI} is negative, it indicates the below-normal vegetation condition/health and, therefore, suggests a prevailing drought situation. The greater the negative departure is, the greater is the magnitude of a drought.



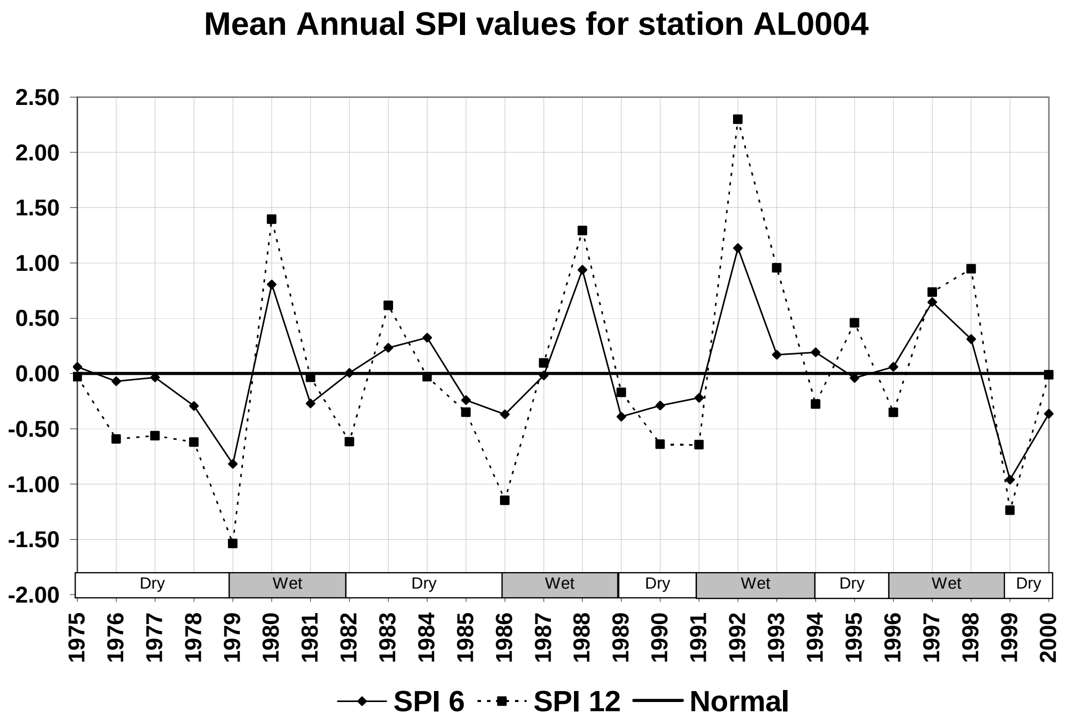
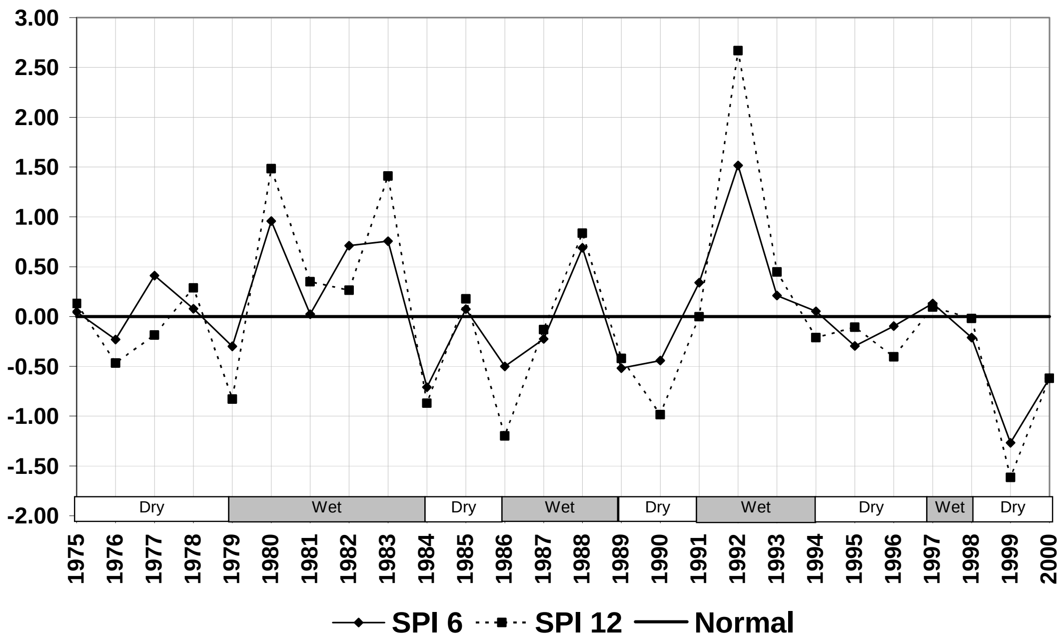


Figure (3): The SPI values for 6 and 12 months for selected stations.

Mean Annual SPI values for station AL0022



Mean Annual SPI values for station AL0048

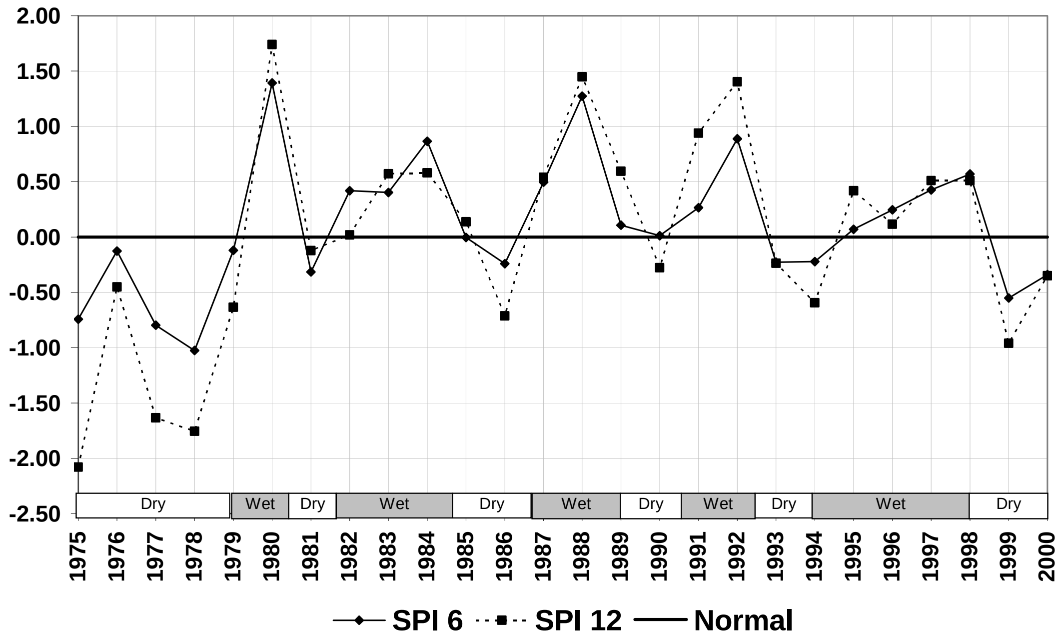


Figure (3): continued.

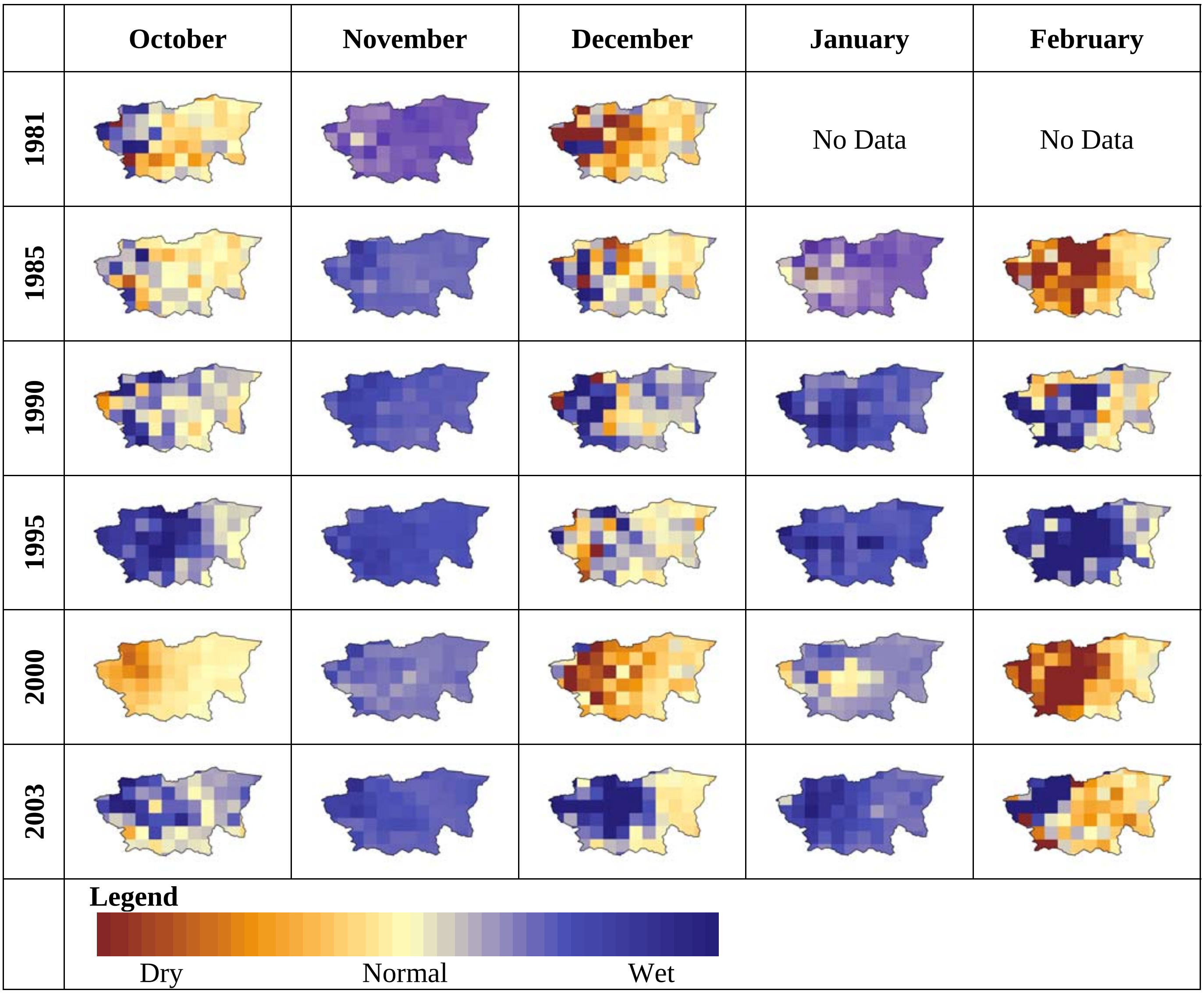


Figure (4): NDVI Drought Index Map for Selected Years and Selected Months.

Drought Severity Using SPI

According to the standard classification of SPI values, a station can suffer extreme drought situation, if the SPI value is below -1.0. The annual SPI values from 1975-2000 for 6 and 12 months for selected rainfall stations are shown in Figure (3). An important phenomenon which can be seen from these charts, is the repetitive manner of the dry seasons over the years. The general trend can be generally described as follows: "There is a dry period that lasts between 3 to 5 years followed by a wet period that lasts between 2 to 3 years." This behavior may vary from one station to another, however, it is always noticed that drought periods take place in a repetitive way. Table (4) shows the drought and wet periods for selected rainfall stations in the study area. This table shows that there are several years that showed drought event as for example the years 1971, 1980, 1991 and 1992 for most of the rainfall stations.

Drought Severity Using NDVI

The NOAA-AVHRR–NDVI composite which is provided by Global Inventory Modeling and Mapping Studies (GIMMS) was downloaded from the University of Maryland Global Land Cover Facility Data Distribution Cente (http://glcf.umiacs.umd.edu/ data/ gimms/).

The composite has a spatial resolution of 8 km and a receptivity cycle of 15 days. Jordan was found to be part of the continental file of Africa (AF) having an image size of 2000 x 1250 cells**.**

The NDVI dataset is having a temporal coverage from July 1981 to December 2003 and its format is IEEE (International Electrical and Electronic Engineers) standard format**.** The downloaded NOAA-AVHRR NDVI composites were used to generate DEV_{NDVI} thematic maps for the whole of Jordan. These maps were generated for the years from 1981 to 2003 for the months: October, November, December, January and February. Figure (4) shows selected monthly DEV_{NDVI} thematic maps, generated using ArcGIS software and Spatial Analyst extension. This figure shows the monthly behavior of drought over the selected period. It can be noted that drought is prevailed in some months like December and October while in other months, like November and January, wet conditions were dominant.

CONCLUSION

Drought is a natural hazard that involves many factors, including meteorological and climatological parameters, having complex inter-relationships. Drought definitions vary from region to region and may depend upon the dominating perception, and the task for which it is defined. Identifying patterns of drought and finding its associations with various indices derived from conventional method and remote sensing techniques are becoming important for monitoring of this natural hazard. Dealing with NDVI and rainfall dataset for a time-series of more than 20 year makes the study not only complicated but also difficult to analyze. This study addresses the need of analyzing and studying the pattern of drought using temporal rainfall datasets and their derived indices such as SPI for time-series dataset and vegetation based index (NDVI).

Rainfall varies spatially and temporally throughout the whole Amman-Zarqa Basin. By analyzing the rainfall for 60 rainfall stations from 1975 to 2000, the minimum and maximum mean rainfall observed during this time period varied from 80 mm to 497 mm, which indicates a large variation in the areal distribution of rainfall in the study area. The highest rainfall was recorded in the northern and north-western part where the least rainfall in the same period was noticed in the southern and south-eastern part of the basin.

Occurrence of drought cannot be monitored by comparing the relative rainfall observed in various stations. To overcome these limitations, the use of SPI for drought monitoring was highlighted. The SPI was computed at a time-scale of 6 and 12 month return period for all stations. By analyzing the obtained SPI values, it was found that drought years were repeated over the 25 years in regular and repetitive periods that last between 2 and 3 years.

NOAA-AVHRR-DVI composites were also used to generate DEV_{NDVI} thematic maps in order to estimate drought for the study area. These maps show the drought conditions which are dominant for specific months. By applying two different drought indices in this study, it was possible to assess the annual variations of drought over a period of 25 years using seasonal variations of the rainfall. Furthermore, it was possible to evaluate the monthly behaviour of drought over a period of 20 years using vegetation conditions.

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