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# Analyzing the Impact of Climate Drought on Moisture Stress and Vegetation in Kirkuk Governorate within Iraq, Using (GIS&RS)

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***Abstract***

*Through analyzing the duration and severity of drought using the drought severity index and employing remote sensing techniques and geographic information systems to analyze Landsat satellite data (5, 7, 8) captured in selected years representative of drought severity, coinciding with the peak of green vegetation growth in the study area, it was found that the drought trends in the study area are moving towards deepening, increasing in frequency and intensity. General trend analysis also showed that the RDI index tends to decrease over time, indicating an increase in drought severity over time. Additionally, the study area suffers from drought risks, which directly impact vegetation cover density. Results from the analysis of Landsat imagery, using digital processing techniques, specifically the Normalized Difference Moisture Index (NDMI) and Normalized Difference Vegetation Index (NDVI), showed a correlation between soil moisture stress levels in the selected years and drought waves. Dry years witness a significant increase in soil moisture stress, directly affecting vegetation cover density in the study area. Conversely, during wet years, areas with moisture-stressed soil shrink, leading to an increase in vegetation cover area and density.*

***Keywords:*** *Climatic Drought, Moisture Stress, Vegetation, Kirkuk.*

## Introduction

Some scientists - those studying climate history - express their concern that rising temperatures accompanied by decreasing rainfall may already be pushing some regions towards a mega-drought (usually defined as a continuous drought period lasting 20 years or more). This is a major concern in many countries that have already struggled to meet water needs during two decades of drought. Climate biologist Park Williams, specializing in bioclimatology at the Lamont-Doherty Earth Observatory at Columbia University, points out that the conditions leading to past mega-droughts are currently unknown to us, but in recent years, he has realized that widespread tree mortality and forest fires, events depicted by Williams for those past occurrences, have indeed occurred in recent years. This led him to compare the recent drought in the area with previous mega-droughts, and he discovered a potential match in terms of severity. If this trend continues, it may represent the first mega-drought in the era of human-induced climate change. (American Scientific magazine met Williams earlier this month for his research at the annual meeting of the Washington).

The research revolves around studying climate-related problems, particularly climate drought

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and its impact on moisture stress and vegetation cover, through the question of what the general trend of climate drought in the study area is. Does the study area experience an increase in the severity and frequency of climate drought waves? Additionally, does drought tend to deepen over time due to climate changes in the study area? Here, the initial hypotheses that can be verified may indicate that drought in the study area is witnessing an increase in frequency and severity over time as a result of global warming. The study area is experiencing an increase in the severity and frequency of climate drought waves. Additionally, drought is deepening in the study area due to negative changes in temperature and rainfall.

**Working Mechanism and Data Analysis**

For the purpose of completing the research and achieving the desired goal, several steps, methods, and statistical and analytical programs were followed, including:

Collecting climate data from three weather stations (Tuz, Kirkuk, Beiji), with Kirkuk being the main station and Tuz and Beiji as supporting stations to obtain more objective results about the reality of drought in the study area.

Extracting data of the Standardized Precipitation Index (SPI) by processing the climate data in the DrinC 1.7 software, which provides SPI results according to its severity.

Researchers used various indicators according to their specialties in climate, agriculture, and hydrology to clearly define the dry period or duration, whether on a monthly, seasonal, or annual basis, by providing a numerical description of drought and then utilizing it to calculate its severity and monitor it. The researchers selected the Reconnaissance Drought Index (RDI) to analyze drought in the study area. The analysis of drought was conducted from several axes, as follows:

- Analyzing the recurrence of drought seasons and their severity as determined by the standard values of the RDI index.

Measuring the severity and sustainability of drought for the study period's halves by analyzing the severity of drought between two periods through examining the pattern and frequency of consecutive drought durations by extracting the average duration of dry seasons, also known as sustainability, and dividing sustainability by severity. The cumulative deficit or severity rate during a specific period or model is extracted according to the equation (Qiang Zhang, et al., Regional Frequency Analysis of Droughts in China: A Multivariate Perspective, Water Resource Manage (springer), 2015, Fig. 2, P.4. (Qiang Zhang, et al., Regional Frequency Analysis of Droughts in China: (A Multivariate Perspective, Water Resource Manage (springer), 2015, Fig. 2, P.4).

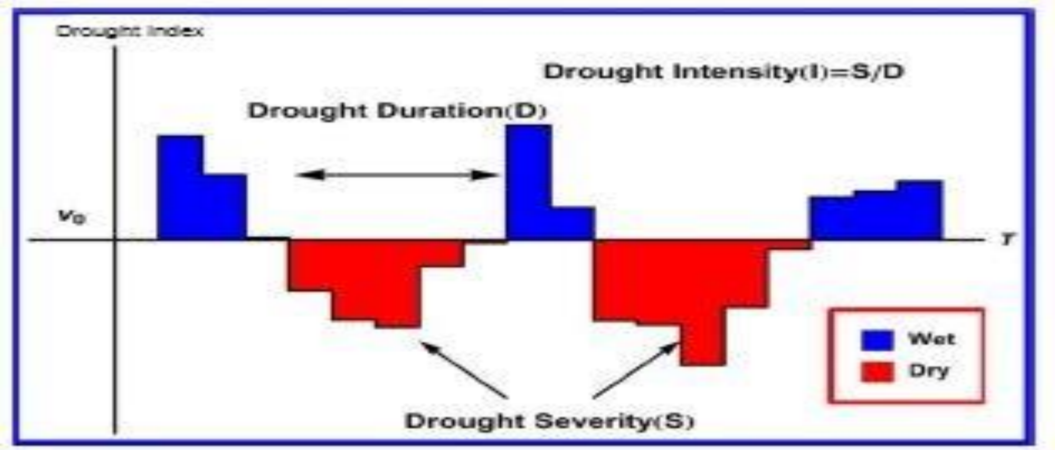
**Intensity = S / D**

**S (Severity)** represents the severity of drought, which is the sum of the drought index values during the period.

**D (Duration)** indicates the recurrence of drought waves during the period.

This index was used to measure the severity and frequency of drought in China using several climatic and statistical variables. Figure (1) illustrates how sustainability and severity are extracted, and then severity is determined.

**Figure (1):** Extracting the Severity and Sustainability of Drought.




**Source:** Qiang Zhang, et al., Regional Frequency Analysis of Droughts in China: A Multivariate Perspective, Water Resource Manage (springer), 2015, Fig. 2, P.5.

**Reconnaissance Drought Indices (RDI)**

This index is considered one of the adopted indicators for assessing drought severity, issued by the World Meteorological Organization (WMO) as part of the Integrated Drought Management Program (IDMP) (G. Tsakiris and H. Vangelis, Establishing a Drought Index Incorporating Evapotranspiration, Lab. of Reclamation Works & Water Resources Management National Technical University of Athens, Iroon Polytechniou, Athens – Greece, 2005, P7.). It includes a set of standardized numerical indicators used in drought studies worldwide (Indicators and Standardized Numbers Guide for Drought Management, Integrated Drought Management Program, World Meteorological Organization (WMO), National Drought Mitigation Center (NDMC) for Nebraska, Publications, 2016, p.17.). Drought values are extracted using the DrinC 1.7 program, a computer program designed for this purpose. This index is expressed in three formulas: the primary RDI: ak (Raw), the normalized RDIn (Normalised), and the standard value (RDIst). The primary formula RDI ak is adopted for the reconnaissance drought index, and the results of this formula are compared according to the standardized values developed by Penman-Monteith for estimating evaporation/transpiration or according to the standardized values developed by Hargreaves, who devised a method for estimating evaporation/transpiration based on maximum and minimum temperatures and elevation above sea level when sufficient climatic data are not available to apply the Penman-Monteith equation. Drought waves are classified according to their severity in this approach, as in the equation (Asadi Zarch M. A., Malekinezhad H., Mobin M.H., Dastorani M.T. and Kousari M.R., 2011. Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran. Water Resources Management, 25(13): 3485-3504.) and according to Table.(1)

Whereas:

Pij: Rainfall for any month j and any year i.

PETij: Potential evapotranspiration for any month j of any year i.

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \quad i = 1 \text{ to N}$$

**Table (1):** Dry Index Numbers according to the Reconnaissance Drought Index, Preliminary Formula RDI ak.

| Severity of drought | (Penman method) | (Hargreavrs method) |
|---|---|---|
| Extremely dry | 0.03> | 0.05> |
| dry | 0.03 – 0.20 | 0.05 – 0.20 |
| Semi dry | 0.20 – 0.50 | 0.20 – 0.50 |
| Semi humid | 0.50 – 0.75 | 0.50 – 0.65 |
| Humid | 0.75< | 0.65< |

**Source:** G. Tsakirisand H. Vangelis, establishing a Drought Index Incorporating Evapotranspiration, Lab. of Reclamation Works & Water Resources Management National Technical University of Athens, Iroon Polytechniou, Athens – Greece,2005, P4.

Through this method, the severity of drought waves in the study area will be analyzed according to standard values based on the Penman-Monteith method, which has been adopted by the FAO as one of the approved methods for studying drought worldwide.

After analyzing the nature of drought in the study area, geographic information systems and remote sensing techniques will be utilized to analyze the spatial data for the selected years based on the severity of drought (severe drought, semi-dry, semi-humid, or humid). Maps will be generated to predict the behavior of the phenomenon and its impact on related phenomena after deriving statistical models for drought according to the aforementioned classification. Specific years representative of each model will be selected to complete the study by utilizing data from the American satellite (Landsat 5, 7, 9) and analyzing the moisture stress and vegetation cover indices through remote sensing techniques.

### 1- MDWI Moisture Stress Index

Moisture stress is one of the spectral indicators used to detect moisture stress that soil or vegetation may experience. It relies on the spectral reflectance values for the mid-infrared and near-infrared wavelengths, according to the following equation:

/ NIR / SWIR+NIR MDWI= SWIR-

The representation values of this indicator range from (0 to 3), with vegetation reflectance falling within the range of (0.4 to 1). A higher value indicates moisture stress for both soil and vegetation, signifying a decrease in water content. (Jinru X. and Baofeng S., "Significant Remote Sensing Vegetation Indices: A Review of Developments and Applications," Journal of Sensors, Series Vol. 17, 2017).

### 2- NDVI Vegetation Index

And it is one of the most important and widely used spectral indicators in environmental studies, first adopted by researcher Rouse et al. as a spectral indicator for studying vegetation covers. It results from the statistical processing of the two spectral channels, red (RED) and near-infrared (NIR), according to the following relationship:

NDVI =Red - NIR / RED +NIR

The NDVI algorithm benefits from the fact that green vegetation reflects less visible light and more near-infrared (NIR) light, while sparse or less green vegetation reflects a greater portion of visible light and less near-infrared. NDVI combines these reflection properties into a ratio, making it an indicator related to photosynthetic capacity. The range of values obtained is between -1 and +1. Only positive values correspond to vegetated areas; the higher the index, the higher the chlorophyll content in the target. NDVI has been used to identify and interpret a range of phenological metrics that describe periodic plant life cycle events and how they are affected by seasonal and annual climate changes. Seasonally integrated NDVI indicates photosynthetic activity during the growing season, while the rate of change in NDVI may indicate the rate of increase or decrease in photosynthesis. These metrics are influenced by several plant characteristics. It is a useful indicator that integrates the effects of climate variations on vegetation cover according to temporal and spatial scales. (Genesis T. Yengoh David Dent Lennart Olsson Anna E. Tengberg Compton J. Tucker, The use of the Normalized Difference Vegetation Index (NDVI) to assess land degradation at multiple scales: a review of the current status)

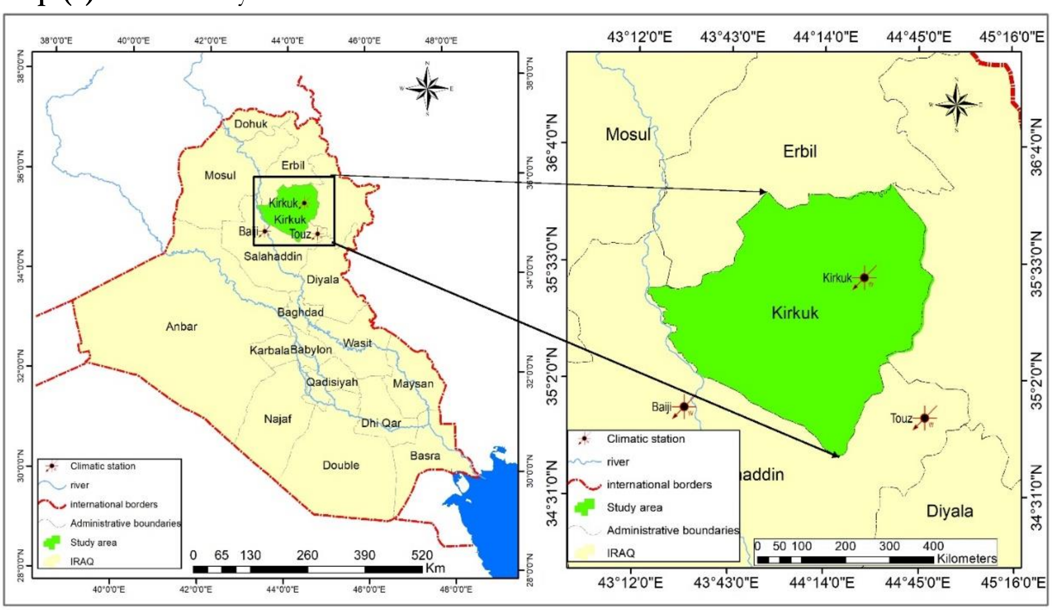
**Study Area Location**

The study area, represented by Kirkuk Governorate, is located to the north of Iraq. It is bordered to the north by Erbil Governorate, while Salah al-Din Governorate borders it to the west and south. To the east, it is bordered by Sulaymaniyah Governorate.

As for its astronomical location, the study area is situated between the latitudes (34°42'15") - (35°52'53") north and the longitudes (43°16'21") - (44°49'20") east.

As for the temporal boundaries, the study was defined over a period extending from (1980 – 2020). This timeframe was chosen as it provides a suitable integration of climatic data from the specified stations in the study. Previous decades before this period lacked complete integration of climatic data, as some stations had older records while others lacked such records and suffered from significant gaps in climatic recording. Therefore, the researcher relied on this period for the study and utilized (3) climatic stations distributed across the study area. Table .(2)

**Map (2):** of the Study Area and the Selected Climate Stations.




**Source:** The Researcher's Work based on the Administrative Map of Iraq at a Scale of 1:1000000, Using the Arc Map 10.2 Program.

**Table (2):** Selected Climate Stations in the Study Area.

| Anatomy number | Height/m | Longitude | Latitude | Station |
|---|---|---|---|---|
| 631 | 115 | 32 43 | 54 34 | Peggy |
| 623 | 843 | 46 44 | 52 34 | Touz |
| 621 | 331 | 24 44 | 28 35 | Kirkuk |

**Source:** Ministry of Transport and Communications, General Authority for Meteorology and Seismic Monitoring.

The study is divided into two axes:

- The first axis will focus on analyzing drought variation using the Standardized Precipitation Index.
- The second axis will analyze both the moisture stress index and vegetation cover in the study area.

## 2. Analyzing Drought Using the Concept of Drought

The program (DrinC 1.7) was adopted for processing climatic data from the selected stations to extract data for the Standardized Precipitation Index and compare it with reference values of the index to determine drought categories or levels and their frequency throughout the study period. The outputs of the program are as follows, as shown in Table:(3)

**Table (3):** Frequency of Drought Waves according to the Reconnaissance Drought Index (RDI) in the Study Area

| Wet | | Semi-Wet | | Almost Dry | | Moderately Dry | | Extremely Dry | | Station |
|---|---|---|---|---|---|---|---|---|---|---|
| Ratio % | Repetition | Ratio % | Repetition | Ratio % | Repetition | Ratio % | Repetition | Ratio % | Repetition | |
| 5.2 | 2 | 2.6 | 1 | 68.4 | 26 | 21 | 8 | 2.6 | 1 | Tooz District |
| 2.6 | 1 | 2.6 | 1 | 65.7 | 25 | 23.6 | 9 | 5.2 | 2 | Baiji |
| 5.2 | 2 | 15.7 | 6 | 63.1 | 24 | 13 | 5 | 2.6 | 1 | Kirkuk |

**Source:** Researchers Worked based on Climate Data for the Stations Studied and Using the Drinc 1.7 Program.

**Severely Dry Seasons:** The Beiji station recorded the highest frequency of this level, with 2 severely dry seasons, while the stations of Tuz and Kirkuk each recorded one season. This level is considered the most severe in terms of drought and is characterized by almost complete absence of rainfall, or when rainfall amounts are mostly less than 100 mm, accompanied by rising temperatures and increased evaporation, which diminishes the actual impact of rainfall on the soil, leading to widespread drought with significant effects on the living environment of arid regions.

**Moderately Dry Seasons:** This category ranks second in terms of drought severity. According to the table provided, Beiji station recorded the highest frequency of dry seasons of this level, with 9 rainy seasons, followed by the Tuz station with 8 seasons, and finally the Kirkuk station with 5 rainy seasons.

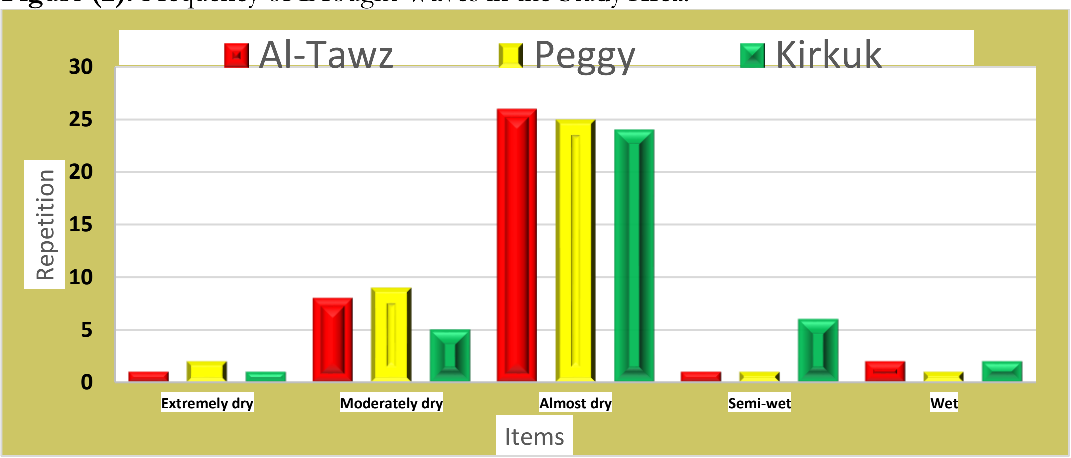
**Semi-Dry Seasons:** This category ranks third among the index categories. The table shows that it recorded the highest number of semi-dry seasons that affected the study area, with the

Tuz station having the highest frequency at 26 semi-dry seasons, followed by the Beiji station with 25, and finally the Kirkuk station with 24 dry seasons.

**Semi-Moist Seasons:** The index transitions from the semi-dry level to the threshold between dryness and moisture, marking the semi-moist seasons associated with an average rainfall of 200 mm. These seasons exhibit hybrid characteristics between humid and arid climates. According to the table above, the Kirkuk station recorded the highest frequency of this level, with 6 semi-moist rainy seasons, while the Tuz and Beiji stations each recorded one season.

▪ **Wet Seasons:** This level represents rainy seasons where the amount of rainfall approaches the values of evaporation during the rainy season. Therefore, the index value in these years approaches (1) as an integer. The number of wet seasons recorded in the studied stations was 2 wet seasons in the Tuz and Kirkuk stations, while one wet season was recorded in the Beiji station.

**Figure (2):** Frequency of Drought Waves in the Study Area.




**Source:** The Researcher based on Table.(3)

Severity and sustainability of drought according to the Reconnaissance Drought Index (RDI) according to the two study periods (1980 – 1999) and.(2017 – 2000) .

The study period was divided into two secondary periods for the purpose of analyzing the frequency and trend of drought events within them, whether there is an increase or decrease in drought frequency during the latter period. This is evident from Table (4), which illustrates the severity and persistence of drought according to the RDI index. The severity and persistence of drought in the studied stations varied between the first and second periods in terms of drought intensity and an increase in drought frequency. All stations recorded an increase in severity, with the severity values in the first period higher than those in the second period, indicating a downward trend in the drought index and thus a deepening of drought in the study area.

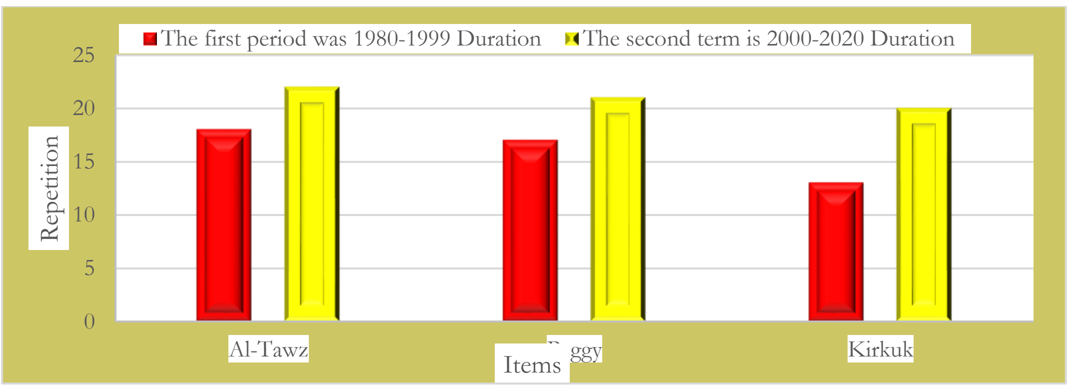
As for frequency, it was found that the study area is within the dry and semi-dry range, and therefore, the stations recorded an increase in drought frequency. The Tuz station recorded the highest frequency in both the first and second periods (18, 22), with an increase of (4) dry seasons, while the Beiji station had an increase of (4) dry seasons as well. However, the Kirkuk station had a difference of (7) dry seasons. An increase in the frequency of drought events between the two secondary periods of the main study period was observed, indicating the impact of climatic changes on the overall climate elements influencing this index in the studied stations during the specified study period.

**Table (4):** Intensity and Frequency of Drought Waves according to the RDI Index During the Two Study Periods.

| The second term 2000-2017 | | | The first period was 1980-1999 | | | Stations |
|---|---|---|---|---|---|---|
| Intensity | Severity | Duration | Intensity | Severity | Duration | |
| 0.21 | 1.96 | 22 | 0.34 | 0.34 | 18 | Al-Tawz |
| 0.24 | 4.62 | 21 | 0.26 | 4.99 | 17 | Peggy |
| 0.30 | 5.12 | 20 | 0.44 | 8 | 13 | Kirkuk |

**Source:** The Researcher Worked according to the Outputs of the Drinc 1.7 Program to Measure the Severity of Drought Waves According to the RDI Index.

**Figure (3):** Intensity and Frequency of Drought Waves according to the RDI index During the Two Study Periods.




**Source:** The Researcher based on Table (4).

- ❖ **The Second Axis is an Analysis of the Indicators of Moisture Stress and Vegetation Cover in the Study Area**

Remote sensing is considered one of the modern and effective methods in studying the Earth's surface and its natural resources, including vegetation, water, and soil distribution, as well as monitoring and tracking environmental phenomena and problems that affect agricultural development processes, especially drought, desertification, and land degradation in both its water and wind aspects. This is achieved through processing and analyzing maps and digital imagery to extract results and indicators that help predict the phenomenon and its impact on the studied area (Hasan Hameed Katia et al., "The Use of Remote Sensing in Distinguishing Land Covers in the West of Lake Razaza Region," Ministry of Water Resources, Environmental Studies Center, 2005, p. 2). By integrating the capabilities of Geographic Information Systems (GIS) and Remote Sensing (RS) technology and applying specific algorithms, changes occurring on the Earth's surface can be monitored at larger spatial and temporal scales than what is possible through conventional surveying techniques. Remote sensing data interprets various spectral signals reaching the sensor after interacting with objects on the Earth's surface. These interpretations can reveal many physical properties of these objects, including surface elevation, temperature, various aspects of vegetation cover, and land cover. In addition to mapping spatial locations using GIS tools, these remotely sensed elements can be used to study the natural environment (vegetation cover, topography, etc.) (Sally Jewell, Suzette M. Kimball, "Use of

Normalized Difference Vegetation Index (NDVI) Habitat Models to Predict Breeding Birds on the San Pedro River, Arizona," U.S. Geological Survey, Reston, Virginia: 2013, p. 2).

Climate conditions, such as significant temperature increases and changes in rainfall patterns due to climate change, lead to a clear increase in the severity of drought episodes. This, in turn, results in a decrease in soil moisture, thereby exacerbating and deepening the dryness significantly over time (Sruthi.S, M.A. Mohammed Aslam, "Agricultural Drought Analysis Using the NDVI and Land Surface Temperature Data; a Case Study of Raichur District," International Conference On Water Resources, Coastal And Ocean Engineering, Dept. of Geology, CUK-Kadaganchi, Gulbarga, Karnataka, 2015, p. 1259).

The capabilities of remote sensing technology have been employed in the field of drought studies to assess the severity of drought in the study area using some spectral indicators used for drought assessment. These indicators have emerged as one of the modern technical means for drought assessment worldwide (Halima Ibrahim Al-Zubaidi, "Assessment of Drought Status Using Remote Sensing Technology: An Applied Study on the Western Regions of Taif Governorate, Saudi Arabia," Journal of Literature and Social Sciences, Sultan Qaboos University, Sultanate of Oman, 2015, p. 63). This is done by analyzing these spectral indicators of imagery captured for the study area for two selected years based on statistical assessment of drought severity. Two rainy seasons were chosen: the first being a very wet season represented by the rainy season of 1993, while the second is an extremely dry rainy season represented by the rainy season of 2009, and the semi-dry rainy season represented by the rainy season of 2015, as shown in Table 5.

**Table (5):** Establishing the basis for types of diversity in the study area.

| Year | 1993 | Description | 2009 | Description | 2015 | Description |
|---|---|---|---|---|---|---|
| Kirkuk | 0.77 | Wet | 0.036 | Extremely Dry | 0.55 | Semi Humid |
| Baiji | 0.71 | Wet | 0.034 | Extremely Dry | 0.41 | Semi Dry |
| Al-Tawz | 0.69 | Semi-Humid | 0.048 | Extremely Dry | 0.49 | Semi Dry |

**Source:** The Researcher based on the Outputs of the Program (DrinC 1.7).

## Moisture Stress Analysis

According to Table (6), it is evident that the categories of the moisture stress index varied in their areas from year to year based on the selected years. Wet years witnessed a decrease in both the high and medium categories of moisture stress, while dry years saw an increase in the areas of these two categories at the expense of the category with no moisture stress:

**Table (6):** Categories and Areas of the Moisture Stress Index in the Study Area for the Selected Years.

| Category | 2009 | Percentage | 2015 | Percentage | 1993 | Percentage |
|---|---|---|---|---|---|---|
| High Stress | 4071.10 | 37% | 2886.95 | 26% | 1838.59 | 17% |
| Medium Stress | 4719.51 | 42% | 6389.34 | 57% | 4355.20 | 43% |
| Stress Free | 2339.04 | 21% | 1853.33 | 17% | 5135.85 | 31% |

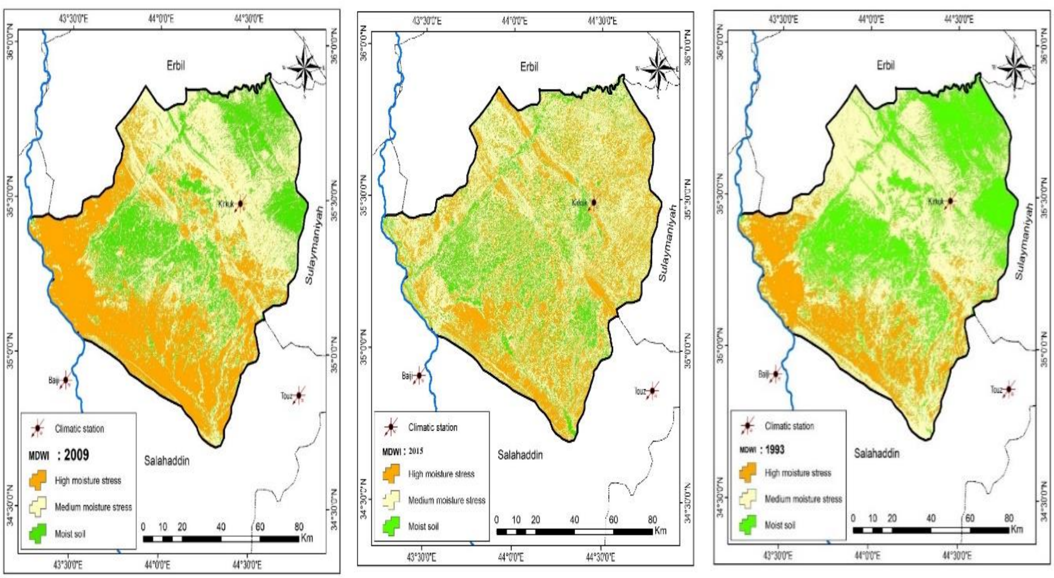
**Source:** The Researcher Worked by Analyzing Satellite Images of the Satellite LANDSAT 5-7-8 and Using the Arcgis 10.8 Program.

- **High Moisture Stress Category:** This represents the lowest values of the index. It is observed that the extremely dry year (2009) recorded the highest area for this category, reaching 4071 square kilometers, while its lowest value was recorded during the wet year

1993, amounting to 1838.6 square kilometers, representing a coverage percentage of 17%. However, its coverage percentage during the semi-dry season was 26% of the total area.

- **Medium Moisture Stress Category:** A clear variation in the areas of this category is noticeable from year to year according to the outputs of the models studied for the selected years. The extremely dry year recorded a larger area for this category, reaching 4071.1 square kilometers, while the wet years had smaller areas within this category, with 4355.2 square kilometers for the year 2015.
- **Moisture Stress-Free Category:** This represents index values higher than zero. There is variability in the areas of this category, with the highest coverage percentage recorded during the wet season of 1993, reaching 31%, with a total area of 5135.8 square kilometers. However, it decreased during the semi-dry season of 2015 to 175 with a coverage area of 1853.3 square kilometers. As for the extremely dry season in 2009, it recorded the lowest coverage percentage at 21%, covering an area of 2339 square kilometers. (Maps 2, 3, 4).

**Map (2,3,4)** of Moisture Stress Index in the Study Area.




**Source:** LANDSAT 5 .7.8 Data for Images Taken in Spring for the Selected Years. Vegetation Index (Ndvi).

**A. Category 1:** Very Dense Vegetation: Table (7) shows that this type of vegetation cover accounted for 11% of the total area of the region, covering an area of 1169.2 square kilometers during the wet model, represented by the rainy season (1993). However, the results of the vegetation cover analysis during the semi-dry season indicated a clear decrease in the coverage percentage of this type, covering 8% of the study area, with an area of 857.5 square kilometers. This decrease is attributed to the relative decrease in rainfall during this model. During the extremely dry season, represented by the rainy season of 2009, there was a sharp decrease in the coverage area of this type, dropping to 4% of the total study area, covering an area of 426.9 square kilometers. This was due to the significant rainfall shortage and the increase in temperature, leading to increased evaporation from the soil and plants, and increasing soil water deficit, directly affecting the density of vegetation cover. (Maps 5, 6, 7).

**Table (7):** Vegetation Cover Types in the Study Area during the Selected Years.

| category | 1993 | Percentage | 2009 | Percentage | 2015 | Percentage |
|---|---|---|---|---|---|---|
| very dense | 1169.2 | 11% | 426.9 | 4% | 857.5 | 8% |
| dense | 2622.2 | 24% | 717.8 | 6% | 1722.6 | 15% |
| Weak | 3841.2 | 35% | 1993.0 | 18% | 4271.2 | 28% |
| Very weak | 3402.6 | 31% | 7960.3 | 72% | 4221.3 | 48% |
| Water | 94.4 | 0.8% | 31.7 | 0.3% | 56.9 | 0.5% |

**Source:** Researchers' Work based on Analysis of Data from the American Satellite Landsat.

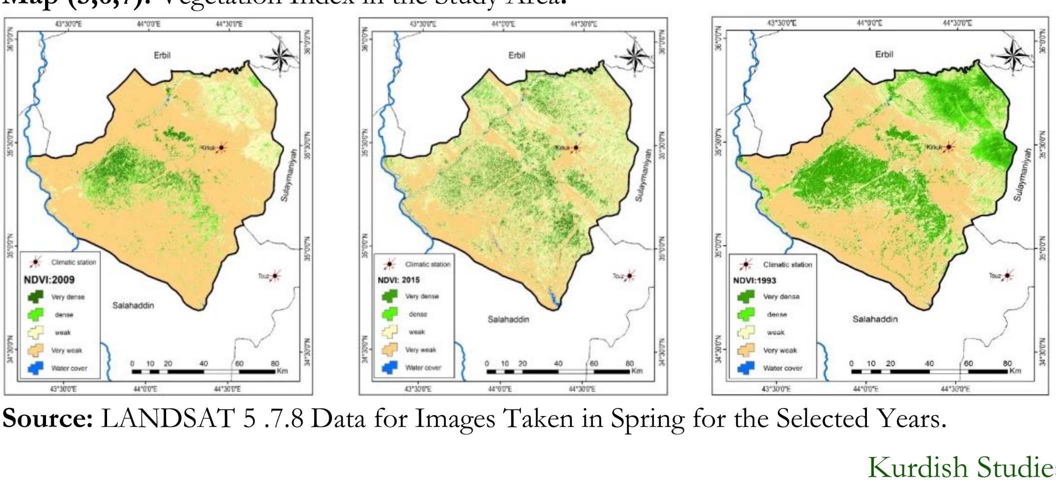
**B. The Second Category: Dense Vegetation Cover:**

This type of vegetation cover ranks second in terms of density among the vegetation covers. Its highest percentage in the area was recorded during the 1993 season, reaching a coverage rate of 24% of the total study area, covering an area of 2622.2 square kilometers. However, the coverage percentage of this type decreased during the dominance of the semi-dry model, represented by the 2015 rainy season, to only 155, covering an area of 1722.6 square kilometers. Meanwhile, during the extremely severe drought wave in 2009, the coverage percentage decreased to only 6% of the total study area, covering an area of 717.8 square kilometers.

**Category C:** Weak Coverage: The percentage of areas covered by this type varied within the study area according to the analyzed models. This type indicates the critical condition of vegetation cover, which is highly sensitive to any climatic changes affecting the prevailing climate conditions. Tracking the distribution pattern in the study area and according to the regions classified, it is evident that this type recorded a percentage of vegetation cover in the area during the presence of the cold wet model, reaching 35%, covering an area of 3841.2 square kilometers of the total area. However, this percentage decreased during the influence of the semi-dry model to reach a coverage percentage of 28%, covering 1993 square kilometers.

**Category D:** Very Weak Coverage: This type represents barren or semi-barren lands with minimal vegetation cover. It recorded varying percentages within the study area according to the selected years. During the severe drought model represented by the year 2009, it covered 72% of the study area, with an area of 7960.3 square kilometers, the highest recorded. However, during the semi-dry season, this percentage decreased to 48% of the total study area, covering 4221.3 square kilometers. Meanwhile, during the wet model in 1993, this category recorded its lowest value, covering 31% of the total study area.

**Map (5,6,7):** Vegetation Index in the Study Area.




**Source:** LANDSAT 5 .7.8 Data for Images Taken in Spring for the Selected Years.

## Conclusions

1- The study reveals that the region is subject to the dominance of moderate drought waves in most rainy seasons, while extreme drought waves occur unevenly and intermittently within the same decade. Wet seasons are rare due to the limited amount of rainfall in the area.
2- Drought tends to deepen and increase in frequency in recent years, reflecting global warming and climate change, which have begun to affect the studied area.
3- Analysis of moisture stress indicators shows that the southern and southwestern parts of the study area experience higher moisture stress compared to other parts. The intensity of this stress fluctuates between wet and dry years, expanding and contracting accordingly.
4- Dense and very dense vegetation cover is closely linked to soil moisture. It expands with lower moisture stress and contracts with increased moisture stress.
5- Information systems and remote sensing technologies provide the capability to study climate change and its environmental impacts, allowing for the extraction of results to make appropriate decisions in dealing with such future crises.

## Recommendations

1- Conducting further specialized climate studies focusing on climate change and addressing other climatic elements to determine their general trends and specify their expected future impacts on the environment in the study area and the rest of the provinces in the region.
2- Installing and equipping more weather stations in the study area, as it is an area severely affected by aridity, and the existing stations do not cover the entire area in terms of data due to significant variations between one area and another due to aridity.
3- Activating remote sensing systems and technologies and integrating them into environmental studies as a fundamental element for analyzing spatial data in order to make appropriate decisions based on the available information.
4- Conducting simultaneous field studies alongside the results obtained from the analysis of spatial data for comparison and evaluation of the accuracy of this data and its results to achieve an objective understanding of the subjects studied by researchers in this field.

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