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RESEARCH ARTICLE

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Survey and Study of Soil Drought Phenomenon in 2000 and 2023 by GIS in Sulaymaniyah and Halabja provinces, Kurdistan Region, Iraq.

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ABSTRACT

Drought is an environmental disaster worldwide, especially in countries with limited water resources and even in other countries affected by this phenomenon. This study aims to conduct a spatial survey of drought signs and causes, monitor, map and evaluate the drought phenomenon using remote sensing and geographic information systems. The study has great importance in knowing the time periods in which droughts occurred and predicting the upcoming dry periods in order to give a clear vision to decision makers to avoid the phenomenon of drought or to reduce its negative effects. The drought indicators normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) have been used for this purpose. Drought areas, vegetation cover and water bodies were calculated by analyzing and evaluating the effects of drought on soil, vegetation cover and water bodies in the study area. The results showed that drought areas increase towards the south of the study area. The study area was greatly affected by the drought phenomenon in 2000, and this can be observed when comparing the image of 2000 with the image of 2023, as the areas of barren lands were large in 2000, and the area of vegetation cover and the area of water bodies decreased. The desertification area decreased in 2023 compared to 2000, as the desertification area in 2000 was 16532.06 km2 or 15435.04 km2 or the desertification area in 2023. The evidence of the NDVI and the NDWI confirms the occurrence of drought in the study area in 2000.

Keywords: *Survey, Sulaymaniyah, Kurdistan Region, Drought, NDVI, NDWI*.

INTRODUCTION

Drought is a natural phenomenon characterized by a prolonged period of insufficient precipitation, resulting in water shortages that affect ecosystems, agriculture, and human societies. This can have significant environmental, economic, and social impacts. The phenomenon of drought is considered an environmental disaster worldwide, especially in countries with limited water sources and even other countries that are affected by this phenomenon. It is a sign from [1] and [2] that RS and GIS can be used in the field of drought monitoring and risk assessment through the integrated analysis of measured ground and satellite data with great and effective capabilities. Now, through geoinformatics techniques, it is possible to obtain accurate and diverse information about the phenomenon of drought in successive periods of time. Also to know and predict its effects so that monitoring and mapping can be achieved, which helps competent institutions in countries to prepare short -, medium-, and long-term agricultural and environmental plans to confront and reduce the negative effects of drought. [3] stated that drought can be detected 4–6 weeks earlier than before, and its effect can be diagnosed before the most important stage of plant growth, which is the harvest stag. Understanding drought has attracted the attention of scientists in geology, hydrology, meteorology, and agriculture, as drought plays an important role in planning and managing water resources [4]. It has been noted that in recent years, sudden events such as droughts and floods have occurred frequently and on a large scale for many reasons, such as regional climate change, geographical location, and terrain conditions [5]. Although the main cause of drought is climatic conditions of low rainfall and high temperatures. The human activities also can be a factor in causing drought [6], either directly through land bearing, forest fires, and natural vegetation fires caused by humans [7], or indirectly, such as global warming caused by greenhouse gases [8]. [9] found through Advanced Very High Resolution Radiometer (AVHRR) and satellite images, from 1982 to 2017, a three-stage decrease in water cover and vegetation led to an increase in arid lands, thus increasing drought areas in Iraq.

There is no doubt that there are many applications of RS and GIS in many areas that serve human society, such as in health disasters [10] and natural disasters [7]. If countries and regions are to make progress in reducing the severe consequences of drought, they must establish a comprehensive and integrated drought information system that includes climate, soil, and water supply factors such as rainfall, temperature, soil moisture, snowpack, reservoir and lake levels, groundwater levels, and stream flow [11]. GIS and modeling have become essential tools in agricultural research and natural resource management, allowing us to eliminate a large part of the field work and financial costs, save time, and carry out agricultural work in large areas, especially in land management and agriculture in general, including addressing the phenomenon of drought. GIS spatial interpolation techniques, such as Inverse Distance Weighting (IDW), spline interpolation techniques, and kriging, are some of the essential tools of ArcGIS application for data reconstruction. To help understand the spatial occurrence and patterns of agroclimatic variables (e.g., precipitation) [12]. Changes in soil moisture under drought conditions should result in significant changes in the spectral reflectance of soil observed in RS images [13]. The phenomenon of drought is a condition related to the amount of soil moisture content as well as the abundance or scarcity of vegetation cover, and since RS and GIS play a prominent role in studies of soil moisture and nutrients in the soil and in increasing soil fertility and agricultural production, as in [14] and [15]. RS and GIS play a major role in studies of soil drought, monitoring, and analysis, as well as in diagnosing, mapping, and analyzing the phenomenon of drought through NDVI and NDWI [16]. Many researchers have developed indicators for identifying, monitoring, and mapping droughts using GIS technologies based on climatic factors and indicators derived from remote sensing data. Recently, many indicators, such as the plant water supply [17], NDVI [18], vegetation status index [3], and Temperature-Vegetation Drought Index (TVDI) [19], have been used in monitoring, analysis, and forecasting of upcoming drought periods. [16] mentioned that the mapping and monitoring of natural disasters, such as drought, as well as the assessment of other environmental problems using geoinformatics technology as the core of the Digital Earth (DE), has become an interesting development in contemporary scientific research. The chronological patterns of drought in the KRI were mapped using RS and GIS with various drought indices. Because aquifer recharge, agricultural activities, and ecological changes are affected by rainfall, the focus is on drought during the agricultural growing season [20]. [21] indicated that the NDVI and Standardized Precipitation index (SPI) can be used effectively to monitor and evaluate agricultural production, where appropriate agricultural policies can be adopted to mitigate the effects of drought. Their results showed that the NDVI is an effective means of monitoring changes in drought conditions, and is cost-effective for monitoring agricultural drought on a small or large scale, as the relationship between the NDVI and rainfall was strong. A drought always begins with a deficiency in precipitation, which has an impact on soil moisture, streams, groundwater, and water bodies, as well as on livestock populations, fires, and human activity. Due to its reliance on water resources, the agricultural industry is frequently the first to suffer from the onset of drought. Due to the low precipitation in recent years, the Kurdistan Region of Iraq (KRI) has been severely impacted by drought. This deficiency in precipitation has resulted in severe drought, which has also reduced water availability for Iraqi farmers, including those in the KRI. This phenomenon has had a severe impact on the Sulaymaniyah Governorate, including its vegetation cover and water resources. [17] highlighted a considerable decline in vegetation cover 56. 7% as well as a drop in soil moisture/vegetation cover 29.9%. In a similar vein, there has been a noticeable reduction in the area of water bodies in the region, such as Lake Dukan, which has shrunk by 32. 5% in surface area.

Several steps must be taken to lessen the severity and dangers of this occurrence, including drilling groundwater wells to irrigate crops and provide drinking water for villagers and livestock. Immediate future measures include planting drought-resistant plants that need little irrigation, establishing green belts, and establishing windbreaks around towns, residential neighborhoods, and agricultural fields to mitigate wind erosion.

The aim of this work is to broaden our knowledge of:

1- Spatial survey of the signs of drought phenomenon occurrence and the causes of occurrence.
2- Monitoring, mapping and assessment of the drought in study areas in years 2000 and 2023 using RS and GIS.
3- Calculating the area of drought, vegetation covers and water body.
4- Analyzing and assessment the effect of the drought on the soil, vegetation covers and water areas.
5- Appropriate solutions have been proposed to reduce the negative effects of drought on the study area.

1-Study Area

The study area was the Sulaymaniyah and Halabja governorates in the Iraqi Kurdistan region. The area is 21057.2694 km^2 (2105726.94 hectares) and lies between longitude 44º 30′ 43.2″to 46º 20′ 56.4″ and latitude 34º 26′ 20.4″ to 36º 28′ 40.8″. Its height ranges between 2611 m and 150 m above sea level (Figure 1). The study area is located within the foothills and the Zagros and Qardagh mountain ranges [22]. Within the tectonic site, it is located within the fold layer [23]. The region is characterized by a semi-continental climate in the southern region (Tables 1a and b). In the northern and northeastern regions, the climate is cold and rainy in winter, and semi-hot and semi-arid in summer [24]. Rain falls in winter and does not fall in summer [25]. Rainfall amounts are usually high in the northern region and low in the central and southern regions. As for temperature, they are at their peak in the summer, and they vary from one region to another, as temperatures in the central and southern regions are higher than those in the northern region. The water sources in the study area are numerous, including surface rivers, springs, and lakes, such as the Darbandikhan and Dukan dams, whose sources are in the mountains of Sulaymaniyah and Halabja governorates. The soils in the study area belong to the orders Vertisols, Inceptisols, Mollisols, and Aridisols (Figure 2), as mentioned in [26]. The lands used for growing cereal crops such as wheat (*Triticum spp*.) 506.8 km^2 (50680 hectares), barley (*Hordeum spp*.) 89.95 km^2 (8995 hectares), and are irrigated. Some are rain-fed (Kurdistan Region Government, Ministry of Agriculture and Water Resources, General Directorate of Agriculture in Sulaymaniyah, Planning and Follow-up Department). In addition to growing vegetable crops, especially in the spring and summer in irrigated areas, but most of the land is not planted in the summer. Natural plants include wild barley (*Hordeum spontaneum*), Bishop's flower (*Ammi majus*), and wild oats (*Avena fatua*) [27].

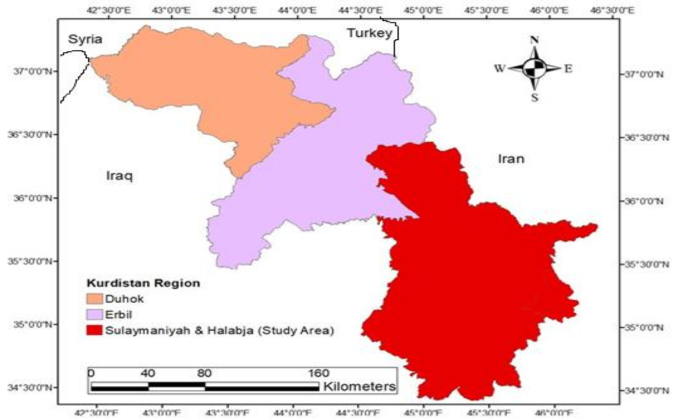

Figure 1: The study area location

Table (1a): Climate data of the study area (* = Precipitation, ** = Temperature)

Month	Sulaymaniyah				Darbandikhan Dam				Dukan Dam			
	2000		2023		2000		2023		2000		2023	
	P. *	T. **	P.	T.	P.		P.	T.	P.	T.	P.	T.
Jan.	147.2	5.4	127.3	7.6	108.1	9.5	86.2	9	150.1	4	59	9
Feb.	45.6	7	57.3	7.6	31.3	10.5	82	9	60.5	5.5	71.8	8
Mar.	37.9	10.6	250.5	14.4	48.9	13.5	133	15.5	37.8	9.5	140	15
Apr.	32.9	18.6	145.1	17.1	13.5	21	110.2	18.5	17.9	17.5	62.4	17.5
May	13.9	23.9	50.5	23.4	3.4	26	17.2	24.5	3.3	23.5	20.4	24
Jun	0	29.8	0	29.4	0	30.5	0	32.5	0	29.5	0	31.5
Jul.	0	35.7	0	33.9	0	36	0	36.5	0	38	0	36
Aug.	0	33	0	34.4	0	35	0	37	0	32.5	0	36.5
Sep.	2.7	27.5	0	29.9	1.7	28.5	0	32	1	28	0	32.5
Oct.	28.2	19.9	9.3	21.9	9.3	22	0.8	24.5	28.4	19.5	9.2	24
Nov.	31.4	13.5	78.9	15.3	14.5	16	136.8	17	22.2	14.5	56.8	17
Dec.	165.3	8.3	59.1	11.7	99.5	12	160.6	13.5	96.4	8	98.4	13
Total	505.1	19.43	778	20.55	330.2	21.71	726.8	22.46	417.6	19.17	518	22

Table (1b): Climate data of the study area from (Sulaymaniyah, Darbandikhan Dam, Dukan Dam, Chamchamal and Kalar weather stations)

Month	Chamchamal				Kalar			
	2000		2023		2000		2023	
	P.	T.	P.	T.	P.	T.	P.	T.
Jan.	133.2	6.08	87.6	8.50	38.5	9.66	56	11.32
Feb.	43.2	7.64	29.9	8.21	11.3	10.38	13.4	13.36
Mar.	14.2	14.58	111.9	14.76	14.2	18.03	76.2	17.32
Apr.	18.7	20.94	129.8	18.13	4.8	25.53	44.6	22.36
May	6	26.32	21.3	24.22	0	30.43	20	29.59
Jun	0	31.13	0	30.45	0	35.48	0	35.73
Jul.	0	35.09	0	34.68	0	38.8	0	38.05
Aug.	0	31.56	0	35.46	0	35.19	0	37.77
Sep.	0.5	24.34	0	30.54	0	28.41	0	32.59
Oct.	26.6	19.10	5	23.09	0	22.64	0	27
Nov.	30.6	12.74	74.5	15.99	29.8	16.44	54.2	20.18
Dec.	95.1	8.92	56.2	12.55	116.5	12.4	22.4	15.95
Total	368.1	19.87	516.2	21.38	215.1	23.62	286.8	25.1

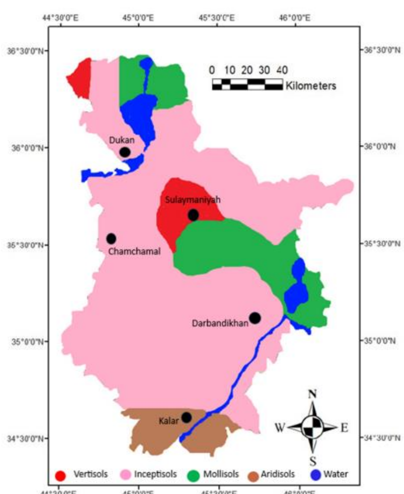

Figure 2: Soil classes of the study area by American Soil Survey Staff [26]

2- Methodology

The drought phenomenon was studied using NDVI and NDWI in the years 2000 and 2023, where the natural field information of the study area was linked to the information obtained from satellite images to employ RS and GIS to study, analyze, and map the drought phenomenon. The diagram (Figure 3) shows the steps to study the drought phenomenon to obtain the expected results.

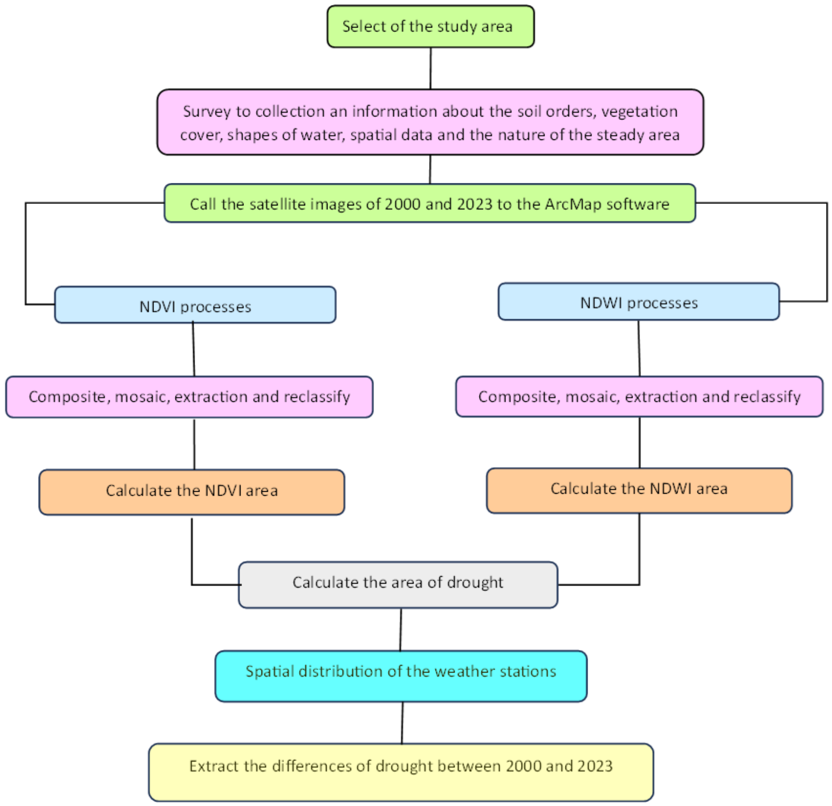

Figure 3: Outline diagram of the study

3-1- Dataset Used

Two types of data were used: field data and satellite data. In the field data, due to the large study area, a field visit was made to some sites in the study area, where information was collected about the physiographic location, geology, terrain, and mountains. Information was also collected about water sources and classes of soils present, as well as the prevailing climate, through meteorological stations in the study area (Figure 4 and Table 2), which are five regions. In addition, the nature of the exploitation of agricultural land and natural plants must be considered. The map prepared by [28] was used for soil survey consultations in the study area, and the map prepared by [29] was used to determine the terrain and geographical features existing in the region. The coordinates of the study sites were obtained using a Global Positioning System (GPS) device. Satellite images were obtained from the United States Geological Survey (USGS) website in July and August. Data were divided into two parts. The first used images from 2000 for the satellite Landsat 7 Enhanced Thematic Mapper Plus (7 ETM+) C2L1, which consists of eight bands, as shown in (Table 3). The second used the satellite image for Landsat 9 OLI/TIRS C2L1 for the year 2023, which consists of 11 bands, as shown in (Table 4).

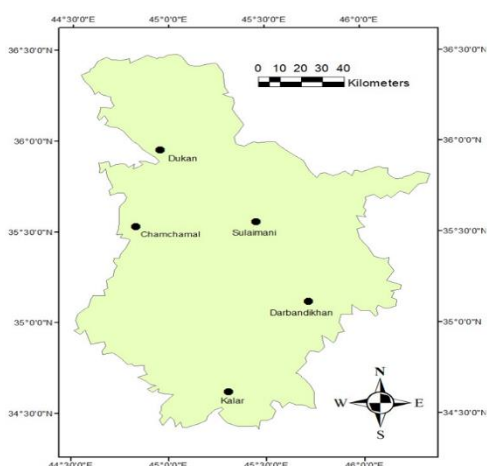

Table 2: Weather stations locations

Location	x (E)	y (N)
Sulaymaniyah	541066.7	3934779
Darbandikhan Dam	565673.2	3886224
Dukan Dam	496196.4	3978533
Chamchamal	484587.9	3931834
Kalar	528082.6	3830955

Table 3: Bands, names, wavelength and resolution of Landsat 7 ETM+

Bands	Name	Wavelength micrometers (µm)	Resolution (meters)
1	Visible Blue	0.45-0.52	30
2	Visible Green	0.52-0.60	30
3	Visible Red	0.63-0.69	30
4	Near Infrared (NIR)	0.77-0.90	30
5	Shortwave Infrared (SWIR) 1	1.55-1.75	30
6	Thermal	10.40-12.50	60 (30)
7	Shortwave Infrared (SWIR) 2	2.09-2.35	30
8	Panchromatic	0.52-0.90	15

Table 4: Bands, names, wavelength and resolution of Landsat 9

Band	Name	Wavelength (µm)	Resolution (m)
1	Visible Coastal Aerosol	0.43 - 0.45	30
2	Visible Blue	0.45 - 0.51	30
3	Visible Green	0.53 - 0.59	30
4	Red	0.64 - 0.67	30
5	Near-Infrared	0.85 - 0.88	30
6	SWIR 1	1.57 - 1.65	30
7	SWIR 2	2.11 - 2.29	30
8	Panchromatic (PAN)	0.50 - 0.68	15
9	Cirrus	1.36 - 1.38	30
10	TIRS 1	10.6 - 11.19	100
11	TIRS 2	11.5 - 12.51	100

3-2- Remotely Sensed Dataset

Due to the large study area, the area was covered by three satellite images for each of the years 2000 and 2023, as shown in (Table 5).

Table 5: Date, path and row of the satellite images

Satellite	Date	Path	Row
Landsat 7 ETM+	14/7/2000	168	35
	14/7/2000	168	36
	22/8/2000	169	35
Landsat 9	14/7/2023	168	35
	14/7/2023	168	36

3-3- Preprocessing of the Landsat Images

The Landsat images were downloaded from the USGS website and loaded into the ArcMap GIS software. As mentioned in [30], Landsat images were projected onto the WGS 84 datum and the UTM N 38 projection zone using the first-order polynomial function and nearest neighbor correction resampling, which was chosen to preserve the radiometric and spectral information in the images.

3-4- Image Processing

To fully cover the study area, three satellite images were called to ArcMap GIS for each year for bands 2 (green), 3 (red), and 4 (NIR) of Landsat 7and 3 (Green)4 (Red) and 5 (NIR) of Landsat 9. Subsequently, the bands were composited to appear in their natural colors. To hide the overlaps between the satellite images, the three images were mosaiced (Figure 5) for each year and for the NDVI and NDWI indicators, each one separately, and the bands specific to each of the NDVI and NDWI were entered into the mathematical equation to extract and classify the vegetation cover and water bodies and give values for NDVI and NDWI. Reclassification and extraction processes were performed. The areas occupied by vegetation cover, water bodies, and baren soils were extracted through Zonal. Finally, maps were exported.

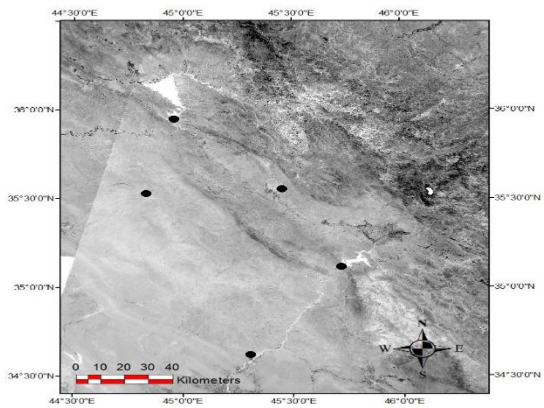

Figure 5: Satellite images Mosaic of the study area

3-5- NDVI

NDVI is an indicator of plant greenness and photosynthetic activity. It is an important indicator for clarifying the density of vegetation cover in the region, which has a direct relationship with rainfall. This is an indicator of the soil dryness. It was proposed by [31] and developed and expanded by [32]. The mathematical formula is as follows:

NDVI= (NIR − RED) / (NIR + RED). (1)

3-6- NDWI

The NDWI index is used to determine the moisture status of the soil, including water bodies, because the higher the soil moisture, the lower the spectral reflectivity. It is a good indicator for providing information about changes in the moisture status of the soil and water bodies at different times, as well as drought and desertification cases in the study area. Where:

NDWI= (Green − NIR) / (Green + NIR) …………. (2)

Result and Discussion

The results of this study show that the severity of drought causes the lack of vegetation cover, and the shrinking of water areas in the year 2000 were significant due to the decrease in rainfall in this year, and this is consistent with the results obtained by [33]. The areas of drought increase towards the south of the study area due to the low rainfall and the scarcity of water sources compared to the north of the study area. As well as the fact that the northern part of the study area is characterized by the presence of forest trees that resist drought, such as pine (*Pinus*) and Cypress (*Cupressus*) trees, this was also indicated by the [34]. Studies have shown that the roots of forest trees absorb water during rainy periods and release it slowly and evenly during the dry season to preserve water reserves [35] and [36], thus, the soil's resistance to drought. From this perspective, it is often assumed that planting trees in degraded soils and drylands restores water to streams [37], [38], [39] and [40]. In addition, the southern region is characterized by seasonal herbaceous plants with shallow roots that cannot tolerate drought. Some studies have concluded a significant decrease in the height of herbaceous plants underground (root length) and root diameter with water shortage [41]. Generally, the results were centred around three main axes that had a direct relationship with the drought phenomenon:

4-1- Vegetation Cover

The vegetation cover represented by the NDVI in 2000 (Figure 6) shows that the vegetation cover is greater in the northern and northeastern regions than in the central and southern regions of the study area due to the high levels of precipitation in the northern and northeastern regions, such as the Sulaimani and Dukan regions, compared to the central and southern regions, such as the Kalar and Chamchamal regions (Table 1a and b). In addition, the central and southern regions are characterized by high temperatures compared to the northern and northeastern regions. As well as by the type of vegetation cover in the northern and northeastern regions, which are forest trees such as Pine and Cypress, which are drought-resistant, compared to the central and southern regions, which are characterised by shallow-rooted grasses that are not drought-resistant. Although there are forest trees in the central region, especially the Qardagh Mountains, they have suffered more from drought than the northern region, because the trees in the northern region are Pine and Cypress trees with needle-like leaves, which have less transpiration and thus resist drought. Unlike the Qardagh Mountain forests, which are oak (*Quercus*)trees with broad leaves, which have more transpiration and thus resist drought. The morphological shape of the leaves plays a major role in the tree's tolerance to thirst; therefore, Pine and Cypress trees with needle leaves have less transpiration and evaporation than broad-leaved oak trees [42]. In addition, the southern regions of the study area, which are the Garmian regions, are characterized by high temperatures, which may sometimes reach a maximum temperature of 50 C°, affecting the evaporation of soil moisture and thus increasing the occurrence of drought.

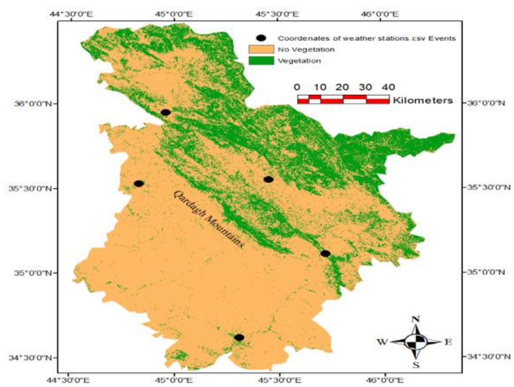

Figure 6: Vegetation cover and baren soil in 2000

On the other side of (Figure 7), the density of vegetation covers in the year 2023 has increased compared to the year 2000, especially in the central and southern regions of the study area. This is due to the high levels of rainfall in those areas in the year 2023 compared to the year 2000 (Table 1a, b), where in Darbndikhan area, the amount of rainfall reached 726.8 mm after it was 330.2 mm in 2000. While in the Chamchamal area, it reached 516.2 mm in 2023 after 368.1 mm in 2000. In the Kalar area, it reached 286.8 in 2023 after 215.1 in 2000. It is worth noting that several factors had a direct impact on the state of drought in the study area. These factors include rainfall, temperature, vegetation type, topography of the region, and soil type. Rainfall is the most influential or effective factor. Despite the stability of other factors in 2000 and 2023, rainfall had a significant impact on alleviating the state of drought by increasing its levels in 2023, as the drought phenomenon disappeared. One of the reasons for the disappearance of the drought phenomenon in 2023 may be the improvement of citizens' living conditions, the increase in people's awareness of not cutting down trees, and the enactment and establishment of special laws to protect the environment and prevent the cutting down of trees.

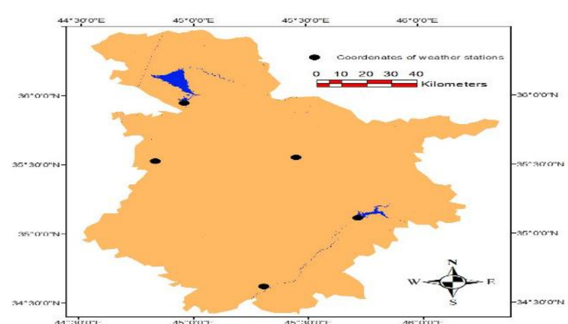

Figure 7: Vegetation cover and baren soil in 2023

From the (Table 6) it is clear that the vegetation cover was 4330.42 km^2 in 2000, with a percentage of 0.26%, but in 2023 this area increased to 5336.58 km^2 and with a percentage of 0.34% of the total area of the study area, which is 21057.2694 km^2, an increase of 1006.16 km^2. It is clear from (Figures 4 and 5) that the increase in vegetation cover area in 2023 was in all study areas, but the largest area was in the middle of the study area, specifically the Qardagh Mountains; in the southern region. The increase in the vegetation cover area was less, and the reason is that the type of vegetation cover in the Qardagh Mountains is Oak trees that benefit from the falling rain because their roots penetrate deep into the soil, so they benefit to the maximum extent from the falling rain. While in the south of the study area where the vegetation cover is grasses with shallow roots do not benefit much from rainwater, especially after it has penetrated deep into the soil. As the southern regions are characterized by the presence of very few trees, and therefore increases the evaporation of soil moisture and thus increases the severity of drought in this region, because the land is devoid of trees, the evaporation of soil moisture is very high [43].

Table 6: The area of vegetation cover in the years 2000 and 2023

Year	Vegetation (km^2)	Other features (km^2)	% Vegetation	Differences in area (km^2)	Differences in %
2000	4330.42	16726.85	0.26	1006.16	0.081
2023	5336.58	15720.69	0.34		

4-2- Soil Moisture and Water Bodies

Undoubtedly, GIS and RS are very important in determining and monitoring the phenomenon of drought, as NDWI is an important indicator in determining the state of drought, as it shows the moisture status of the soil, either in the form of soil moisture or water bodies. [44] Found that increasing soil moisture in bare soil leads to a decrease in spectral reflectance values because with the increase in soil moisture, it absorbs an amount of sunlight, and thus the spectral reflectivity decreases. From (Figure 8) Darbandikhan Lake and Dukan Lake were affected by drought due to the lack of rainfall in 2000, which led to a significant decrease in their water levels, especially for Darbandikhan Lake, which depends largely on falling rain and melting snow. There is no doubt that in 2000, the amount of falling rain was very small, which affected Darbandikhan Lake, as well as the snow, if it was not sufficient in that year to supply Darbandikhan Lake with sufficient amounts of water. The water bodies in the study area shrank to 194.7933 km2 in 2000 (Table 7). This small area is due to the lack of rainfall in 2000 and the lack of supplies to this lake from snow falling from the surrounding mountains; the water areas in the study area occupied 0.009% of the total area. The reason for the lack of water areas in 2000 was due to the lack of rain and snow falling that year, which reached 330.2 mm in Darbandikhan and 417.6 mm in Dukan (Table 1a). The high temperatures that follow rainfall, especially in spring, lead to the evaporation of water from the soil and the occurrence of drought conditions, as in the alluvial plain area represented by the central and southern regions of the study area, where temperatures increase.

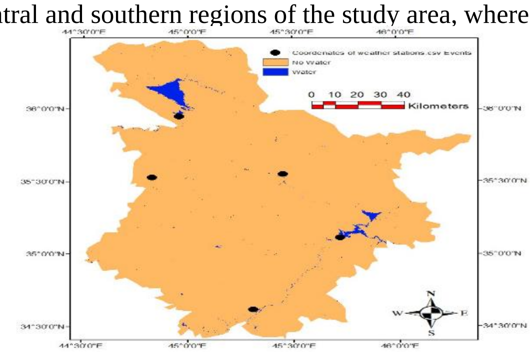

Figure 8: Water bodies and baren soils in 2000

Table 7: The area of water bodies of the study area in 2000

Year	Water (km^2)	Other features (km^2)	% Water
2000	194.79	20862.48	0.009

The Results are shown in Figure 9. The water areas have increased, especially in Darbandikhan Lake, and the water areas are located in the middle and south of the study area. This is due to the increase in rainfall in 2023, as the rainfall level in the Darbandikhan area rose to 726.8 mm after it was 330.2 mm in 2000, an increase of 396.6 mm. The same is the case in the Dukan area, where the rainfall level was 417.6 mm and then increased to 518 mm, an increase of 100.4 mm. This played an effective role in increasing the water area of the Darbandikhan Lake. Rainfall rates also increased in the central and southern areas of the study area. Therefore, it is noted that the water areas in this area have increased. Still, Darbandikhan Lake has benefited greatly from rainfall because the rainfall rate is higher than in other areas of the study area. The water bodies in the study area reached 285.65 km^2 of the total area of the study area. This increase is due to the high amount of rainfall that fell in 2023, which led to an increase in the level of Darbandikhan and Dukan lakes, as well as an increase in the water areas in the study area, especially in the centre and south of the study area. As shown in Figure 9 and Table 8, 0.014% of the total study area. Therefore, it is noted that the number of water areas has increased in 2023, and the shapes of the water areas have changed and expanded, especially in Darbandikhan Lake, where it is noted from Figure 9 that the lake has clearly increased in area. The results shown in Figures 8 and 9 and Table 9 show that Darbandikhan Lake was more affected by the drought phenomenon in 2000 than Dukan Lake, as its area decreased significantly. The area of Dukan Lake has also decreased, but to a much lesser extent. The reason for this is that rainfall was very little in 2000 on Darbandikhan lake, 330.2 mm, while the amount of rainfall increased to 726.8 mm, an increase of 396.6 mm in 2023. Therefore, there is a clear difference in the area change of the Darbandikhan Lake. In general, the water area increased by 90.86 km2 in 2023 compared with 2000, and by 0.004%.

Table 8: The area of water bodies of the study area

Year	Water (km^2)	Other features (km^2)	% Water
2023	285.65	20771.62	0.014

Table 9: The area of water bodies in the years 2000 and 2023

Year	Water (km^2)	Other features (km^2)	Water %	Differences in area (km^2)	Differences in %
2000	194.79	20862.48	0.009	90.86	0.004
2023	285.65	20771.62	0.014		

4-3-Barren Soils and Desertification

The southern regions of the study area are characterized by a significant lack of vegetation cover, whereas the central region has more vegetation cover than the southern region. In general, both regions were affected by drought in 2000, although the southern region was more affected. This is due to the condition of the soil and lack of organic matter [45]. In addition to the lack of rainfall in the southern region, which is the Kalar and Chamchamal regions, water infiltrated quickly to the bottom of the soil or evaporated because of the high temperatures in those regions. Thus, plants do not benefit much from their growth, which leads to soil desertification. From the (Table 10) it is clear that the area of desertification is decreased in 2023, compressed with 2000, where the area of desertification in 2000 was 16532.06 km^2 then it became 15435.04 km^2 that means the area of desertification in 2023 decreased by 1097.02 km^2 of the total area of the study area which is 21057.27 km^2. The percentage of desertification was 78.51 % in 2000, while it became 73.3 % in 2023, which means that desertification in 2023 decreased by 5.21%.

Table 10: Area, percentage, difference in desertification in 2000 and 2023

Desertification in 2000 (km^2)	16532.06
Desertification in 2023 (km^2)	15435.04
% Desertification in 2000	78.51
% Desertification in 2023	73.30
Difference between 2000&2023 (km^2)	1097.02
% Difference between 2000&2023	5.21
Tota of study area (km^2)	21057.27

In addition, most of the lands in the central and southern regions are sedimentary plains, so torrents and floods increase, leading to soil erosion, including a surface layer rich in organic materials. This is another reason for the lack of dense plant growth, which increases the aridity of the soil, which results in the phenomenon of drought and desertification after several years of recurrence of this climatic condition of low rainfall and high temperatures. Moreover, the vast majority of wild plants in the central and southern regions are seasonal herbaceous plants. They grow and die quickly and are unable to retain soil moisture as forest trees in the northern regions of the study area. This is another reason for the loss of soil moisture, drying of the land, and increased chance of drought occurrence. In general, (Table 11 and Figure 10) show an increase in rainfall amounts in 2023 compared to 2000, which led to an increase in the areas of vegetation cover as well as water areas in 2023 compared to 2000.

Table 11: Amount of precipitation in years 2000 and 2023

Regions	Year 2000 (mm)	Year 2023 (mm)
Sulaymaniyah	505.1	778

Darbandikhan	330.2	726.8
Dukan	417.6	518
Chamchamal	368.1	516.2
Kalar	215.1	286.8

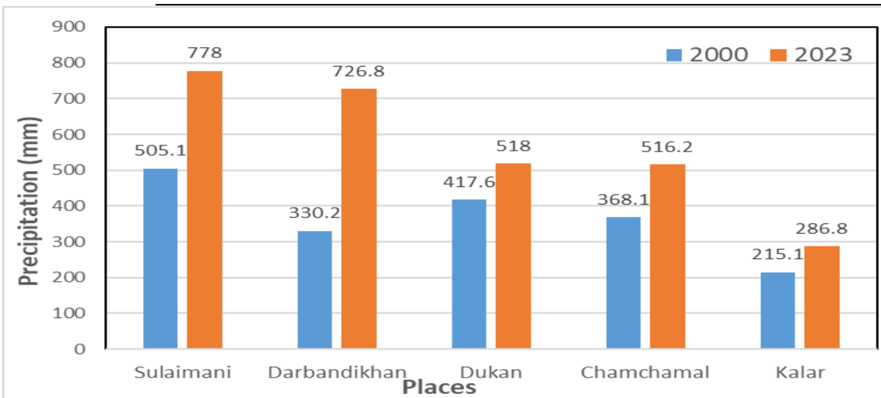

Figure 10: The change of precipitation between 2000 ana 2023

Conclusion

In summary, the study area was greatly affected by the drought phenomenon in 2000, and this can be observed when comparing the 2000 image with the 2023 image, as the areas of barren lands were large in 2000, which was at the expense of the decrease in the areas of vegetation cover as well as the decrease in water areas. This can be observed in lakes, especially Darbandikhan Lake, due to the lack of rainfall in that area in 2000 compared to 2023. On the other hand, the areas of vegetation cover were much smaller than the rest of the study areas because of the lack of rainfall, especially in 2000, as well as the physiographic nature of the area, in the areas of alluvial plains, where the chances of floods and torrents increase. In addition, the soils of this area are shallow and poor in organic material, and only seasonal herbaceous wild plants grow in it. These unlike forest trees, which conserve soil moisture, these plants cannot conserve water. The study area was greatly affected by the drought phenomenon in 2000, and this can be observed when comparing the 2000 image with the 2023 image, as the areas of barren lands were large in 2000, which was at the expense of the decrease in the areas of vegetation cover as well as the decrease in water areas. This can be observed in lakes, especially Darbandikhan Lake, due to the lack of rainfall in that area in 2000 compared to 2023. On the other hand, the areas of vegetation cover were much smaller than the rest of the study areas because of the lack of rainfall, especially in 2000, as well as the physiographic nature of the area, in the areas of alluvial plains, where the chances of floods and torrents increase. In addition, the soils of this area are shallow and poor in organic material, and only seasonal herbaceous wild plants grow in it. These unlike forest trees, which conserve soil moisture, these plants cannot conserve water. Despite the limitations caused by the lack of sufficient weather stations in all areas of the study area, especially in the year 2000, the research achieved an important study of the drought phenomenon. The results provide a significant first step towards to know the most damaged area by drought in the study area and to mapping and monitoring the drought phenomenon also to give a vision to the decision maker for planning to reduce the drought phenomena.

Recommendation

Based on the results of this study, we recommend the following.

1- The cultivation of forest trees, especially in bare soils, reduces the risk of drought.
2- Establishing many dams in suitable places to reduce the waste of rainwater and benefit from it, and modern and highly efficient methods to irrigate agricultural crops to conserve water include sprinklers and drip irrigation methods.
3- More research is needed on the drought phenomenon in the Kurdistan region to develop appropriate and effective plans to confront it in the future.

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مسح ودراسة ظاهرة جفاف التربة في عامي 2000 و2023 باستخدام نظم المعلومات الجغرافية في محافظتي السليمانية وحلبجة، إقليم كردستان، العراق.

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الخلاصة

يُعدّ الجفاف كارثة بيئية عالمية، لا سيما في الدول ذات الموارد المائية المحدودة، بل وحتى الدول الأخرى المتأثرة به. تهدف هذه الدراسة إلى إجراء مسح مكاني لعلامات الجفاف وأسبابه، ورصده ورسم خرائطه وتقييمه باستخدام تقنيات الاستشعار عن بُعد ونظم المعلومات الجغرافية. وتكتسب الدراسة أهمية بالغة في معرفة الفترات الزمنية التي تزامنت مع الجفاف، والتنبؤ بفترات الجفاف القادمة، بما يُسهم في إعطاء رؤية واضحة لصانعي القرار لتجنب ظاهرة الجفاف أو الحد من آثارها السلبية. وقد استُخدمت مؤشرات الجفاف، مثل مؤشر الفرق الطبيعي للغطاء النباتي *(NDVI)*ومؤشر الفرق الطبيعي للمياه *(NDWI)*، لهذا الغرض. وقد تم حساب مناطق الجفاف والغطاء النباتي والمسطحات المائية من خلال تحليل وتقييم آثار الجفاف على التربة والغطاء النباتي والمسطحات المائية في منطقة الدراسة. وأظهرت النتائج ازدياد مناطق الجفاف باتجاه جنوب منطقة الدراسة. تأثرت منطقة الدراسة بشكل كبير بظاهرة الجفاف عام ٢٠٠٠، ويمكن ملاحظة ذلك عند مقارنة صورة عام ٢٠٠٠ بصورة عام ٢٠٢٣، حيث كانت مساحات الأراضي القاحلة كبيرة في عام ٢٠٠٠، وانخفضت مساحة الغطاء النباتي ومساحة المسطحات المائية. كما انخفضت مساحة التصحر في عام ٢٠٢٣ مقارنةً بعام ٢٠٠٠، حيث بلغت مساحة التصحر في عام ٢٠٠٠ ١٦٥٣٢.٠٦ كيلومترًا مربعًا أو ١٥٤٣٥.٠٤ كيلومترًا مربعًا أو مساحة التصحر في عام ٢٠٢٣. وتؤكد دلائل مؤشر الفرق الطبيعي للغطاء النباتي *(NDVI)*ومؤشر الفرق الطبيعي للمياه *(NDWI)* حدوث الجفاف في منطقة الدراسة عام ٢٠٠٠.

الكلمات المفتاحية: المسح، السليمانية، إقليم كردستان، الجفاف، مؤشر الفرق الطبيعي للغطاء النباتي (*NDVI*)، مؤشر الفرق الطبيعي للمياه (*NDWI*).