Spectral and Meteorological based Indices for Drought Monitoring: A Case Study in Sulaimaniya, the Iraqi Kurdistan Region

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Abstract

- **Drought** has dramatically affected Iraq throughout the last two decades, which was characterized by a large drop in rainfall averages.

- To study drought status and its impacts, three spectral based drought indices (**NDVI**, **LST**, and **NDWI**) were derived from Landsat imageries of 1990, 2007, and 2008, while the **SPI** has been used as a meteorological based drought index.

- This study aimed to investigate role of the **NDVI** and **SPI** indices and their integration for monitoring drought status in some districts of Sulaimaniya province of the Iraqi Kurdistan in a span of 18 years.
• The results showed that the vegetative cover was significantly decreased by **28.6%** in **2008** compared with **2007**.

• **Dukan** Lake’s surface area in the study site, had a significantly shrunk by **16.5%** and **32.5 %** in **2007** and **2008**, respectively, compared with its size in **1990**.

• Generally, the results of the combined **NDVI-SPI** maps emphasized the harsh impact of drought on the vegetative cover, which occurred in **2008**.
Introduction
Drought in Iraq

- Drought is a natural hazard that results from a lack of precipitation to be insufficient to meet the demands of human activities and the environment.

- Iraq is experiencing its acute drought owing to well-below normal rainfall averages and significant irrigation supply shortages in its two main rivers (Tigris and Euphrates) and their tributaries in the last decade.

Courtesy of NASA
• Several indices have been used by researchers for drought monitoring and assessment its impacts.

• A **drought index value** is typically a single number, can be derived from hydro-meteorological data and remote sensing dataset.

• One of the meteorological based drought indices is the Standardized Precipitation Index (**SPI**), which can be utilized to assign a single numeric value as an indicator of drought.
Drought in the Iraqi Kurdistan

• Severe drought has affected the Iraqi Kurdistan region (north of Iraq) as well as the other parts of the country throughout the last years which was characterized by a significant drop in rainfall amounts (Fadhil, 2011: Eklund and Seaquist, 2014).

• Particularly, the region was considered the Iraqi’s historical breadbasket, where rain-fed wheat is grown.
• The **winter wheat crop** in Iraqi Kurdistan depends on the **rain** that falls between **October** and **April**.

• Since the crop has little access to other sources of water, the vegetation situations show a direct response to the lack of rainfall.
• In the cropping year 2007/2008, there was approximately 41% of decrease in precipitation compared with the rainfall average which led to a severe drought (Fadhil, 2011: Alobaidy et al., 2010).

• The aim of this study was to investigate the role of integration of NDVI and SPI for drought monitoring in Iraqi Kurdistan during 1990, 2007, and 2008.
Materials and Methods
The Study Area

• It is situated in **Sulaimaniya** governorate (fig. 1) , one of the three governorates of the Iraqi Kurdistan.

• **Sulaimaniya** is located in the NE part of Iraq, about **331 km NE** to Baghdad and its populations more than **1.2 million**, and accounting for **1.6%** of the entire area of Iraq.
Fig. 1. Location map of the study area in the Sulaimaniya, Iraq, where 1: Dukan, 2: Sharbazher, 3: Sulaimaniya, and 4: Halabja
• Sulaimaniya becomes increasingly mountainous towards the eastern border with Iran.

• The study area includes four administrative districts: 1: Dukan, 2: Sharbazahr, 3: Sulaimaniya, and 4: Halabja, it also includes fertile lands such as Sharazor and Peshdar plains.
Climate in Iraqi Kurdistan

- The mean annual rainfall ranges between 600-1,200 mm depending on the geographical location.
- It increases from the SW toward NE parts of the region.
- The mean annual temperature ranges between 12 and 20 °C.
Fig. 2. The rainfall amounts and the mean annual of the rainfall in the four studied districts during the study periods.
Soil Samples Preparations

In order to characterize the chemical and physical properties of the study area’s soils, and to correlate them with their spectral characteristics, soil samples were taken from 22 sites at a depth of (0-15 cm) in the Sharazor and Peshdar plains.

Their location coordinates were taken using a GPS receiver during July of 2008.

The soil samples were air dried at the laboratory before being sieved with a 2 mm sieve, and then prepared for the chemical and physical analyses, which included the primary soil properties.
Remotely Sensed Datasets

• Three Landsat images (168/35) were downloaded from the USGS data server (glovis.usgs.gov) and used in this study.

• The first and second images were Landsat 5 TM acquired on 13 Sep. 1990 and 12 Sep. 2007, respectively, while the third imagery was a Landsat 7 ETM+ acquired on 22 Sep. 2008.
The Standardized Precipitation Index (SPI)

• The SPI was developed for drought monitoring, and requires only one input variable (McKee et al., 1993).

• A drought event occurs any time the SPI is continuously negative and reaches (≤-1.0), while drought event ends when SPI value becomes positive.
• An MS-Excel based application was developed to perform SPI calculations using rainfall data from 1971 to 2008 of the study area.

• In order to get the spatial pattern of drought status in the study area, Kriging interpolation for SPI values in a GIS environment were conducted.

SPI, based on probability of precipitation for any time scale, is calculated as:

$$SPI = \frac{X - Xm}{\sigma}$$

Where

- $X$ = Precipitation for the station
- $Xm$ = Mean precipitation
- $\sigma$ = Standardized deviation
Remote Sensing based Drought Indices

• To monitor drought situation, some remote sensing based drought indices related to vegetation, soil, and water status in this study have been utilized.

• The Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and the Normalized Differential Water Index (NDWI) have been used and derived from the Landsat imageries.
The NDVI

• The **NDVI** was initially proposed by Rouse et al. (1974).

• The NDVI derived from the ratio of Band 3 (red (R): 0.63-0.69 mm) and Band 4 (near infrared (NIR): 0.76-0.90 mm) of **Landsat TM/ETM+** imageries.

\[
\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}}
\]

• It was applied for monitoring the vegetation changes in this study.
The LST

• The **LST** is sensitive to the vegetation and soil moisture.

• Therefore, it can be used to monitor the drought situation in the study area.
The NDWI

- The NDWI was used to oversee the conditions of soil moisture and the water bodies status.

- The ratio between band 3 (R) and band 5 (short-wave IR (SWIR): 1.55-1.75 mm) spectral region clearly enhanced water bodies to the brighter pixels (CPM 2003).

\[
NDWI = \frac{R - SWIR}{R + SWIR}
\]
Results and Discussions
The NDVI

• The NDVI results and rainfall amounts in 1990, 2007, and 2008 showed a positive relation between the rainfall and the vegetation cover.

• The results (fig. 3, tabs. 1 and 2) showed the total vegetation coverage area was (41.7% of the total area) in 1990.

• The vegetation decreased to be (16.6%) in 2008.
Fig. 3. The spatial distribution of the NDVI based vegetative cover in the study area for the years 1990, 2007, and 2008
Table 1. The total vegetative cover in the four studied districts for the years 1990, 2007, and 2008.

<table>
<thead>
<tr>
<th>District Name</th>
<th>District Area</th>
<th>Total Veg. Cover 1990</th>
<th>Total Veg. Cover 2007</th>
<th>Total Veg. Cover 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km²</td>
<td>km²</td>
<td>%</td>
<td>km²</td>
</tr>
<tr>
<td>Dukan</td>
<td>1,537.9</td>
<td>574.1</td>
<td>37.3</td>
<td>772</td>
</tr>
<tr>
<td>Sharbazher</td>
<td>2,387.8</td>
<td>1,304.1</td>
<td>54.6</td>
<td>1,444.9</td>
</tr>
<tr>
<td>Sulaimaniya</td>
<td>2,018.3</td>
<td>661</td>
<td>32.7</td>
<td>602.4</td>
</tr>
<tr>
<td>Halabja</td>
<td>920.3</td>
<td>334.7</td>
<td>36.3</td>
<td>281.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,864.3</strong></td>
<td><strong>2,873.9</strong></td>
<td><strong>41.7</strong></td>
<td><strong>3,100.4</strong></td>
</tr>
</tbody>
</table>
• There was a remarkable decrease in the vegetative area in Sulaimaniya district (23%) during a span of eighteen years from 1990 to 2008.

• The decline can be attributed to lack of irrigation water and water resources during drought periods, as well as to the huge urban sprawl in the Sulaimaniya city happened in the last years.

<table>
<thead>
<tr>
<th>District name</th>
<th>2008-2007 Change rate</th>
<th>2008-1990 Change rate</th>
<th>2007-1990 Change rate</th>
<th>%</th>
<th>Km². year⁻¹</th>
<th>%</th>
<th>Km². year⁻¹</th>
<th>%</th>
<th>Km². year⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dukan</td>
<td>-38.2</td>
<td>-587.6</td>
<td>-25.3</td>
<td>-21.6</td>
<td>12.9</td>
<td>11.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sharbazher</td>
<td>-30.5</td>
<td>-728.4</td>
<td>-24.6</td>
<td>-32.6</td>
<td>5.9</td>
<td>8.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulaimaniyah</td>
<td>-23.3</td>
<td>-472</td>
<td>-26.3</td>
<td>-29.4</td>
<td>-2.9</td>
<td>-3.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halabja</td>
<td>-18.7</td>
<td>-172.2</td>
<td>-24.5</td>
<td>-12.5</td>
<td>-5.8</td>
<td>-3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>-28.6</td>
<td>-25.3</td>
<td>3.3</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
• The decrease of vegetation cover was due to the low rainfall amounts in 2007/2008.

• Therefore, that **rainfall decrease** led to a **significant reduction** in surface and subsurface water resources such as the rivers, lakes, groundwater, and consequently decrease the soil moisture content.
• The results showed a significant shrinkage (23%) in the water bodies areas such as the lakes and rivers from 1990 to 2008.

• The entire water surface area was 187.4 km² in 1990, while it shrank to 153.8, 125.6 km² in 2007, and 2008, respectively.
• It was clear that the surface size of Lakes Dukan and Darbandikhan have significantly shrunk during study years.
• **Dukan** Lake area it lost **16.5%** and **32.6%** from its total area in **2007** and **2008**, respectively.
• **Darbandikhan Lake** shrunk to be a narrow stream as a result of the harsh effects of drought in 2008.
The LST

- Generally, the LST tends to decrease in orientation SW to NE associated with altitude increasing.
- Consequently, there were large differences in LST values between the hottest and the coldest sites in the study area.
• It was found that the bare lands or the poor vegetative cover had the high LST values coupled with low soil/vegetation moisture content.

• The statistical results revealed a negative significant relation between LST & soil/vegetation moisture (-0.453), (-0.551), and (-0.233) for 1990, 2007, and 2008, respectively.

• The decreasing in the correlation coefficient in 2008 indicates the declining of water role in soil wetting during the drought year of 2008.
The SPI

- The results of **SPI** values and its interpolated maps for the hydrological years 2006/2007 and 2007/2008 were presented in figs. 6, and 7.
Fig. 7. The interpolated SPI categories maps of the study area for the hydrological years of 2006-2007 and 2007-2008.
• The results showed the SPI was more influential on vegetative growth in 2007 than 2008 as a result of the significant relation between SPI and the NDVI in 2007.

• Furthermore, the drought severity in 2008 was much higher than 2007.
• The difference between the SPI results of 2007 and 2008 was a result of the severe drought in 2008.

• Briefly, the rainfall reduction in all districts during 2007/2008 led to a huge decrease in the vegetation cover and to a severe dry class.
The Combined NDVI-SPI Drought Maps

• Generally, in Iraqi Kurdistan, vegetation is mainly dominated by the availability of rainfall.

• GIS analysis (in ArcGIS) was conducted and reclassification was done to produce the combined NDVI-SPI maps.

• First and last classes of the combined NDVI-SPI maps represent dense vegetation and extremely drought conditions, respectively, while the other classes represent the rest classes.
• As the region is mostly relied on rainfall, therefore, a **positive relation** between **vegetation** cover and **rainfall** was found.

• Based on this, the combined **NDVI-SPI** maps were generated to provide a better understanding of drought impacts through overlay method.
• The strong relation between rainfall and vegetation over the region causes an increase in the rainfall amounts which led to accelerate the vegetation growth and vice versa.
• In order to understand the relation between SPI and NDVI and their role to depict drought status, a combined NDVI-SPI drought maps were developed and it was promising in this study.
• During 2007, the Sulaimaniya governorate showed normal vegetation and rainfall.

• However, the vegetation experienced stress and loss in 2008, mainly due to lack of rainfall.
• From fig. 8 that there was a large increase in the areas of the first three classes of drought (extreme, severe and moderate) in 2008.

• Likewise, a considerable decline of vegetation area in 2008 compared to 2007.
• The combined NDVI-SPI maps also showed that drought in 2008 had a huge impact on the vegetation in the region.

• There was a large increase in percentage of drought classes, particularly the extreme, severe and moderate classes over the region in 2008.

• On the other side, large decline of vegetation classes was also observed including dense, moderate and poor from 2007 to 2008.
• The **highest percentage** of the **extreme drought** area over the region was recorded for **Sulaimaniyah** district (**9.7%**) in 2008.

• Therefore, the combined NDVI-SPI index behavior has been assessed for drought events that happened in 2008, showing its capability to distinguish between areas affected by drought.
The Statistical Analysis

• Statistical analysis was applied to investigate correlations among the various variables which have been employed in this study.

• The results showed a positive correlation between NDVI and SPI.

• Increasing rainfall and then moisture are helping to vegetation growth over the region as the region is mostly rain-fed area.
• A positive relation was also found between NDVI and band 4 (NIR) of Landsat images, as the reflectance in NIR is much higher than that in the visible bands.

• However, negative correlations were found between NDVI and each of the bands 1, 2, 3, 5, and 7.
In regard to the soil properties, **positive** correlations were found between NDVI and EC, O.M. and CaCO₃, while negative correlations were found with pH and CEC.

This result explained that some soil chemical properties might help plant growth improving.

The results showed that the statistical correlation between the SPI and NDVI indices was much higher in 2007 than 2008.
Conclusions

• Developing an integrated index for quantifying drought severity is a challenge for decision makers.

• Due to restrictions of the indices in drought assessing, a combined NDVI-SPI drought index has been developed using the NDVI and SPI indices.

• Generally, the spatial distribution of rainfall is highly varied with respect to altitudinal variation.

• This study found that the combined NDVI-SPI was promising in depicting drought severity than the use of NDVI or SPI individually.
References


The UNOOSA/Pakistan/PSIPW 4th Int. Conf. on Space Technology for Water Management, Islamabad, Pakistan, 26/2-3/2018.
Thank You for Your Attention!