RESEARCH ARTICLE OPEN ACCESS

Applicability of a Combined Drought Index to Monitoring Drought in Jordan

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ABSTRACT
Drought is a complex natural hazard with variable patterns and severity that has become a trending phenomenon in all countries across the globe, impacting all sectors negatively. Due tothe importance of drought monitoring and early warning in terms of enhancing drought resilience and preparedness, drought characterization and vulnerability have beeninvestigated repeatedly during the last decade, leading to the development of various drought indices. However, a single drought index may not provide a clear understanding of drought spatial and temporal patterns and the impacts on various sectors; thus, a combination of various indices could provide a key tobetter interpolationand forecasting.

The present study explores and evaluates the potential of using a combined drought index (CDI) based onprecipitation (PDI), temperature (TDI), and vegetation (VDI) drought indices, to characterise drought variability and trends in Jordan based on 1-, 2-, 3-, 6-, and 12-month timescales. The CDI was computed as a weighted average of the PDI, TDI, and VDI indicators as derived from daily rainfall, air temperature, and NDVI data respectively for 21 meteorological stations for dates from 1980 to 2017.

Although the CDI is simply a statistical index that measures how much present conditions deviate from the reference level, CDI applicability to monitoring and its correlation with sector impacts is much better than for any single drought indicator. Generated CDI maps also provide better interpolation for national and local drought characteristics in terms of severity, amplitude, and duration, and, as such,the CDI can clearly trace the footprints of droughts in Jordan. However, the relative weights of the PDI, TDI, and VDI may require further assessments through sensitivity analyses for improvedsector based responses (specific crop yields, groundwater recharge, etc.). The use of timescale CDI also enables the potential use of indicators for detailed short duration investigations for the development of an-early warning system or long term forecasting for adaptation planning and capacity building.

Keywords: Drought index, precipitation, temperature, vegetation, combined index, Jordan.

Date Of Submission: 10-07-2019 Date Of Acceptance: 28-07-2019

I. INTRODUCTION

Drought is one of the most complex natural hazards; it is considered to be a slow accumulative process ofindefinite commencement and terminationthat affects many more persons as compared to other hazards (Tannehill 1947; Hagman, 1984). Although there is no single definition of drought applicable to all spheres, the term drought generally implies water scarcity resulting from insufficient precipitation, high evapotranspiration, or over-exploitation of water resources, or a combination of these parameters (Bhuiyan, 2004;Dracup, et al., 1980;Gillette, 1950;Meigh et al., 1999; Wilhite, 2000; Wilhite and Glantz, 1985; Mishra and Singh, 2010; Zargar et al., 2011).

Droughtimpacts on all sectors, withwater, agricultural, industrial, environmental, socio-economical, and political aspects. According to the literature, droughtimpacts include effects on drinking water supplies, the environment (mortality of fish species, river bank biodiversity reduction, biodiversity loss in terrestrial areas, wetland impacts, forest fire risk increased, and worsened ecological status), socio-economic uses (industrial uses, power production, short and long term agriculture and food security, market problems,tourism, water rights, and transport), and politics (armed conflicts, shared watersheds), and it can also be associated with other hazards such as extreme heat and wildfires (Bhuiyan et al., 2006: TigkasandTsakiris, 2015; Tsakiris et al., 2010; Sandford, 1979; Schmidt and Karnieli, 2002; Wilhite, 2000; Wilhite, 2005; FAO, 2016; EC, 2007; Farrell et al., 2010).

Based onthe importance of drought monitoring and early warning in terms of enhancing the resilience and preparedness of countries and regions towards drought, drought characterisation and vulnerability have beeninvestigated repeatedly overthe last decade to help ensure proper drought management and operational planning (Bachmair et al., 2016). Researchers have developed various physical and statistical drought indices to map, monitor, and assessdrought risks globally based on typology(i.e. meteorological, hydrological, and agricultural drought) (Palmer, 1965). However,there is no consensus on which indicator best represents drought impact occurrence for any given sector (Tsakiris et al., 2013; Heim, 2002, Mishra and Singh, 2010; Zargar et al., 2011; Tigkas et al., 2016). The Percent Normal Drought Index (PNDI), Precipitation Decile Index (PDI), Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI),Weighted Anomaly Standardized Precipitation (WASP), Palmer Hydrological Drought Index (PHDI), the Palmer Z-index (PZI), Standardized Water-level Index (SWI),Surface Water Supply Index (SWSI), Keetch-Byram Drought Index (KBDI), Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Crop Moisture Index (CMI),Temperature Condition Index (TCI), Reclamation Drought Index (RDI)and Vegetation Health Index (VHI)are allcommon examples of well-developed drought indices (CaparriniandManzella, 2009; Komuscu, 1999;Singh et al., 2003; Kogan, 1990;Kogan, 1995;Kogan, 2001;Kogan, 2002; Kogan et al., 2003; Wilhite and Buchanan-Smith, 2005;Sreeja et al., 2013; Edwards and McKee, 1997; Gibbs and Maher, 1967; Hayes, 2000; Heim, 2002; Mendicino et al., 2008; Morid et al., 2006; Nair et al., 2013; Palmer,1965;Singhet al., 2013; Sullivan et al., 2006;Tucker, 1979; Willeke et al., 1994; Cutter et al., 2003).

Generally, the selection of drought indicator is based ondata availability and the purpose of use; in addition, some of these indices require continuous data observation without gapsand may not take into accountthe persistence of stress periods (Nair et al. (2013; Keyantash and Dracup, 2002; Hayes, 2006). Therefore, the effectiveness of the drought indices in terms of reflectingactual status is questionable. However, several new approaches have generated multi-indices (combined drought measures) by incorporating additional variables such as temperatureto represent time-series changes and trends.Combined drought indices represent a new approach that may couple dry spells inlocal conditions to regional-scale climate change conditions and their impacts. These combined indices consider as many drought attributes as possible, and they can thus be easily adapted to various monitoring purposes (Tigkas et al., 2013; Al-Faraj et al., 2014; ShokoohiandMorovati, 2015; Zarch et al., 2015; Eriyagama et al., 2009; Zongxue et al., 1998; Sehgal et al., 2013).

One of the most commonly used combined drought indices wasdeveloped bySomalia Water and Land Information Management (SWALIM); this incorporates six drought-creating parameters: (1) rainfalldeficits, (2) persistence of dryness, (3) temperatureexcesses, (4) persistence of high temperatures, (5)soilmoisturedeficits, and(6) persistence of dry soil conditions (Balint et al., 2011). The SWALIM-CDI reflects the combined effects of three drought indices: thePrecipitationDroughtIndex (PDI), theTemperatureDroughtIndex(TDI), andtheVegetationDroughtIndex(VDI),which acts asasubstitutefortheSoilMoisture Drought Index on various timescale bases (10-day, month, season,year,or longer periods) and which canbeusedindata-scarceenvironments where there may be datagapsintheobserved series.

Water scarcity is the main constrain that limits Jordan's progress towards achieving sustainable development; the current scarcity significantly impacts all other sectors, especially agriculture (MWI, 2015). With its dry climatic conditions with limited water resources, Jordan is forecast to be the first inhabited country in the world to “run out” of water (Allan, 2001). The annual per capita water availability had declined toless than 100 m^3/year in by 2017 due to rapid population growthand the impact of refugee surges and migrations. This pressure on local water is exacerbated by the observed and projected adverse impacts of climate change and global warming, with water sources being projected to decline by at least 20% by 2100 (Agoumi, 2001; MoEnv., 2013). Although the country has developed many water catchment areas including desert dams, ponds, and desert excavations with a total capacity of 90.3 MCM (million m^3), as well asadopting various programmes for rationalising water use at all sectors, the available water is still not sufficient to compensate for the high water demand, which reached 1008.8 MCM in 2015.

Arid to semi-arid countries such as Jordan that are challenged by limited water resources areprone to drought because their annual rainfall amount depends critically on only a few rainfall events; therefore, even where an individual drought severity is moderate, the impact may be severe (Sun et al., 2006;Qinna et al., 2011). The objective of this research is thus to evaluate the use of a combined drought index to characterize droughts in Jordan to developapplicable monitoring processes.This approach is expected to improve the understanding of drought patterns in Jordan and enhance the applicability offuture drought assessments, especially in arid climate conditions.

II. METHODOLOGY

2.1 Study area and data

Jordan is a Middle Eastern developing country located about 80 kilometres east of the Mediterranean Sea, between 29°11' to 33°22' N, and 34°19' to 39°18' E, covering an area of 89,318 km^2. The kingdom's area is distributed over88,794 km^{2}ofland area which consists topographicallyof 550 km^2 of heights, 10,000 km^{2}of plains, 8,244 km^{2}of the Rift valley, and 70,000 km^{2}of desert, including the Badia. The kingdom's territorial waters cover 524km^{2}including theDead Sea, and theGulf of Aqaba at 430km^2 and 94km^2, respectively (Figure 1).The highest peak in Jordan is the Um Dami Mountain (1,854 m above sea level), while the lowest point in Jordan is the Dead Sea (416 meters below sea level).

Generally, Jordan is divided into three main climatic regions (FAO, 2012); the Lowlands (Ghor Region), the Highlands, and the Desert lands (Badia). The Lowlands; as a part of the Great Rift Valley (JRV), extend from the north western part of the country towards the south western corner, with elevation ranges from 197 m below msl in the north to 417 below mslat the Dead Sea. The Highlands and Marginal Steeps Region extends north-south to the east of the JRV, stretchingfrom the Yarmouk River in the north to Ras El-Naqab in the south. The mountains peaks' elevations vary from 1150m amsl in RasMuneef to 1365m amsl in Al–Shoubak, and the height exceeds 1500m at El-Qurain. The Desert lands extend north-south from the eastward foot of the Highlands with elevations ranging from 600 to 750 mamsl.

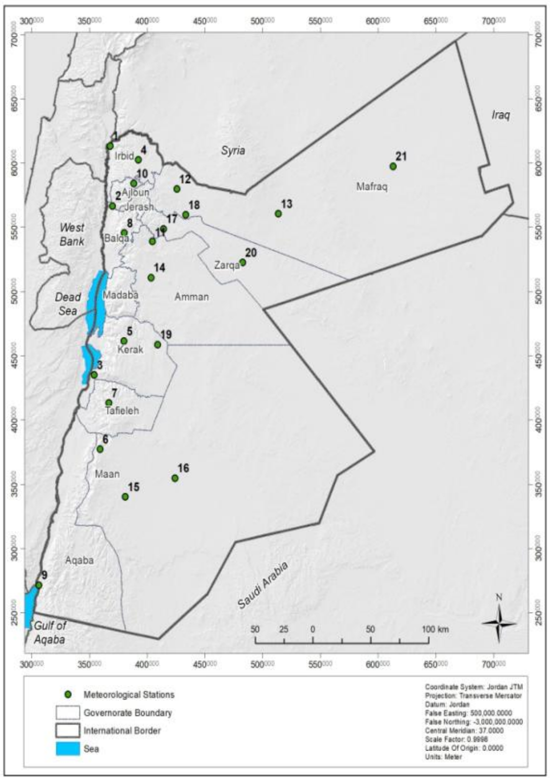


Figure 1: The map of the Hashemite Kingdom of Jordan as a study area.

2.2 Data collection

In order to assess the drought patterns in the country, daily rainfall and air temperature data for 21 meteorological stations were obtainedfrom the Jordan Meteorological Department (JMD). This climatic data representslong-term records from 1980 to 2017. The characteristics of the meteorological stations are presented in Table 1.

Table 1: Statistical Summary ofAnnual Precipitation Data by Station

No	Station Name	Altitude (m)	Precipitation (mm)		
			Mean Annual	Min	Max
1	Baqura	-170	392.4	174.3	918.3
2	DeirAlla	330	282.3	117.0	599.0
3	Ghor Safi	-350	72.4	18.3	151.8
4	Irbid	616	459.6	216.8	912.9
5	Rabba	920	337.3	138.0	606.0
6	Shoubek	1365	251.6	95.0	482.0
7	Tafieleh	1200	203.8	85.0	358.0
8	Salt	796	550.1	246.0	1130.
9	Aqaba	51	25.6	1.0	86.0
10	RasMunief	1150	463.9	217.0	913.0

11	Amman Airport	790	254.2	111.0	548.0
12	Mafreq	686	154.8	65.0	301.0
13	Safawi H5	674	70.1	16.0	158.0
14	Queen AIA	722	155.9	56.0	326.0
15	Maan	1069	41.2	12.0	108.0
16	Al-Jafer	865	31.4	1.0	135.0
17	Zarqa	664	129.5	48.0	258.0
18	WadiDhuleil	575	141.0	54.5	276.0
19	Qatraneh	730	97.3	25.0	156.0
20	Azraq South	610	54.0	9.0	149.0
21	Reweished H4	683	81.2	16.0	168.0

2.3 Calculation of PDI, TDI and VDI

The PDI, TDI, and VDI were calculated using the following equations for base investigation periods of 1, 2, 3, 6, and 12 month intervals:

$$PDI_{i,m} = \frac{\frac{1}{\mathrm{IP}}\sum_{j=0}^{IP-1} P^{*}_{i,(m-j)}}{\frac{1}{(\mathrm{n}*\mathrm{IP})}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} P^{*}_{(m-j),k}\right]} * \sqrt{\left(\frac{RL^{(P^{*})}_{m,i}}{\frac{1}{\mathrm{n}}\sum_{k=1}^{n} RL^{(P^{*})}_{m,k}}\right)} \quad (1)$$

$$TDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1}\left[T^{*}_{i,(m-j)}\right]}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} T^{*}_{(m-j),k}\right]} * \sqrt{\left(\frac{RL^{(T^{*})}_{m,i}}{\frac{1}{n}\sum_{k=1}^{n} RL^{(T^{*})}_{m,k}}\right)} \quad (2)$$

$$VDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1} NDVI^{*}_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} NDVI^{*}_{(m-j),k}\right]} * \sqrt{\left(\frac{RL^{(NDVI^{*})}_{m,i}}{\frac{1}{n}\sum_{k=1}^{n} RL^{(NDVI^{*})}_{m,k}}\right)} \quad (3)$$

where P* is the modified monthly precipitation amount,T* is the modified monthly temperature,NDVI* is the modified monthly average Normalized Difference Vegetation index, IP is the interest period (1, 2, 3, 6, and 12 months),RL(P) (run-length) is the maximum number of successive months below long-term average rainfall in the interest period,RL(T) is the maximum number of successive months above long term averagetemperature,RL (NDVI) is the maximum number of successive months below long-term average NDVI in the IP,n is the number of years with relevant data,j is a summation running parameter covering the IP, andk is the summation parameter covering the years for which relevant data are available.

The modified temperature, modified NDVI, and modified rainfall data were obtained using equations (4, 5, 6, and 7) to avoid dividing by zero in certain cases, as rainfall in Jordan ismostly characterized by a distinct long dry season; this also helped to unify the ranges of the drought index values:

$$T^{*} = (T_{max} + 1) - T \quad (4)$$

$$RL^{*} = (RL_{max} + 1) - RL \quad (5)$$

$$NDVI^{*} = NDVI - (NDVI_{min} - 0.01) \quad (6)$$

$$P^{*} = (P + 1) \quad (7)$$

where P, T, and NDVI are the original precipitation, temperature, and NDVI values and RLis the original run-length.

Normalized Difference Vegetation Index (NDVI) values were computed according to Kogan (1990, 2001) using the ratioof responses in the near infrared (NIR) and visible red portion of the spectrum (R) bands of the Advanced Very High Resolution Radiometer (AVHRR) at the National Oceanic and Atmospheric Administration (NOAA), as represented in equation(8).

$$NDVI = \frac{NIR - R}{NIR + R} \quad (8)$$

The NDVI data was provided by Global Inventory Modelling and Mapping Studies (GIMMS) downloaded from the University of Maryland Global Land Cover Facility Data Distributioncentre (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 as part of the continental file for Africa (AF), with an image size of 2000 x 1250 cells.

2.4 Calculation of the Combined Drought Index (CDI)

The combined drought index was computed as a weighted average, as in equation (9), from the precipitation, temperature and soil moisture drought indices. Weights were assigned at 50%weight for PDI and 25% weight each for TDI and VDI, as recommended by Balint et al. (2011).

$$CDI_{i.m} = w_{PDI} * PDI_{i.m} + w_{TDI} * TDI_{i.m} + w_{VDI} * VDI_{i.m} \quad (9)$$

where w is the weight of the individual drought index.

ACDI of 1.0 thus represents average weather conditions; if the CDI is greater than 1.0, this represents wetter than average conditions, and if it is below 1.0, this represents dryer than average conditions. Five drought categories were adopted in this study, as presented in Table 2.

Table 2: Adopted CDI Drought Categories (Balint et al., 2011)

Drought Category	CDI Value
No drought	>1.0
Mild	1.0 – 0.8
Moderate	0.8 – 0.6
Severe	0.6 – 0.4
Extreme	<0.4

2.5 Spatial and statistical Interpolations

A simple Krig interpolation technique was used to interpolate the spatial extent of each of four droughts using the Geostatistical tool within the ArcGIS package (ESRI,2013). To compare the four generated droughts, drought years were selected that highlighted local and national variability. In addition, a correlation analyses was made between the four droughts to develop an understanding of the relationshipbetween drought coincidence spatial impacts on barley production in Jordan. The necessary barley yields were thus obtained from the department of statistics as a governorate average (DOS, 2017).

III. RESULTS AND DISCUSSION

3.1 Precipitation, Temperature, and Vegetation Indicator Time Series Variability

Based on equations 1,2,and 3, PDI, TDI, and VDI indicators were generatedfor each meteorological station at intervals of 1, 2, 3, 6, and 12 months. In order to develop a visual expression for the variation over time, the annual droughts were classified using the adopted categories (Tables 3, 4, and 5).

Drought magnitudes and severitywere examined from 1980 to 2017 in terms of the three indices,which were temporally and spatially variable. The variability in PDI wasclearer than in the other indices, which proves the assumption that more weight should be given to PDI rather than TDI or VDI.

The drought severity presented by PDIshows that the country faced many drought events over this period as measured by different stations. The severity varied from year to year, from mild to extremely severe (Table 3). The drought pattern seemed to generally increase in severity over time, however, thus suggesting that the country is facing a major precipitation drought threat, and encouraging it to act rapidly in terms of preparing short and long term adaptation plans and drought contingency plans.

On the other hand, the temperature drought indicator changed more smoothly over the years (Table 4). The TDI values from 1980 to 1997 were generally above the threshold level, varying from 1.0 to 1.5, indicating non-drought events (temperature below the long-term average temperature). Nevertheless, temperature drought severity in the last decade has become more obvious, with magnitudes ranging from 0.3 to1.0 (mild to severe).It is important to highlight that 2010 represented the most severe case,as the temperature drought affected the whole country in that year, as indicated by it affecting all stations.

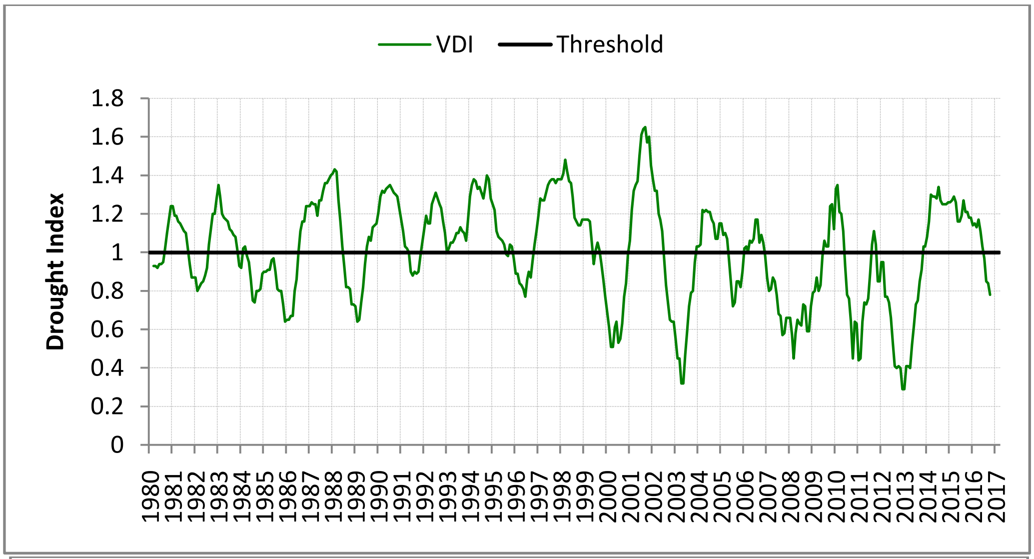
The VDI variability differs fromthat ofthe other indicators, changing alternatively from no-drought to extreme drought throughout the study period (1980 to 2017) (Table 5). The lag of impact is estimated to be about 2 to 3 years, though the magnitude of impact increases over time, especially after 2001 where it become more significant with a shortedlag time of around 2 years (Table 5). The vegetation drought index is generally influencedby the temperature and precipitation droughts. Therefore, when PDI and TDI indicators act simultaneously to decrease the amount of available ground water and available soil moisture for plant growth,imposed stresses from higher temperatures will eventually stress the plants and thus the vegetation index magnitude will also drop.

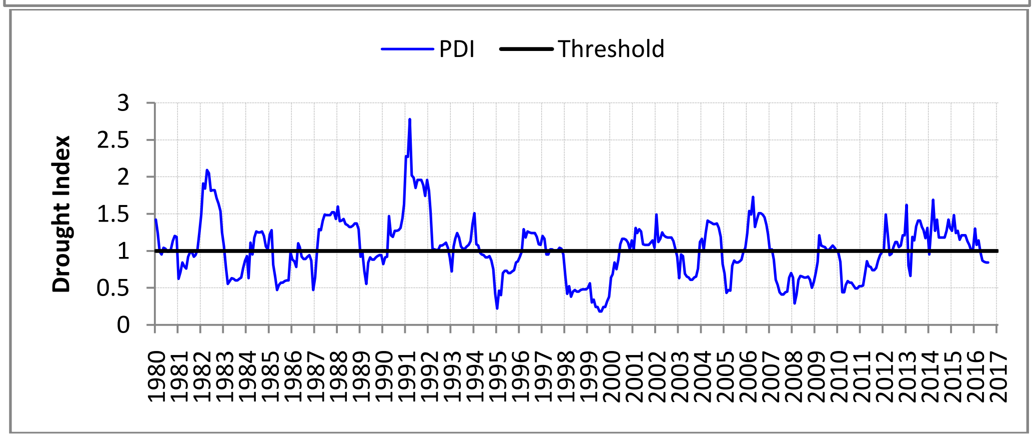
It is important to realize that the rainfall or temperature in a given area is likely to affect the vegetation of the area at about three months to oneyear lag. It is thus not necessarily valid for time units onthe order of 1 month to showconsistency or correlation between VDI and PDI or TDI. Therefore, from a monitoring stand point, longer periods of data gathering are recommended to identify and present the variability in indicators based on average long term variables.

To illustrate the monthly variation inthe three indicesused, the PDI, TDI, and NDVI values for ErRabba station arepresented in Figure 2 as an example of astational point. The PDI magnitudes varyfrom 0.2 to 2.8, with the majority lying below the critical threshold of 1.0; the smaller the index, the more severe the drought. The peaks illustrate monthly variability, which doesnot reflect the long term average, instead indicating small periodic events or lags. The monthly PDI suggests that precipitation droughts are highly temporal with magnitude changes from one month to another.

The variability in TDI is less scatteredthan that ofPDI in terms of affected years. The temperature indicator seems to have morea homogenous pattern that started to show its impacts after 1998. Bothmagnitude and severity havebecome more obvious over the last decade, and the drought peaks repeat every two to three years, suggesting that temperature drought is becomingmore common with its concomitant temperature excesses and persistence of high temperature impacts.

The VDI time series variability also seems to have a repeating pattern with a cyclic mannerandimpact. The magnitude and amplitude of the cycle is variable with time, becoming more frequent in the last decade. The VDI pattern mimics the pattern seen in PDI but with variable magnitudes. The VDI figure for Er Rabba suggests that vegetation is not only affected by rainfall and temperature, but also by other factors controlling plant health such as meteorological factors (humidity, wind, etc.), hydrological factors (soil moisture level), or even agriculture management factors (disease, soil fertility status, etc.). This means that, although VDI is only an indicator of the soil moisture, changes in vegetation conditions depend on other factors apart from soil moisture, contributingto thevegetation's delayed reaction to rain.





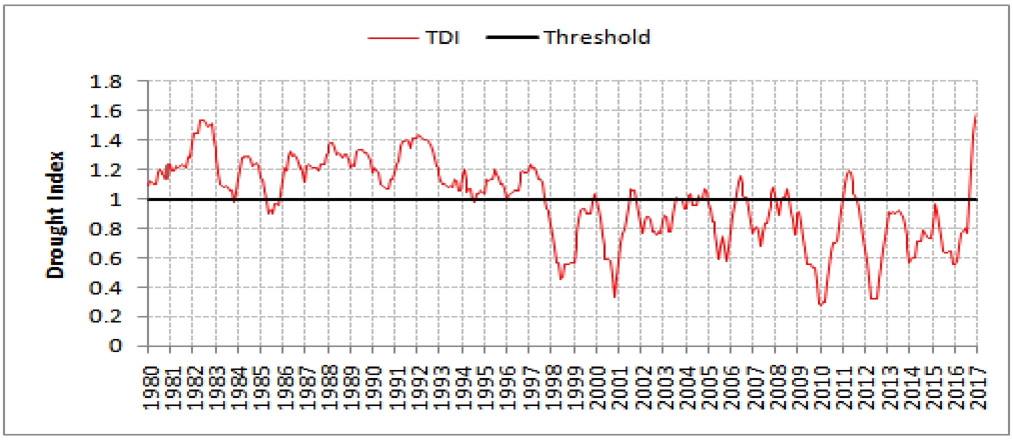


Figure 2: Time Series Variability in PDI, TDI, and VDI at ErRabba Station.

Although there is huge variability between drought indicators seen at variousstations and between years, temporal variability analysis by month indicates that PDI is most likelyto go below a value of 1 and head towards a value less than 0.4 (a move from mild to extreme drought conditions) during October, the beginning of the rainfall season, and during May and April, the spring period in Jordan (Figure 3).

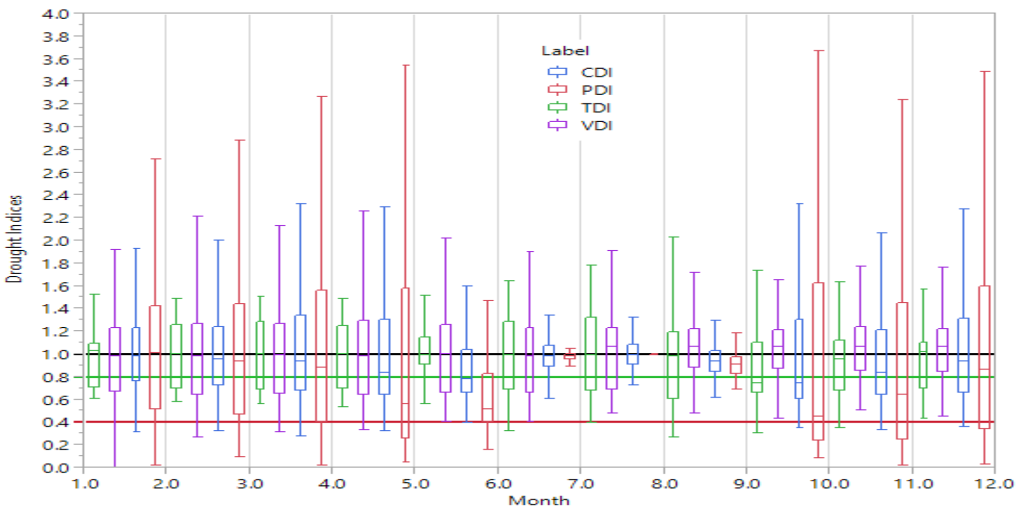


Figure 3: Drought Indices'Variability by Month.

3.2 Combined Indicators' Time Series Variability

Based on CDI calculations using equation (9), the CDI magnitudes were generated as presented in Table 6. Following the selected drought categorization methodology (Table 2), the CDI values were categorized into non-drought, mild, moderate, severe, and extremely severe cases. Throughout the period of study (1980 to 2017), no single extreme drought case was presented on an annual basis; these were all presented on a seasonal basis. This might indicate that it is better to investigate such impacts seasonally, at station level, rather than annually at national level.

As the PDI had more weight than the TDI and VDI, the variability of the CDI wasgenerally similar to that of the PDI, with changes only when the TDI and VDI values demonstrated an extreme opposite effect.

The generated yearly CDIsfrom 1980 to 1999 indicate thatthe CDI ranged from non-drought to mild-drought, with a few stations being characterized by moderate-drought as at Ghores Safi, Tafieleh,Zarqa,WadiDhuleil, and QAI Airport (Table 6). After 1999, the CDI values clearly dropped below the threshold for drought, ranging from mild to severe drought mainly because of the effect of TDI.

The variability in monthly CDI at each meteorological station is presented in Figure 4. The time series variability for each station provides a clear indication of the drought characteristics and provides more flexibility for analysing the various lengths of drought duration. The short term drought events are increasing in number over time, while the severity of long term droughts is also increasing over time.

Drought trends or patterns in time series CDI variations vary by station, indicating unique drought characteristics for each location. Monthly CDI is recommended for detailed investigations at a local scale to develop understanding of the drought impacts or threats on various sectors during short term drought events. However, it is better to use seasonal yearly CDI for long-term monitoring programs.In addition, more severe droughts that causewider-ranging impacts and national catastrophes are better investigated or illustrated usingannual basis CDI.

It is also important to highlight that the CDI does not measure the physical parameters of either vegetation or soil, and it does not attempt to simulate either physical phenomena or the water balance. The CDI is simply a statistical index that measures how much the present conditions deviate from the reference level, set as the multi-year long-term average for the interest period.

Table 3: PDI values per station calculated on an annual basis.

Name	Baqoura	DairAlla	Ghor Safi	Irbid	Rabbah	Shoubak	Tfieleh	Sult	Aqaba	RasMuneif	m. Air	Mafraq	Sfawi	QAI Airpor	Ma'an	Jafir	Zarqa	W.Dhuleil	Qatraneh	Azraq	Ruwshid
1980	1.27	1.31	1.4	1.36		1.52	2.04	1.23	1.75	0.94	1.78	1.67	1.52	1.79	1.9	2.24	1.69	1.71	0.8	0.87	0.69
1981	0.77	0.68	0.6	0.64		0.59	0.28	0.85	0.59	0.68	0.57	0.76	0.47	0.33	0.19	0.19	0.31	0.49	0.18	0.65	0.38
1982	1.25	1.25	1.1	1.19	1.49	2.2	1.58	1.01	2.13	1.13	1.21	1.49	1.83	1.53	1.36	1.35	1.37	1.75	1.53	1.75	3.51
1983	1.37	1.37	0.43	1.07	1.06	0.99	0.94	1.6	0.6	1.02	1.57	1	0.34	1.14	0.72	0.65	1.21	1.18	0.73	0.36	0.61
1984	0.73	0.73	1.47	1.37	0.93	0.54	0.92	1.05	0.48	0.88	0.89	1	0.62	0.99	0.47	0.32	0.65	1.03	0.97	0.85	1.07
1985	0.85	0.85	1.32	0.86	1.22	1.61	1.49	1.05	1.46	0.75	1.11	1.01	1.13	1.24	1.53	2.12	0.92	0.97	1.45	1.55	0.92
1986	1.56	1.56	1.13	1.57	0.88	0.89	0.86	1.51	1.56	1.8	1.12	1.26	1.19	1.02	1.1	1.45	1.49	1.45	1.01	0.99	1
1987	0.63	0.63	1.53	0.9	0.64	0.71	0.53	0.82	2.46	1.12	0.9	1.02	0.62	1.06	0.87	2.86	1.12	1.14	1.26	1.13	1.23
1988	1.15	1.15	0.71	1.17	1.6	1.94	1.95	1.21	1.47	1.48	1.96	1.93	3.56	1.56	2.78	2.74	2.48	1.98	1.85	2.61	2.12
1989	0.87	0.87	1.28	0.52	1.29	0.72	0.51	0.91	1.28	0.75	0.3	0.75	0.64	0.47	0.94	1.32	0.54	0.71	0.7	0.95	0.55
1990	0.74	0.74	1.61	0.83	0.82	0.94	0.81	0.72	2.06	0.69	0.88	0.92	1.77	1	1	1	0.75	0.99	1.03	1.96	1.15
1991	2.07	2.07	0.86	1.54	2.28	2.4	2	2.32	1.38	1.72	1.66	1.9	1.96	1.24	1.39	1.25	1.4	1.74	1.26	2.15	0.9
1992	1.87	1.87	1.31	2.08	1.81	1.82	1.51	1.81	0.74	2.08	2.11	1.72	0.84	1.7	0.65	0.58	1.69	1.56	1.26	0.88	1.45
1993	0.42	0.42	1.84	0.55	0.72	0.52	0.3	0.5	1.59	0.56	0.89	0.5	0.75	0.8	1.38	1	0.56	0.44	0.98	0.82	1.05
1994	1.63	1.63	0.45	1.4	1.51	1.93	2.13	1.8	2.21	1.58	1.54	2.06	1.28	1.62	2.38	2.04	1.83	1.45	1.39	1.76	1.9
1995	0.25	0.25	0.45	0.54	0.22	0.78	0.36	0.25	0.68	0.51	0.24	0.41	1.05	0.33	0.66	0.61	0.18	0.27	0.19	0.6	0.82
1996	1.12	1.12	0.82	0.86	0.92	0.98	0.74	0.99	0.24	1	1.12	1.15	1.55	1.16	1.19	1.26	1.06	1.21	1.02	0.38	1.22
1997	2.15	2.15	1.52	1.33	1.2	1.11	1.49	1.2	1.44	1.81	1.32	1.33	1.31	1.4	1.8	1.2	1.37	1.54	0.93	1.23	1.32
1998	0.63	0.63	1.01	0.76	0.67	0.94	0.53	0.46	0.43	0.81	0.57	0.67	0.67	0.33	1.19	0.74	0.62	0.68	1.08	0.97	0.61
1999	0.26	0.26	0.74	0.26	0.5	0.46	0.52	0.28	1.04	0.19	0.26	0.36	0.48	0.34	0.5	0.55	0.25	0.25	0.19	0.51	0.3
2000	1.5	1.5	0.68	0.93	0.64	0.6	1.17	0.99	0.58	1.12	0.91	0.91	0.33	1.12	0.43	0.22	1.01	1.17	0.74	0.39	0.62
2001	0.88	0.88	0.73	0.63	1.02	0.95	1.84	0.71	0.69	0.74	0.9	1.1	0.99	0.97	1.21	1.57	0.83	0.77	1.66	0.75	1.17
2002	1.39	1.39	1.25	1.56	1.49	1.53	0.46	1.47	0.88	1.35	1.31	1.59	1.6	1.46	0.71	1.18	1.61	1.2	1.39	0.97	1.05
2003	1.24	1.24	0.84	1.88	0.63	0.4	1.3	1.15	0.48	1.54	1.26	1.17	1.37	1.01	0.43	0.34	1.26	1.27	0.97	1.46	1.22
2004	0.8	0.8	2.17	1.01	1.16	1.12	0.48	0.81	0.34	0.87	0.78	0.69	0.64	0.74	1.18	0.28	0.72	0.67	1.27	1.2	0.99
2005	0.8	0.8	0.85	1.01	0.69	0.48	1.21	1.16	0.25	1.18	0.89	0.87	0.81	0.75	0.33	0.6	0.75	0.64	0.66	1.16	0.98
2006	1.16	1.16	1.01	0.9	1.24	1.08	0.76	0.84	0.59	0.79	0.76	0.63	0.53	0.92	0.91	1.04	0.98	0.82	1.89	0.46	0.94
2007	0.72	0.72	0.57	0.91	0.99	0.75	0.9	1	0.47	1.13	1.13	0.43	0.43	1.07	0.92	0.58	0.92	0.69	0.98	0.56	1.3
2008	0.61	0.61	0.41	0.52	0.64	0.54	0.94	0.5	0.33	0.76	0.7	0.49	0.7	0.6	0.73	0.65	0.69	0.53	0.74	0.5	0.49
2009	0.94	0.94	0.32	1.48	0.7	0.44	1.08	1.31	0.23	1.18	0.89	0.96	0.4	0.97	0.53	0.26	1.08	0.91	0.75	0.59	0.2
2010	0.49	0.49	0.59	0.6	0.97	0.64	1.04	0.62	1.23	0.47	0.86	0.52	1.22	0.91	1.08	0.75	0.94	0.66	0.91	1.15	1.53
2011	0.86	0.86	1.15	1.12	0.52	0.65	0.76	0.9	0.49	1.17	0.83	1.09	0.59	0.85	0.22	0.53	1.04	1.02	0.55	0.64	0.83
2012	1.02	1.02	0.55	1.26	1.01	0.54	0.76	1.5	1.08	1.14	0.97	1.05	0.45	0.99	0.74	0.48	0.84	0.93	0.49	0.57	0.37
2013	1.32	1.32	0.66	1.44	1.62	1.14	0.76	1.31	0.95	1	1.23	1.06	0.88	1.26	1	0.96	0.97	1	0.97	0.35	1.33
2014	1.08	1.08	2.02	0.68	0.95	1.13	1.28	0.97	1.79	0.79	0.91	1.07	0.87	1.12	1.53	1.18	1.08	1.15	1.29	0.7	1.27
2015	1.03	1.03	2.29	0.94	1.27	1.39	1.19	0.98	1.28	0.79	1.26	1.16	1.91	1.08	1.51	2.16	1.43	1.57	1.6	2.31	0.77
2016	1.05	1.05	0.89	0.85	1.3	1.5	1.5	1.06	2.03	1.08	1.07	0.92	1.19	1.34	1.66	1.4	1.12	0.87	1.71	1.86	0.97
2017	0.16	0.16	0.23	0.17	0.36	0.37	0.14	0.17	0.61	0.12	0.2	0.19	1.04	0.36	0.26	0.44	0.25	0.38	0.61	0.82	0.5

Table 4: TDI values per station calculated on an annual basis.

Name	Baqoura	DairAlla	Ghor Safi	Irbid	Rabbah	Shoubak	Tfieleh	Sult	Aqaba	RasMuneif	Amm. Airport	Mafraq	Safawi	QAI Airport	Ma'an	Jafir	Zarqa	W.Dhuleil	Qatraneh	Azraq	Ruwshid
1980	1.16	1.2	1.2	1.12	1.09	0.85	0.89	1.18	1.13	1.04	1.24	1.07	1.01	1.25	0.92	1.12	1.21	1.23	0.48	1.38	1.08
1981	1.19	1.19	1.27	1.22	1.23	1.13	1.02	1.27	1.19	1.08	1.22	1.17	1.13	1.22	1.19	1.16	1.2	1.21	0.73	1.13	1.14
1982	1.37	1.37	1.38	1.34	1.38	1.31	1.21	1.41	1.25	1.31	1.36	1.19	1.32	1.37	1.33	1.18	1.35	1.36	1	1.33	1.43
1983	1.32	1.32	1.23	1.29	1.33	1.32	1.22	1.42	1.2	1.25	1.3	1.14	1.25	1.29	1.27	1.18	1.28	1.29	1.01	1.26	1.33
1984	1.06	1.06	1.2	1.13	1.13	1.06	1.07	1.28	1.14	1.06	1.11	1.08	1.1	1.1	1.16	1.12	1.17	1.07	1.26	1.05	1.25
1985	1.16	1.16	1.08	1.15	1.15	1.15	1.06	1.29	1.13	1.09	1.13	1.13	1.17	1.13	1.11	1.16	1.25	1.21	1.27	1.13	1.19
1986	1.13	1.13	1.28	1.11	1.12	1.14	1	1.22	0.95	1	1.09	1.02	0.94	1.02	1.03	1.01	1.02	0.96	1.05	0.95	0.92
1987	1.2	1.2	1	1.17	1.11	1	0.94	1.26	1.01	1.05	1.03	1.02	0.99	1.08	1	1.01	1.02	1.04	1.16	1	0.9
1988	1.21	1.21	1.22	1.17	1.31	1.17	0.92	1.34	1.07	1.14	1.16	1.13	1.14	1.26	1.25	1.17	1.13	1.03	1.27	1.07	1.15
1989	1.21	1.21	1.18	1.15	1.27	1.29	1.03	1.34	1.19	1.11	1.15	1.08	0.91	1.16	1.15	1.12	1.15	1.17	1.31	1.07	1.22
1990	1.18	1.18	1.07	1.16	1.18	1.1	1.07	1.21	1.13	1.12	1.15	1.07	1.07	1.12	1.07	1.06	1.14	1.15	1.17	1.13	1
1991	1.05	1.05	1.2	1.16	1.18	1.14	1.03	1.28	1.07	1	1.11	1.07	1.01	1	0.95	1.01	1.14	1.16	1.16	1.07	1.07
1992	1.37	1.37	1.07	1.42	1.41	1.35	1.31	1.45	1.25	1.36	1.39	1.19	1.33	1.31	1.36	1.18	1.37	1.38	1.38	1.34	1.44
1993	1.07	1.07	0.94	1.17	1.17	0.99	0.94	1.12	1.01	1.11	1.15	1.18	1.13	1.14	1.01	1.06	1.15	1.16	1.03	1.13	1.22
1994	1.01	1.01	1.07	0.98	1.16	1.1	0.96	1.04	1.13	1.02	1.05	0.95	0.91	1.04	1.12	1.11	1.03	0.85	1.12	0.98	1.04
1995	1.04	1.04	1.07	1.09	1.03	1.18	0.87	0.99	1.19	1.05	1.01	1.13	0.94	1.06	0.93	1	1.13	1.02	1.09	0.93	0.99
1996	1.01	1.01	0.89	1.07	1	0.93	0.77	0.83	1.01	1.02	0.97	0.89	0.82	0.96	0.94	0.88	0.83	0.84	0.98	0.83	0.88
1997	1.22	1.22	1.18	1.19	1.19	1.27	0.92	1.1	1.13	1.15	1.17	1.02	1.16	1.17	1.11	1.01	1.1	1.11	1.11	1.1	1.1
1998	0.84	0.84	0.79	0.83	0.82	0.56	0.61	0.65	0.87	0.8	0.66	0.89	0.66	0.81	0.65	0.81	0.66	0.58	0.66	0.66	0.69
1999	0.58	0.58	0.62	0.82	0.57	0.72	1.01	0.72	0.87	0.78	0.66	0.95	0.67	0.57	0.81	0.94	0.75	0.68	0.75	0.83	0.35
2000	1.02	1.02	1.12	1	0.99	1.05	1.13	0.98	1.01	1.04	0.98	1.01	0.99	0.98	1.06	1.06	1.06	1.01	1.07	1.06	1.06
2001	0.34	0.34	0.79	0.57	0.58	0.73	1.03	0.31	0.94	0.86	0.57	0.75	0.75	0.74	0.82	1	0.96	0.77	0.9	0.89	0.79
2002	0.71	0.71	0.79	0.83	0.84	0.74	1.14	0.86	0.87	0.89	0.85	0.95	0.84	0.83	0.85	0.94	0.82	0.86	0.84	0.85	0.72
2003	0.8	0.8	0.71	0.85	0.85	0.89	1.09	0.82	0.79	1.08	1.1	1.07	1.1	1.11	1.12	0.94	1.07	1.13	1.03	1.04	0.96
2004	0.96	0.96	0.98	0.77	0.93	1.03	1.01	0.74	0.79	0.94	0.98	1.01	0.97	0.83	0.98	1	0.89	1	0.98	0.97	0.51
2005	1.09	1.09	0.9	1.05	0.97	1.03	1	0.82	1.01	1.09	1.04	1.07	1.1	1.04	1.1	0.94	0.96	1.07	1.04	1.05	0.96
2006	1.2	1.2	1.05	1.06	0.78	0.98	1.03	0.91	0.87	0.99	1.05	0.88	1	0.77	0.93	0.82	0.9	1.02	0.94	1	0.63
2007	0.58	0.58	0.89	0.77	0.77	0.98	1	0.66	0.94	0.75	0.76	0.95	0.83	0.83	0.98	1.05	0.66	0.77	0.84	0.84	0.88
2008	0.86	0.86	0.72	0.75	1.02	0.99	1.13	0.83	0.94	0.86	0.88	0.89	1.03	0.73	1.02	1.06	0.74	0.76	0.89	0.76	0.82
2009	0.88	0.88	0.79	0.89	0.9	1	0.28	0.86	0.79	1	0.9	1.06	1.21	0.9	1.09	0.94	0.87	0.85	1.15	1.2	1.02
2010	0.3	0.3	0.33	0.29	0.28	0.28	1.13	0.27	0.6	0.27	0.29	0.33	0.3	0.29	0.28	0.33	0.28	0.3	0.29	0.3	0.3
2011	0.95	0.95	0.9	1.02	1	0.98	0.82	1.03	0.94	1	0.99	1.02	1.07	1.01	1.06	1.06	0.91	1.01	1.09	1.01	0.74
2012	0.68	0.68	0.68	0.67	0.66	0.66	0.82	0.65	0.86	0.64	0.65	0.82	0.67	0.68	0.67	0.66	0.63	0.67	0.66	0.66	0.71
2013	0.85	0.85	0.86	0.97	0.82	0.95	1.07	0.82	0.94	1.06	0.95	1.01	1.02	0.99	0.83	1	0.93	1.05	1.08	0.97	0.97
2014	0.77	0.77	0.35	0.56	0.57	0.81	0.99	0.92	0.61	0.96	0.65	0.89	0.96	0.97	0.66	0.88	0.98	0.83	0.66	0.83	0.8
2015	0.82	0.82	0.92	0.73	0.82	0.88	0.89	0.81	0.79	0.77	0.87	0.82	0.82	0.88	0.8	0.81	0.87	0.9	0.82	0.81	0.85
2016	0.46	0.46	0.48	0.54	0.56	0.55	0.85	0.54	0.7	0.69	0.55	0.67	0.86	0.55	0.56	0.74	0.53	0.57	0.73	0.45	0.49
2017	1.9	1.9	1.97	1.64	1.59	1.4	1.49	1.46	1.24	1.37	1.56	1.04	1.53	1.54	1.52	1.03	1.57	1.58	1.59	1.58	3.14

Table 5: VDI values per station calculated on an annual basis.

Name	Baqoura	DairAlla	Ghor Safi	Irbid	Rabbah	Shoubak	Tafieleh	Sult	Aqaba	RasMunef	Amm. Airport	Mafraq	Safawi	QAI Airport	Ma'an	Jafir	Zarqa	W.Dhuleil	Qatraneh	Azraq	Ruwshid
1980	1.07	0.78	0.4	0.64	0.93	0.99	1.22	0.72	1.24	0.86	1.36	0.87	1.3	1.05	1.27	1.21	1.09	0.68	1.26	1.07	1.08
1981	1.09	0.83	0.3	0.91	1.19	1.02	1.3	0.95	1.21	0.87	1.38	0.95	1.24	1.11	1.27	1.24	1.12	0.89	1.29	1.14	1.09
1982	1.03	1.03	0.65	0.83	0.82	0.84	1.16	0.94	1.19	0.84	1.3	0.85	1.32	0.98	1.2	1.13	0.94	0.74	1.25	0.9	1.04
1983	1.28	1.28	0.61	1.07	1.2	1.27	1.39	1.06	1.15	0.96	1.5	1.12	1.31	1.25	1.25	1.2	1.42	1.17	1.31	1.1	1.1
1984	0.88	0.88	0.47	1.05	1.03	0.99	1.21	1.17	1.22	1.12	1.3	0.81	1.02	1.3	1.27	1.18	1.04	0.63	1.16	1.22	0.99
1985	0.4	0.4	0.61	1.09	0.91	0.81	1.15	0.59	1.13	0.56	1.26	0.93	1.25	0.65	1.18	1.16	1.16	0.99	1.14	1.06	0.94
1986	0.96	0.96	0.82	0.27	0.67	0.94	1.16	0.78	1.27	0.68	1.03	0.77	1.22	0.46	1.23	1.04	0.89	0.48	1.12	0.62	0.89
1987	1.22	1.22	0.62	1.07	1.25	0.78	0.95	1.01	1.16	1.14	1.39	1.27	1.27	1.32	1.23	1.12	1.26	1.2	1.14	0.83	1
1988	1.27	1.27	0.22	1.07	1.42	1.07	1.17	0.88	1.2	1.04	1.23	1.16	1.16	1.26	1.14	0.63	1.18	0.89	1	1.18	0.86
1989	0.78	0.78	0.61	0.65	0.64	0.49	0.96	0.33	0.45	0.76	0.79	0.83	0.93	0.96	0.81	0.61	0.71	0.49	0.83	1.18	0.38
1990	0.93	0.93	0.27	1.26	1.32	0.8	1.26	0.88	1.05	1	1.06	1.15	1.34	1.08	1.16	1.09	0.84	0.51	1.11	1.02	0.92
1991	0.88	0.88	0.85	1.05	1.03	1.16	1.29	0.84	1.21	0.91	1.26	1.08	1.38	1.16	1.23	1.15	1.06	0.67	1.16	1.19	0.69
1992	1.13	1.13	0.61	0.98	1.15	1.05	1.32	0.8	1.1	0.79	1.21	1.22	1.22	1.28	1.25	1.11	1.22	1.09	1.29	1.19	0.86
1993	1.29	1.29	0.6	0.79	1.05	1.02	1.33	0.9	1.09	1.11	1.2	1.1	1.34	0.99	1.11	1.08	1.17	0.84	1.13	1.2	1
1994	1.24	1.24	0.67	1.15	1.38	1.21	1.44	1.01	1.19	0.79	1.41	0.73	1.11	1.09	1.21	1.1	1.18	0.92	1.31	1.16	0.81
1995	1.22	1.22	0.67	1.1	1.11	1.21	1.31	1.26	1.22	1.08	1.17	1.34	1.23	1.17	1.28	1.22	1.27	1.07	1.16	1.14	1.12
1996	1.12	1.12	0.66	0.71	0.84	0.97	1.17	0.88	1.21	1.1	1.19	0.89	1.2	1.09	1.14	1.1	0.94	0.89	0.81	1.35	1.03
1997	0.97	0.97	0.82	1.2	1.27	1.02	1.16	1.13	1.3	1.12	1.36	1.12	1.38	1.12	1.18	1.21	1.32	1.07	1.15	1.2	1.12
1998	1.22	1.22	0.86	1.17	1.48	1.12	1.08	1.11	1.2	1.21	1.39	1.17	1.32	1.14	1.19	0.98	1.28	1.11	1.12	1.26	1.12
1999	1.19	1.19	0.99	0.73	1.17	0.98	1.19	0.89	1.44	0.82	1.22	0.98	1.29	0.85	1.28	1.01	0.86	0.77	1.04	1.06	1.13
2000	0.93	0.93	1.3	0.52	0.51	0.29	0.36	0.32	0.4	0.34	0.27	0.27	0.42	0.22	0.77	0.72	0.33	0.89	0.27	0.99	1.01
2001	1.34	1.34	1.45	1.28	1.32	1.28	0.95	1.36	0.28	1.22	1.01	0.75	1.04	1.39	0.77	0.32	1.03	1.19	0.28	0.78	1
2002	0.83	0.83	1.38	1.26	1.32	1.13	0.68	1.22	0.65	1.08	0.71	1.12	0.67	1	0.7	1	0.85	1.29	0.74	1.1	1.12
2003	1.24	1.24	1.43	1.28	0.45	1.11	0.93	1.09	0.65	1.18	0.86	1.63	0.83	1.74	0.7	0.95	1.34	1.38	0.93	1.13	1.11
2004	0.98	0.98	1.46	1.19	1.22	1.27	0.76	1.08	0.95	1.07	0.87	1.25	0.83	0.79	0.7	0.74	1.11	1.33	0.73	1.1	1.09
2005	0.99	0.99	1.49	1.26	1.1	1.35	1.03	1.18	0.83	1.26	0.88	1.11	0.82	1.33	0.44	0.73	0.97	1.14	0.88	1.14	1.01
2006	1.52	1.52	1.58	1.47	1	0.92	0.26	1.47	1.07	1.28	0.9	0.79	1.04	0.67	0.85	0.56	1.14	0.99	0.84	0.97	1.13
2007	1.11	1.11	1.43	1.14	0.81	1.16	1.07	1.28	0.78	1.13	0.61	0.65	0.81	1.1	0.85	1	0.84	0.85	1.12	0.97	1.12
2008	0.68	0.68	1.44	0.54	0.45	0.88	0.65	0.92	0.83	0.89	0.5	0.77	0.29	0.43	0.85	0.95	0.55	0.89	1.03	0.98	1.12
2009	1.03	1.03	1.42	1.23	0.87	0.81	0.79	1.13	0.65	1.14	0.74	0.72	0.29	0.64	0.85	0.99	0.71	0.94	0.9	0.95	1.12
2010	0.79	0.79	1.48	1.3	1.21	1.2	0.66	1.37	0.88	1.18	0.87	1.18	0.29	1.13	0.85	1.07	1.21	1.48	1.05	0.72	1.13
2011	0.8	0.8	1.48	1.38	0.64	0.92	0.65	1.28	1.04	1.33	0.62	1.14	0.51	0.66	0.85	1.08	0.89	1.4	0.98	0.84	1.12
2012	0.6	0.6	1.37	1.14	0.77	0.29	0.58	0.91	0.92	1.1	0.5	1.12	0.29	0.67	0.62	1.08	0.32	1.18	0.59	0.64	1.04
2013	0.26	0.26	1.29	0.78	0.41	0.89	0.58	0.84	0.94	1.07	0.47	1.1	0.51	0.7	0.69	1.08	0.72	1.16	1.01	0.93	1.01
2014	1.14	1.14	1.52	0.95	1.3	1.17	1.14	0.91	1.07	0.85	0.85	1.06	1.05	0.92	1.13	1.16	0.79	1.02	0.98	0.94	1.13
2015	1.22	1.22	1.57	1.25	1.29	1.28	1.27	1.31	1.08	1.15	1.07	1.26	1.06	1.44	1.12	1.18	1.19	1.42	1.11	0.86	1.06
2016	1.31	1.31	1.78	0.81	1.13	1.49	0.98	1.48	1.06	1.24	0.91	1.24	1.2	1.51	0.92	1.05	1.27	1.55	0.98	0.84	1.11
2017	0.57	0.57	0.7	0.36	0.26	0.58	0.38	0.56	0.47	0.46	0.32	0.54	0.51	0.66	0.4	0.37	0.55	0.67	0.42	0.19	0.41

Table 6: CDI values per station calculated on an annual basis.

Name	Baqoura	DairAlla	Ghor Safi	Irbid	Rabbah	Shoubak	Tfeileh	Salt	Aqaba	RasMuneif	Amm Airport	Mafraq	Sfawi	QAI Airport	Ma'an	Jafir	Zarqa	WDhuleil	Qatraneh	Azraq	Ruwshid
1980	1.19	1.15	1.1	1.12	1.22	1.22	1.55	1.09	1.47	0.95	1.54	1.32	1.34	1.47	1.5	1.7	1.42	1.33	0.84	1.05	0.89
1981	0.96	0.85	0.7	0.85	0.92	0.83	0.72	0.98	0.9	0.83	0.94	0.91	0.83	0.75	0.71	0.7	0.74	0.77	0.6	0.89	0.75
1982	1.23	1.23	1.06	1.14	1.3	1.64	1.38	1.09	1.68	1.1	1.27	1.26	1.58	1.35	1.31	1.25	1.26	1.4	1.33	1.43	2.37
1983	1.34	1.34	0.68	1.13	1.16	1.14	1.12	1.42	0.89	1.06	1.49	1.07	0.81	1.21	0.99	0.92	1.28	1.21	0.95	0.77	0.91
1984	0.85	0.85	1.15	1.23	1.01	0.78	1.03	1.14	0.83	0.99	1.05	0.97	0.84	1.1	0.84	0.74	0.88	0.94	1.09	0.99	1.1
1985	0.82	0.82	1.08	0.99	1.13	1.3	1.3	1	1.3	0.79	1.15	1.02	1.17	1.07	1.34	1.64	1.06	1.04	1.33	1.32	0.99
1986	1.3	1.3	1.09	1.13	0.89	0.97	0.97	1.26	1.34	1.32	1.09	1.08	1.14	0.88	1.12	1.24	1.22	1.09	1.05	0.89	0.95
1987	0.92	0.92	1.17	1.01	0.91	0.8	0.74	0.98	1.77	1.11	1.06	1.08	0.88	1.13	0.99	1.96	1.13	1.13	1.21	1.02	1.09
1988	1.2	1.2	0.72	1.15	1.48	1.53	1.5	1.16	1.3	1.29	1.58	1.54	2.36	1.41	1.99	1.82	1.82	1.47	1.49	1.87	1.56
1989	0.93	0.93	1.09	0.71	1.12	0.81	0.75	0.87	1.05	0.84	0.64	0.85	0.78	0.77	0.96	1.09	0.74	0.77	0.89	1.04	0.68
1990	0.9	0.9	1.14	1.02	1.04	0.95	0.99	0.88	1.58	0.88	0.99	1.02	1.49	1.05	1.06	1.04	0.87	0.91	1.09	1.52	1.06
1991	1.52	1.52	0.94	1.32	1.69	1.78	1.58	1.69	1.26	1.34	1.42	1.49	1.58	1.16	1.24	1.17	1.25	1.33	1.21	1.64	0.89
1992	1.56	1.56	1.08	1.64	1.55	1.51	1.41	1.47	0.96	1.58	1.71	1.46	1.06	1.5	0.98	0.86	1.49	1.4	1.3	1.07	1.3
1993	0.8	0.8	1.31	0.77	0.92	0.76	0.72	0.76	1.32	0.84	1.03	0.82	0.99	0.93	1.22	1.04	0.86	0.72	1.03	0.99	1.08
1994	1.38	1.38	0.66	1.23	1.39	1.54	1.67	1.41	1.69	1.24	1.39	1.45	1.15	1.34	1.77	1.57	1.47	1.17	1.3	1.42	1.41
1995	0.69	0.69	0.66	0.82	0.65	0.99	0.73	0.69	0.94	0.79	0.67	0.82	1.07	0.72	0.88	0.86	0.69	0.66	0.66	0.82	0.94
1996	1.09	1.09	0.8	0.88	0.92	0.97	0.86	0.92	0.68	1.03	1.1	1.02	1.28	1.09	1.12	1.13	0.97	1.04	0.96	0.74	1.09
1997	1.62	1.62	1.26	1.26	1.22	1.13	1.27	1.16	1.33	1.47	1.29	1.2	1.29	1.27	1.47	1.16	1.29	1.32	1.03	1.19	1.22
1998	0.83	0.83	0.92	0.88	0.91	0.89	0.69	0.67	0.73	0.91	0.8	0.85	0.83	0.65	1.06	0.82	0.8	0.76	0.99	0.97	0.76
1999	0.57	0.57	0.77	0.52	0.69	0.66	0.81	0.54	1.1	0.5	0.6	0.66	0.73	0.53	0.77	0.76	0.53	0.49	0.54	0.73	0.52
2000	1.24	1.24	0.95	0.85	0.7	0.64	0.96	0.82	0.64	0.91	0.77	0.78	0.52	0.86	0.67	0.56	0.85	1.06	0.71	0.71	0.83
2001	0.86	0.86	0.93	0.78	0.99	0.98	1.42	0.77	0.65	0.89	0.85	0.93	0.94	1.02	1	1.12	0.91	0.88	1.13	0.79	1.03
2002	1.08	1.08	1.17	1.3	1.29	1.23	0.69	1.26	0.82	1.17	1.05	1.31	1.18	1.19	0.74	1.08	1.22	1.14	1.09	0.97	0.99
2003	1.13	1.13	0.96	1.47	0.64	0.7	1.16	1.05	0.6	1.34	1.12	1.26	1.17	1.22	0.67	0.64	1.23	1.26	0.98	1.27	1.13
2004	0.89	0.89	1.7	1	1.12	1.14	0.68	0.86	0.61	0.94	0.85	0.91	0.77	0.78	1.01	0.58	0.86	0.92	1.06	1.12	0.9
2005	0.92	0.92	1.02	1.08	0.86	0.84	1.11	1.08	0.59	1.18	0.93	0.98	0.89	0.97	0.55	0.72	0.86	0.87	0.81	1.13	0.98
2006	1.26	1.26	1.16	1.08	1.07	1.02	0.7	1.02	0.78	0.96	0.87	0.73	0.78	0.82	0.9	0.87	1	0.91	1.39	0.72	0.91
2007	0.78	0.78	0.87	0.93	0.89	0.91	0.97	0.99	0.67	1.04	0.91	0.62	0.63	1.02	0.92	0.8	0.84	0.75	0.98	0.73	1.15
2008	0.69	0.69	0.75	0.58	0.69	0.74	0.92	0.69	0.61	0.82	0.7	0.66	0.68	0.59	0.83	0.83	0.67	0.68	0.85	0.69	0.73
2009	0.95	0.95	0.71	1.27	0.79	0.67	0.81	1.15	0.48	1.13	0.86	0.93	0.58	0.87	0.75	0.61	0.94	0.9	0.89	0.83	0.64
2010	0.52	0.52	0.75	0.7	0.86	0.69	0.97	0.72	0.99	0.6	0.72	0.64	0.76	0.81	0.82	0.73	0.84	0.78	0.79	0.83	1.12
2011	0.87	0.87	1.17	1.16	0.67	0.8	0.75	1.03	0.74	1.17	0.82	1.09	0.69	0.84	0.59	0.8	0.97	1.11	0.79	0.78	0.88
2012	0.83	0.83	0.79	1.08	0.86	0.51	0.73	1.14	0.99	1.01	0.77	1.01	0.47	0.83	0.69	0.68	0.66	0.93	0.56	0.61	0.62
2013	0.94	0.94	0.87	1.16	1.12	1.03	0.79	1.07	0.95	1.03	0.97	1.06	0.82	1.05	0.88	1	0.9	1.05	1.01	0.65	1.16
2014	1.02	1.02	1.48	0.72	0.94	1.06	1.17	0.94	1.32	0.85	0.83	1.02	0.94	1.03	1.21	1.1	0.98	1.04	1.06	0.79	1.12
2015	1.03	1.03	1.77	0.97	1.16	1.24	1.14	1.02	1.11	0.88	1.12	1.1	1.43	1.12	1.24	1.58	1.23	1.37	1.28	1.57	0.86
2016	0.97	0.97	1.01	0.76	1.07	1.26	1.21	1.04	1.46	1.02	0.9	0.94	1.11	1.19	1.2	1.15	1.01	0.97	1.28	1.25	0.89
2017	0.7	0.7	0.78	0.59	0.64	0.68	0.54	0.59	0.73	0.52	0.57	0.49	1.03	0.73	0.61	0.57	0.66	0.75	0.81	0.85	1.14

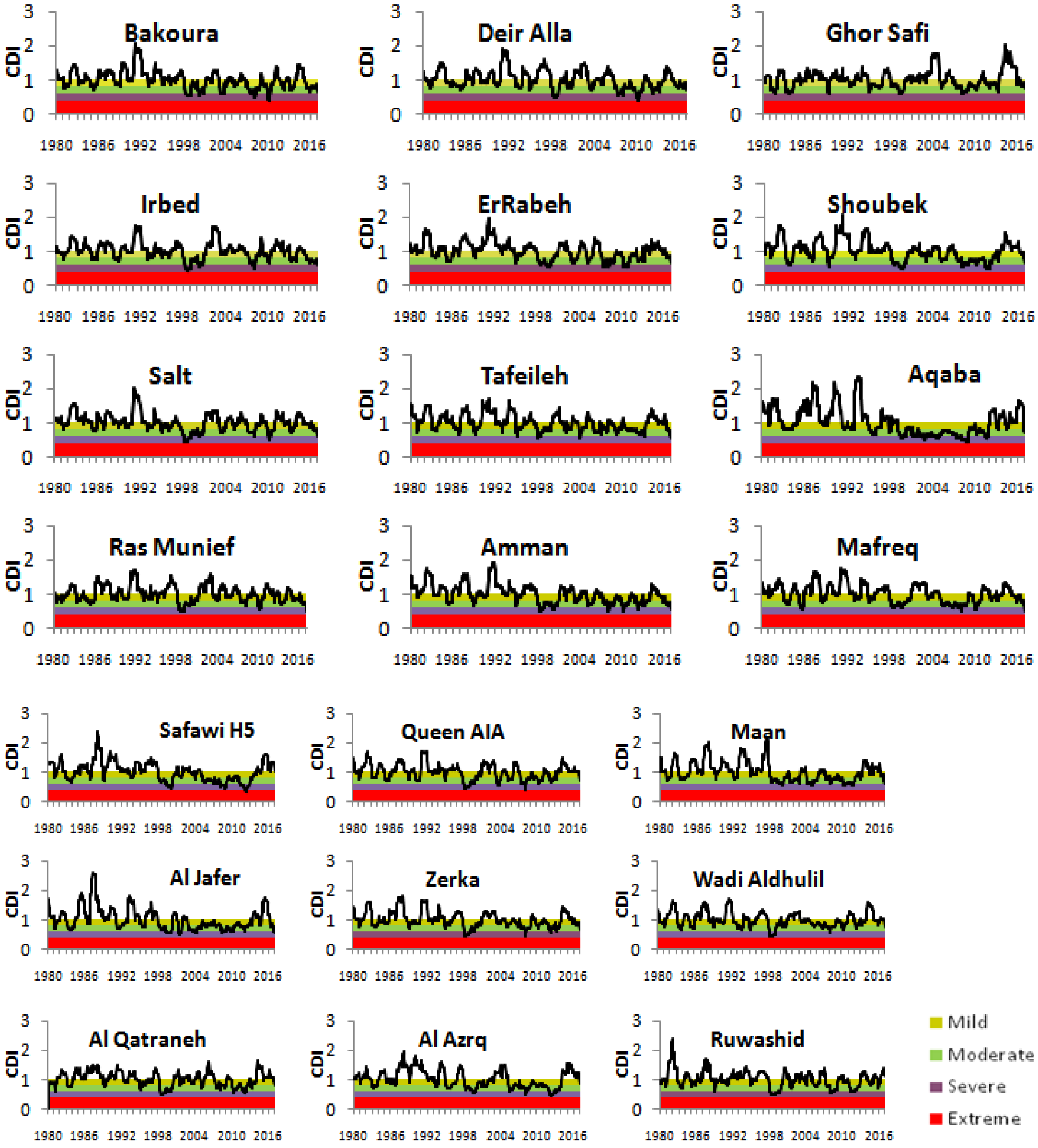


Figure 4: Monthly CDI variability over time from 1980 to 2017 by station.

3.3 Temporal Variability of Combined Drought Indicators

The four drought indices for 1, 2, 3, 6, and 12 month timescales were temporally analysed using linear regression. The linear trend analysis indicated that all drought indicators seemed to decrease significantly by time in terms of drought index value. As drought severity increases as drought index values decrease in magnitude, this suggests that the four droughts' severities increasedwith time. The rate of drought severity increase varied from as low as 0.001 per year for VDI, to 0.008 per year for both PDI and CDI (Table 7).

The significance, and thus the confidence, level of the linear trends were enhanced when the timescale were amended from 12 months to 1 month, mainly due to the increase in the number of samples. This illustrates the importance of sampling periods in drought monitoring programmes, and highlights thatmore granular timescales are always preferred.

Table 7: Linear trend analyses for drought indices at different timescales.

Timescale	Drought Index	Equation	R^2	Root Mean Square Error	Prob>F
12	PDI	PDI = 16.30 - 0.008*Year	0.0265	0.493	<.0001**
	TDI	TDI = 28.68 - 0.015*Year	0.4123	0.1770	<.0001**
	VDI	VDI = 3.22 - 0.001*Year	0.0019	0.274	0.2301
	CDI	CDI = 16.08 - 0.008*Year	0.0823	0.269	<.0001**
6	PDI	PDI = 1.75 - 2.3e-10*Date	0.0137	0.665	<.0001**
	TDI	TDI = 2.20 - 4.1e-10*Date	0.2894	0.219	<.0001**
	VDI	VDI = 1.36 - 1.2e-10*Date	0.0181	0.287	<.0001**
	CDI	CDI = 1.77 - 2.5e-10*Date	0.0520	0.358	<.0001**
3	PDI	PDI = 1.39 - 1.1e-10*Date	0.0026	0.765	0.0048*
	TDI	TDI = 2.13 - 3.9e-10*Date	0.1971	0.267	<.0001**
	VDI	VDI = 1.15 - 4.6e-11*Date	0.0027	0.298	0.0040**
	CDI	CDI = 1.52 - 1.7e-10*Date	0.0191	0.403	<.0001**
2	PDI	PDI = 1.48 - 1.4e-10*Date	0.0030	0.885	0.0002**
	TDI	TDI = 2.05 - 3.6e-10*Date	0.1692	0.271	<.0001**
	VDI	VDI = 1.16 - 4.9e-11*Date	0.0031	0.298	0.0001**
	CDI	CDI = 1.54 - 1.8e-10*Date	0.0162	0.461	<.0001**
1	PDI	PDI = 1.53 - 1.6e-10*Date	0.0031	0.892	<.0001**
	TDI	TDI = 2.00 - 3.6e-10*Date	0.1522	0.282	<.0001**
	VDI	VDI = 1.16 – 5.2e-11*Date	0.0033	0.302	<.0001**
	CDI	CDI = 1.55 - 1.9e-10*Date	0.0167	0.452	<.0001**

* represents significant trends at 95% probability level, ** represents significant trends at 99% probability level,

3.4 Spatial Variability of Combined Drought Indicators

The spatial variability of CDIs was mapped using a Krig interpolation technique for 1, 2, 3, 6, and 12 month timescales. The spatial modelling of the CDI for most years was log-normally distributed with a direction of influence of around 20 to 80 degrees in terms of non-isotropical behaviour (Figure 5).

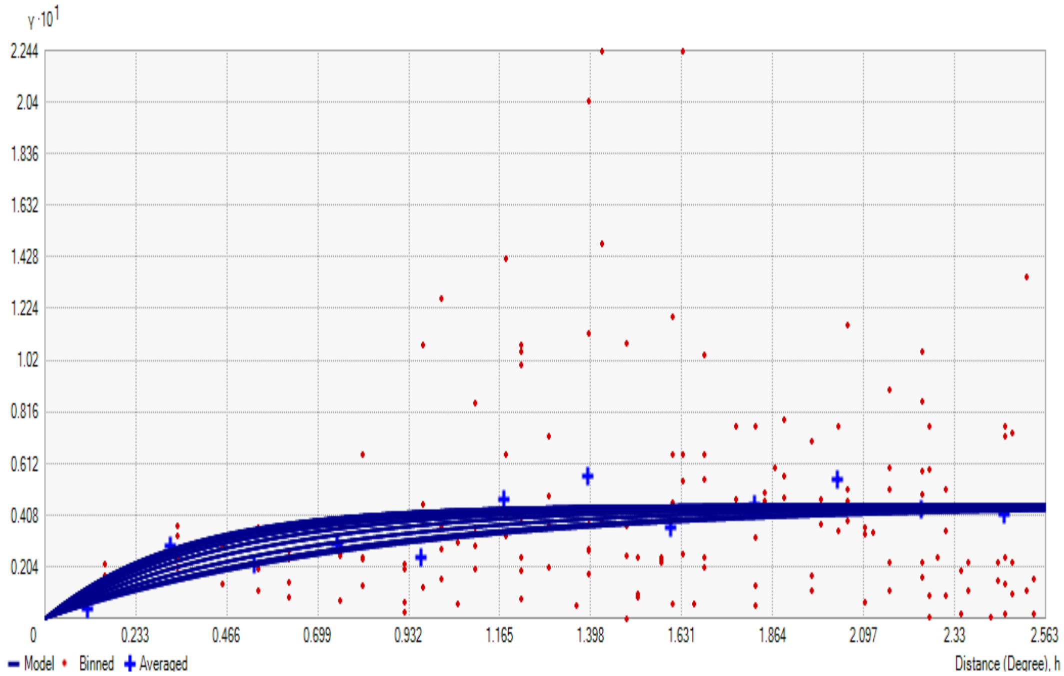


Figure 5: Typical semivariogram developed for CDI using an exponential model for non-isotropical behaviour.

The generated Krig CDI maps provide better interpolation and visualisation of the droughts' extent (Figure 6). Unlike PDI, the CDI maps indicate that there is no national severe drought affectingthe country. National mild to moderate droughts were evident in 1981, 1998, 1999, 2000, and 2008, while severe local droughts were detected in 1999 and 2017 in the northern part of the country, in 2009 in the southern part of the country, and in 2012 in the eastern part of the country.

The potential drought events' occurrence at local scale within the mild to moderate drought categories is about 70% in all investigated years. The ratio of annual droughts to no-drought cases is an indication of repeatable patterns of drought occurrence. The spatial extent of drought impact, drought severity, and drought incidence increases with time, especially after 1998.

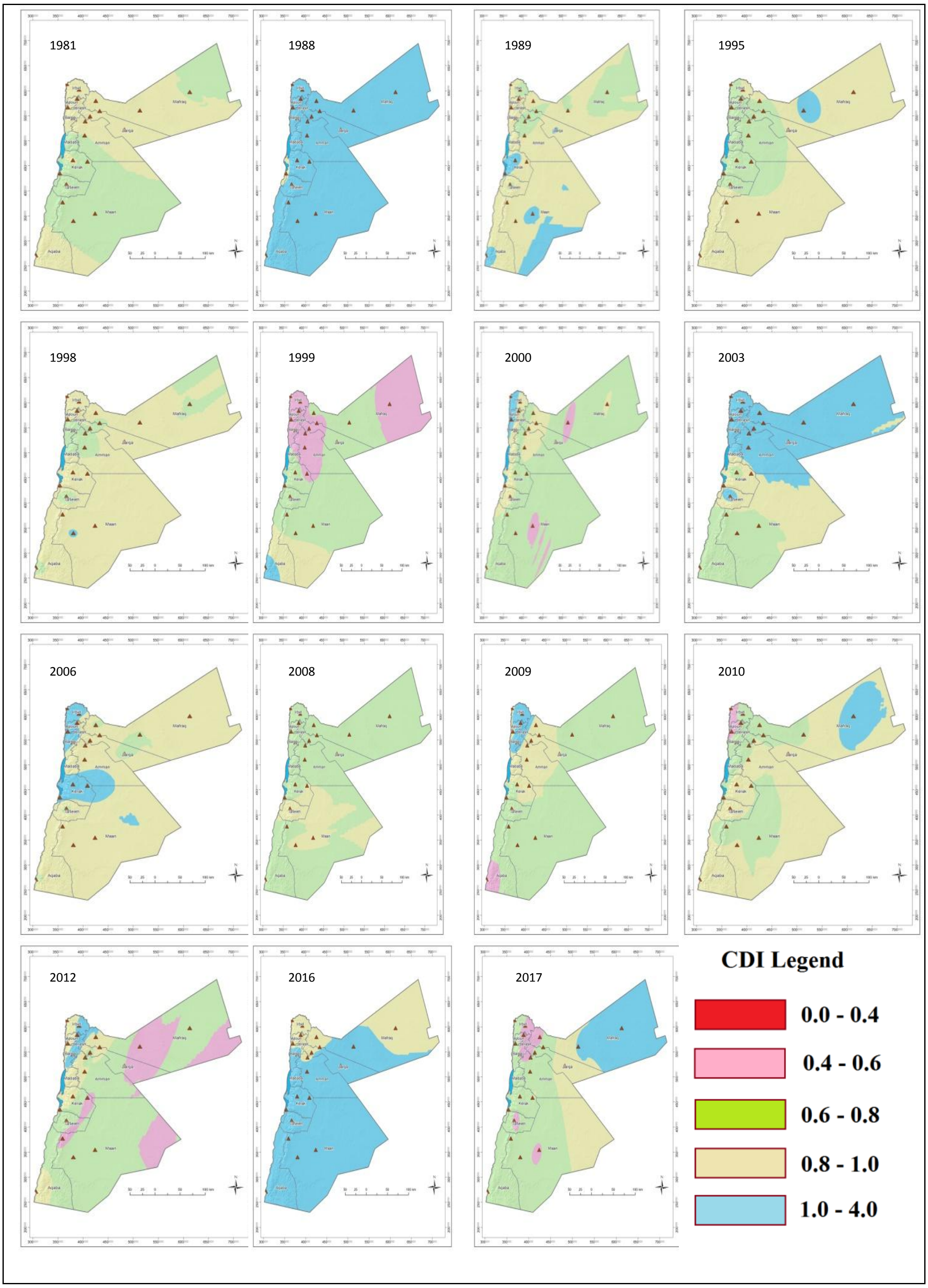


Figure 6: CDI spatial Krig maps for selected years generated using geospatial investigations.

3.5 Applicability of the Combined Drought Indicator

Using a single index to study global trends for all drought types is impossible and unrealistic; thus the use ofacombined drought index to correlate all impacts on specific sectors is recommended. The PDI, TDI, and VDI correlation matrix using Pearson's correlation (r) was determined for all data regardless of meteorological station. The matrix indicated weak to moderate relationships between PDI, TDI, and VDI drought indicators. The correlations varied from 0.063 to 0.21 (Table 8). The relationship also varies by month, withthe highest correlations found in the three-month interval April, May, and June. This is most likely because vegetation coverin Jordan is seasonal and the widest range appears in the spring season.

The CDI correlations with VDI, TDI, and PDI drought indicators were moderate to high, at0.31, 0.37, and 0.95, respectively. This could, however, be a result of bias, as the CDI was estimated as a weighed regression function of the drought indicators. The high correlation withPDI can thus be attributed to high weight given in equation (9).

On the other hand, it is important to investigate variability between drought indicators across the timescale observations to identify the time and lag of variability and the correlations between the drought indicators. Thecorrelation coefficients between droughts indices were improved when the timescale of observations was reduced from 12 months to 2 months (Table 8). The correlation matrix highlights the timescales at which the relationships between indices and their effects on crop production are significant. In terms of seasonality, the wet season demonstrateshigher correlation of CDI, PDI, and TDI. On the other hand, the CDI correlation with VDI is low compared to that seen in the dry season. Similarly, on the basis of the three months' timescale, the highest correlations between CDI, PDI and TDI were revealed in the wet months atJFM and ONS where most rainfall events occur in Jordan. On the other hand, the highest correlation between CDI and VDI occurred in JUS in months that represent spring in Jordan, when the vegetation cover becomes clearer, especially on the rangelands that cover more than 30% of the country. The two months' timescale supports these relationships, making it even clearer that the VDI relationship is effective only during spring.

The lowest variability between TDI and VDI drought indicators exists during the March and April, while the highest variability is evident during the beginning of the autumn season (September and October). This contrasts with to PDI and CDI, where the lowest variability was evident during the beginning of the autumn season. Based on Figure 7, the lowest variability between drought indicators appears to exist at the end of the spring season (June to July), andthe variabilityis maximised in September, especially for TDI and other drought indicators.

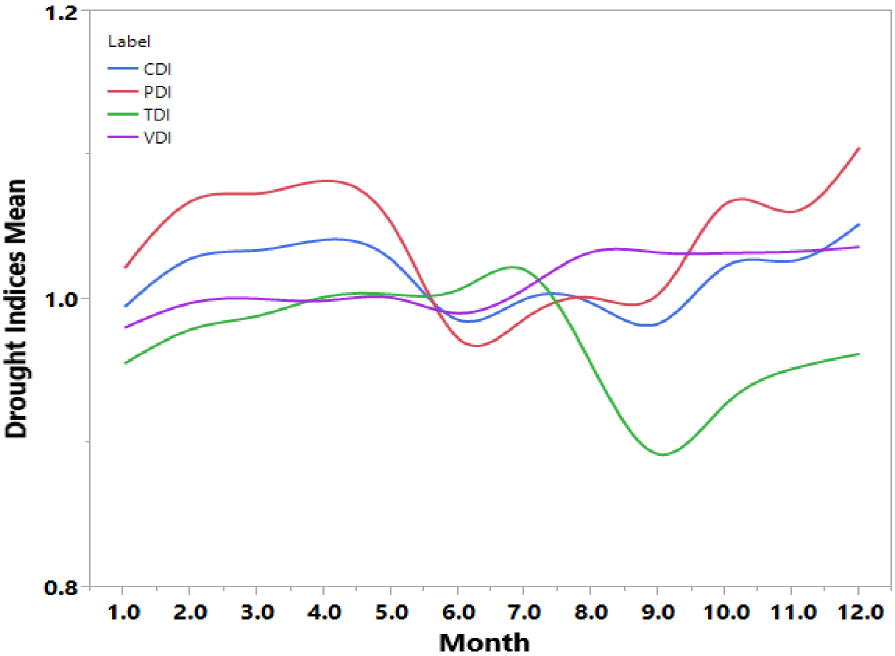


Figure 7: Drought variability per month.

In terms of drought indices' relationships to crop production, the relationshipbetween barley yield and drought indices ranges from weak for TDI to moderate for CDI. The highest annual correlation was found between the CDI and barley yield (r = 0.4587). This indicates that applicability of the CDI is much more powerful for this purpose compared to PDI, TDI, or VDI alone. This is most clear in cases when drought consequences in the agriculture sector are extreme, especially where extreme precipitation deficits are accompanied by high temperature anomalies.

Timescale correlation analysis proves that the CDI can be used to monitor crop production for crops such as barley. The main factors governing barley production in Jordan include precipitation during the first months of therainy season (September and October), which is where the highest correlation exist (r = 0.5641).

It is important to note that no single drought index that is capable of accurately capturing the diverse set of drought impacts in all sectors exists. However, it remains critical to select an appropriate drought index based on the impacted sector's key indicators. Therefore, sensitivity analysis for a combined drought index should be performed before establishing any monitoring plan; as drought impacts are related to various factors, every index provides specific information and hence is viable for the monitoring of drought conditions under certain impacts.

Table 8: Pearson correlations between Annual Drought indicators

		PDI	TDI	VDI	CDI	Barley Yield
12 months	**PDI**	1.0000				
	TDI	0.2055	1.0000			
	VDI	0.0909	-0.0631	1.0000		
	CDI	**0.9533**	**0.3725**	**0.3116**	1.0000	
	Barley Yield	0.1624	0.1256	0.2511	**0.4587**	1.0000
6 months / dry season	**PDI**	1.0000				
	TDI	0.1536	1.0000			
	VDI	0.1728	0.1310	1.0000		
	CDI	**0.8472**	**0.3563**	**0.4206**	1.0000	
	Barley Yield	0.0921	0.1044	0.2822	0.2515	1.0000
6 months / wet season	**PDI**	1.0000				
	TDI	0.1881	1.0000			
	VDI	0.0892	0.0017	1.0000		
	CDI	**0.9727**	**0.3423**	0.2497	1.0000	
	Barley Yield	0.2423	0.1427	0.1421	**0.5244**	1.0000
3 months / JFM	**PDI**	1.0000				
	TDI	0.2546	1.0000			
	VDI	0.0725	-0.0447	1.0000		
	CDI	**0.9521**	**0.4204**	0.2999	1.0000	
	Barley Yield	0.2357	0.1549	0.1654	**0.3147**	1.0000
3 months / AMJ	**PDI**	1.0000				
	TDI	0.0640	1.0000			
	VDI	-0.0116	0.0907	1.0000		
	CDI	**0.9796**	0.1969	0.1496	1.0000	
	Barley Yield	0.2815	0.1165	0.1024	**0.5474**	1.0000
3 months / JUS	**PDI**	1.0000				
	TDI	-0.0076	1.0000			
	VDI	-0.0078	0.0183	1.0000		
	CDI	**0.8376**	**0.4442**	**0.3106**	1.0000	
	Barley Yield	0.0746	0.1978	0.2147	0.2167	1.0000
3 months / ONS	**PDI**	1.0000				
	TDI	0.1375	1.0000			
	VDI	0.0780	0.0009	1.0000		
	CDI	**0.9804**	0.2679	0.2187	1.0000	
	Barley Yield	**0.3147**	0.1349	0.1574	**0.5265**	1.0000
2 months / JF	**PDI**	1.0000				
	TDI	0.2113	1.0000			
	VDI	-0.0215	-0.0861	1.0000		
	CDI	**0.9622**	**0.3555**	0.1888	1.0000	
	Barley Yield	0.2745	0.1847	0.1024	**0.4951**	1.0000
2 months /MA	**PDI**	1.0000				
	TDI	0.1215	1.0000			

		PDI	TDI	VDI	CDI	Barley Yield
	VDI	0.1028	0.1758	1.0000		
	CDI	**0.9721**	0.2806	0.2916	1.0000	
	Barley Yield	0.1868	0.1244	0.1741	0.**3535**	1.0000
2 months /MJ	**PDI**	1.0000				
	TDI	0.1395	1.0000			
	VDI	-0.0703	0.0449	1.0000		
	CDI	**0.9606**	0.2777	0.**3730**	1.0000	
	Barley Yield	0.0441	0.1341	0.2164	0.2122	1.0000
2 months /JA	**PDI**	1.0000				
	TDI	-0.0572	1.0000			
	VDI	-0.0281	0.0285	1.0000		
	CDI	**0.4213**	**0.7248**	**0.5178**	1.0000	
	Barley Yield	0.1414	0.2451	0.2674	0.1518	1.0000
2 months /SO	**PDI**	1.0000				
	TDI	-0.0459	1.0000			
	VDI	0.0648	-0.1602	1.0000		
	CDI	**0.9885**	0.0517	0.1633	1.0000	
	Barley Yield	**0.4258**	0.0574	0.1521	**0.5641**	1.0000
2 months / ND	**PDI**	1.0000				
	TDI	0.2426	1.0000			
	VDI	0.0362	0.1052	1.0000		
	CDI	**0.9802**	**0.3753**	0.1868	1.0000	
	Barley Yield	**0.4145**	0.1847	0.1644	**0.5321**	1.0000

IV. CONCLUSIONS

Since drought impacts are related to various factors, every index provides specific information and hence is viable to monitor drought condition for certain impacts. Single drought indicators are good to indicate or monitor single type of drought, but can't correlate with all sectorial impacts. The PDI provided clear indication of the precipitation deficit manifested by time over Jordan. The TDI delineated the clear inflection waves of extreme temperature stress conditions especially after the year 1998. The VDI time series variability proved the presence of a repeatable cyclic pattern with variable magnitudes and amplitudes over the years.

Although the CDI is just a statistical index that measures how much the present conditions deviate from the reference level, the CDI generated Krig maps provided more flexibility to analyse the drought spatial and temporal patterns. The CDI maps suggest short term drought events becoming more frequent with closer duration, while long term national droughts are seldom that becoming more severe especially at last decades.

Finally, the CDI analyses may be helpful in designing adaptation strategies for future droughts. Combining the PDI, TDI, and VDI improved the correlation with sectorial indicator as barley yield, however this may not be true for other crops or other sectorial indicators. Therefore, weight parameterization of the drought indicators should be developed using sensitivity analysis.

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Haitham Aladaileh" Applicability of a Combined Drought Index to Monitoring Drought in Jordan"International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.07, 2019, pp. 20-39