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Iraq has suffered severely from drought in recent years and the year 2008 was the driest, particularly in the Iraqi Kurdistan region. This study incorporated Geoinformation technology into mapping the drought that severely affected the Kurdistan region in the years 2007–2008. Geoinformation technology provides support in the theories, methods and techniques for building, and development of Digital Earth aspect. Five vegetation, soil, water, and land surface temperature (LST) indices were applied to two Landsat 7 ETM+ imageries of June 2007 and June 2008, to assess the drought impacts in Erbil governorate Kurdistan during the study period. The indices that were employed in this study were Normalized Difference Vegetation Index, Bare Soil Index, Normalized Differential Water Index, Tasseled Cap Transformation Wetness, and LST. The results revealed a significant decrease in the vegetative cover (56.7%) and a decline in soil/vegetation wetness (29.9%) of the total study area. Likewise, there was a significant reduction in the water bodies surface area in the region such as Dokan Lake, which lost 32.5% of its surface area in comparison with the previous year, 2007. The study results showed that the soil moisture content was the most effective actor on the vegetative cover, LST, and drought status in the study area.

Keywords: Geoinformation technology; Digital Earth; Landsat-7 ETM+; drought; Iraqi Kurdistan region

1. Introduction

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman 1984). It is a serious and ubiquitous climatological phenomenon in almost all of the world's climatic regions. It has played a significant role in many human affairs. Drought always starts with the lack of precipitation, affecting soil moisture, streams, groundwater, water bodies, ecosystems, and human activities. This leads to the identification of different types of drought (meteorological, agricultural, socio-economic, and ecological), which reflect the perspectives of different sectors on water shortage (Sharma 2006). Agriculture is often the first sector to be affected by the onset of drought due to dependence on water resources and soil moisture reserves during various stages of crop growth.

The conceptual vision of Digital Earth (DE) originated with the published version of a speech of the US former vice president Al Gore (Gore 1998). DE is a

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virtual representation of the planet, an information system with a tremendous amount of multi-resolution and multi-scale data as shown in multiple dimensions. The advent of 'DE' enables us to use digital and global data with a computer and its network systems for processing, analyzing, and managing these data to meet our demands on solving problems for global sustainable development (Guo and Wang 2003). Geoinformation technology (Geographical Information System (GIS); remote sensing (RS); and Global Positioning System (GPS)) is an aspect of DE and has offered a sophisticated system for generating, storing, checking, manipulating, and analyzing the geometric and semantic information about the spatial elements.

The changes of soil moisture under drought conditions would lead to significant changes of soil spectral reflectance observed on RS images (Gao *et al.* 2008). Bowers and Hanks (1965) found that the increase of soil humidity in bare surface would lead to the decrease of soil reflectivity. A number of different indices have been developed by many researchers to quantify, monitoring, and mapping the drought depending on the climatological factors and the indices extracted from the remotely sensed data. In recent decades, several indices, such as Vegetation Condition Index (Kogan 1990), Normalized Difference Vegetation Index (NDVI; Wilhite 2000), Temperature–Vegetation Drought Index (Sandholt *et al.* 2002), Vegetation Supply Water Index (Carlson *et al.* 1990), and Normalized Differential Sand Dune Index (Fadhil 2009) were proposed for drought monitoring on the basis of vegetation indices and land surface temperature (LST). Thus, the researchers have begun to focus on the response of vegetation cover to drought stress, and likewise on RS of vegetation as an indirect observation of drought stress.

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 from neighboring countries. Northern Iraq (which includes the Kurdistan region), is the country's historical breadbasket, where rain-fed wheat is grown. The winter wheat crop depends on the rain that falls between October and April. Since the crop has little access to other sources of water, the vegetation conditions show a direct response to the lack of rainfall at the end of the critical rainfall period in April. Therefore, the winter crops were severely affected in the period 2007–2008. The three governorates of the Kurdistan region (Erbil, Sulaimaniyah, and Duhok) seriously suffered from the water deficiency due to the low annual average precipitation through the last years. In the winter of 2007 and spring of 2008 (hydrologic year 2007–2008), there was a continuous high air temperature and approximately 41% precipitation decrease by contrast with the average in the Iraqi Kurdistan region and other parts of Iraq. That reduction led to a severe drought occurring once in the last decades. The drought has also scaled down water supplies available for the Kurdistanian and other Iraqian farmers through the rivers and water bodies in the Kurdistan region and other parts of Iraq.

The objectives of this study were:

(1) Monitoring, mapping, and assessment of the drought phenomenon for some sites in the Iraqi Kurdistan region during the severe period of drought during the years 2007–2008 at a district level with the aid of Geoinformation technology.
(2) Analyzing the impacts of drought on the vegetative cover, soil/vegetation moisture, LST, water bodies surface area, and estimating the statistical

relationships (correlations and regressions) among the studied indices to find the most effective factor on the studied indices.

(3) Suggesting some solutions to mitigate the negative impacts of the recurring droughts in the Iraqi Kurdistan region.

2. Study area

The Iraqi Kurdistan region is located in the northern part of Iraq. It consists of three governorates, Erbil (the region's capital), Sulaimaniyah, and Duhok. The study area (Figure 1), which covers seven districts entirely (Choman, Erbil, Koya, Makhmour, Shaqlawa, Soran, and Rania), is located in Erbil and the surrounding area encompassing 1,256,022.2 ha (12,560.2 km^2). It extends from latitude 35°23′55″ to 36°58″21′ N and longitude 43°11′47″ to 45°09′53″ E. Erbil city is the capital of the

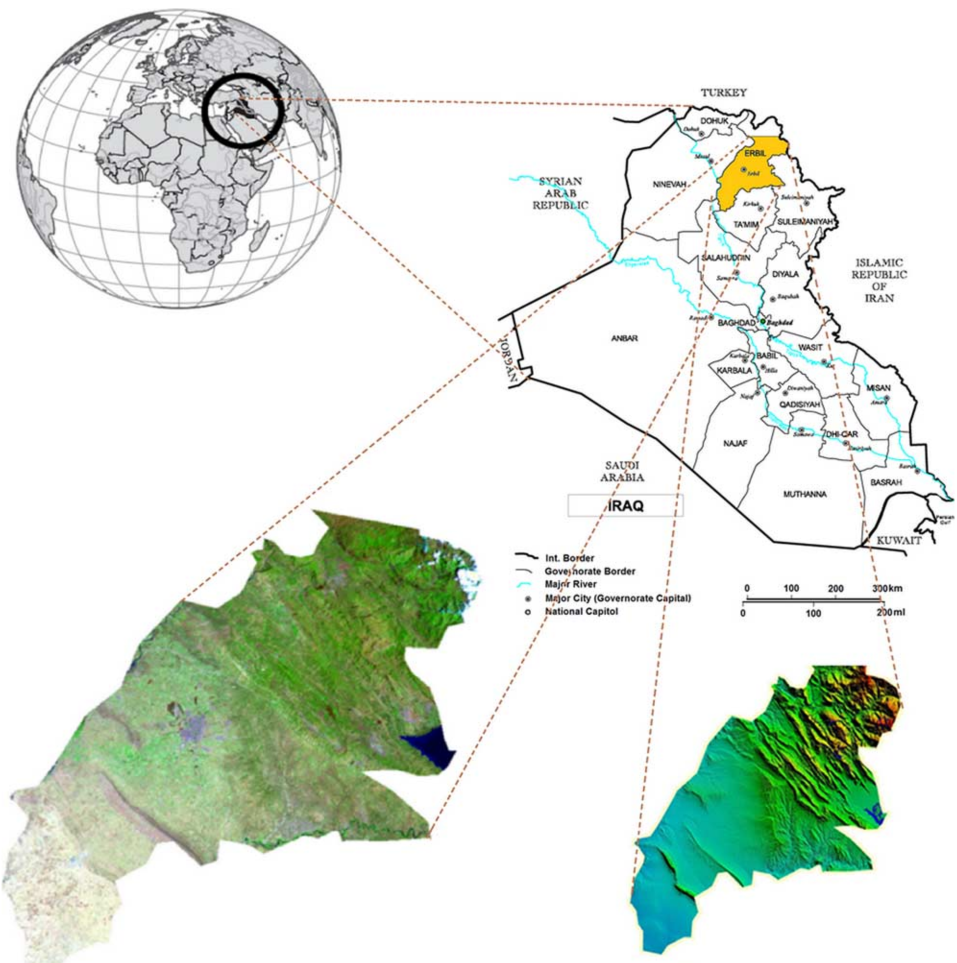

Figure 1. Location map of the study area in the Iraqi Kurdistan region and its 2007s ETM+ and DEM images.

Kurdistan region with a population of more than 1.2 million and located 382 km north of Baghdad, the capital of Iraq.

2.1. Physiography

The main features of the Iraqi Kurdistan region can be summarized as follows. The region is divided into three main physiographic zones, namely: (1) the northern range of the Zagros Mountains; (2) the central range of the border folds; and (3) the southern plains of the Tigris River. The north-northeastern part of the region is characterized by the Iraqi Zagros Mountain range with heights up to 3600 m above sea level (asl). Snow coverage is common at high altitudes and vegetation cover is widespread, constituting both grasses and forests. A smoother morphology occurs in the central part; the area being characterized by an anticline/syncline system (Boccaletti and Dainelli 1982), which gives rise to a relief with a general orientation NW–SE. Heights of up to 2000 m (asl) are reached.

2.2. Hydrology

2.2.1. Surface water resources

Significant surface water resources occur in the northern part of the Iraqi Kurdistan region. The major perennial rivers are the Great and the Small Zab (both in a NNE–SSW orientation). The rivers' flows reduce toward the South and ultimately, on the plains, all tributaries are ephemeral and dry out regularly by the end of springtime (end of May). It is important to note that almost all the major rivers crossing the study area have their origin outside it, namely in Turkey (the Great Zab) or in Iran (the Small Zab), thus their entire watershed covers broad regions outside the study area. Only the Small Zab has a catchment area that extends, for a limited portion, beyond the northern Iraqi borders.

2.2.2. Groundwater resources

There is good quality subterranean water in the region, in which the main sources of recharge are the rainfall and snowfall amounts in the mountain areas of the Iraqi Kurdistan region. Groundwater is the main source of drinking water and irrigation purposes in the region (Abbas 2008).

2.3. Soil and vegetation

The soil in the mountain valleys, foothills, and adjacent plains of the Kurdistan region were formed by erosion processes. The hills are covered by shallow to medium chestnut soil and rendzian, and the valleys are covered by shallow to deep chestnut soil, whereas the foothills have mainly brown soil (Stevanovic and Markovic 2003). Wheat and barley are the main crops in the winter season depending on the rainfall, while many other agricultural crops grow depending on underground water resources during the summer. In Erbil governorate, about 41% are arable and 59% are non-arable lands, while 93% are rain-fed and 7% are irrigated lands (DSMA 2007).

2.4. Climate

The climate of the Iraqi Kurdistan region is characterized by cold and snowy winters, and warm dry summers. On the plains, typical semi-arid climatic conditions prevail. Precipitation occurs from October to May, decreasing from the NE to SW. A strong correlation between the number of rainy days and the geographical locations (altitude) in the Kurdistan region has been found by Ismail (1994). The mean annual rainfall in Erbil plain for the period 1941–1970 was 425 mm/year, while observed yearly values range between 200 and 700 mm. The recent meteorological data of the years 2007–2008 showed a significant reduction of about 70% in the rainfall amount as compared to the average. Figure 2 presents the total rainfall amounts in the studied districts for the two years 2007 and 2008 in comparison with the general mean values.

3. Methodology

3.1. Satellite-based remote sensing (RS) data

The Landsat images of earth observation satellites provide a unique historical dataset for change detection studies. Two Landsat 7 ETM+ images (path 169/row 35) acquired on 23 June 2007 and 9 June 2008 were assembled for this study. The first one (of the year 2007) was purchased from http://www.usgs.gov which covers the study area, while the second image (of the year 2008) which was downloaded from the same source was a SLC-off data type image. Gap-filling procedure was adopted using model maker menu of Erdas Imagine to run a model which was particularly created to perform the task. The two images were then pre-processed, processed, and analyzed for the purposes of this study. In view of the objectives of the study, Landsat 7 ETM+ datasets were selected as acquired in the dry season, to evidentate features (vegetation and soil moisture) concerning the occurrence of drought and to avoid

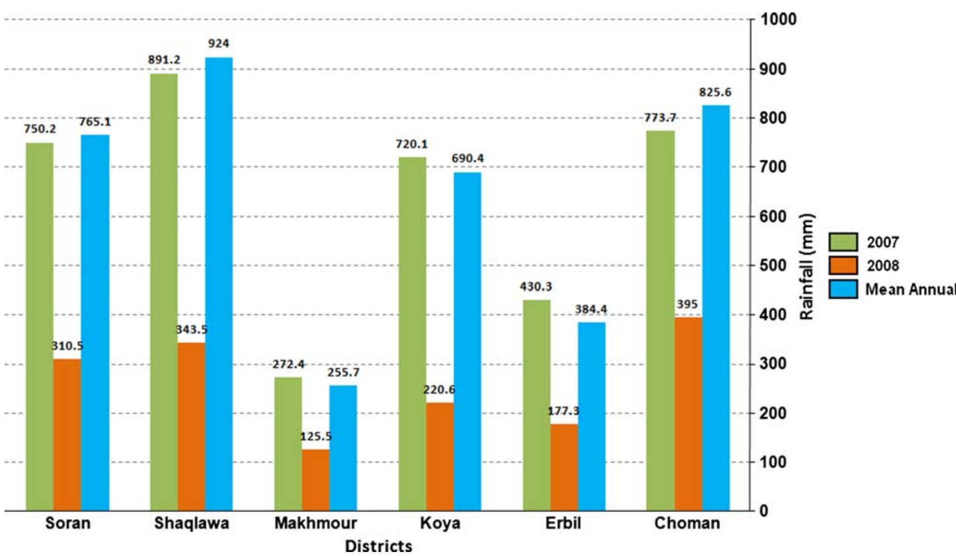

Figure 2. The reduction in rainfall annual depth in the studied districts for the years 2007 and 2008 in comparison with the mean annual values.

overshadowing by too much vegetation. The ETM+ imageries were subset in order to focus on the study area (Figure 1).

3.2. Pre-processing

The raw satellite images were converted from Geo Tag Image file format (GeoTiff) to ER Mapper raster format (ers) using ER Mapper for process and analysis. The pre-processing stage included radiometric calibration and image registration. Rectification and registration for ETM+ images were based on ground control points using 50 points. The remotely sensed dataset were then geometrically corrected in the datum WGS84 and projection UTM zone N38 using the first order (linear) of polynomial function and nearest-neighbor rectification re-sampling, which was chosen in order to preserve the radiometry and spectral information in the imagery (Richards and Jia 1999). Image-to-image registration has been done in order to register the ETM+ image (dated 9 June 2008) with the geocoded ETM+ image dated 23 June 2007 (master image). The RMS errors of the registration were between 0.20 and 0.25 pixel.

3.3. Drought indices

To track and monitor the drought situation in the region under study, and because there is no single definition for the drought, it is vital to employ some drought indices related to the vegetation, soil, and water status in this study. Vegetative cover, soil/vegetation moisture, and LST were utilized as indicators of the drought. The status of water bodies in addition to the utilization of meteorological data of the study area during the study period were also used in the study.

3.3.1. Vegetation, soil, and water indices

The Landsat 7 ETM+ Bands 1, 2, 3, 4, 5, 7, and Band 6 (thermal infrared) of the two images were utilized to derive the studied indices. Satellite-based derived indices images were then produced in order to assess the impacts of drought on vegetation, soil moisture, and water bodies in the study area during the years 2007 and 2008.

3.3.1.1. The Normalized Difference Vegetation Index (NDVI). NDVI was initially proposed by Rouse *et al.* (1974). The NDVI derived from the ratio of Band 3 (red (R): 0.63–0.69 μm) and Band 4 (near infrared (NIR): 0.76–0.90 μm) of the Landsat ETM+ images. The NDVI is the most commonly used vegetation index as it has a desirable measurement scale ranging from -1 to 1, with 0 as an approximate value of no vegetation. Negative values represent non-vegetated surfaces, whereas values close to 1 have very dense vegetation. The NDVI has the ability to reduce external noise factors, such as topographic effects and sun-angle variations (Anyamba *et al.* 2005). It is found that the NDVI is sensitive to the rainfall and there is a positive relationship between them (Kogan 2008). The NDVI algorithm was applied for monitoring vegetation changes in this study.

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

3.3.1.2. The Normalized Differential Water Index (NDWI). The Normalized Differential Water Index (NDWI) was used to oversee the condition of the soil moisture and the water bodies status in the study area. The ratio between Band 3 (R) and Band 5 (short-wave IR (SWIR): 1.55–1.75 μm) spectral region clearly enhanced water bodies to the brighter pixels (CPM 2003).

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

3.3.1.3. Bare Soil Index (BSI). Bare Soil Index (BSI) was computed to identify the bare soil, which includes bare areas (houses, roads, urban, rural built up areas, eroded areas, and non-agriculture areas). The bare soil areas were enhanced using the 'BSI' (Jamalabad and Abkar 2004). The ratio among Bands 5, 3, and Band 2 (Blue (B): 0.45–0.52 μm) is calculated as below:

$$\mathrm{BSI} = \frac{(\mathrm{SWIR} + \mathrm{R}) - (\mathrm{NIR} - \mathrm{B})}{(\mathrm{SWIR} + \mathrm{R}) + (\mathrm{NIR} + \mathrm{B})} + 1$$

3.3.2. Tasseled Cap Transformation Wetness (TCW)

Tasseled Cap Transformation Wetness (TCW) was updated by Crist (1985) for use with Landsat TM data. It was used to determine the amount of moisture being held by the vegetation or soil, thus termed wetness, as well as to other indicators point to the vegetation and the brightness of soil. TCW images were derived from ETM+ images of the study area using tasseled cap transformation algorithm with ER Mapper according to the following equation:

$$\mathrm{TCW} = 0.1509\ (\mathrm{B}) + 0.1973\ (\mathrm{G}) + 0.3279\ (\mathrm{R}) + 0.3406\ (\mathrm{NIR}) - 0.7112\ (\mathrm{SWIR}) - 0.4572\ (\mathrm{SWIR}_2)$$

3.3.3. Land surface temperature (LST)

Two factors let the vegetative cover play a positive role in mitigating land surface warming. One is the shielding effect of the forest canopy, which blocks and absorbs energy from the sun. The other one is the evaporation from the leaf surface, which mitigates warming. The source of thermal information was the infrared band of ETM+ images (Band 6). The temperature calibration of the thermal infrared band into the value of ground temperature has been done using Equations (1) and (2).

$$L = L_{\min} + ((L_{\max} - L_{\min})/255) * Q) \quad (1)$$

$$T = K_2/(\ln (K_1/L + 1)) \quad (2)$$

where L is value of radiance in thermal infrared; T is ground temperature (K); Q is digital record; K_1 and K_2 are calibration coefficients: $K_1 = 666.09$ W/(m^2 ster μm) and $K_2 = 1282.71$ K; $L_{\min} = 0.1238$ W/(m^2 ster μm); and $L_{\max} = 1.500$ W/(m^2 ster μm).

3.4. Change detection

RS-based change detection is the process through which changes in the state of an object or a phenomenon are identified by observing it over repeated time intervals (Beland *et al.* 2006). The change detection technique was used to map and to assess the land cover changes between two or more time periods; in addition, it is an essential tool for drought monitoring activities. The post-classification comparisons (for two dates) and the image differencing techniques were adopted in this study to find out and to estimate the land cover changes in the study area during the years 2007 and 2008. The produced indices images were converted then from raster to vector format in order to use them in a GIS environment. An accuracy assessment of the NDVI fraction image classification was done.

3.5. Meteorological data

Meteorological data for studied districts were assembled from the meteorological station in Erbil, Iraqi Kurdistan region.

3.6. Ancillary data and software packages

The districts administrative boundaries map of the Iraqi Kurdistan region was digitized, and then projected in order to be used in GIS environments. DEM, district-level socio-economic data, meteorological data, and several packages were used to perform the tasks of this study. ER Mapper ver 7.1 and Erdas Imagine ver 9.2 packages were utilized for image processing, extracting the studied indices, and analyzing. ArcView GIS and ArcGIS ver 9.3 were also used for analyzing and presenting the results. Statgraphics Centurion XVI and Microsoft Excel were employed for statistical analyses and arrangement of data.

3.7. Geographical Information System (GIS) environment

The produced fraction images, such as NDVI, TCW, NDWI, BSI, LST, and classified NDVI image which was produced using ER Mapper and the related algorithms were then exported as GeoTiff file format to open them in a GIS environment. In ArcView GIS software, the files were then converted to a shape file format using spatial analysis extension. Each dataset was aligned to a map coordinate system for precise area location. Several layers (themes) were done for both years 2007 and 2008 represented the studied indices in addition to the districts boundary themes. Overlay technique and select by theme method were adopted to calculate the thematic layer area for each district.

4. Results and discussion

Five vegetation, soil, and water satellite-based indices were used to evaluate and to map the impacts of drought on the vegetative cover, soil/vegetation moisture, water bodies dryness circumstance, and the LST for seven districts in Erbil and the surrounding areas. The study then endeavored to find the statistical relations among the studied indices and the most effective factor on the drought.

4.1. Impacts of drought in the Kurdistan region of Iraq

Iraq (including the Kurdistan region) has been experiencing one of the worst droughts in the last decades. There are several impacts of drought, such as economic, environmental, or social in the region as in the other areas of Iraq. Drought impacts were commonly referred to as primary (direct) impacts, such as reduced vegetative cover and decreased soil/vegetation moisture. Those effects consequently lead to less crop productivity, diminish water bodies surface areas, degrade numbers of livestock herds, and increased fire hazard. While the secondary (indirect) impacts of drought leading to restrict the income of farmers as well as having to provide food needs by purchasing from local markets. All those impacts have occurred in the region throughout the study period. Acute drought conditions have predominated the entire winter growing season of 2007–2008, and have severely impacted non-irrigated grain production in the region and likewise to other parts of Iraq. Most of the Kurdistanian farmers depend on the rainfall in their non-irrigated agriculture. The non-irrigated agriculture crops depend directly on the rain as their main water source. In the case of no rain, the crops do not get the water they need to survive, and then they will fail. That was exactly what happened for the growing crops in the Kurdistan region in the growing season of the hydrologic year 2007–2008. A severe dryness has in addition affected the whole water bodies in the Kurdistan region, as with the big and small rivers, tributaries, lakes, and reservoirs such as Dokan and Darbandikhan Lakes.

The results of this study reflected many faces of the harsh impacts of the drought that severely hit the Iraqi Kurdistan region on the vegetative cover, soil/vegetation moisture, LST, and the water bodies surface size. The following paragraphs attempt to show and discuss the results.

4.2. The vegetative cover

The decline and shrinking areas of vegetation (forests, winter crops, farm lands, and natural vegetation) in the region due primarily to lower soil moisture content caused by the low averages of annual rainfall during the period from October 2007 to May 2008. Most of the cultivated areas in the region are non-irrigated crops. Thus, low rates of annual rainfall in the year 2008 by more than 41.2% in comparison to the annual mean led to acute dryness in the water bodies and water resources, in addition to a significant decline in the soil/vegetation moisture content. This situation caused a big failure in the cultivated area of winter crops, such as wheat and barley in the region, and to a significant reduction in the pasture areas suitable for grazing sheep and cattle.

NDVI algorithm was utilized in the present study as an indicator of the vegetative cover status. The index results showed a significant decrease for the vegetative cover areas during the period of the study. Figure 3 and Table 1 clearly show the decrease in the vegetative cover in the studied districts. There was a significant decline in the

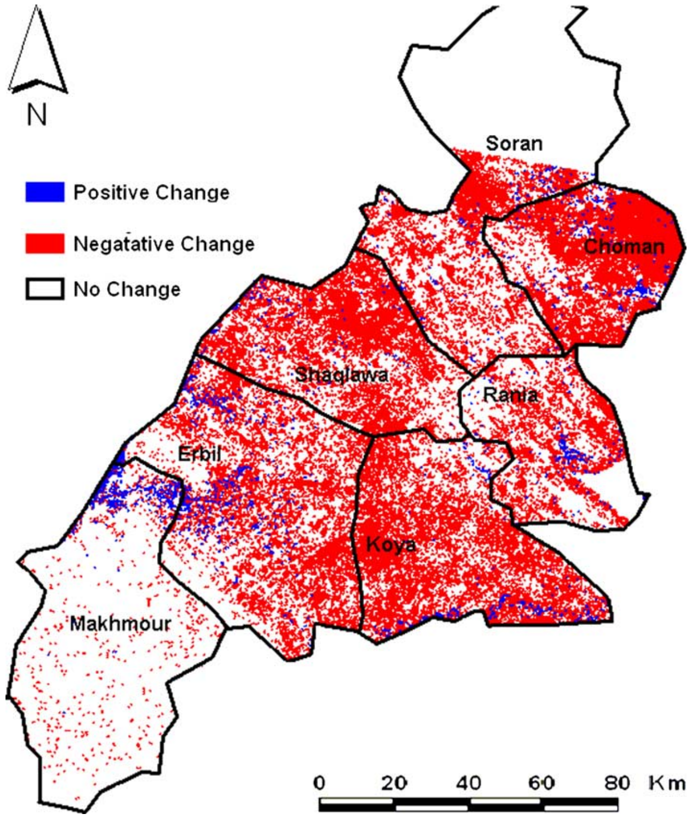

Figure 3. The spatial distribution of the positive, negative, and no changes in the vegetative cover for the study area during the period from 2007 to 2008.

extent of vegetation cover in the remote areas of river basins, lakes, and those characterized by high population density. That explains the results of irrigation water deficiency, the pressure of animal grazing, and human use. Adverse soil moisture content and temperature conditions in combination with low rainfall averages create sundry different types of vegetative cover stress.

4.3. Soillvegetation moisture and water bodies surface area

The results of soil/vegetation moisture indicator TCW demonstrate an obvious decrease in the soil/vegetation moisture during the study period. Particularly, in districts located north of Erbil, which are normally characterized by rainfall averages higher than rainfall averages of the districts located south of Erbil. The positive and negative changes in soil/vegetation moisture were less in the Makhmour district in comparison with other districts. The little changes were due to the little differences in the annual rainfall amounts of 2007 and 2008 in Makhmour. The considerable differences between the annual rainfall amounts of 2007 and 2008 in the other districts then led to significant differences in the vegetative cover extent percentage and soil/vegetation moisture content as presented in Figure 4 and Table 2.

Table 1. District-level NDVI results of the study area for the period from 2007 to 2008.

	District area	NDVI positive		NDVI negative		No change		2007/2008	
District name	ha	ha	%	ha	%	ha	%	ha	%
Choman	125,321.50	1050.8	0.838	47,381.60	37.8	76,889.1	61.4	−46,330.8	−37.0
Erbil	255,852.50	2407.6	0.941	35,566.10	13.9	217,878.8	85.2	−33,158.5	−13.0
Koya	190,952.60	883.3	0.463	37,606.40	19.7	152,462.9	79.8	−36,723.1	−19.2
Makhmour	251,138.50	1735.4	0.691	4283.10	1.7	245,120.0	97.6	−2547.7	−1.0
Rania	123,923.90	867.6	0.700	14,738.90	11.9	108,317.4	87.4	−13,871.3	−11.2
Shaqlawa	165,469.20	551.5	0.333	31,710.90	19.2	133,206.8	80.5	−31,159.4	−18.8
Soran(1/2)	143,363.95	491.7	0.343	19,367.40	13.5	123,504.9	86.1	−18,875.7	−13.2
Sum	1,256,022.2	7987.9	0.6	190,654.4	15.2	1,057,379.9	84.2	−182,666.5	−14.5

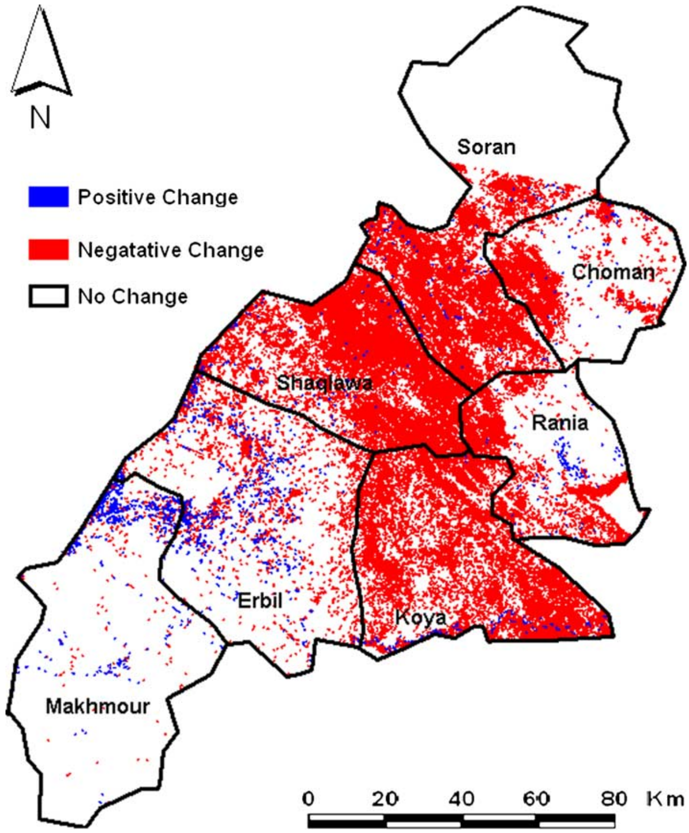

Figure 4. The spatial distribution of the positive, negative, and no changes in the TCW for the study area during the period from 2007 to 2008.

NDWI fraction images were derived from the Landsat ETM+ images for the years 2007 and 2008 by applying NDWI algorithm. Image differencing as a change detection method has been adopted to map and assess the differences in the water bodies surface extent for the study area, such as the rivers and Dokan Lake. The produced raster files were converted to vector format using ER Mapper package in order to perform the spatial analysis in a GIS environment. It has been found from results that the rivers were narrowed and a significant dryness in Dokan Lake occurred in the year of drought from June 2007 to June 2008. The shrinkage percentage of Dokan Lake surface area in 2008 was about 32.5% in comparison with its surface area in the year 2007. Figure 5 shows the shrinkage in Dokan Lake surface area during the period from 2007 to 2008.

4.4. Land surface temperature (LST)

Generally, LST of the study area tends to decrease in the orientation SW toward NE in combination with the increase in the land altitude of the study area. Figure 6 demonstrates the LSTs variation in the study area. The results showed large differences in the LST between the hottest and the coldest locations in the study

Table 2. District-level TCW results of the study area for the period from 2007 to 2008.

	District area	TCW positive		TCW negative		No change		2007/2008	
District name	ha	ha	%	ha	%	ha	%	ha	%
Choman	125,321.50	286.2	0.228	11,785.8	9.4	113,249.5	90.4	−11,499.6	−9.2
Erbil	255,852.50	3022.1	1.181	10,266.3	4.0	242,564.1	94.8	−7244.2	−2.8
Koya	190,952.60	461.0	0.241	74,806.9	39.2	115,684.7	60.6	−74,345.9	−38.9
Makhmour	251,138.50	2206.9	0.879	1629.2	0.6	247,302.4	98.5	577.7	0.2
Rania	123,923.90	477.3	0.385	54,009.3	43.6	69,437.3	56.0	−53,532.0	−43.2
Shaqlawa	165,469.20	491.1	0.297	154,699.9	93.5	10,278.2	6.2	−154,208.8	−93.2
Soran (1/2)	143,363.95	360.8	0.252	71,697.4	50.0	71,305.8	49.7	−71,336.6	−49.8
Sum	1,256,022.2	7305.4	0.6	378,894.8	30.2	869,822.0	69.3	−371,589.4	−29.6

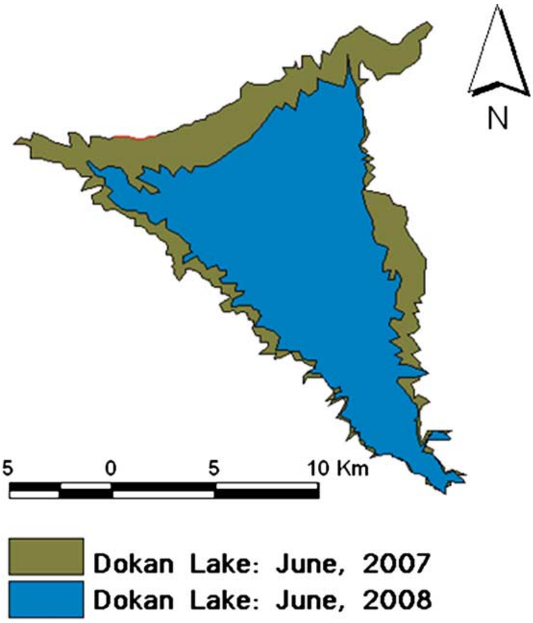

Figure 5. The shrinkage in surface area of the Dokan Lake during the study area derived by NDWI.

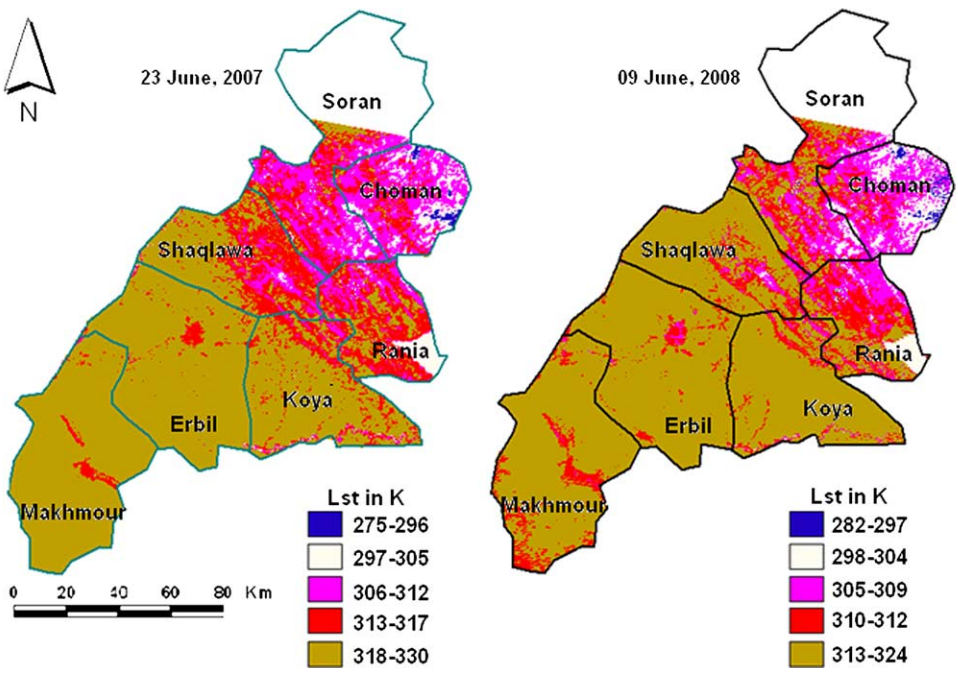

Figure 6. The land surface temperature for the studied districts from 23 June 2007 and 9 June 2008.

Table 3. Correlations matrix among the studied indices for the year 2007.

	NDVI	NDWI	TCW	BSI	LST	DEM
NDVI	1	0.5843	0.4331	−0.5136	−0.6180	0.4771
NDWI	0.5843	1	0.8385	−0.9162	−0.5603	0.2445
TCW	0.4331	0.8385	1	−0.8754	−0.4521	0.1605
BSI	−0.5136	−0.9162	−0.8754	1	0.4942	−0.1750
LST	−0.6180	−0.5603	−0.4521	0.4942	1	−0.7716
DEM	0.4771	0.2445	0.1605	−0.1750	−0.7716	1

area. It is evident that the bare land or the land with a sparse vegetative cover has a high LST and a low soil/vegetation moisture content compared to the land covered by vegetation or land with a high soil/vegetation moisture content. The statistical analyses results (Tables 3 and 4) illustrate and consolidate these findings.

4.5. Normalized Difference Vegetation Index (NDVI)-based spatial distribution of drought

The ability of NDVI to detect drought stress and the vegetative cover status has been verified by getting the ground truth through the field work in the study area using GPS receiver. An unsupervised classification algorithm was adopted to classify the vegetative cover in the study area that derived from NDVI into five density classes. The five vegetation cover density classes were: very dense (VD), dense (D), medium (M), weak (W), and very weak (VW). The post-classification comparison method for the classified NDVI fraction images of the years 2007 and 2008 was adopted to map, assess, and analyze the differences between the vegetation cover density class areas in the study area for 2 years. The results (Figure 7) indicated a significant decrease in all vegetation cover density classes in the study area for the drought year 2008. The decline percentage in the VW, W, M, D, and VD vegetation cover classes were 55.1, 61.2, 55.7, 50.7, and 62.1, respectively. Generally, the decrease in the percentage of the whole vegetation cover classes in the study area in 2008 was 56.7% compared with the percentage of vegetation cover in 2007.

The results revealed that the drought status in Koya and Erbil districts were the worst cases among all the studied districts. The two districts lost 74.1 and 73.1% of their vegetative cover areas throughout the years of drought from 2007 to 2008. The other districts, such as Shaqlawa, Rania, Soran, Choman, and Makhmour lost 50.5, 40.8, 22.4, 19.6, and 10.5% of their vegetative cover areas through the same period.

Table 4. Correlations matrix among the studied indices for the year 2008.

	NDVI	NDWI	TCW	BSI	LST	DEM
NDVI	1	0.4124	0.2024	−0.3420	−0.4611	0.5003
NDWI	0.4124	1	0.8054	−0.9265	−0.4822	0.2995
TCW	0.2024	0.8054	1	−0.8635	−0.3706	0.1369
BSI	−0.3420	−0.9265	−0.8635	1	0.4700	−0.2501
LST	−0.4611	−0.4822	−0.3706	0.4700	1	−0.7699
DEM	0.5003	0.2995	0.1369	−0.2501	−0.7699	1

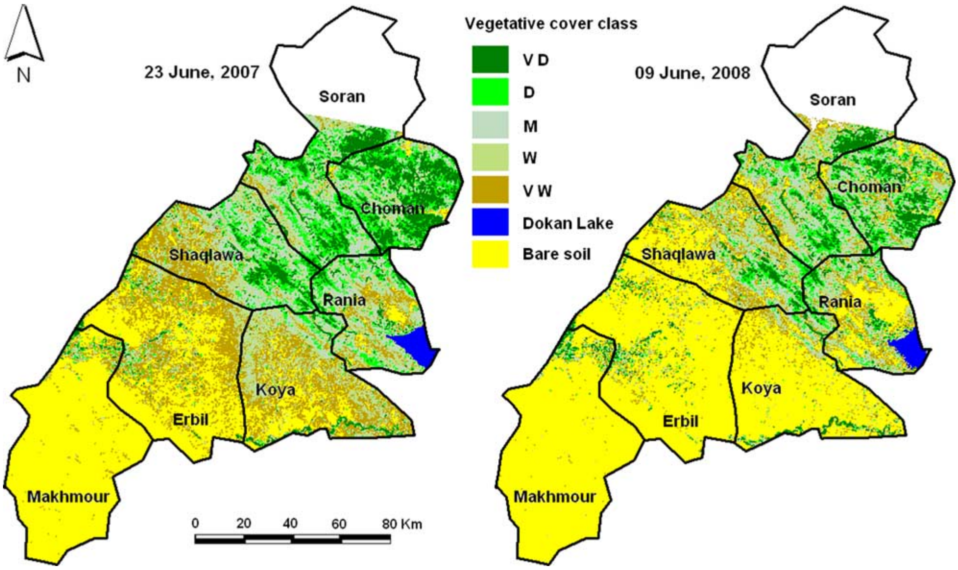

Figure 7. The spatial distribution of the vegetative cover density class derived by NDVI for the study area during the years 2007 and 2008 (VD, very dense; D, dense; M, medium; W, weak; VW, very weak).

Broadly speaking, the decline of vegetative cover density in the study area was in orientation from NE to SW in combination with the decrease in the land altitude, rainfall averages, and soil/vegetation moisture content. Accuracy assessment using random points in the NDVI fraction image as well as ground truth validation points was conducted on the classification results. The estimated accuracy of the vegetation cover density classification results for the study area was 89.4%.

Water availability is one of the restricting factors for vegetation growth. When the moisture requirements of vegetation (cultivated and/or natural) are being accomplished, then this healthy and dense vegetation will be obvious from its higher reflectance in NIR region. On the other side, the decrease in water availability can limit healthy vegetation and result in reduced reflection in the NIR region of electromagnetic spectrum. This can be supported by the findings of this study. Firstly, denser vegetation was found mainly in the districts with higher rainfall averages and higher altitude. A decrease in denser vegetation is noticeable towards the south-west parts of the study area where the rainfall averages are less than the other studied districts. Secondly, in the rain-fed areas the temporal change in vegetation cover takes place due to the change in rainfall form. The years with normal–good rainfall averages are characterized by healthy vegetation whereas in the drought years the vegetation growth becomes limited and weak, and likely sporadic vegetation chances also become less.

4.6. Statistical analyses

Multiple variable correlation analyses were performed for the studied indices' results of the years 2007 and 2008 and presented in Tables 3 and 4. The results revealed statistically significant correlations among the studied indices. The most powerful negative significant correlations were found among the water–soil moisture indices (NDWI, TCW and the BSI). It is well known and well documented the high negative correlation between water availability and bare soil. The water existence creates and encourages a convenient environment for growing of vegetation and vice versa. Consequently, significant positive correlations were found among the NDVI and the NDWI, TCW indices (Tables 3 and 4).

4.7. Drought mitigation strategies

Drought mitigation measures, relief, and rehabilitation will minimize the impact of drought on production systems and livelihoods. These can range from providing emergency water supplies and livestock fodder. In view of the substantial negative effects which result from the drought, such as failure of the planted winter crops and the inability of farmers to provide feed for sheep and drinking water. Accordingly, several measures are necessary to reduce and mitigate the impacts of drought. These measures, such as digging of groundwater wells to provide water to irrigate crops, orchards, and forests in order to prevent dry out during the hot summer. In addition to supplying drinking water to the inhabitants of villages and herds of livestock through the delivery of water tankers to the villages affected by drought. Creation and establishment of green belts and windbreaks surrounding cities, residential areas, and agricultural fields is an urgent resolution to reduce the effects of wind erosion, which becomes active during the periods of drought. The conservation practices also play an important role in managing different soil moisture conditions. Crop residue together with no-till systems can minimize soil moisture loss from the soil's surface and maximize soil moisture storage during the no-rain times.

5. Conclusion

The mapping and monitoring of natural disasters, such as drought, and assessing the other environmental issues using Geoinformation technology as the core of DE have become an interesting development in contemporary scientific research. This study created a relationship between the Geoinformation technology (RS, GIS, and GPS) and drought impacts in the study area in the Kurdistan region of Iraq. The results of this study showed a significant decrease in the soil/vegetation moisture caused by low rainfall averages in the year 2008 which led to a significant decrease in the growing plants and the vegetative cover as well as to a consequential shrinkage in the surface area of the water bodies in the Kurdistan region. In summary, NDVI, BSI, NDWI, TCW, LST, post-classification comparisons, and image differencing techniques have proven to be useful and accurate methods for tracing the environmental changes in the study area. The statistical analysis results revealed and highlighted the importance of the studied indices in drought mapping and monitoring.

Notes on contributor

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