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**.

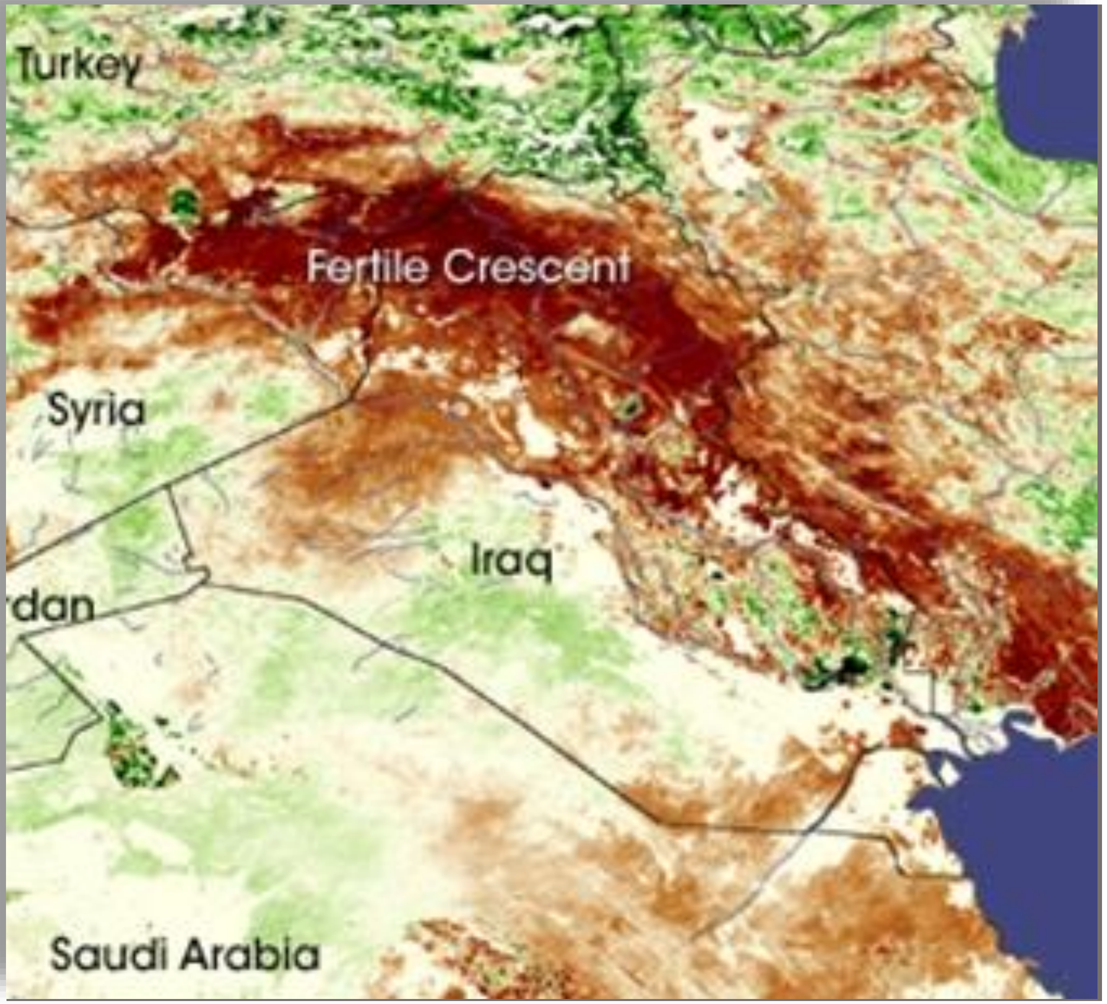
- Generally, the results of the combined **NDVI-SPI** maps emphasized the harsh impact of drought on the vegetative cover, which occurred in **2008**.

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 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).

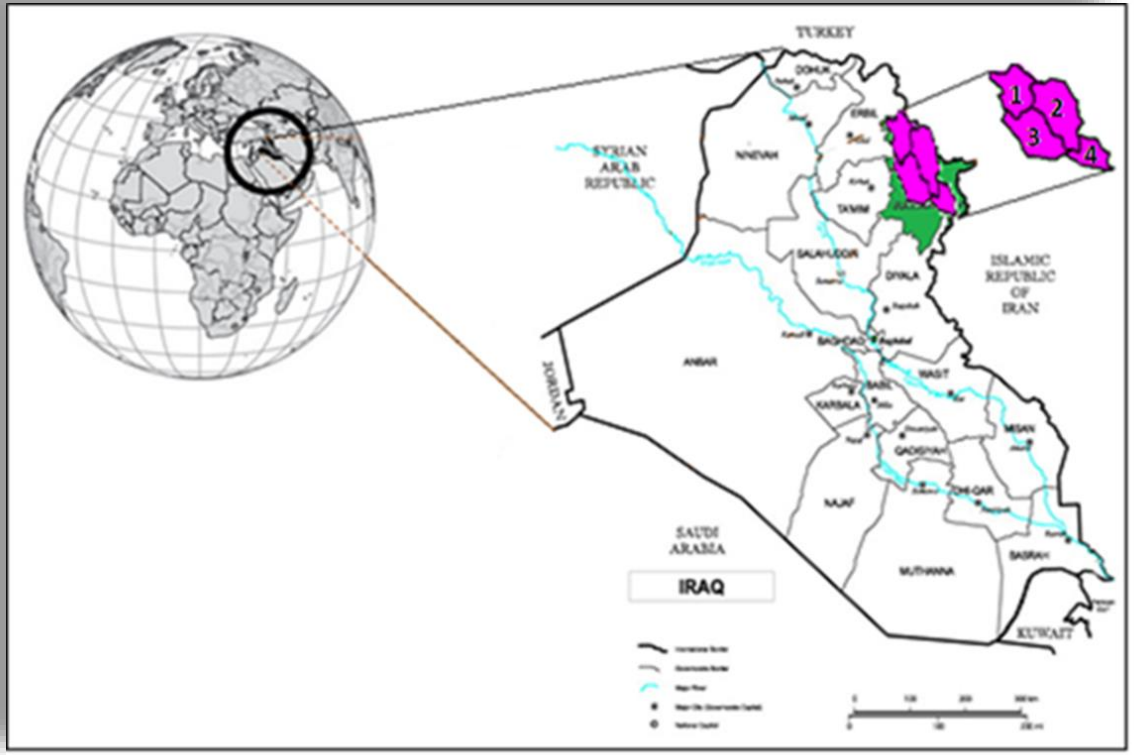
- The aim of this study was to investigate the role of **integration** of **NDVI** and **SPI** for drought monitoring in Iraqi Kurdistan during 1990, 2007, and 2008.

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.



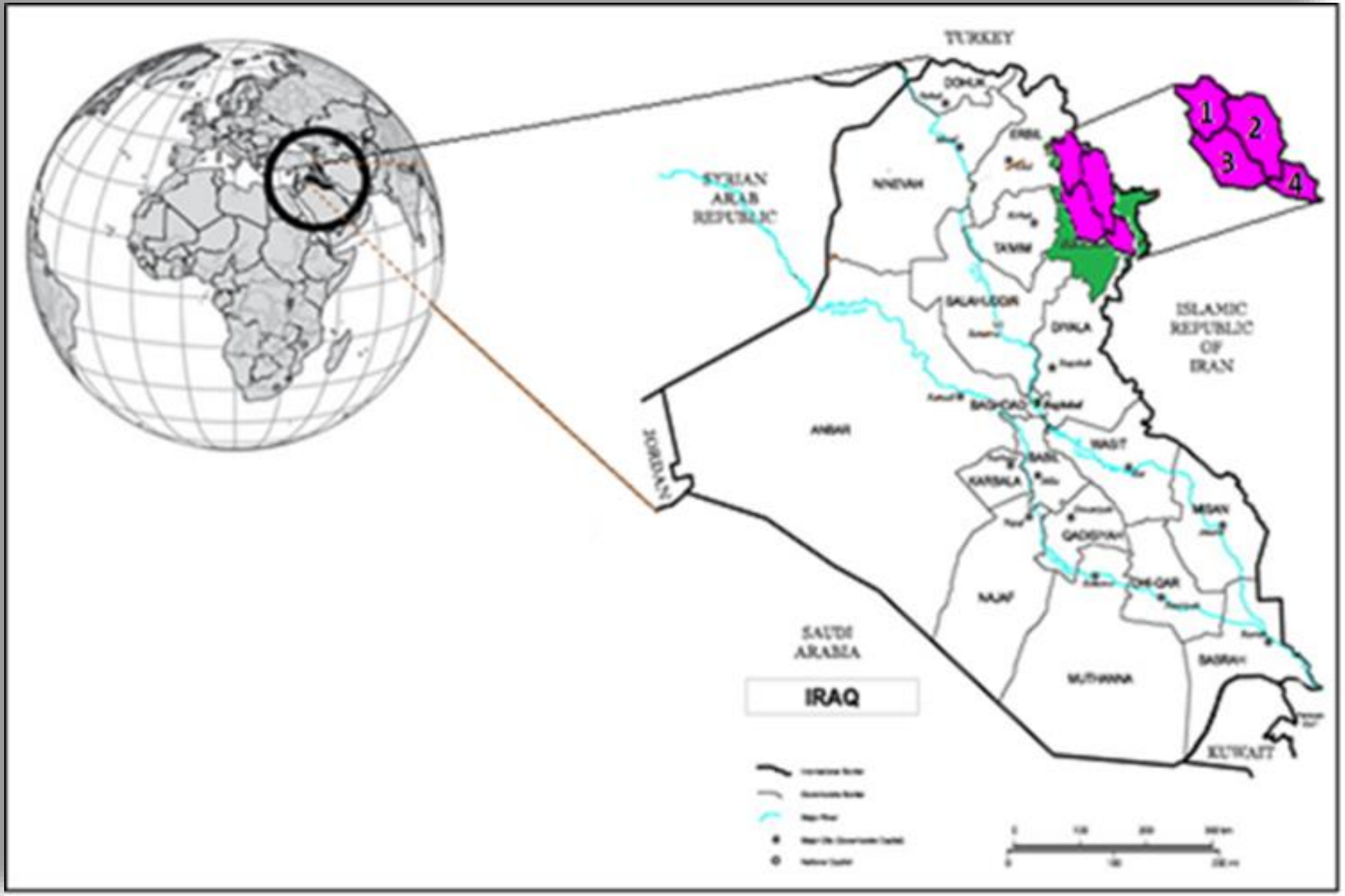


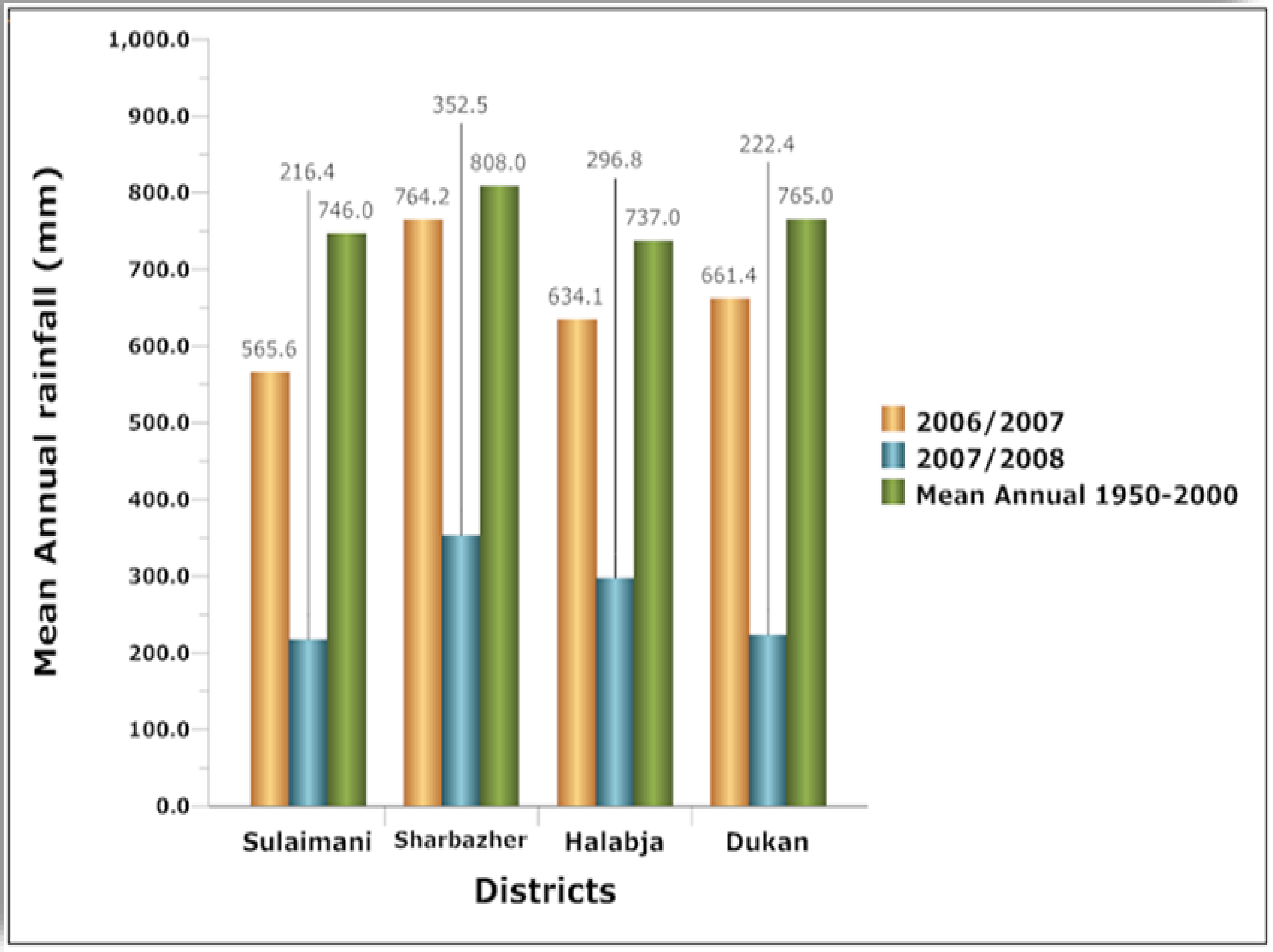
Fig. 1. Location map of the study area in the Sulaimaniya, Iraq, where 1: Dukan, 2:Sharbazher, 3: Sulaimaniya, and 4: Halabja

- 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°.



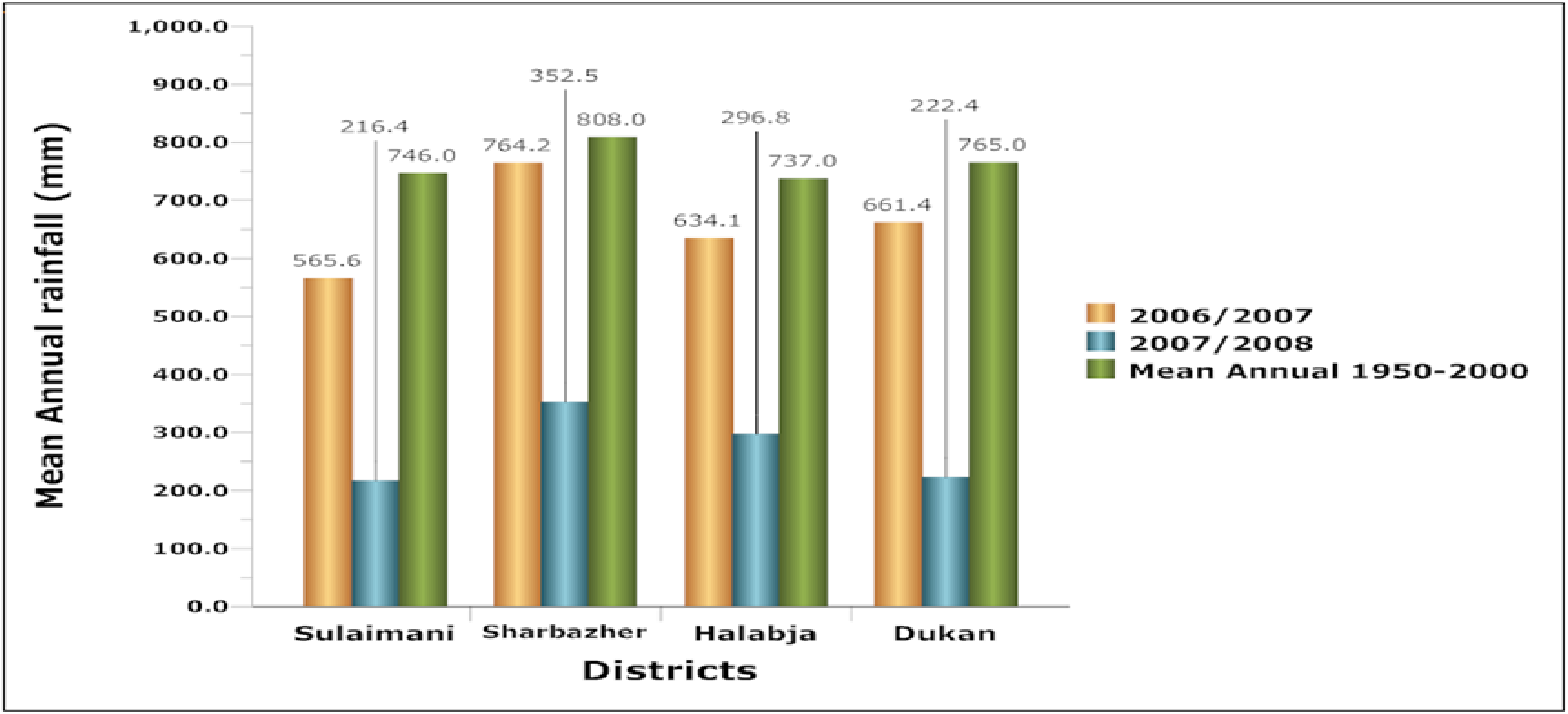


Fig. 2. The rainfall amounts and the mean annual of the rainfall in the four studied districts during the study periods.

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**.

SPI Value	Class
SPI > 2,00	Extreme wet
1,50 < SPI ≤ 2,00	Severe wet
1,00 < SPI ≤ 1,50	Moderate wet
-1,00 < SPI ≤ 1,00	Normal
-1,50 < SPI ≤ -1,00	Moderate dry
-2,00 < SPI ≤ -1,50	Severe dry
SPI < -2,00	Extreme dry

- 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

σ = 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.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

- 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**.

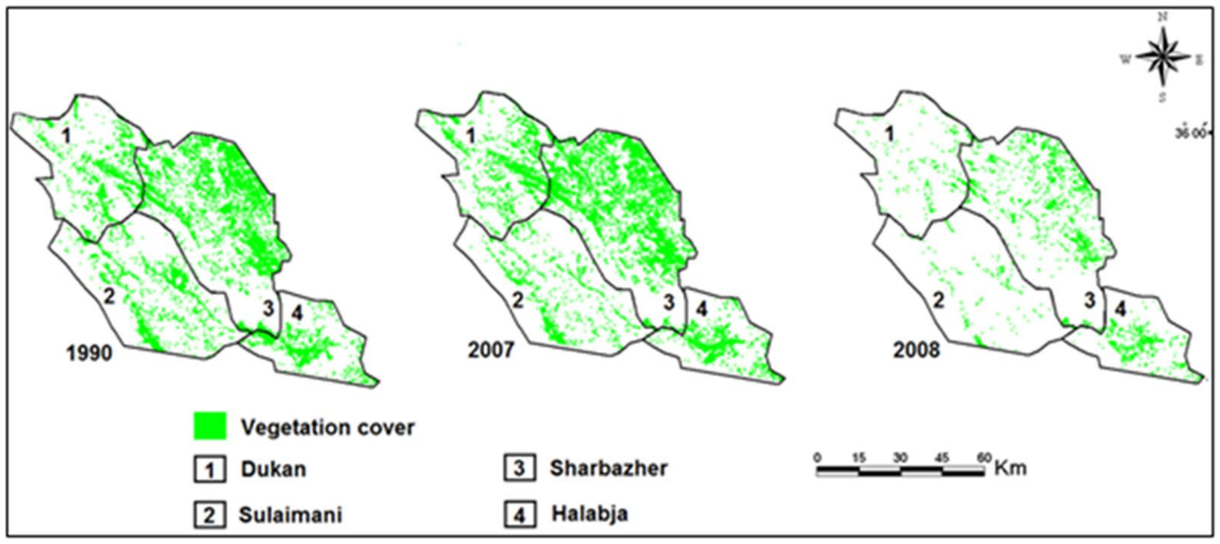
- The ratio between **band 3** (R) and **band 5** (short-wave IR (SWIR): 1.55-1.75 mm) spectral region clearly enhanced water bodies to the brighter pixels (CPM 2003).

$$\mathrm{NDWI} = \frac{\mathrm{R} - \mathrm{SWIR}}{\mathrm{R} + \mathrm{SWIR}}$$

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**.



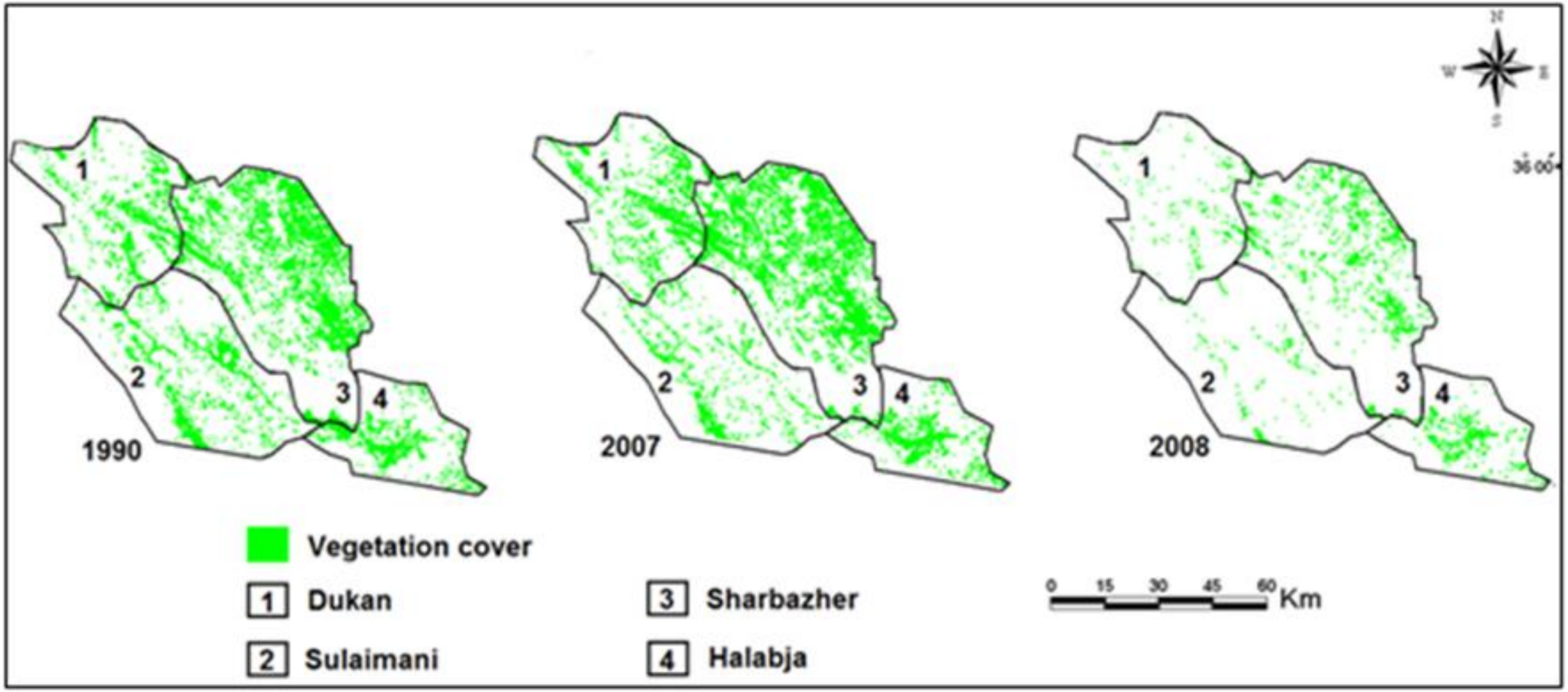


Fig. 3. The spatial distribution of the NDVI based vegetative cover in the study area for the years 1990, 2007, and 2008

Table 1. The total vegetative cover in the four studied districts for the years 1990, 2007, and 2008.

District Name	District area	Total Veg. Cover 1990		Total Veg. Cover 2007		Total Veg. Cover 2008	
	km^2	km^2	%	km^2	%	km^2	%
Dukan	1,537.9	574.1	37.3	772	50.2	184.4	11.9
Sharbazher	2,387.8	1,304.1	54.6	1,444.9	60.5	716.4	30
Sulaimaniya	2,018.3	661	32.7	602.4	29.8	130.4	6.4
Halabja	920.3	334.7	36.3	281.1	30.5	108.9	11.8
Total	6,864.3	2,873.9	41.7	3,100.4	45.2	1,140.1	16.6

- 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.

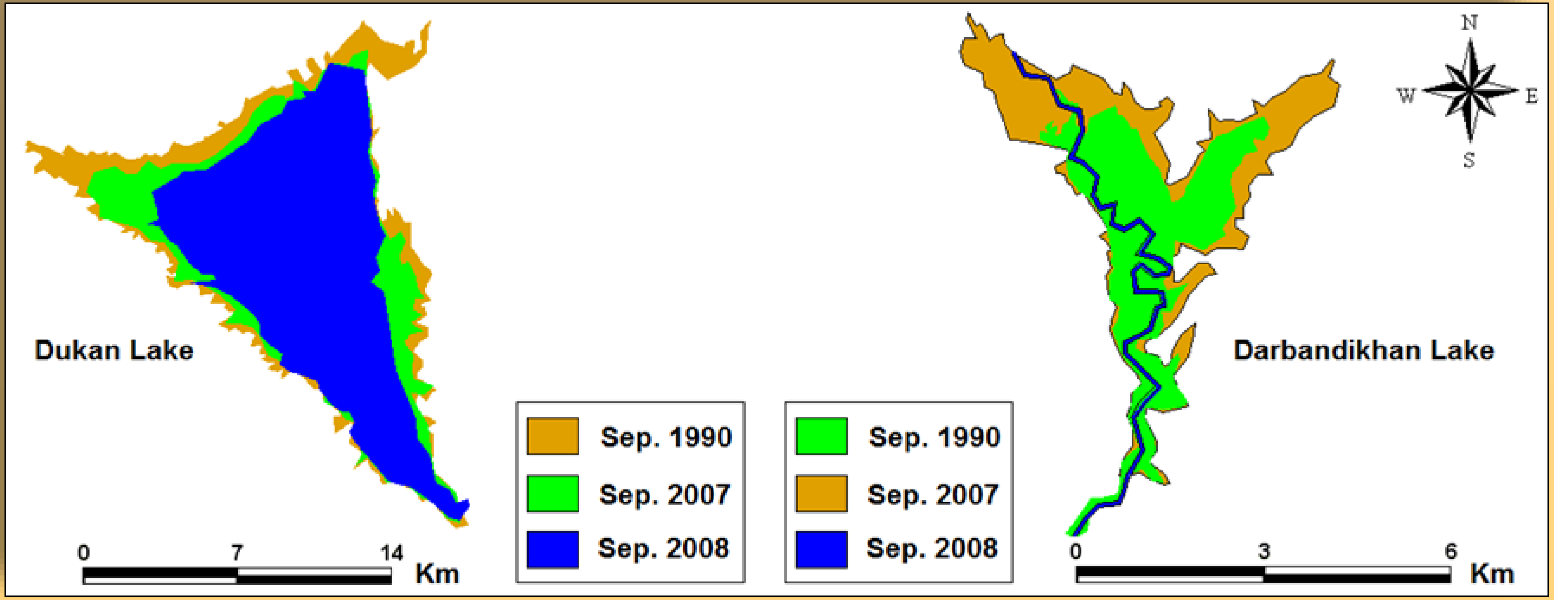
District name	2008-2007	Change rate	2008-1990	Change rate	2007-1990	Change rate
	%	Km^2. $year^{-1}$	%	Km^2. $year^{-1}$	%	Km^2. $year^{-1}$
Dukan	-38.2	-587.6	-25.3	-21.6	12.9	11.6
Sharbazher	-30.5	-728.4	-24.6	-32.6	5.9	8.2
Sulaimaniyah	-23.3	-472	-26.3	-29.4	-2.9	-3.4
Halabja	-18.7	-172.2	-24.5	-12.5	-5.8	-3.1
Total	-28.6		-25.3		3.3	

- The decrease of vegetation cover was due to the low rainfall amounts in 2007/2008.

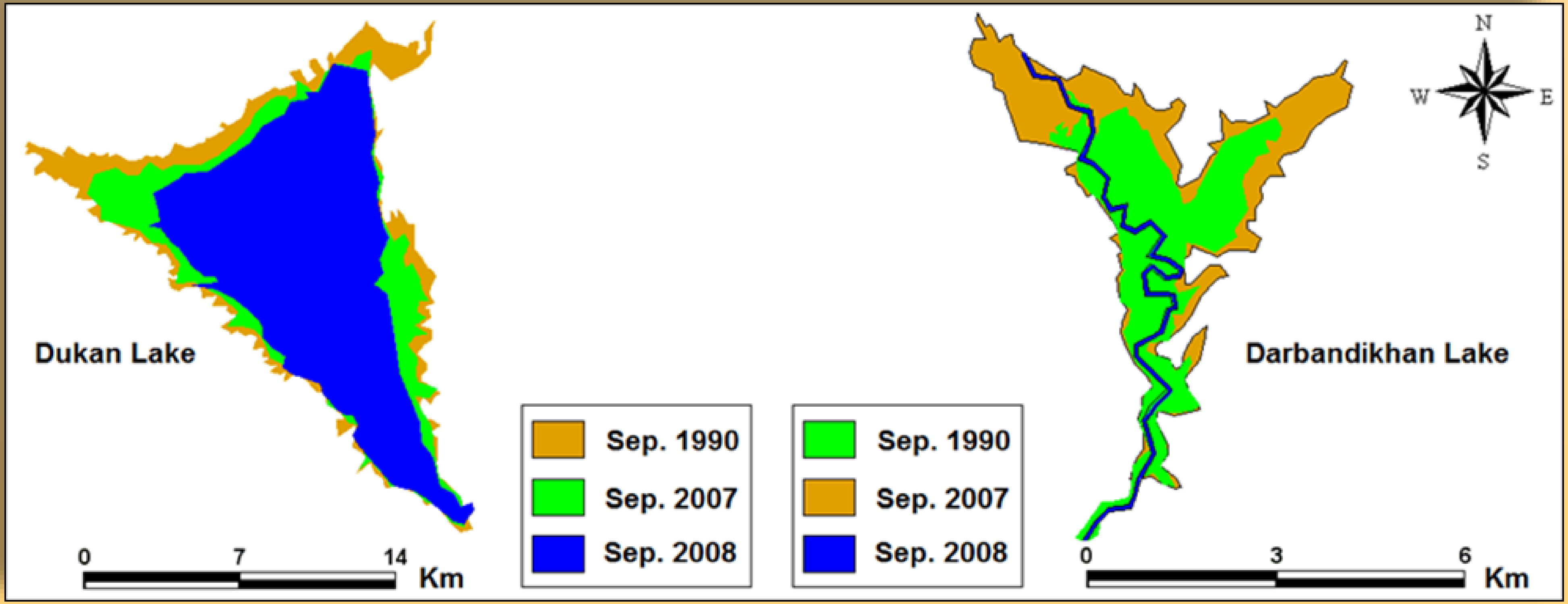
- Therefore, that **rainfall decrease** led to a **significant reduction** in surface and subsurface water resources such as the rivers, lakes, groundwater, and consequently decrease the soil moisture content.

The NDWI

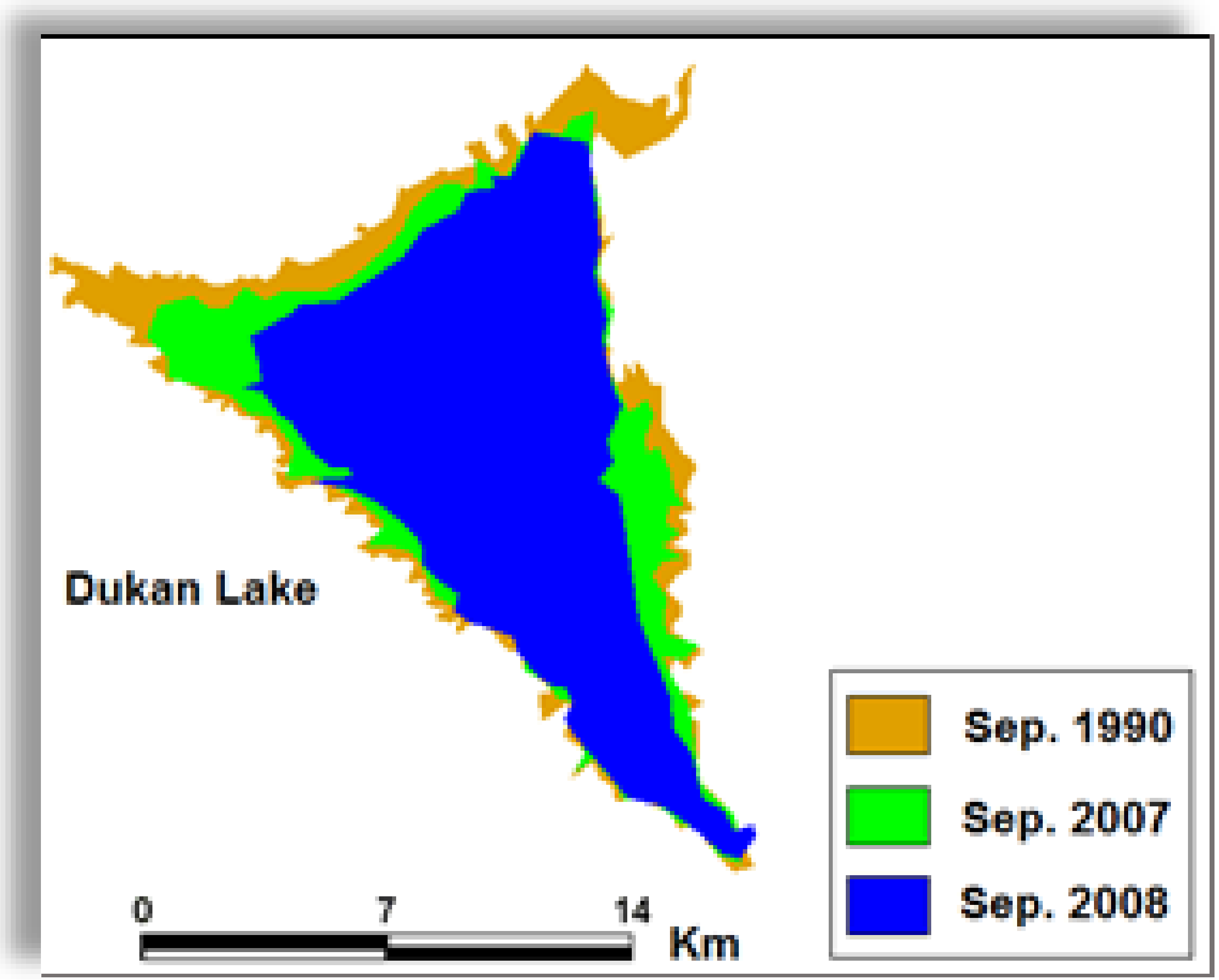
- The results showed a significant shrinkage (**23%**) in the water bodies areas such as the lakes and rivers from **1990 to 2008**.
- The entire water surface area was **187.4 km²** in **1990**, while it shrank to **153.8**, **125.6 km²** in **2007**, and **2008**, respectively.



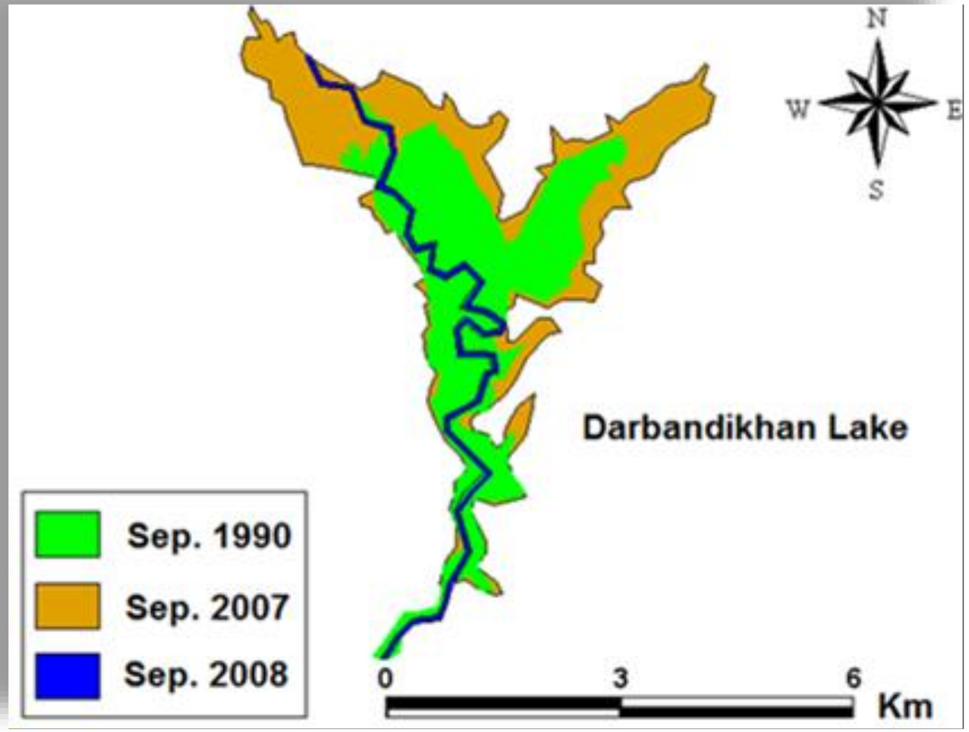
- It was clear that the surface size of **Lakes Dukan** and **Darbandikhan** have significantly shrunk during study years.



- **Dukan** Lake area it lost **16.5%** and **32.6%** from its total area in **2007** and **2008**, respectively.

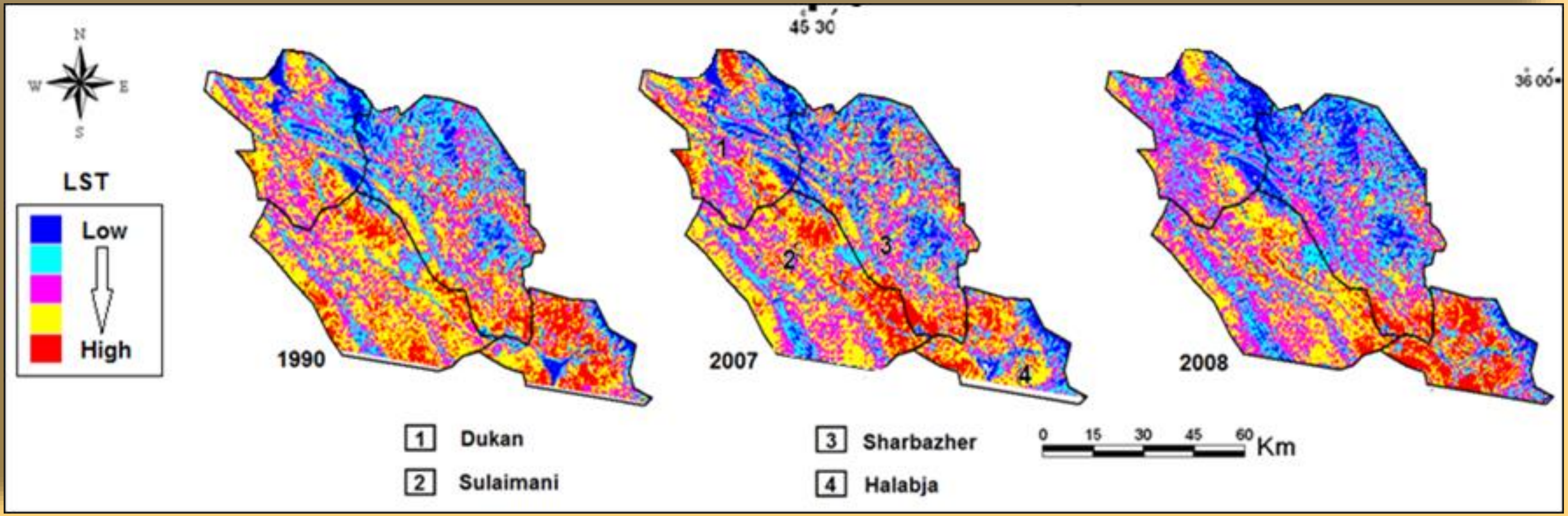


- **Darbandikhan Lake** shrunk to be a narrow stream as a result of the harsh effects of drought in **2008**.



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.



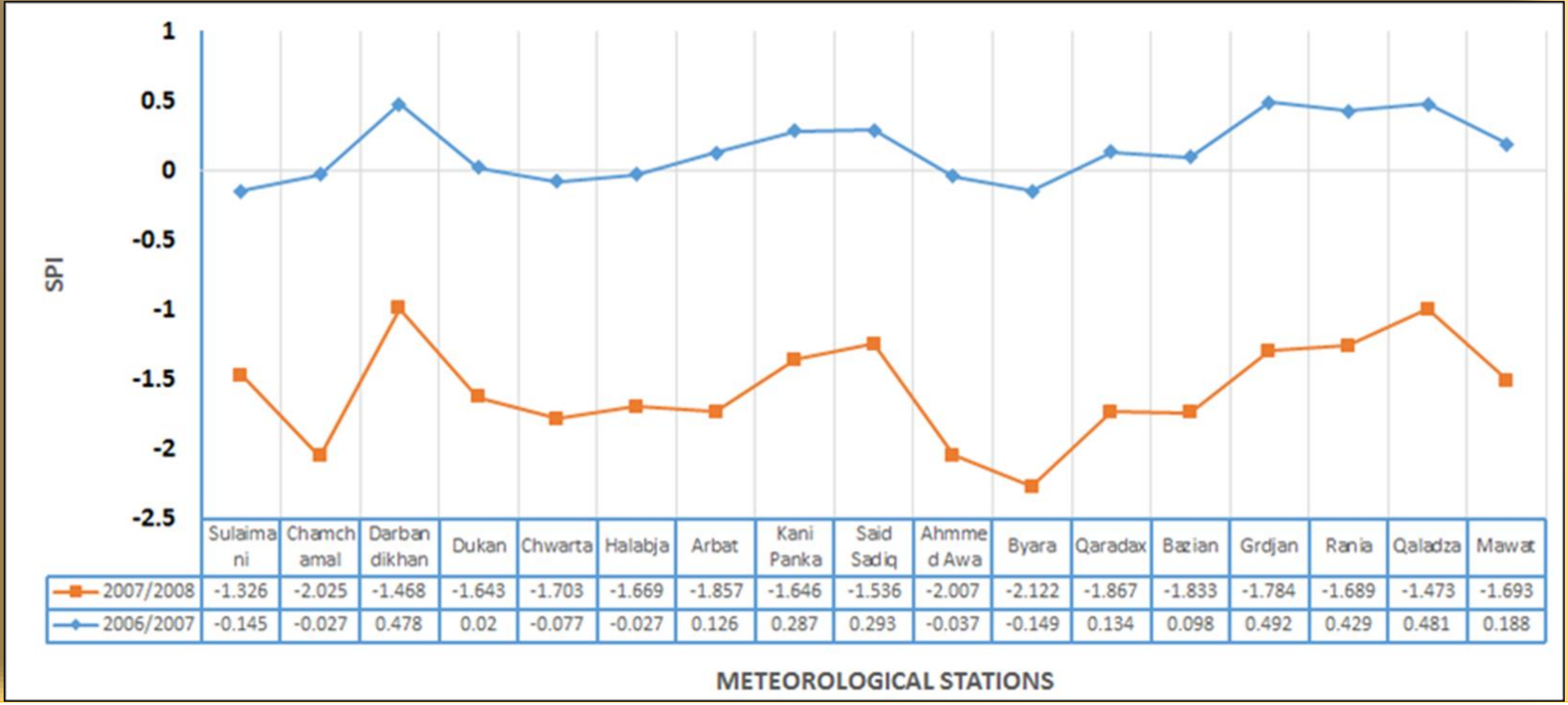
- It was found that the **bare lands** or the **poor vegetative cover** had the high **LST** values coupled with **low** soil/vegetation moisture content.

- 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.



	Sulaimani	Chamchamal	Darbandikhan	Dukan	Chwarta	Halabja	Arbat	Kani Panka	Said Sadiq	Ahmmed Awa	Byara	Qaradax	Bazian	Grdjan	Rania	Qaladza	Mawat
2007/2008	-1.326	-2.025	-1.468	-1.643	-1.703	-1.669	-1.857	-1.646	-1.536	-2.007	-2.122	-1.867	-1.833	-1.784	-1.689	-1.473	-1.693
2006/2007	-0.145	-0.027	0.478	0.02	-0.077	-0.027	0.126	0.287	0.293	-0.037	-0.149	0.134	0.098	0.492	0.429	0.481	0.188

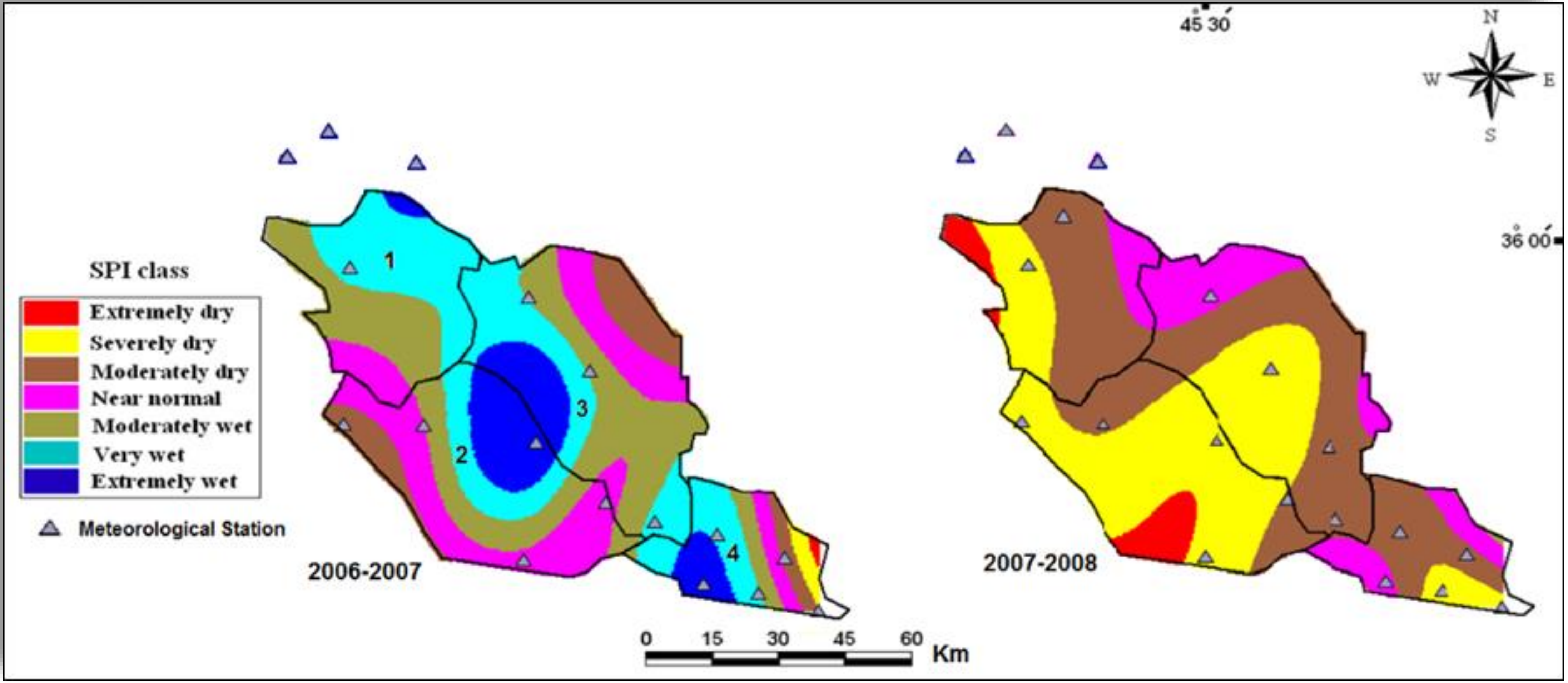


Fig. 7. The interpolated SPI categories maps of the study area for the hydrological years of 2006-2007 and 2007-2008.

- 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 sever dry class.

The Combined NDVI-SPI Drought Maps

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

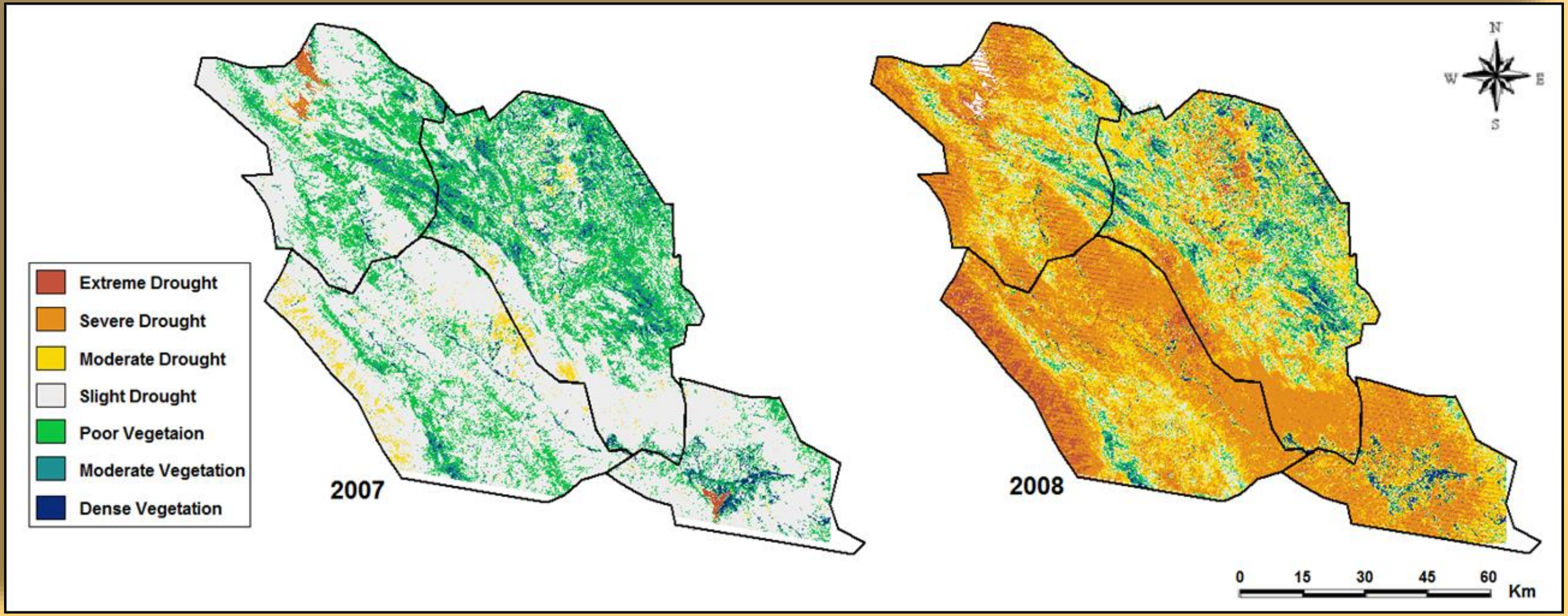
- GIS analysis (in ArcGIS) was conducted and reclassification was done to produce the combined NDVI-SPI maps.

- **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.



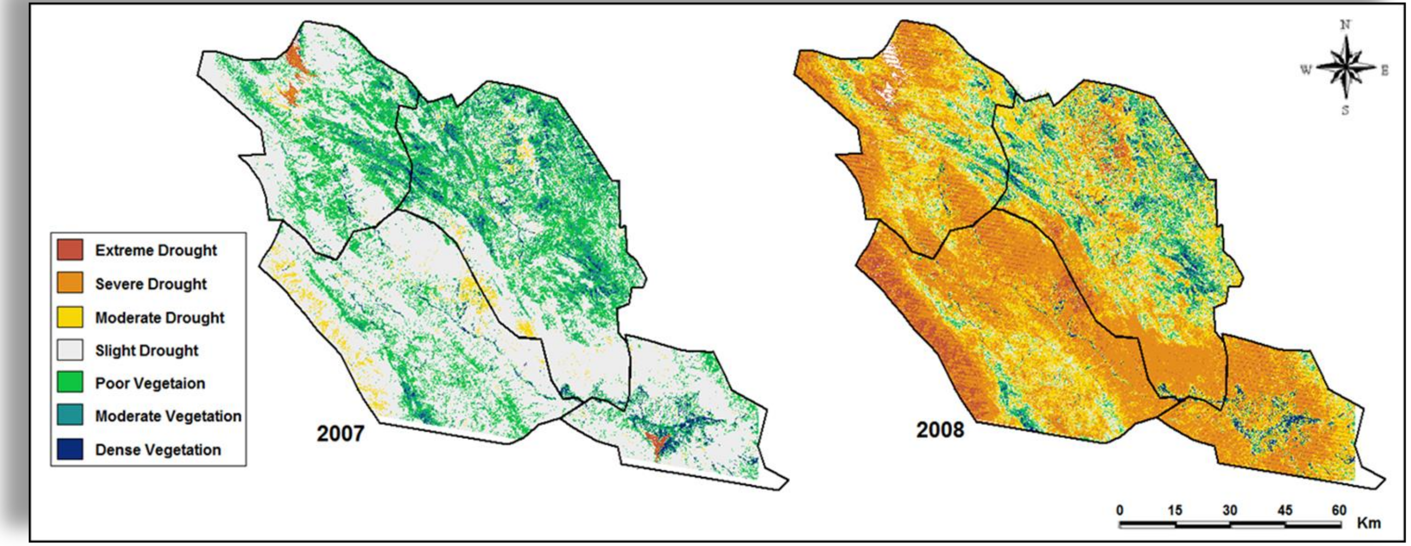
- In order to understand the relation between **SPI** and **NDVI** and their role to depict drought status, a combined **NDVI-SPI** drought maps were developed and it was promising in this study.

- 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 **$CaCO_3$**, 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.

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