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# Modeling Rainfall Changes and Their Effects on Soil Moisture Stress and Vegetation Cover in Sulaymaniyah Governorate Using GIS and Remote Sensing (RS)

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A B S T R A C T

Modern studies have shown that climate elements, especially rainfall, have started to show general trends of decrease in many countries, serving as a significant and clear indicator of climate change, which has become an undeniable reality. Numerous global, regional, and local studies confirm this, as clearly observed in the study area. Analyzing trends across four stations within the study area revealed a marked decrease in rainfall quantities during the selected period (1991–2020). This change varied from -36.2 mm at Dukan station to -8.1 mm at Halabja station, reflecting a significant climatic shift during this period. Furthermore, Iraq and the study area are characterized by high rainfall variability between wet seasons, with variations in both positive and negative fluctuations across stations. For instance, the range of fluctuation at Sulaymaniyah station was between -163.8 mm and 162.2 mm, while Dukan station recorded fluctuations between -180.5 mm and 192.5 mm. Halabja station displayed a clear variability between positive and negative fluctuations, with a difference of 18.7 mm (-131.3 mm to 150.0 mm). Darbandikhan station recorded fluctuation rates between -173.7 mm and 100.5 mm, with a difference of up to 73 mm, impacting soil moisture and, consequently, vegetation density in the study area. Through the use of remote sensing and geographic information systems (GIS) to analyze data from Landsat (5, 7, 8) satellites, focusing on images captured during the spring to coincide with peak vegetation growth, results were derived using indices such as the Normalized Difference Moisture Index (NDMI) and the Normalized Difference Vegetation Index (NDVI). The findings demonstrated a correlation between soil moisture stress levels in the selected years and rainfall amounts. There was an inverse relationship with high and moderate soil moisture stress levels (-0.222 and -0.787, respectively), while a positive correlation was found with moderately moist and very moist lands (0.595 and 0.636). Additionally, rainfall amounts were inversely correlated with weak and very weak vegetation cover (-0.732 and -0.461, respectively) but positively correlated with dense and very dense vegetation (0.555 and 0.848), highlighting the significant impact of rainfall change and fluctuation on the environment in the study area.



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# نمذجة تغير الأمطار وأثره في الاجهاد الرطوبي للتربة و الغطاء النباتي في محافظة السليمانية باستخدام (Gis&Rs)

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**المستخلص**

أثبتت الدراسات الحديثة ان عناصر المناخ وخصوصا الأمطار بدأت تسجل اتجاهات عامة نحو التناقص في العديد من الدول، كأحد المؤشرات المهمة والواضحة على التغير المناخي الذي أصبح حقيقة لا يمكن تجاهلها إذ أثبتت العديد من الدراسات العالمية والإقليمية والمحلية ذلك وهذا ما ظهر جليا في منطقة الدراسة من خلال تحليل الاتجاه العام لأربعة محطات ضمن منطقة الدراسة اذ بينت ان هنالك اتجاها واضحا نحو التناقص في كمية الأمطار فيها مما نتج عنه تغير في كميتها خلال مدة الدراسة المختارة من (١٩٩١-٢٠٢٠) اذ تراوح مقدار التغير من (-٣٦,٢ ) ملم في محطة دوكان الى (-٨,١) ملم في محطة حلبجة، وهذا يعد تغيراً كبيراً خلال هذه المدة المناخية فضلاً عن ان الصفة المِميزة لأمطار العراق ومنطقة الدراسة، هو التذبذب العالي في كمية الأمطار بين موسم مطري وآخر، والذي تباين في شدة التذبذب السالب والموجب بين محطة وأخرى، اذ اكان تذبذب محطة السليمانية ما بين (- ١٦٣,٨ الى١٦٢,٢) ملم بينما سجلت محطة دوكان معدل تذبذب ما بين (- ١٨٠,٥، ١٩٢,٥) ملم أما محطة حلبجة فقد سجلت تبايناً واضحاً بين التذبذب الموجب والسالب وبفارق ١٨,٧ملم ( -١٥٠,٠،١٣١,٣) أما محطة دربنديخان فقد كانت معدلات التذبذب تقع ما بين (- ١٧٣,٧، ١٠٠,٥) ملم وبفارق يصل الى ٧٣ ملم مما ينعكس على رطوبة التربة وبالتالي على كثافة الغطاء النباتي في منطقة الدراسة.

ومن خلال استخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية لتحليل معطيات القمر( Landsat 5,7,8) المتمثلة بالمرئيات الملتقطة في سنوات مختارة ممثلة لنماذج تغير الأمطار وملتقطة في فصل الربيع تزامنا مع قمة النمو الخضري للغطاءات النباتية في منطقة الدراسة واستخلاص نتائج المعالجات الرقمية لها المتمثلة بمؤشر الإجهاد الرطوبي NDMI ومؤشر الغطاء النباتي NDVI أظهرت النتائج وجود علاقة ارتباط بين مستويات الإجهاد الرطوبي للتربة في السنوات المختارة وكمية الأمطار وبلغت اذ كانت علاقة عكسية مع الإجهاد الرطوبي العالي والمتوسط (-٠,٢٢٢،-٠,٧٨٧) على التوالي بينما كانت علاقة طردية مع فئتي الأراضي المعتدلة الرطوبة والرطبة جداً (٠,٥٩٥، ٠,٦٣٦) وكذلك بين كمية الأمطار وأصناف الغطاء النباتي ومساحاته في منطقة الدراسة اذ كانت قيم الارتباط عكسية مع الغطاء النباتي الضعيف والضعيف جداً (-٠,٧٣٢،-٠,٤٦١) على التوالي بينما كانت طردية مع الصنف كثيف والكثيف جداً ( ٠,٥٥٥، ٠,٨٤٨) مما يؤشر التأثير الواضح للتغير والتذبذب المطري في البيئة بشكل عام في منطقة الدارسة .

**الكلمات المفتاحية:** تغيرات هطول الأمطار، رطوبة التربة، الغطاء النباتي، نظم المعلومات الجغرافية والاستشعار عن بعد.

## Introduction

Extensive studies on climate changes globally have shown that Earth's climate is undergoing clear alterations over time. These changes involve dynamic shifts in most climate elements, and given the interconnected nature of these elements, any variation in one component inevitably impacts the others, either positively or negatively. Global warming, driven by human activities and an increase in greenhouse gases in the Earth's atmosphere, has intensified the greenhouse effect, consequently altering the overall atmospheric cycle of the planet. Rainfall, as one of the climate elements affected by global warming, has shown a notable decrease in certain climate zones over the past four decades, while other regions experience an increase. In Iraq, with its characteristic dry and semi-dry climate zones, some climatic studies indicate a noticeable change in rainfall patterns, with a general trend towards decline over time. This decrease impacts the land, affecting soil moisture and reducing both the area and density of vegetation cover, leading to environmental degradation during drier years due to the variability in rainfall.

This study focuses on understanding climate change issues and its impact on soil moisture and vegetation cover, by examining the following questions:

1. Are rainfall quantities changing in general trends over time across the stations within the study area?
2. Is there significant rainfall variability between different wet seasons, and how do these changes impact soil moisture stress in the study area?
3. What is the effect of these changes on vegetation cover, and can remote sensing techniques effectively assess the impact of rainfall fluctuations on soil moisture stress and vegetation cover to evaluate the expected level of impact?

The initial hypotheses suggest that rainfall in the study area is experiencing a decreasing trend in annual totals over time, likely due to global warming. Variability and changes in rainfall significantly affect soil moisture in the study area, causing marked soil and vegetation stress during dry years, and vice versa. Therefore, remote sensing is one of the best methods available for climate and environmental studies, enabling effective assessment of climate change impacts and approaches to adaptation and mitigation over time.

## Methodology and Data Analysis

To complete the research and achieve the intended objectives, several steps, tools, and statistical and analytical programs were applied:

1. **Collecting Rainfall Data**: Climate data from four stations (Sulaymaniyah, Darbandikhan, Halabja, Dukan) were gathered. This data was used to analyze fluctuations, general trends, and changes in rainfall quantity at these stations. The data was classified into "wet," "semi-wet," and "dry" years to facilitate modeling and the analysis of soil moisture stress and vegetation indices within the study area. The **Mann-Kendall trend test** (Arun Mondal, 2012, p.72) was used to analyze trends and changes, as it is one of the most comprehensive and up-to-date statistical tests for analyzing time series trends (Azzawi, 2019, p.109).

Fluctuation is defined as the extent to which values deviate from their average, with greater differences indicating higher variability. **Mean deviation** is a dispersion measure (Tayie, 2013, p.113) used to analyze fluctuations. Higher values of mean deviation indicate greater fluctuation in the time series. Both positive and negative fluctuations can be analyzed independently to determine the time series' sensitivity to values above or below the average, which affects the overall trend (Awad, 2021, p.55).

2. **Rainfall Modeling**: The data was modeled to classify years as wet, semi-wet, or dry using normal distribution based on the average and standard deviation of rainfall data. Modeling is an effective tool in environmental research to simulate reality, enabling results that mirror actual conditions. Models can be statistical, relying on statistical tools and relationships to categorize data into specific classes, each representing a particular probability or effect (Qirbah, 2005, p.2).

   Geographic Information Systems (GIS) and remote sensing techniques were also used to create map-based models, predicting the behavior of phenomena and their impacts on related factors. Both methods were applied in modeling rainfall to generate classifications (wet, moderately moist, dry) for the studied stations, representing potential changes. These models were created by processing the rainfall data according to the normal distribution model (Spiegel & Others, 2004, pp. 55-56), with recurrence rates mapped using **ArcGIS** software. This established a foundation for selecting Landsat satellite data to study soil moisture stress and vegetation cover.

3. **Satellite Data and Vegetation Analysis**: Specific years were selected to represent each rainfall model for further study, using satellite data from **Landsat 5, 7, and 9** to analyze soil moisture stress and vegetation indices through remote sensing techniques.

4. **Moisture Stress Index (MDWI)**: Moisture Stress is a spectral index used to detect moisture stress in soil or vegetation, relying on the spectral reflectance values of mid-infrared (SWIR) and near-infrared (NIR) wavelengths. The index is calculated using the following equation:

   $$MDWI{=}SWIR{+}NIRSWIR{-}NIR$$

   This index ranges between 0 and 3. Vegetation reflectance typically falls between -0.4 and 1, with higher values indicating greater soil and vegetation moisture stress and lower water content (Jinru X. and Baofeng S, 2017, p.17).

5. **Normalized Difference Vegetation Index (NDVI)**: NDVI, one of the most widely used spectral indices in environmental studies, was first proposed by Rouse et al. as a spectral measure for vegetation. It combines red (RED) and near-infrared (NIR) spectral bands:

   $$NDVI{=}NIR{+}REDNIR{-}RED$$

   NDVI leverages the fact that green vegetation reflects less visible light and more NIR light, whereas sparse vegetation reflects more visible and less NIR light. This ratio correlates with photosynthetic activity, with values between -1 and +1, where positive values represent vegetated areas. Higher values indicate increased chlorophyll content. NDVI can determine and interpret several phenological metrics describing the life cycle of plants and how they respond to seasonal and annual climate variations (Genesis, 2014, p.7).

**Study Area**

The study area, **Sulaymaniyah Province** in northeastern Iraq, is bordered by Iran to the east, Erbil to the north, Kirkuk and Salah ad-Din to the west, and Diyala to the south. Geographically, it lies between longitudes 44°32' and 46°20' and latitudes 34°32' and 36°31', covering an area of 17,645 km² (Map 1).

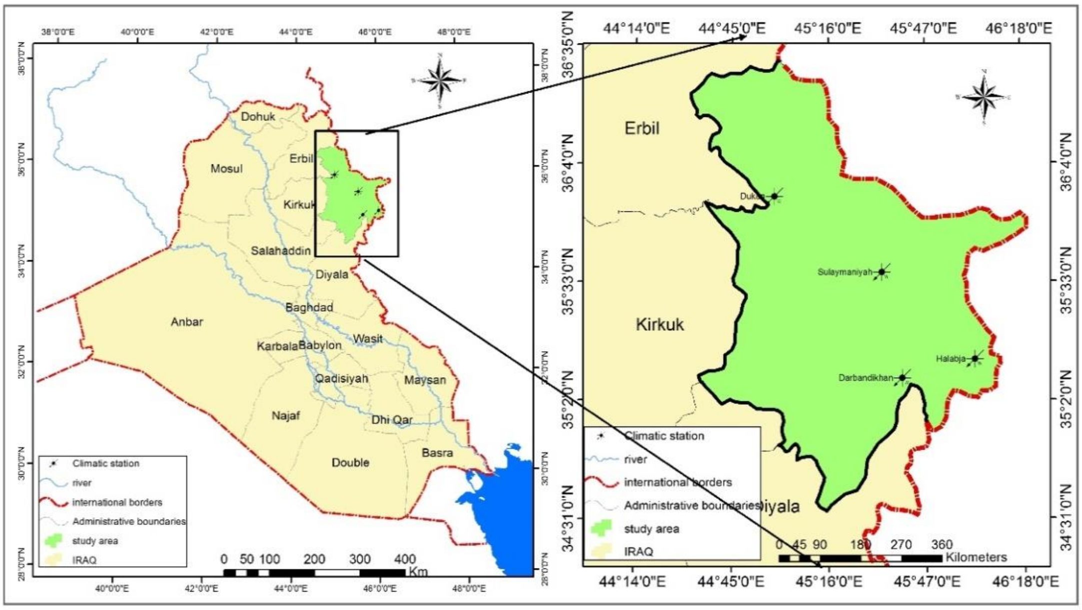
This study utilized rainfall data from four stations within the area—Sulaymaniyah, Dukan, Halabja, and Darbandikhan (Table 1 and Map 1).

**Table (1):** Selected Climate Stations

| Station | Latitude | Longitude | Height above sea level |
|---|---|---|---|
| Sulaymaniyah | 35-33 | 46-27 | 884.8 |
| Darbandikhan | 35-17 | 45-15 | 523 |
| Halabja | 35-11 | 45-58 | 695 |
| Dukan | 35-55 | 44-57 | 555 |

**Source:** R.A.O Representation in Iraq, F.A.O Sulaymaniyah Sub-Office. Agro-meteorological.

**Map (1): Study Area and Selected Climate Stations**




**Source: General Authority for Survey, Iraq Administrative Map, Scale 1:1,000,000**

**The study is divided into two main sections:**

- **Section One**: Analyzes rainfall changes and modeling at the selected stations.
- **Section Two**: Analyzes the moisture stress and vegetation cover indices in the study area.

**Section One**: Analyzes rainfall changes and modeling at the selected stations.

- **Trends and Changes in Rainfall Quantity**

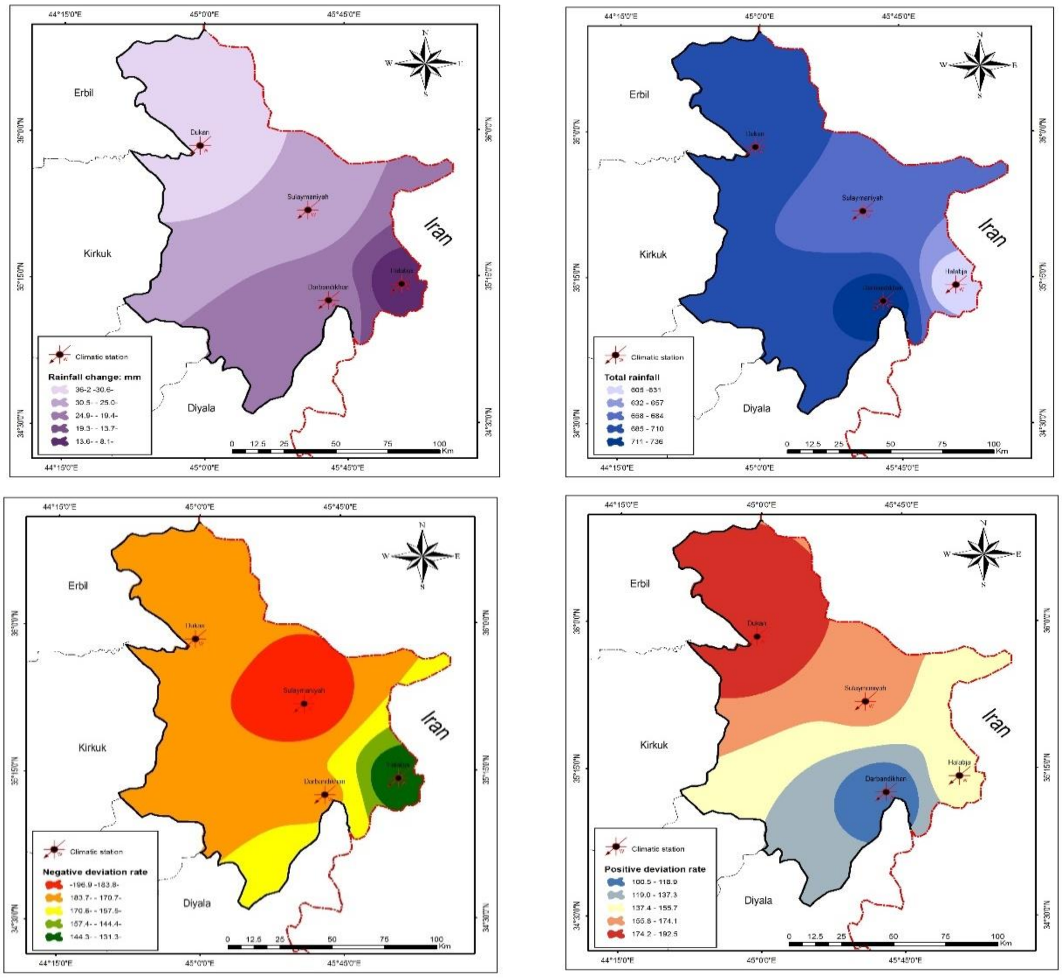
**Table (2):** Changes and Fluctuations in Rainfall Quantity in the Study Area (1990-2020)

| Climate Station | Time Series (Years) | Annual Change | Change Over Study Period | p-value | Mean Deviation | Average Positive Deviations | Average Negative Deviations |
|---|---|---|---|---|---|---|---|
| Sulaymaniyah | 30 | -3.019 | -90.57 | 0.050 | 162.9 | 162.2 | -163.8 |
| Darbandikhan | 30 | -2.325 | -69.6 | 0.029 | 127.4 | 100.5 | -173.7 |
| Halabja | 30 | -0.813 | -24.39 | 0.014 | 140.0 | 150.0 | -131.3 |
| Dukan | 30 | -3.07 | -92.1 | 0.02 | 186.3 | 192.5 | -180.5 |

**Source:** Researchers' work based on the Xlstst program

Dukan station recorded the highest trend and change value, with a trend coefficient of (-3.07) mm and a total rainfall change of (-92.1) mm over the study period. Sulaymaniyah station ranked second, with a trend coefficient of (-3.019) mm per year, resulting in a total change of (-90.57) mm during the study period. Darbandikhan station showed the third highest change, with a total change of (-69.6) mm over the study period. Halabja station had the lowest rainfall change, with a total of (-24.39) mm. See Table (2) and Maps (2).

**Maps (2)** illustrate the rainfall quantity, rate of change, and fluctuations in values for the study area over the study period.

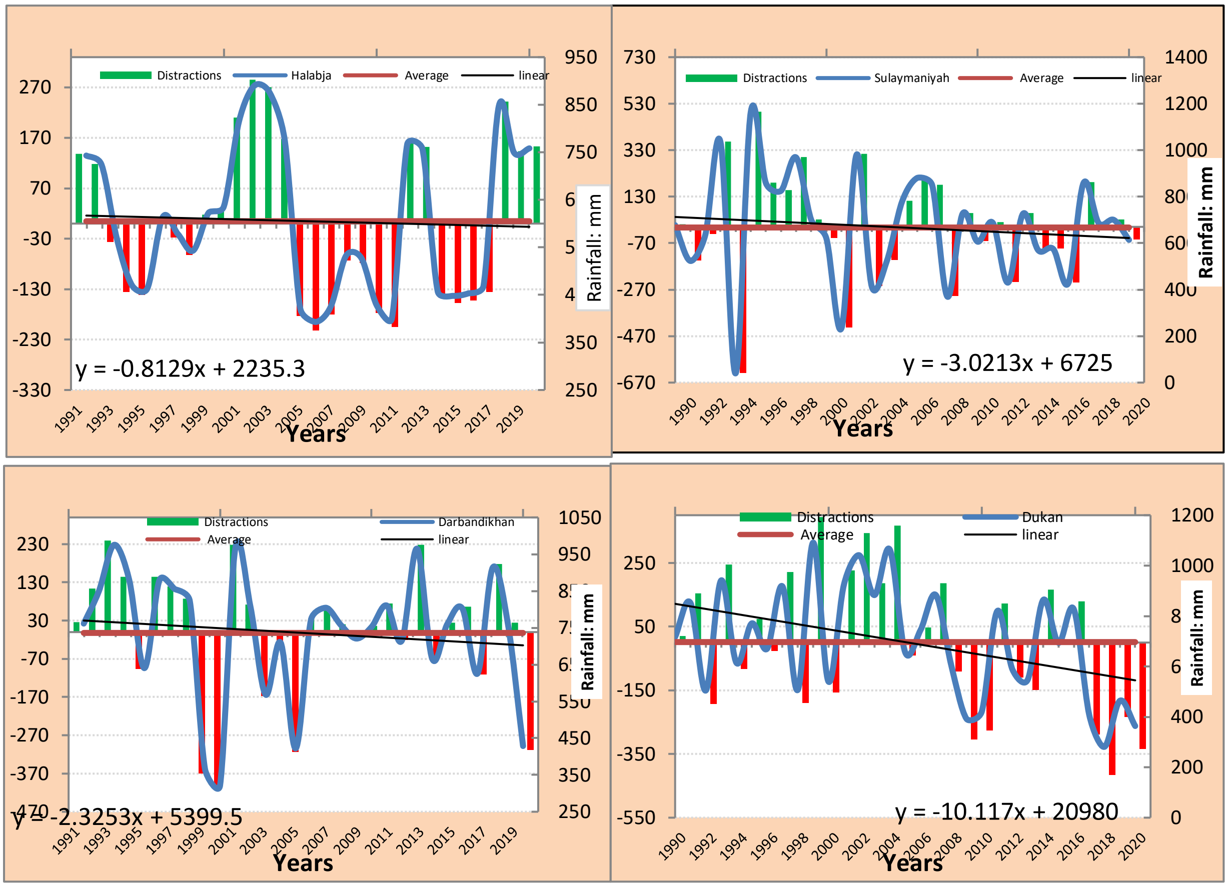



**Source: Researcher's work based on ArcGIS 10.8**

Table (2) shows that the highest mean deviation was recorded at Dukan station, reaching 186.3 mm, followed by Sulaymaniyah, Halabja, and Darbandikhan stations with values of 162.9 mm, 140 mm, and 127.4 mm, respectively. This indicates that Dukan station experiences highly fluctuating rainfall, impacting its general trend and resulting in the highest recorded change in rainfall quantity.

Regarding positive and negative fluctuations, Dukan station also recorded the highest values, with the positive fluctuation reaching 192.5 mm and the negative fluctuation at -180.5 mm. Observing Figure (1), it is clear that values above the mean were concentrated in the first half of the time series, while values below the mean were more frequent in the second half. This shift contributed to a downward trend in the overall rainfall rate over time. Sulaymaniyah station also exhibited high fluctuation overall, with a relatively balanced positive and negative fluctuation. However, the frequency of years with below-average rainfall played a significant role in directing the general trend of the series toward a decrease over time.

**Figure (1):** General Rainfall Trend at Stations in the Study Area Over the Study Period




**Source:** Researchers' work based on Excel and data from the General Authority for Meteorology and Seismology.

## Modeling Rainfall Changes

It is evident from the table that the proposed rainfall models varied in their frequency between stations as follows:

The **wet model**, representing years with total rainfall amounts deviating from the mean by more than half a standard deviation, recorded the lowest frequencies among the other models, with values of (9, 8, 7, 8) for Sulaymaniyah, Darbandikhan, Halabja, and Dukan stations, respectively. These correspond to percentages of (27%, 23%, 27%, 30%). It is noteworthy that most of these occurrences were recorded in the first half of the 30-year time series.

The **moderate model**, which represents years that fall within less than half a standard deviation (above or below the mean), was the most frequently recorded model among the others. Darbandikhan station showed the highest frequency, followed by Sulaymaniyah, Halabja, and Dukan stations with frequencies of (14, 13, 11, 11), respectively. It is observed that the frequencies of this model were relatively evenly distributed across both halves of the time series

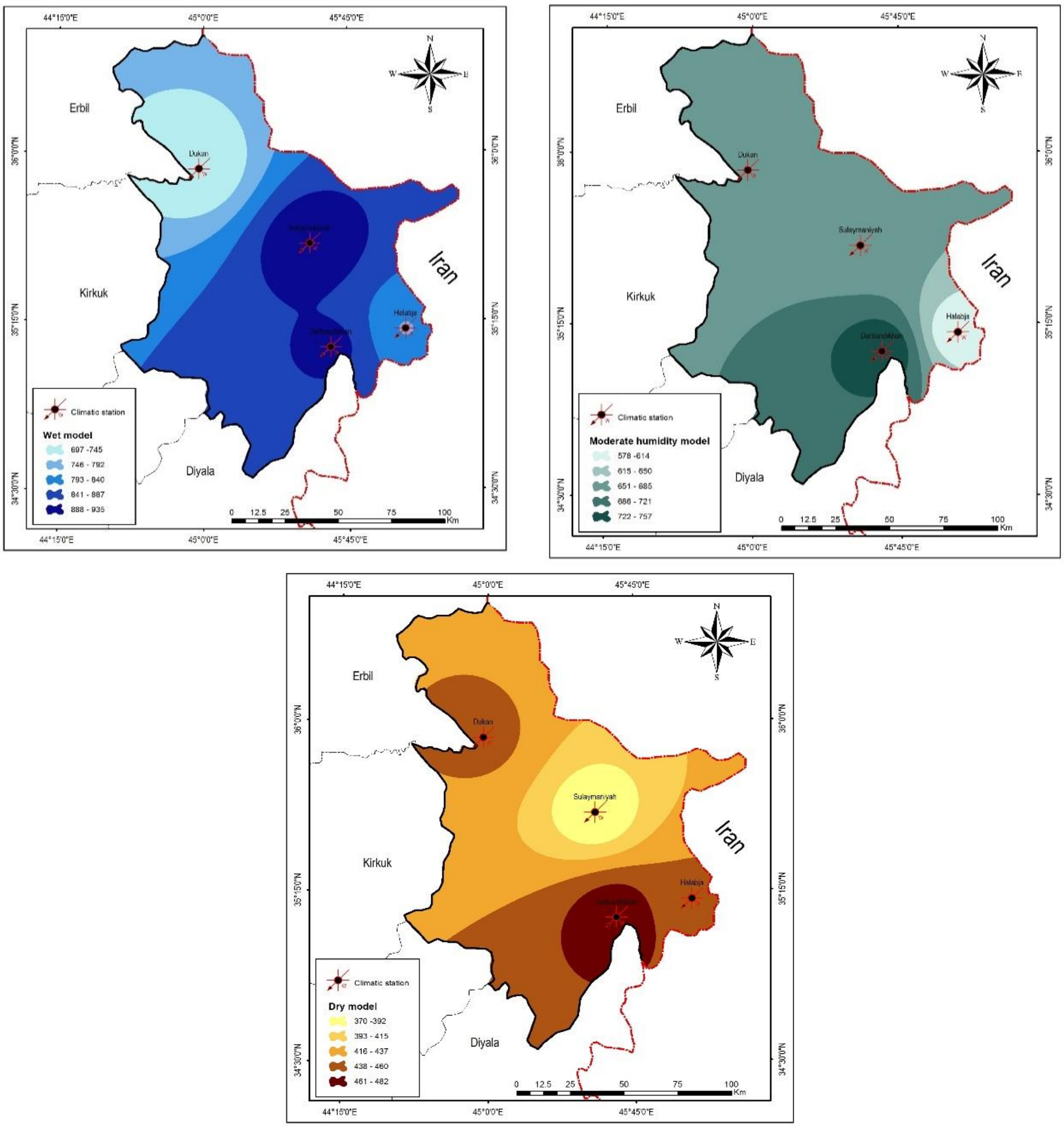
**Table (3):** Statistical Models of Rainfable (3): Statistical Models of Rainfall Changes at Stations in the Study Area

| Station | Average | Deviation | Model | Frequency | Total | Percentage |
|---|---|---|---|---|---|---|
| Sulaymaniyah | 667 | 237.0 | Dry Model | 9 | 370 | 30% |
| | | | Moderate Model | 13 | 664 | 43% |
| | | | Wet Model | 8 | 935 | 27% |
| Durbendikhan | 736 | 171 | Dry Model | 9 | 482 | 30% |
| | | | Moderate Model | 14 | 757 | 47% |
| | | | Wet Model | 7 | 900 | 23% |
| Halabja | 605 | 160 | Dry Model | 11 | 439 | 40% |
| | | | Moderate Model | 11 | 578 | 37% |
| | | | Wet Model | 8 | 791 | 27% |
| Dukhan | 697 | 221 | Dry Model | 10 | 443 | 40% |
| | | | Moderate Model | 11 | 673 | 33% |
| | | | Wet Model | 9 | 697 | 30% |

**Source:** Researchers' work through the statistical processing of rainfall data for the stations in the study area.

- The **dry model** represents the years that recorded annual rainfall below the average by half a standard deviation (average – half a standard deviation). The highest frequency was recorded at the Halabja station, followed by Dukak, Sulaymaniyah, and Darbandikhan (11, 10, 9, 9), respectively. It is notable that most years within this model were concentrated in the second half of the selected time series in the study, indicating the validity of the Mann-Kendall test results, which show that the overall trend of rainfall is decreasing over time. This trend has been corroborated by numerous studies on Iraq in general and the study area in particular.

**Maps (3):** Spatial Modeling of Rainfall at the Stations in the Study Area According to the Proposed Statistical Models During the Study Period




**Source: Work by the researchers using ArcGIS 10.8**

## Section Two: Analysis of Moisture Stress and Vegetation

### Analysis of Moisture Stress and Vegetation

After analyzing the time series using the Mann-Kendall test, statistically and cartographically modeling them, and classifying the years of study according to the climatic models of the selected stations in the study area, specific years were chosen based on the above models to study and analyze the indicators of moisture stress and vegetation. This was achieved through the analysis of imagery from the American Landsat satellites (5, 7, 8). The images were selected for capture during the spring season, as natural vegetation and the rainy season are at their best in terms of timing and plant growth. The following years were selected for the analysis of satellite imagery, as shown in Table (4).

**Table (4):** Selected Years According to Precipitation Models in the Study Area

| Year | Precipitation Amount (mm) | Description within the Models |
|---|---|---|
| 1995 | 926 | Very Wet |
| 2001 | 423 | Semi-Wet |
| 2009 | 455 | Extremely Dry |
| 2015 | 631 | Dry |
| 2017 | 928 | Very Wet |
| 2020 | 508 | Extremely Dry |

**Source:** Prepared by the researcher.

It is evident from Table (5) that the categories of the moisture stress index varied in their areas from one year to another according to the previously established rainfall models. The wet years experienced a decrease in the areas of both high and moderate moisture stress categories, while the dry years saw an increase in the areas of these two categories at the expense of the other categories. Conversely, the wet and semi-wet categories were positively correlated with the amount of rainfall; an increase in rainfall leads to an expansion in the area of each category, as follows:

**Table (5)** Categories and Areas of the Moisture Stress Index in the Study Area for the Selected Years

| Year | High Stress | Moderate Stress | Semi-Wet | Wet | Water Cover |
|---|---|---|---|---|---|
| 1995 | 1289 | 4305 | 6890 | 4552 | 402 |
| Percentage | 7% | 25% | 40% | 26% | 2% |
| 2001 | 2757 | 6618 | 5245 | 2610 | 208 |
| Percentage | 16% | 38% | 30% | 15% | 1% |
| 2009 | 2348 | 6818 | 6406 | 1744 | 114 |
| Percentage | 15% | 49% | 37% | 10% | 1% |
| 2015 | 2216 | 5391 | 5637 | 3945 | 249 |
| Percentage | 7% | 31% | 38% | 23% | 1% |
| 2017 | 1566 | 3087 | 5165 | 7171 | 449 |
| Percentage | 15% | 18% | 24% | 41% | 3% |
| 2020 | 3344 | 5540 | 6578 | 1795 | 180 |
| Percentage | 19% | 32% | 38% | 10% | 1% |

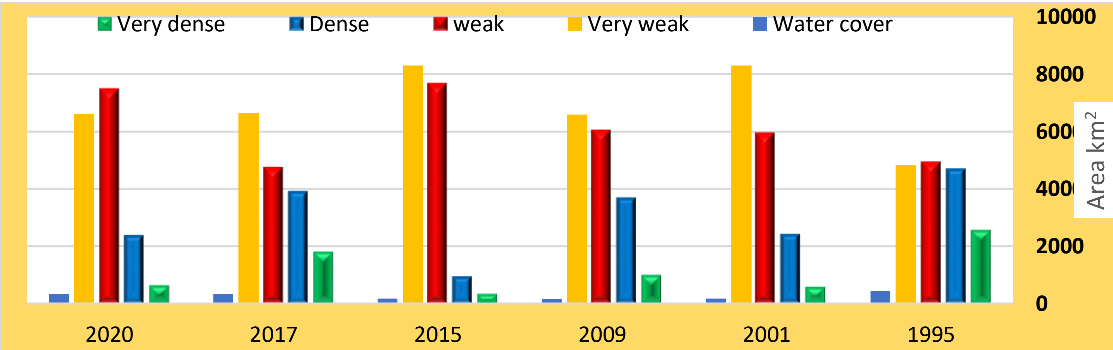
**Source:** Researcher's work through the analysis of satellite imagery from LANDSAT 5, 7, and 8 using ArcGIS 10.8 software.

• High **Moisture Stress:** This represents the lowest values of the moisture stress index. It is noted that the very dry years (2001, 2020, and 2009) recorded the highest areas for this category, measuring (2757, 2348, and 3344) km², respectively. In contrast, this category recorded its lowest area during the wet years, measuring (1289, 2106, and 1566) km² for the years (1995, 1999, and 2017), as shown in Figure (2).

• Medium **Moisture Stress:** The table above indicates a clear variation in the areas of this category from year to year, based on the results of the studied models for the selected years. The severely dry years, characterized by the lowest amounts of rainfall, exhibited larger areas compared to their wet counterparts, measuring (6618, 6818, and 5540) km² for the years (2001, 2009, and 2020), respectively. In contrast, the wet years had relatively smaller areas within this category, measuring (4305, 5717, and 3087) km² for the years (1995, 1999, and 2017), as shown in Figure (2).

• Semi-**Humid Category:** This category represents values of the moisture stress index above zero. There is a slight variation in the areas of this category across the selected years, with minimal differences that were not significantly affected by the rainfall characteristics during the study period. The highest area was recorded in 1995, measuring 6890 km², while 2017 recorded the lowest area at 5165 km². The remaining years fell between these two, showing very close area values.

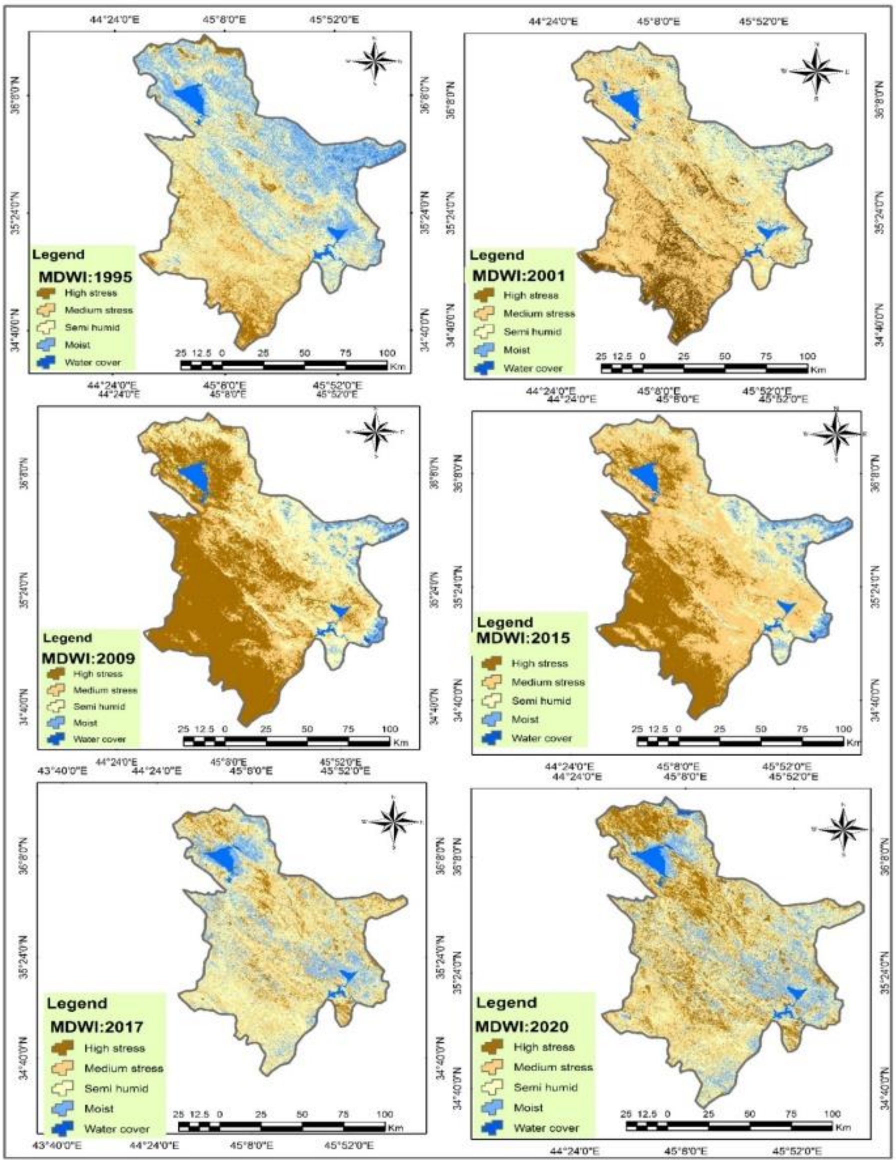
**Figure (2):** Areas of Moisture Stress Index Categories




**Source:** Researchers' work based on Table (5).

- **Wet Class:** It is observed that this class recorded its highest area during wet years, while the lowest area was recorded in dry years. The highest value was in 2017, reaching 7,171 km², followed by the years 1995 and 1999, with areas of 4,552 km² and 3,965 km², respectively. In contrast, the lowest recorded values occurred in 2009 and 2020, with areas of 1,744 km² and 1,795 km², respectively (Maps 4).

**Maps (4):** Drought Stress Index in the Study Area for Selected Years.




**Source:** Data from the American Landsat 5, 7, and 8 satellites for images captured in spring during the selected years.

**NDVI (Normalized Difference Vegetation Index)**

From Table (6), which illustrates the ratios and categories of vegetation cover in the study area, it is evident that there is a variation in the density of vegetation and water cover according to the selected years and classifications as follows:

1. **Very Dense Vegetation Cover**: The table indicates a clear variation in ratios and density based on the available water cover for the selected years. The highest area for this category was recorded in the spring of 1995, with a coverage area of (2526.3) km², accounting for 14% of the total area of the study region. This was followed by the year (2017), with an area of (1782.8) km², representing 10% of the total area of the study region. The rainfall factor played a significant role in increasing the coverage in these two years, as 1995 and 2017 are identified as wet years based on statistical modeling of rainfall

data. Observing the other years within the studied models, there is a noticeable decline in coverage areas, moving from moderately wet conditions to dry conditions represented by the years (2009, 2015, 2020). This category recorded the lowest coverage areas during these years, with coverage ratios of (6%, 2%, 4%) respectively. This directly reflects the rainfall data during these seasons on soil moisture, which significantly influenced the variation in vegetation types in the study area.

2. **Dense Vegetation Cover**: The ratios for this category varied according to the selected years that represent the rainfall models. It can be noted that this category was also positively affected by the amount of rainfall, with coverage ratios increasing as rainfall amounts rise when transitioning from wet to semi-arid or arid conditions. The highest coverage ratio was recorded in 1995, with an area of (4693) km², accounting for 27% of the total area of the study region, followed by 1999 with a coverage area of (4337) km², representing 25%. The year 2017 ranked third with a coverage area of (3916) km², accounting for 22%. Interestingly, 1999 ranked second in coverage despite not being second in rainfall amounts, as it was classified as semi-arid in the rainfall models. This can be attributed to the fact that this type of vegetation does not require a high amount of rainfall but prefers a more moderate distribution throughout the rainy season. The lowest coverage for this type was observed in the dry years represented by (2001, 2015, 2020), with 2015 recording the lowest coverage at (957) km², which is 5% of the total area.

3. **Weak Vegetation Cover**: There is also a variation in ratios according to the previously identified rainfall models. This category tends to increase inversely with rainfall characteristics, meaning that coverage areas expand as rainfall decreases when moving from wet to semi-arid and dry conditions. The highest coverage was recorded in 2015, representing a dry year with a coverage area of (7658) km², accounting for 44% of the total area of the study region. In tracking the other years and based on each model, there is a noticeable decrease in coverage areas when moving to semi-arid and wet models. The year 2017 recorded the lowest coverage at (4763) km², representing 27%. These results align closely with the statistical modeling outcomes for rainfall and the analysis of soil moisture characteristics based on the moisture stress index in the study area.

**Table (6)** Categories and Ratios of Vegetation Cover Types in the Study Area

| Year | Very Dense | Dense | Weak | Very Weak | Water Cover | Percentage of Total Area (%) |
|---|---|---|---|---|---|---|
| 1995 | 2526.3 | 4693.4 | 4956.8 | 4826.1 | 434.9 | 14%, 27%, 28%, 28%, 2% |
| 2001 | 584.0 | 2422.4 | 5955.5 | 8302.8 | 172.9 | 3%, 14%, 34%, 48%, 1% |
| 2009 | 980.6 | 3682.3 | 6039.3 | 6586.6 | 149.3 | 6%, 21%, 35%, 38%, 1% |
| 2015 | 346.5 | 3957.4 | 6658.0 | 6802.8 | 172.9 | 2%, 5%, 44%, 48%, 1% |
| 2017 | 1782.8 | 3916.9 | 4763.3 | 6638.0 | 336.5 | 10%, 22%, 27%, 38%, 2% |
| 2020 | 631.7 | 2389.7 | 7477.9 | 6603.8 | 334.4 | 4%, 14%, 43%, 38%, 2% |

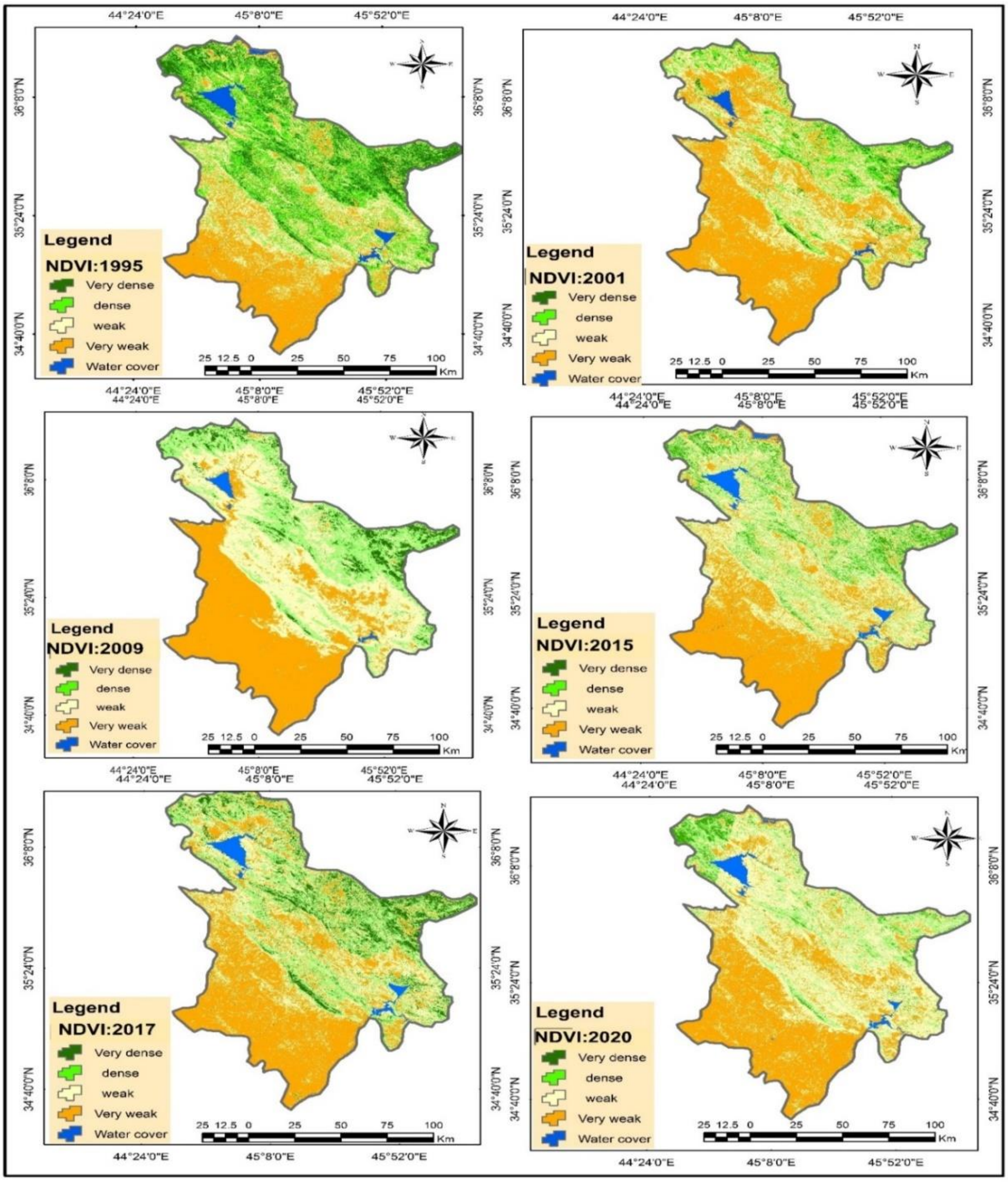
**Research conducted by the authors based on the analysis of data from the American Landsat satellite.**

**Weak Vegetation (Bare Land)**

This category represents areas with little to no vegetation cover or barren lands. An analysis of the vegetation index reveals a clear inverse relationship with precipitation levels, which directly affects soil moisture. As rainfall decreases, the area classified as weak vegetation expands significantly, and conversely, it shrinks with increased rainfall.

Notably, the years categorized as "dry" recorded the largest areas of bare land, followed by the "semi-humid" years. In contrast, the areas of weak vegetation were minimal during the years representing the "humid" model. The highest coverage for this category was recorded in 2001, with an area of **8,334 km²**, accounting for **48%** of the total area.

**Maps (5):** Vegetation Index in the Study Area for Selected Years




Data from American satellites LANDSAT 5, 7, and 8 for images captured in the spring for the selected years.

The total area of the study area is significantly impacted by the variations in vegetation cover, especially during the wet years. In particular, in 1995, the area of barren land reached 4,826 km², accounting for 28% of the total area of the study region. This type of land is spatially concentrated in the south and southwest of the study area, which is situated in the marginal zone of the 300 mm rainfall line. This rainfall fluctuates significantly between wet and dry years, causing this portion of the area to be largely covered by barren land. **Table (6)**: Types and percentages of vegetation cover in the study area for the selected years. This variation in vegetation density is linked to the level of moisture stress and water cover in the study area. As soil moisture stress increases, vegetation density decreases, leading to a reduction in water cover, and vice versa, as shown in Table (6) and Maps (5).

## Statistical Analysis of the Relationship Between Moisture Stress and Vegetation Cover

To determine the impact of different categories of moisture stress on the types of vegetation cover and the correlation between them, the available data for both indicators were subjected to Pearson's correlation coefficient test. This was done to assess the strength and nature of the relationship between the two variables, where the moisture stress index was treated as the independent variable and the vegetation cover index as the dependent variable influenced by the moisture stress index.

As shown in **Table (7)**, it was found that all categories of vegetation cover were significantly affected by the first category of moisture stress (high stress). A strong inverse relationship was observed with the category of dense vegetation, with a correlation coefficient of **-0.817**, which is statistically significant. Additionally, a moderate inverse relationship was found with the category of dense vegetation, with a correlation coefficient of **-0.589**, also statistically significant. Conversely, a strong positive correlation was observed with the category of very weak vegetation, with a value of **0.729**, and with the category of weak vegetation, which had a value of **0.486**.

The variable (moderate stress) had a relatively lesser impact on the categories of vegetation cover, as the strength of the relationship between it and the vegetation cover indices was moderate, with correlation coefficients of **-0.644**, **-0.318**, **0.489**, and **0.338**. These relationships were inversely correlated with the very dense and dense vegetation categories, while they were positively correlated with the weak and very weak categories.

As for the relationship between the semi-humid land variable and the categories of vegetation cover, it was found to be moderate to weak. The correlation was **0.292** with very dense cover and **0.224** with dense cover, indicating a weak and nearly negligible relationship with the weak vegetation category. In contrast, a moderate inverse relationship was observed with the very weak vegetation category, which had a correlation value of **-0.50**.

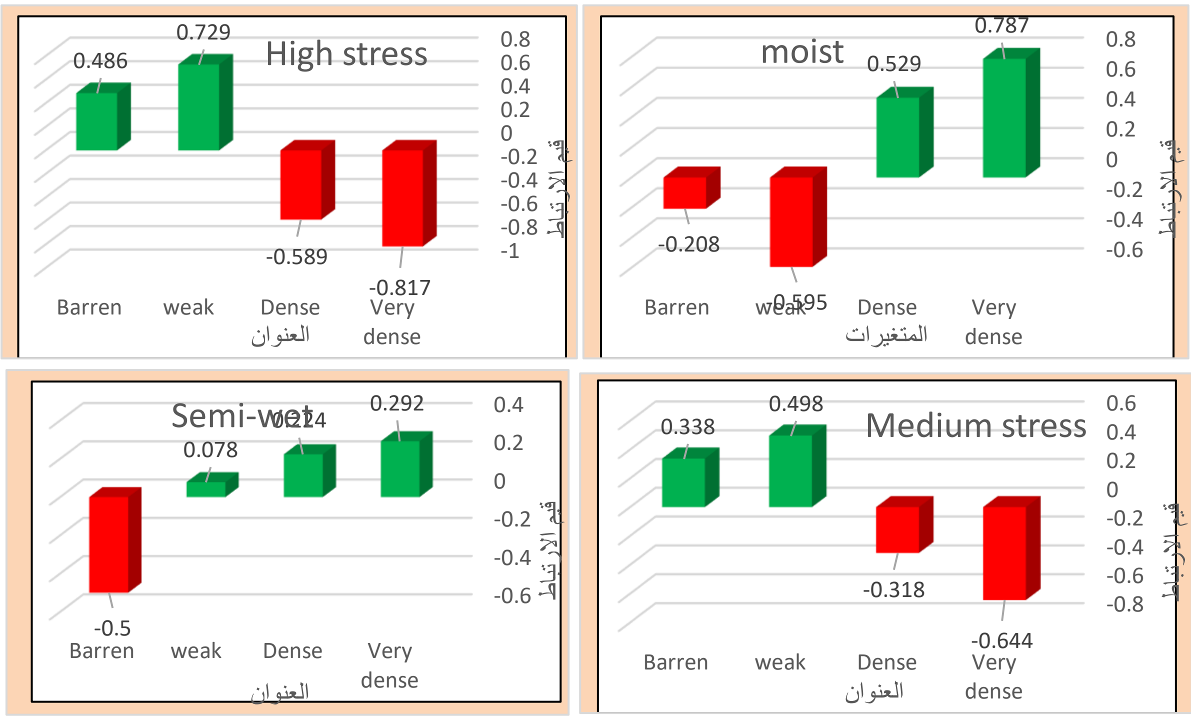
**Table (7)** Correlation between Moisture Stress and Vegetation Cover in the Study Area

| Types of moisture stress | Types of vegetation | Very dense | Dense | weak | Barren |
|---|---|---|---|---|---|
| **High stress** | Pearson Correlation | -.817* | -0.589 | 0.729 | 0.486 |
| | Sig. (2-tailed) | 0.025 | 0.04 | 0.033 | 0.039 |
| **Medium stress** | Pearson Correlation | -0.644 | -0.318 | 0.498 | 0.338 |
| | Sig. (2-tailed) | 0.019 | 0.027 | 0.035 | 0.049 |
| **Semi-wet** | Pearson Correlation | 0.292 | 0.224 | 0.078 | -0.5 |
| | Sig. (2-tailed) | 0.026 | 0.063 | 0.868 | 0.253 |
| **moist** | Pearson Correlation | 0.787 | 0.529 | -0.595 | -0.208 |
| | Sig. (2-tailed) | 0.026 | 0.041 | 0.309 | 0.655 |

**Source:** Researchers' work using SPSS V28 software.

Finally, the category of wet soil had the most significant effect on the very dense vegetation category, with a correlation of (0.787), indicating a strong positive relationship. It showed a medium-strength correlation with the dense category, at (0.529). Meanwhile, the relationship was negative with the other categories, exhibiting medium to weak correlation strengths, as shown in Table (7).

**Figure (3):** Simple Correlation Values between the Moisture Stress Index and Vegetation Cover




**Source**: Researchers' work based on SPSS V28.

## Conclusions

1. The study revealed a significant downward trend in rainfall over time, with reductions reaching nearly 100 mm in some stations within the study area.
2. Statistical modeling of rainfall identified three distinct patterns (dry, moderately humid, and humid). It was found that the dry pattern was the most frequently occurring during the study period, while the humid pattern was predominantly present in the first half, and the dry pattern was concentrated in the second half of the study period.
3. Analysis of moisture stress indicated that the southern and southwestern parts of the study area experience higher moisture stress compared to other regions, with the intensity of this stress fluctuating between wet and dry years, leading to expansion and contraction of affected areas.
4. Very dense and dense vegetation is closely linked to soil moisture, expanding with decreased moisture stress and contracting as moisture stress increases.
5. Remote sensing and Geographic Information System (GIS) technologies provide valuable tools for studying climatic changes and their environmental impacts, which can help in deriving insights for making informed decisions to address such crises in the future.

## Recommendations

1. **Conduct Further Climate Studies**: Undertake additional specialized climate studies focusing on climate change and other meteorological elements to determine their general trends and diagnose expected future impacts on the environment in the study area and other regions within the province.
2. **Establish More Meteorological Stations**: Install and equip additional meteorological stations in the study area, as it is highly rugged. The existing stations do not adequately cover the entire area, resulting in significant data gaps due to topographical variations.
3. **Enhance Remote Sensing Systems**: Activate and integrate remote sensing technologies into environmental studies as a fundamental element for analyzing spatial data, enabling informed decision-making based on available information.
4. **Conduct Field Studies**: Implement concurrent field studies alongside the results obtained from spatial data analysis to compare and evaluate the accuracy of this data and its outcomes, facilitating an objective understanding of the phenomena being researched by scholars in this field.

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