Drought Vulnerability and Mitigation Measures in Jordan based on Spatio-temporal Assessment of Single and Composite Meteorological Drought Indices

PhD Dissertation

By

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1. Introduction & Aims

Drought is a general term referring to a consequence of an extended period (e.g., season, year, or more) of deficient precipitation compared to the statistical long-term average for a region. These events result in water shortages that impact on the functioning of natural ecosystems, and bring great hardship and disruption to human activities (Sivakumar, 2005).

Drought remains the most complex natural phenomenon affecting the economy, environment and society at global, regional and local level (Parsons et al, 2019); (Rohli et al., 2016). During the last two decades, the frequencies and severity of drought as well as the affected area have increased (Dai, 2013), (Pachauri et al., 2014).

Droughts have been a recurring feature of the Jordan climate. The historical drought event in the 1986 resulted in an 83% reduction in wheat production as compared to 1987 levels, and the 1997 drought led to a 30% reduction in Jordan’s sheep flock because of disease, malnutrition, or premature slaughter (ESCWA, 2005). According to (UN-DESA, 2016) limited precipitation during the 1998-2000 agricultural season led to a sharp drop in dam water levels, seriously reducing agricultural production and exacerbating the economic problems facing the country. Rainfall in 1999 dropped by as much as 70% in some zones of the country, leaving agricultural yields and production the worst recorded in the last four decades.

Based on the importance of drought monitoring and early warning in terms of enhancing the resilience and preparedness of countries and regions towards drought, drought characterization and vulnerability have been investigated repeatedly over the 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 assess drought risks globally, however, there is no consensus on which indicator best represents drought impact occurrence for any given sector (Surendran et al, 2017; Van Loon, 2015).

Precipitation Decile Index (PDI), Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI) and other dozen indices are all common examples of well-developed drought indices (Caparrini & Manzella, 2009; Gupta, Nair, & Nathawat, 2013)

The nature of the indicator, local conditions, data availability, and validity are the factors that usually determine which indicator is to be applied (Gupta et al., 2013; Keyantash & Dracup, 2002). Therefore, the effectiveness of the drought indices in terms of reflecting actual status is questionable.

The main aims of this study were the following:

1. Investigate the presence of spatial and temporal drought trends in Jordan through various drought indices using long-term historical precipitation and temperature records.

2. Evaluate the use of a combined drought index as an applicable monitoring processes to characterize droughts in Jordan.

3. Generate a drought vulnerability map for the Jordanian groundwater system based on assessment of the climatic exposure, groundwater basins sensitivity and actual adaptive capacity at district level.

4. Propose set of adaption measures based on groundwater sector impact chain analysis to improve the country's drought preparedness for likely future.

The main hypothesis of this study is that there is a potential of some drought indicators to represent the historical Jordan drought conditions and are applicable to be used for further vulnerability analysis. However, their capability and specifications are unknown and to be defined. The main hypothesis is that drought conditions in Jordan cannot be monitored by one indicator, thus a combined drought index should be developed to mitigate the occurrence of a drought. Testing the hypothesis was achieved by the following:

1 – Assessment of drought characterizations using historical data;

2 – Comparison of the patterns of different drought indicators with Jordanian conditions;

3 – Validating the effectiveness of a combined drought index to represent one actual response (impact on Jordanian rainfed crop production);

4 – Implementing the developed combined drought index to assess other responses (e.g. ground water vulnerability).

2. Material and Methods

The study area represented Jordan as one of the developing countries in the Middle East, located about 80 kilometers east of the Mediterranean Sea. One of the most serious problem in the country is the water scarcity. Monthly rainfall and air temperature data for 29 meteorological stations covering the whole country were obtained from the Jordan Meteorological Department (JMD) for 38 years (1979/1980 to 2016/2017). Normalized Difference Vegetation Index (NDVI) values were computed according to Kogan (Kogan, 1990; 2001) using the ratio of 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).

The study implies four sections:

1- Preliminary statistical analyses (including measures of central tendency, dispersion, and distribution) and temporal trend analyses using simple and multiple linear regressions in addition to Mann–Kendall test performed using JMP statistical software (JMP, 2011).

2- Drought characterization using the following indices:

a) Standardized Precipitation Index (SPI) (McKee, Doesken, & Kleist, 1995) on annual (SPI_{12}), 6-months (SPI_6), and 3-months (SPI_3) basis.

b) Normalized Difference Vegetation Index on annual, 6-months, 3-months, 2 months, and one-month basis.

c) Precipitation Drought Index (PDI) on annual, 6-months, 3-months, 2 months, and one-month basis.

d) Temperature Drought Index (TDI) on annual, 6-months, 3-months, 2 months, and one-month basis.

e) Vegetation Drought Index (VDI) on annual, 6-months, 3-months, 2 months, and one-month basis.

f) Combined Drought Index (CDI) on annual, 6-months, 3-months, 2 months, and one-month basis (Balint, Mutua, & Muchiri, 2011).

3- Drought validation with real impacted sector, correlation analyses was made between the drought indices and barley production in Jordan as obtained from the department of statistics (DOS, 2017) for the 38 years of the study.

4- Drought vulnerability assessment for the twelve groundwater basins in Jordan with implementation of the generated CDI maps. This included development of groundwater impact chain framework with emphasis on

Exposure (scored based on drought severity and probability of occurrence), groundwater sensitivity (scored as cumulative function of groundwater safe yield, exploitation, and depletion), and groundwater basin adaptive capacity (scored from experts' judgments on the associated basin economic, institutional, technological, knowledge and awareness-based, and infrastructure aspects).

5- Drought maps were generated using ordinary kriging spatial interpolation technique to characterize the spatial distribution of drought in Jordan. Also, the spatial and temporal patterns of drought throughout the country was achieved through Temporal analysis using multilinear regression and a clustering technique of SPI values.

3. Results and Discussion

The main important scientific results of this study are the following:

1. Rainfall distribution in Jordan is highly spatial and temporal, where the increasing water scarcity is quantified to be caused by not only by the decreasing rainfall but obviously rather by the shortening of the wet season.

2. SPI analysis indicated that Jordan is experiencing periodic cycles of drought with various severity and frequency of about once every two to three years.

3. SPI clustering identified three main micro-climatic patterns; northern, eastern, and southern, where each has specific trends on rainfall changes.

4. In contrast to PDI, VDI, and TDI that has separate specific meaningful use in characterization drought, the CDI is further recommended as it provides detailed investigations of drought deviation from the reference level for all combined meteorological, hydrological, and agricultural droughts investigations.

5. The applicability of drought indices to monitor crop production impacts varies by the timescale assessment; thus sensitivity analysis is required to guide the selection of time scale of CDI investigation.

6. The applicability of CDI technique in investigating groundwater vulnerability in Jordan is effective and realistic. Generated drought vulnerability map indicated Azraq and Dead Sea groundwater basins being the most vulnerable basins. The high generated vulnerability scores were derived from the high impacts and low adaptive capacity.

More criteria about thesis points:

Ad 1. Jordan experienced significant annual rainfall reduction trends ranging from of 0.01 to 5.2 mm/year. The trends significance and reduction rates were related to both the geographic locations and altitudes. Jordan Highlands seem to be most affected by the reduction followed by Jordan Rift Valley and desert region. The rainfall reduction was highly obvious at both March and November, and at both sides of the wet season.

Ad 2. Drought spatial and temporal generated maps indicated that Jordan experienced periodic cycles of drought with various severity and frequency. The use of drought indicators enabled the investigation for the drought event' characteristics. The standardized precipitation index (SPI) provided clear tool to indicate drought frequency and magnitude trends that appeared to be once every two to three years with a significant increase rate of occurrence. Although SPI12 is less effective in providing clear understanding on the rainfall shifts and monthly reduction as compared to SPI3, however it provides a general indication of the droughts especially if was coupled with Krig interpolation technique. The generated drought Krig maps revealed the presence of two drought trends; local and national. With the implicitly of statistical tools as cluster analyses, three main regions of droughts were grouped in terms of severity holding similar micro-climatological conditions; northern, eastern, and southern.

Ad 3. SPI cluster grouping actually identifies three main regions in the kingdom: northern, eastern, and southern, where each region holds similar micro-climatological conditions. The northern region is characterized by wet patterns with rainfall above 250 mm. Followed by the southern region that is characterized by the average annual rainfall of less than 250 mm, and finally the eastern regions with an average annual rainfall of less than 100 mm.

Ad 4. The type of drought indicator is function on the objective of the use; meteorological, hydrological, or agricultural drought investigations.

Precipitation drought indicator (PDI) as indication of rainfall deficit over time is highly variable and provides similar results as SPI. However, temperature drought indicator (TDI) is less dispersive and can be modelled easily. The vegetation drought index (VDI) is only indicator of the soil moisture deficit and vegetation cover health which can be used to indicate drought agricultural impacts. Since VDI is generally influenced by the temperature and precipitation droughts, therefore combining VDI, PDI and TDI indicators will provide further information on droughts imposed stresses in terms of soil-water-air-plant system.

Ad 5. Although the CDI does not measure the physical parameters of either vegetation or soil, and it does not attempt to simulate either physical phenomena or water balance, however the CDI provided clear indications of the drought deviation from the reference level and also provided the flexibility for analyzing the various lengths of drought duration. 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 or yearly CDI for long-term monitoring programs as national catastrophes.

With emphasis on the use of CDI to interpret sector drought impact, Pearson's correlation of barley yield in Jordan showed weak to moderate relationships with PDI, TDI, and VDI drought indicators, while it showed strong relationship with

CDI. The relationship of drought indices varies by the timescale assessment (i.e. annual, seasonal, 3 months, or 2 months' intervals). Results were able to demonstrate the applicability to use the CDI to monitor crop production in Jordan, however the weight of each index and the timescale of measurements should be tested using sensitivity analysis.

Ad 6. The generated drought vulnerability map indicates that the whole country is subject to drought events ranging from moderate to high vulnerability. The extreme vulnerability was found at the Azraq and Dead Sea groundwater basins due to both high groundwater sensitivity and weak adaptive capacities. Similarly, both Disi and Yarmouk groundwater basins are highly vulnerable to drought due to political aspects, particularly weak enforcement of transboundary agreements. On the other hand, the Zarqa groundwater basin displayed moderate vulnerability despite suffering from high abstraction, which is attributed by the presence of investments at district level associated with mega projects to generate alternative water sources and local plans to reduce water loss.

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2. **Applicability of a Combined Drought Index to Monitoring Drought in Jordan.** Haitham AlAdaileh, Mohammed Al Qinna, KárolyBarta, Emad Al-Karablieh, Jawad Al Bakri, János Rakonczai. *Journal of Engineering Research and Application, ISSN: 2248-9622 Vol. 9, Issue 7 (Series-VI) July 2019, pp 20-39.* **DOI: 10.9790/9622- 090706203920**

3. **A Drought Adaptation Management System for Groundwater Resources Based on Combined Drought Index and Vulnerability Analysis**. Haitham Al Adaileh, Mohammed Al Qinna, Karoly Barta, Emad Al-Karablieh, Janos Rakonczai, Adel Alobeiaat. *Earth Systems and Environment (2019) 3:445–461. https://doi.org/10.1007/s41748-019-00118-9*

Other Publications

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- Managing Water Scarcity in River Basins: Innovation and Sustainable Development 4-6 October 2018, Agadir, Morocco
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- ***Drought-Management Policies and Institutional Mandate in Jordan***. Tala H. Qtaishat, Emad K. Al-Karablieh, Haitham AlAdaileh, and Mohammad Samir El-Habbab. *1st International Conference on Sustainable Energy-Water-Environment Nexus in Desert Climate – QEERI, December 2019. Processing – accepted for publishing in Springer,*