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Rainfall Variability and Vegetation Dynamics in the Semi Arid Environment of Basra Southern Iraq

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Abstract

Understanding rainfall variability and its influence on vegetation response is essential for sustainable water-resource and environmental management in semi-arid regions. This study investigates the spatiotemporal characteristics of rainfall and vegetation cover in the Basra region, southern Iraq, during the period 2010-2024. Satellite-derived rainfall data, ground-based rainfall observations, and Normalised Difference Vegetation Index (NDVI) data derived from Landsat 8 and Landsat 9 imagery were integrated to evaluate rainfall patterns, assess the reliability of remote-sensing rainfall products, and examine vegetation response to climatic variability. Rainfall validation was performed using regression analysis, while K-means clustering was applied to identify rainfall regimes. Vegetation response was analysed through spatiotemporal NDVI assessment and rainfall-NDVI correlation analysis.

The results revealed significant interannual variability in rainfall, with no evidence of a persistent long-term decline. Comparison between satellite-derived and ground-station rainfall records showed a moderate overall agreement (R^2 = 0.42). However, K-means clustering identified three distinct rainfall regimes (dry, moderate, and heavy rainfall), indicating that satellite performance varies with rainfall intensity and is most reliable during moderate rainfall conditions. Spatial NDVI analysis showed denser vegetation in northeastern Basra and sparser vegetation in the western desert areas. Although vegetation generally improved during wetter years, the relationships between NDVI and annual rainfall (R^2 = 0.199) and cumulative rainfall (R^2 = 0.065) were weak, suggesting that rainfall alone cannot adequately explain vegetation dynamics. The study results will improve understanding of climate variability and ecosystem response in semi-arid environments and provide useful information for future environmental and water-resource management in southern Iraq.

Keywords: Rainfall regime, satellite data, vegetation cover, NDVI, Basra, southern Iraq.

Introduction

Understanding rainfall patterns is essential for effective water resource planning and management [1] This is especially true in regions like Basra, southern Iraq, where water scarcity affects both economic activities and daily life [2]. Despite its abundant water resources, Iraq has faced freshwater shortages in recent decades due to climate change and water management projects built on these resources nearby [3, 4].

Rainfall plays a significant role in promoting the distribution and expansion of green covers that contribute to climate improvement [5]. Many researchers [6-9] are interested in determining the most suitable statistical distributions for analysing rainfall data, a challenging meteorological parameter because of its spatial and temporal variability. Annual total rainfall shows considerable spatial variability, highlighting the need to select appropriate analytical methods to accurately characterise rainfall patterns in the region.

Several measuring techniques determine precipitation, such as rain gauges, radar, and satellites, with the latter (satellite technique) being the most useful tool for collecting land use and vegetation cover. Rainfall data are available for both land and water [10]. Recent geospatial applications using Google Earth Engine (GEE) have demonstrated high efficiency in monitoring vegetation dynamics and land-use transformations in complex landscapes [11]. Satellite imagery is currently one of the most dependable sources for measuring climate elements such as rainfall and temperature [8, 12]. This plays a crucial role in monitoring key climate elements and estimating vegetation cover [9].

In the Basra region studied here, where ground-based weather stations are sparse or unavailable, satellite data is a vital tool [13] for quantifying climate-related ecosystem services [14] when combined with field rainfall data. Many studies show that satellite-derived rainfall datasets can reliably capture rainfall variability and spatial patterns, but they need validation with ground observations [8, 10, 14] to reduce uncertainty.
Hydro-meteorological and biophysical characterisation using geospatial frameworks has been widely applied to quantify
climatic influences on semi-arid ecosystems [15[. Furthermore, previous studies in Iraq have reported contrasting conclusions about long-term rainfall behaviour, with some authors suggesting no clear increasing or decreasing trend and emphasising strong interannual variability instead [5]. Regarding the response of vegetation to rainfall, it remains complex, and the question is whether there is a direct relationship between rainfall and vegetation cover in a semi-arid zone like the Basra region, since vegetation growth is often controlled by a number of environmental factors in addition to rainfall, including soil type and moisture availability, salinity, groundwater conditions, and land-management projects [16, 17].

Therefore, this study investigates rainfall variability and vegetation dynamics in the Basra region, southern Iraq, using an integrated remote-sensing and ground-based approach. The study first analyses long-term rainfall patterns during 2010-2024, evaluates consistency between satellite-derived and ground-station rainfall measurements, identifies distinct rainfall regimes using K-means clustering, and examines vegetation cover responses to rainfall variability through NDVI analysis.

1.1 Climatic characteristics of the Basra region

Iraq, where the Basra region is located, is considered the fifth most susceptible to climate breakdown [18]. It faces a semi-arid climate with long, hot summers and short, mild winters. The wet season usually occurs between November and May, a period associated with the arrival of medium depressions in Iraq [19].
The rainfall in Basra is seasonal, starting in October with a monthly average of < 1 mm and reaching 29 mm in December, then declining to 7.8 mm in May. The annual average relative humidity in the city is 60%, rising to 78% in January and falling to 48% in August, though it may reach 90% on some days due to the influence of the humid Arabian Gulf when winds are easterly.
Average monthly rainfall for the future period also ranged between the lowest and highest values, averaging 16.84 mm, a decrease of about 36.47% compared to the historical record for the same months [20].
Basra experiences extremely high summer temperatures, often reaching 40 °C and frequently approaching 45 °C in July, whereas winters are temperate, with averages of 20 °C [20, 21].

Methods and materials

2.1 The site description

This study selected the Basra area in southern Iraq. Administratively, it is bounded between latitudes 29.05° to 31.18° north and longitudes 46.33° to 48.34° east. As shown in the location map in Fig 1, Basra is bordered by Maysan district to the north, Dhi Qar district to the northwest, and Muthanna district to the southwest. The eastern and southeastern boundaries are marked by the borders with Iran and the Arabian Gulf, respectively. To the south, the region shares borders with Kuwait. The Basra region is divided into two main soil types (Fig 1): the eastern side consists of fine-grained soils from the floodplain of the Euphrates-Tigris-Shatt al-Arab River system, part of the lower Mesopotamian basin [22]. On the western Basra side, it consists of coarse-grained soils belonging to old deposits of the Dibdiba Formation.

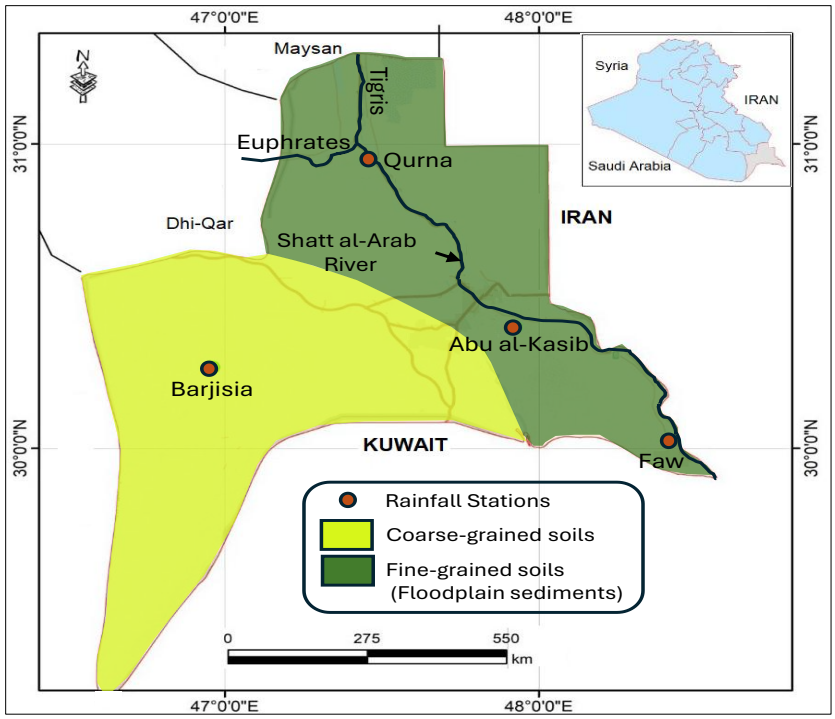


Fig. 1 Location map of Basra area relative to Iraq areas and international countries, in addition to illustrating the measurement stations.

2.2 Data collection

This study used several approaches to collect rainwater data.
Long-term satellite-derived rainfall and NDVI datasets (2010–2024) were used for trend and correlation analysis, whereas high-resolution vegetation mapping was restricted to 2021–2023, as follows;

2.3 Meteorological Data

Meteorological data, specifically precipitation data, were obtained from the Prediction of Worldwide Energy Resources database for the period 2010–2024. The data were processed and spatially analysed in ArcGIS. Spatial distribution maps were generated using Spatial Analyst Tools, followed by interpolation using the Kriging method to produce continuous rainfall surfaces [23, 11].

2.4 Vegetation Cover Data (NDVI)

Vegetation cover data for the period 2010–2024 were acquired from the United States Geological Survey (USGS). Satellite imagery from the Landsat 8 and Landsat 9 missions was downloaded and processed in ArcGIS. The Normalised Difference Vegetation Index (NDVI) was calculated to assess vegetation density using the following Equation 1:

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4} \quad \ldots\ldots\ldots\ldots (1)$$

where bands 5 and 4 are the near-infrared (NIR) and red bands, respectively, derived from satellite imagery.

2.5 Ground Station Data

Ground-based rainfall station data were obtained from the Agricultural Meteorological Centre, affiliated with the Ministry of Agriculture in Iraq. The data were collected from four stations: Barjesia, Abu Al-Khasib, Faw, and Qurna, and used to support satellite-derived observations.

Statistical analyses and graphical visualisations were performed using regression analysis, rainfall-regime classification, and NDVI-rainfall comparative assessment to evaluate spatiotemporal rainfall variability and vegetation response in the Basra region.

2.6 Statistical and Correlation Analysis

Rainfall Data Validation and Classification. To evaluate agreement between satellite-derived rainfall data and ground-based rainfall measurements, we applied scatter-plot analysis and linear regression. The coefficient of determination (R^2) was used to assess the strength of the relationship between the two datasets. In addition, K-means clustering was used to classify paired satellite and ground rainfall observations into distinct rainfall regimes. This approach was used to investigate whether the performance of satellite-derived rainfall estimates varies according to rainfall intensity.

2.7 Vegetation-Rainfall Relationship Analysis

To evaluate vegetation cover's response to rainfall variability, annual average NDVI values were compared with annual rainfall records for 2010-2024. Average rainfall was calculated from the investigated rainfall stations (Barjesia, Abu Al-Khasib, Faw, and Qurna). Linear regression analysis was used to test and evaluate the relationship between NDVI and the annual rainfall, while a cumulative rainfall index was applied using the average rainfall of two consecutive years (Equation 2);

$$R_c = \frac{R_t + R_{t-1}}{2} \quad \ldots\ldots\ldots (2)$$

where:
R_c= cumulative rainfall index,
R_t= rainfall in the current year,
R_{t-1}= rainfall in the preceding year.
We then assessed the relationship between cumulative rainfall and NDVI using regression analysis to determine whether antecedent rainfall conditions better explain vegetation dynamics than current-year rainfall alone.

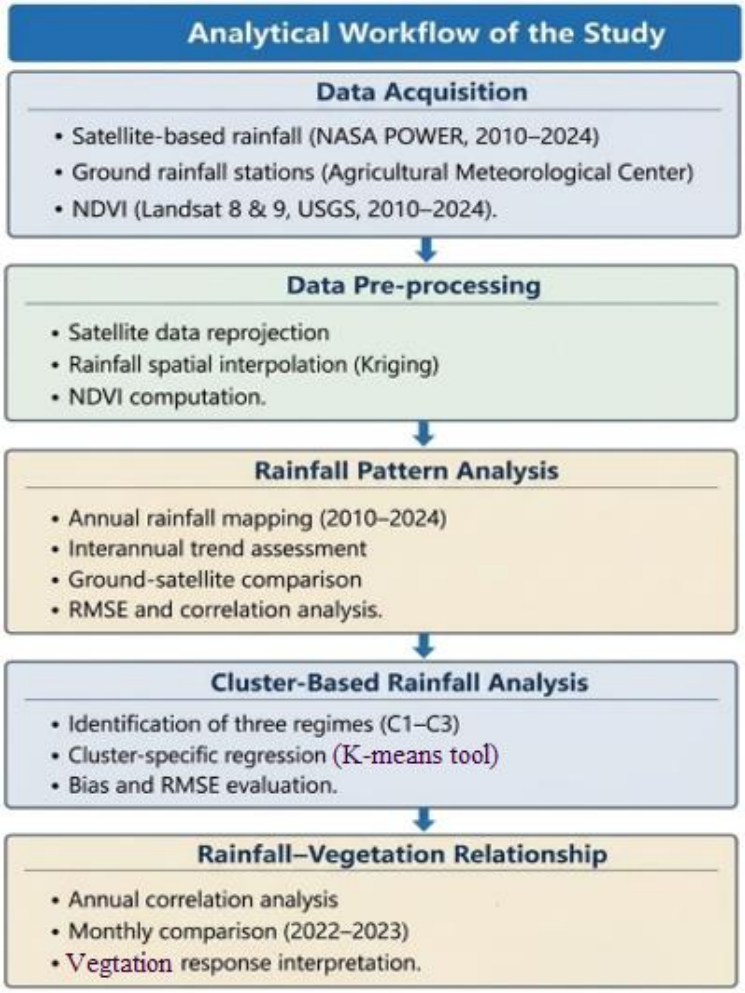


Fig 2: Analytical workflow of the study, including rainfall mapping, satellite-ground rainfall validation, K-means rainfall-regime classification, NDVI extraction, and vegetation-rainfall relationship analysis.

Results and discussion

3.1 Rainfall data analysis

Fig 3 shows the spatial distribution of annual rainfall across the Basra region from 2010 to 2024, derived from satellite-based data. Each map visualizes yearly rainfall levels using a tonal scale over the 15-year period, where rainfall patterns show significant spatial and temporal variability. The northeastern part of the study area, where Qurna station, consistently receives higher rainfall, with values often ranging between 120 mm and 230 mm, most highlighting in years like 2018, 2019, and 2023, which may contribute to better vegetation conditions as observed in the NDVI analysis (Next section). While, the western side of the region, high gravel and sand soil content, tends to experience lower rainfall**,** typically between 19 mm and 74 mm**,** as seen in 2010, 2011, 2017, 2021, and 2024. There are some exceptional rainfalls, such as 2018 and 2023 where values reached up to 230 mm and 210 mm, respectively.

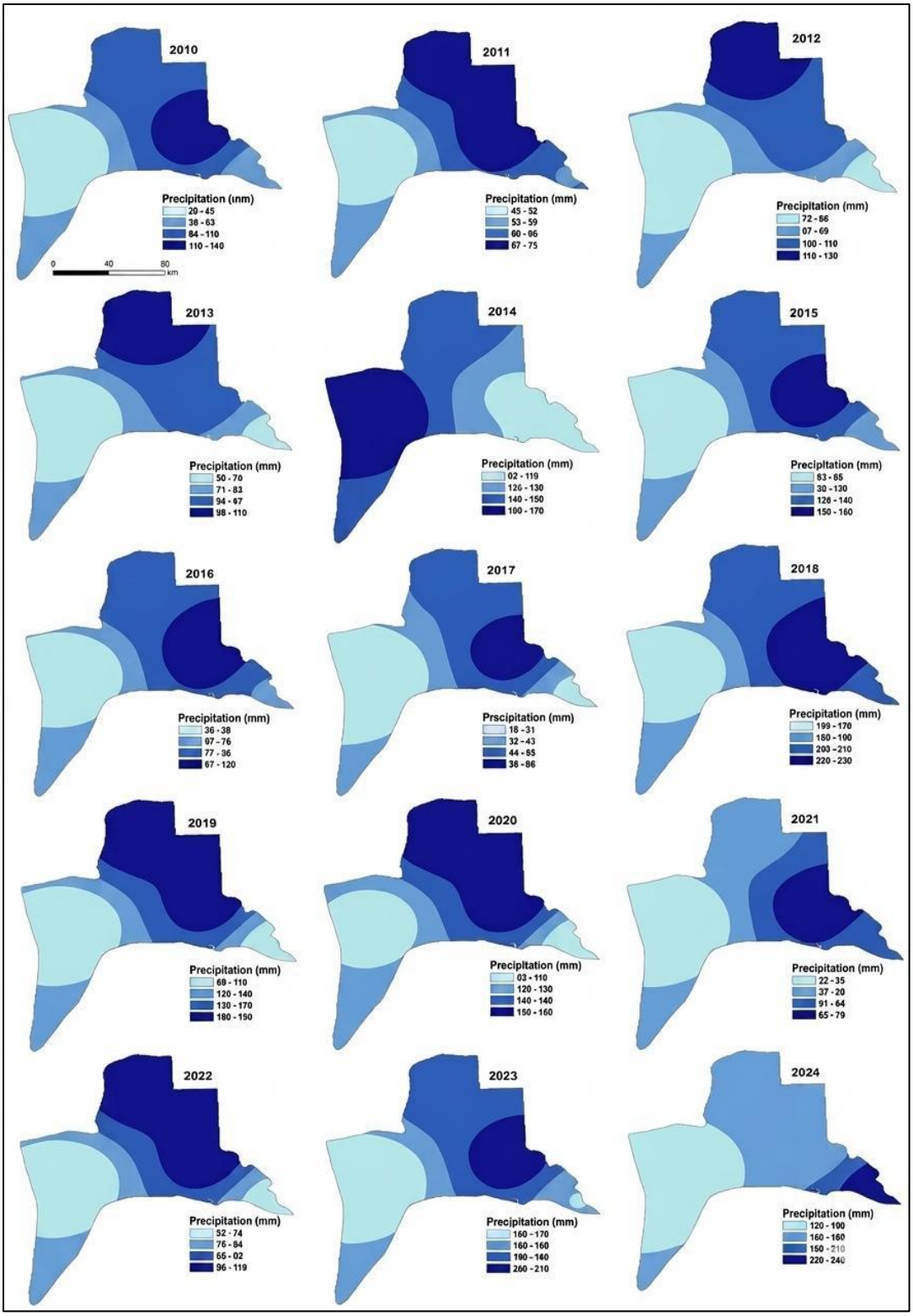


Fig 3 : Satellite-derived rainfall data for the period 2010–2024 across the Basra region.

Fig 4 illustrates the annual rainfall patterns from 2010 to 2024 for four key locations in the Basra region: Barjesia, Abu al-Kasib, Faw, and Qurna, where the red dashed line indicates the overall linear trend of measurements across the

15-year period. In general, there is a slight increase in annual rainfall overtime but not statistically significant with relatively stable average rainfall. The Figure clearly shows internal variability, where some years have experienced notable reductions in rainfall, such as 2017 (25-35 mm) and 2021 (20- 40 mm), followed by years of substantial increases, 2018 (150- 230 mm) and 2023 (160- 220 mm).

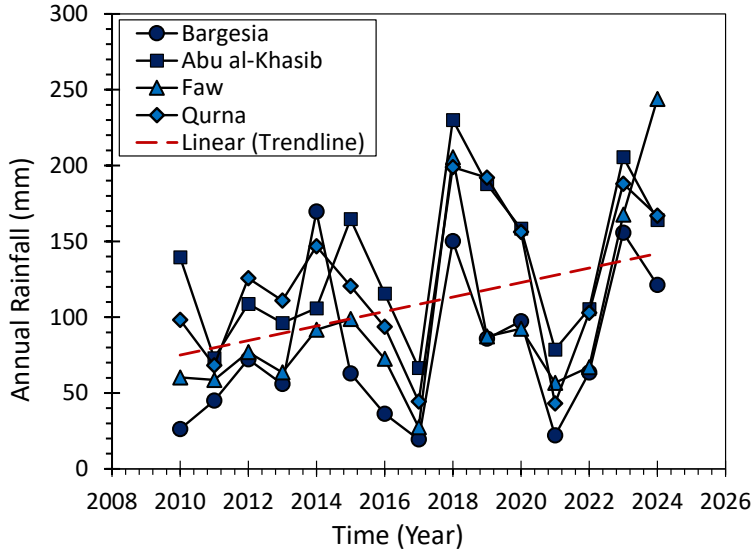


Fig 4: Annual rainfall from 2010 to 2024, for four locations: Barjesia, Abu al-Kasib, Faw, and Qurna.

This rainfall variability is consistent with [5], whose rainfall data analysis (2000-2021) for the entire Iraq region showed that Iraq does not exhibit a clear long-term trend toward either increasing or decreasing precipitation amounts. This fact was also revealed by [12] who reported that precipitation in middle and northern Iraq showed irregular sharp fluctuations, and not a smooth long-term increase. This pattern of interannual variability reflects Iraq's semi-arid climate, where rainfall is influenced more by seasonal atmospheric factors than by long-term climatic trends. In summary, although rainfall levels vary significantly across the studied years, there is no clear decline. Yet, it can rather be described as a periodic rainfall fluctuation over the four studied locations, which contradicts [5], who describe Iraqi rainfall as "highly dynamic" and lacking a cyclical pattern. The findings (Fig 4) reveal increased caution and the need for a large future rainfall dataset to verify a certain pattern.

Fig 5 presents a scatter plot that correlates the rainfall data collected from satellite sources (Sd) and ground-based stations (Gd). The linear best (red-dotted) fit line presented in Fig. 5a, where Gd = 0.7284Sd + 3.2038, has R^2 equals to 0.42. The R^2 shows a relatively weak correlation, and the reasons as reflected in the overall RMSE, might attribute to the fact that satellite-based rainfall data cover an area over grid cells with average rainfall, whereas ground stations provide point-based measurements [24].

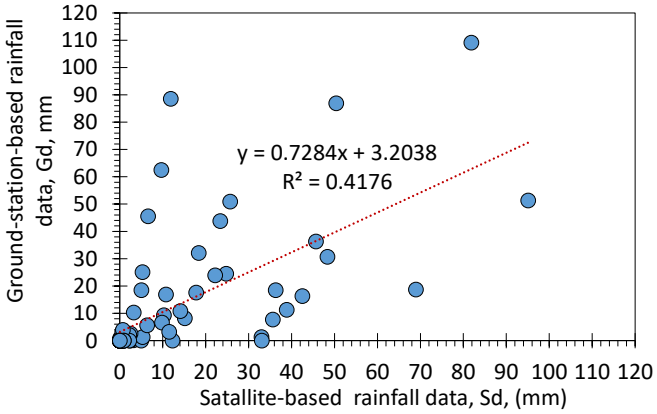


Fig 5: The correlation between two datasets; satellite-based rainfall (Sd) and ground-based rainfall station (Gd).

To deep insight on this variability, it was noted that the dataset seems has three distinctive groups (C-1, C-2, and C-3), which can be analyzed separately using K-means rainfall-regime analysis.

3.2 K-means rainfall-regime analysis:

To deciphering rainfall variability observed in Fig 5, K-means cluster analysis was applied to the paired satellite-derived rainfall (S) and ground station rainfall (G) records. Three clusters were identified corresponding to dry, moderate, and heavy rainfall regimes, as revealed in Fig 6. The results indicate that rainfall observations do not form a single homogeneous gathering. Instead, distinct rainfall regimes most likely exist within the dataset, and each exhibit different relationship between satellite and ground measurements.

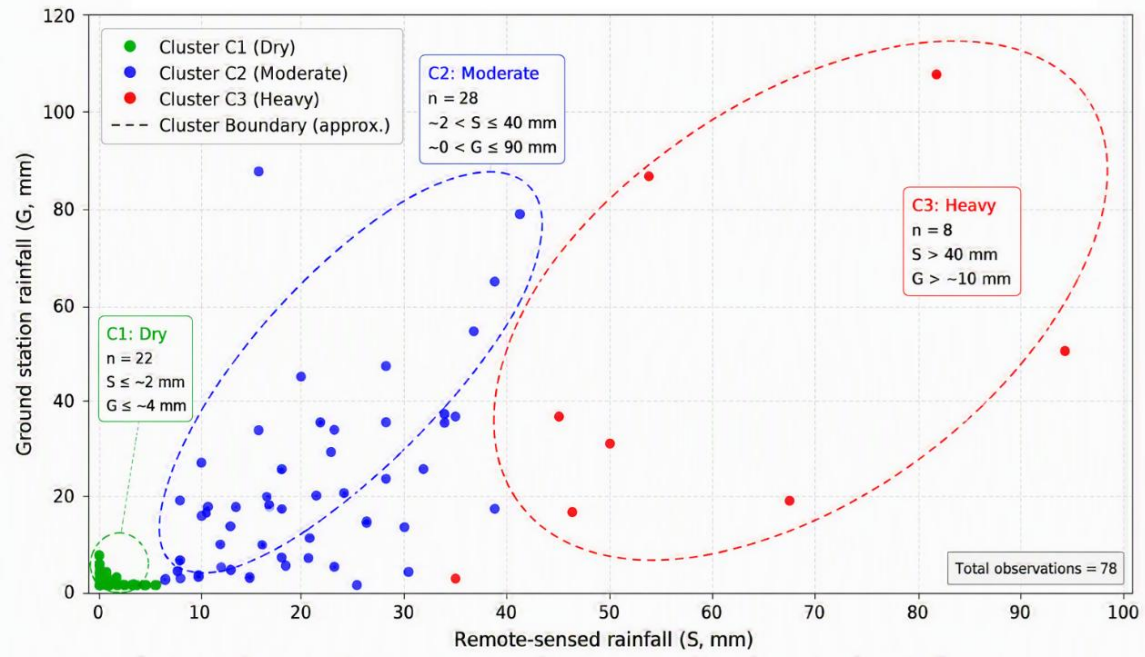


Fig 6: K-means clustering of satellite-derived rainfall (S) and ground-station rainfall (G), showing three rainfall regimes: dry (C1), moderate (C2), and heavy rainfall events (C3). *To be noted, the dashed ellipses were drawn to help to illustrate the three rainfall regimes. They are not mathematically computed cluster boundaries. In real K-means every point belongs to the cluster whose centroid is closest in Euclidean distance. The boundaries are determined by Voronoi partitions, not ellipses. Therefore, points can appear outside a hand-drawn ellipse and still legitimately belong to that cluster.*

Cluster C1 represents low-rainfall events and contains observations concentrated near the origin of the scatterplot. In this regime, both satellite and ground measurements generally indicate little or no rainfall. The agreement between the two datasets is relatively stable because measurement uncertainties are small. Cluster C2 represents moderate rainfall conditions and forms the densest concentration of observations. This cluster exhibits the highest consistency between satellite estimates and ground observations. Consequently, this rainfall regime is considered the most reliable range for satellite-based rainfall estimation in the Basra region. Cluster C3 corresponds to intense rainfall events. Although both datasets record high rainfall amounts, the dispersion of observations increases substantially. This behaviour suggests greater uncertainty during extreme rainfall events and reflects the difference between pixel-averaged satellite estimates and point-based gauge measurements. Extreme rainfall events are often localized, and therefore may not be fully captured by satellite datasets. The data naturally separate into three proposed rainfall regimes showing in Table 1 and its K-means analysis results in Table 2:

Table 1: the three proposed rainfall regimes; Dry, Moderate, and Heavy rainfall regimes.

Cluster	Rainfall type	Typical range	Regime type
C1	Dry events	0-5 mm	Rainfall Regime I (Dry)
C2	Moderate rainfall	5-40 mm	Rainfall Regime II (Moderate)
C3	Heavy rainfall	>40 mm	Rainfall Regime III (Heavy)

Table 2: Characteristics of K-means rainfall regimes

Cluster	Regime	Number of observations	Satellite behaviour	Ground behaviour	Interpretation
C1	Dry	high	Low S	Low G	Good agreement during dry periods
C2	Moderate	moderate	Moderate S	Moderate G	Best correspondence
C3	Heavy	low	High S	High G	Large uncertainty and rainfall extremes

Hence, cluster analysis revealed that the moderate overall correlation reported for the complete dataset does not arise from uniformly poor satellite performance. Rather, it results from the combination of multiple rainfall regimes with different statistical characteristics. This finding demonstrates that satellite rainfall products perform differently under varying rainfall conditions and should therefore be evaluated according to rainfall regime rather than using a single global regression model.

3.3 Monthly rainfall data analysis

Fig 7 shows a comparative analysis of monthly rainfall data, specifically for the years 2022 and 2023, collected from both ground-based weather stations (Gd) and satellite remote sensing (Sd) across the four locations (Barjesia, Abu al-Kasib, Faw, and Qurna) in the Basra region. Each subplot depicts rainfall trends from January to December. Even though discrepancies in monthly rainfall were highlighted in certain months and locations, seasonal peaks during wet months showed general consistency between Gd and Sd. At Barjesia, for example, in 2022 shows low values, below 5 mm, during summer months, where both Sd and Gd remained around 0–5 mm, and clear peaks during winter months. Satellite-derived rainfall (Sd) slightly exceeds (~2–5 mm) higher than ground observations (Gd) during low-rainfall months, while during peak months both datasets converge to reach around 90 mm. In 2023, rainfall values increase by 20–30 mm in peak (wet) months markedly compared to 2022, with higher winter peaks and improved consistency between Sd and Gd.

Regarding the Abu al-Kasib station, the monthly rainfall in 2022 remained low for most of the dry season, generally below 10 mm at both Sd and Gd measurements. While, during the wet months specifically (Jan., Dec., and Nov.), the satellite-derived rainfall (Sd) exceeded 25 mm, yet the Gd observations remained less than 10 mm, exceptional for Jan. and Feb. in which the rainfall record reached 25 mm and close enough to the Sd records. In 2023, showed similarity of rainfall behavior between Sd and Gd records, yet an increase noticeably, where winter peaks reaching approximately 40–90 mm, compared to about 25 mm in 2022.

For the coastal station of Faw, rainfall in 2022 is consistently low according to Gd and Sd values, mostly below 5 mm, for much of the year, except for the three winter months (Nov., Dec., and Jan.), exceeded 15 mm. In 2023, rainfall increases substantially, with peaks rising to 80–120 mm according to Sd, while Gd indicates lower but clearly elevated values (about 50–80 mm).

In north Basra, at Qurna station, where there is no Gd record due to technical issues in the station dial gauge during 2022. However, Sd showed the same monthly rainfall pattern of the rest of the location where there less than 10 mm rainfall during the dry season while the peaks winter (Nov., Dec., and Jan.) reached to (20-48 mm). In 2023, rainfall increases markedly compared to 2022, but there was inconsistency with winter peaks that rise to 42 mm, 68mm, and 48mm in Nov., Jan., and Mrch., respectively. While Dec. and Feb. stayed less than 10mm just like the dry months.

Overall, monthly rainfall pattern across the four locations shows consistently higher values in 2023 compared to 2022, particularly during the winter season. In 2022, rainfall values at most stations remain relatively low during summer months, with Sd and Gd generally below 5mm, while winter peaks typically range between 30–70 mm, depending on location. However, 2023 exhibited a marked increase in rainfall intensity, with winter peaks reaching 80–110 mm. Although both datasets capture this increase, discrepancies between Sd and Gd persist, particularly in peak rainfall months. Since records are nearly absent in the dry season, comparing Gd and Sd is generally not meaningful at all of studied locations.

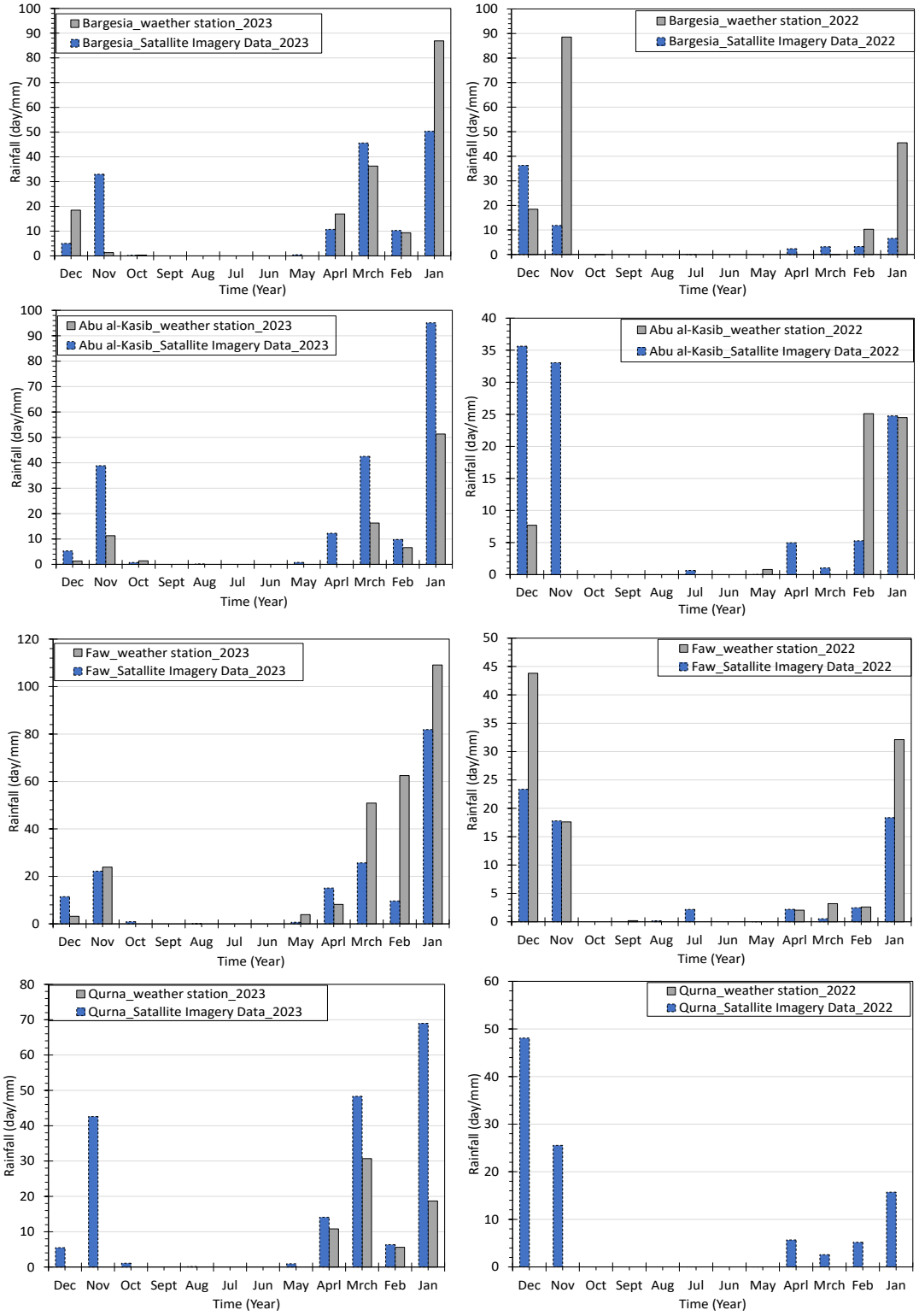


Fig 7: Monthly rainfall data (2022 and 2023) collected from both ground weather stations (Gd) and satellite remote sensing (Sd) for four locations: Barjesia, Abu al-Kasib, Faw, and Qurna.

3.4 The Normalised Difference Vegetation Index (NDVI) analysis

Fig. 8 presents the spatial and temporal distribution of the Normalised Difference Vegetation Index (NDVI) of the Basra region from 2010 to 2024. In the figure, the northeastern side consistently shows higher NDVI values, typically ranging between 0.45 and 0.6, indicating relatively denser and more stable vegetation cover. While the western side, the Barjesia site which characterized by the sandy and gravelly Dibdiba Plain deposits (Fig. 1), shows lower NDVI values, generally around 0.1 to 0.25.

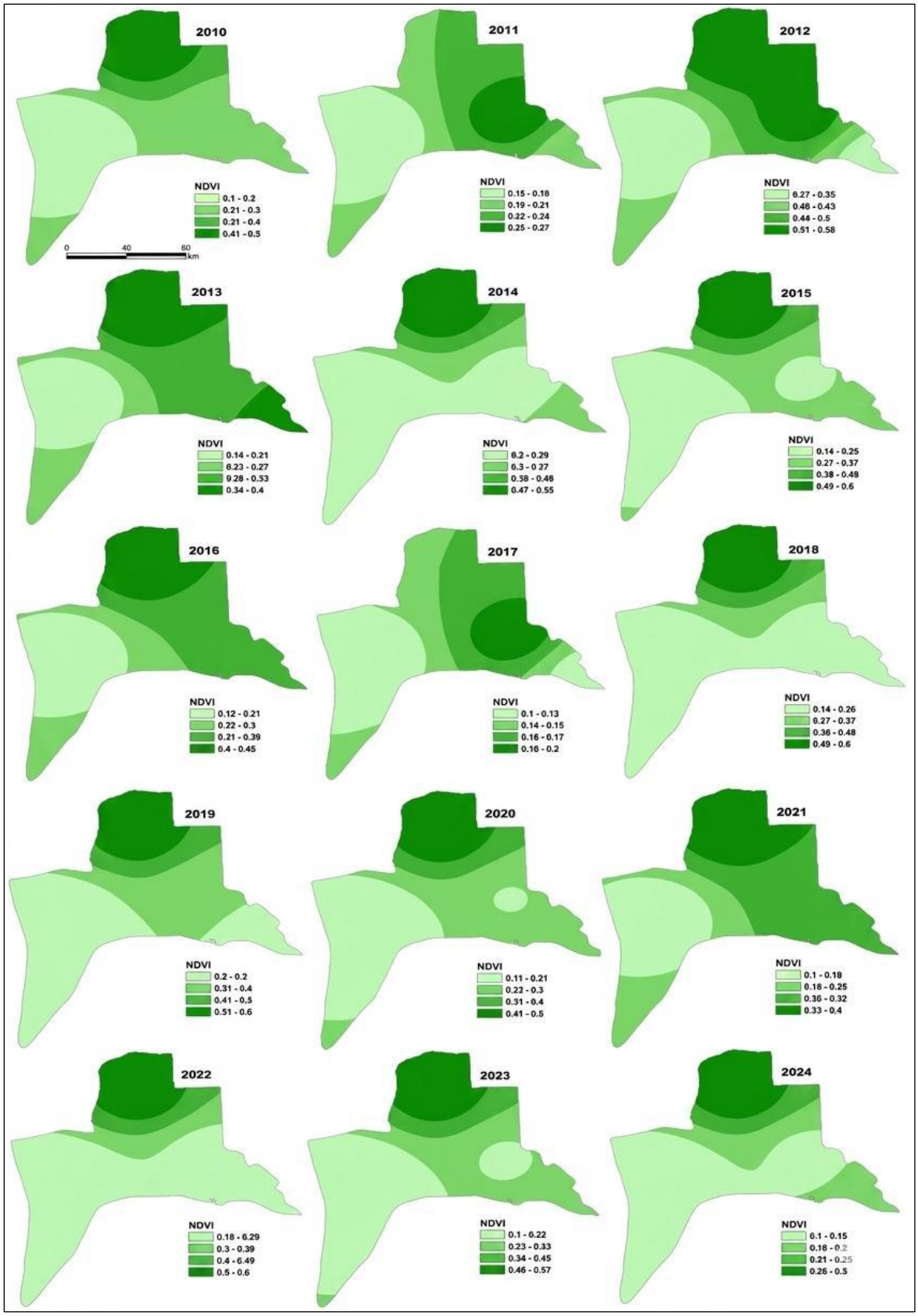


Fig 8: NDVI (2010–2024) of the study area, derived from satellite data.

Fig 9 illustrates the temporal variation in NDVI at the study region (2010-2024). The graph shows both the minimum and maximum NDVI values for each year, highlighting the annual fluctuations in vegetation cover. Over the 15-year period, the minimum NDVI values fluctuated between 0.10 and 0.26, and the maximum NDVI values range from approximately 0.20 to 0.61. the NDVI reveals no clear (positive or negative) trend along these 15 years. several peaks and troughs are observed in the vegetation index over the 15-year study period, as shown in Fig 9. The peak values occur in the years 2012, 2015, 2019, and 2023, while corresponding minimum NDVI values are observed in 2011, 2013, 2017, and 2021, respectively. Despite this highlighted interannual variability, the overall long-term trend remains indistinct (neither a sustained increase nor decrease in general). which is quite similar to the rainfall behavior.

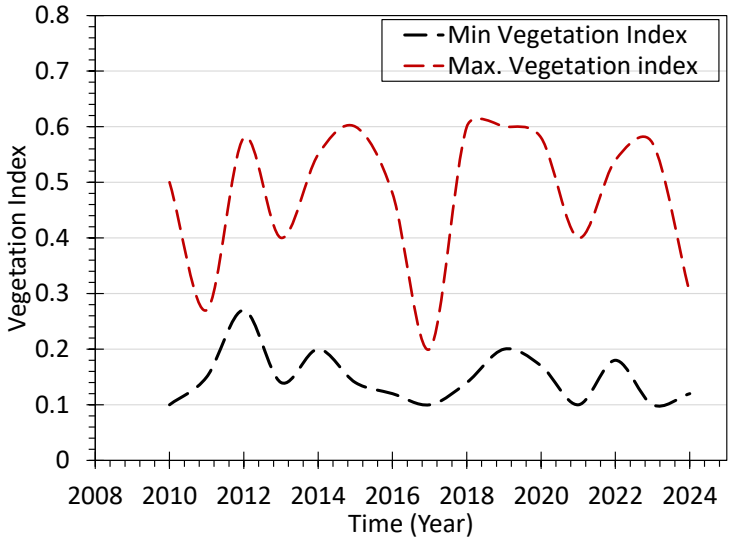


Fig 9: The NDVI ranges from 2010-2024.

Fig 10 shows the relationship between rainfall and vegetation of the four investigated locations over the 15-year period (2010–2024). In each graph, ((a) Qurna, (b) Abu al-Kassib, (c) Barjesia, and (d) Faw), the rainfall (mm) is plotted within the minimum and maximum values of NDVI, comparing how vegetation responds to precipitation patterns. The data reveals seasonal and interannual fluctuations in vegetation cover. As shown in the Figs, the peaks and troughs of NDVI curves most likely shift with the rainfall data due to late response of vegetation growth. Moreover, the magnitude and timing of vegetation response vary by location. Faw station, an example of coastal site, exhibit delayed or dampened NDVI peaks due to high salty fine-grained soil with limited freshwater availability. While inland zones like Qurna can show less time response of vegetation recovery following rainfall events.

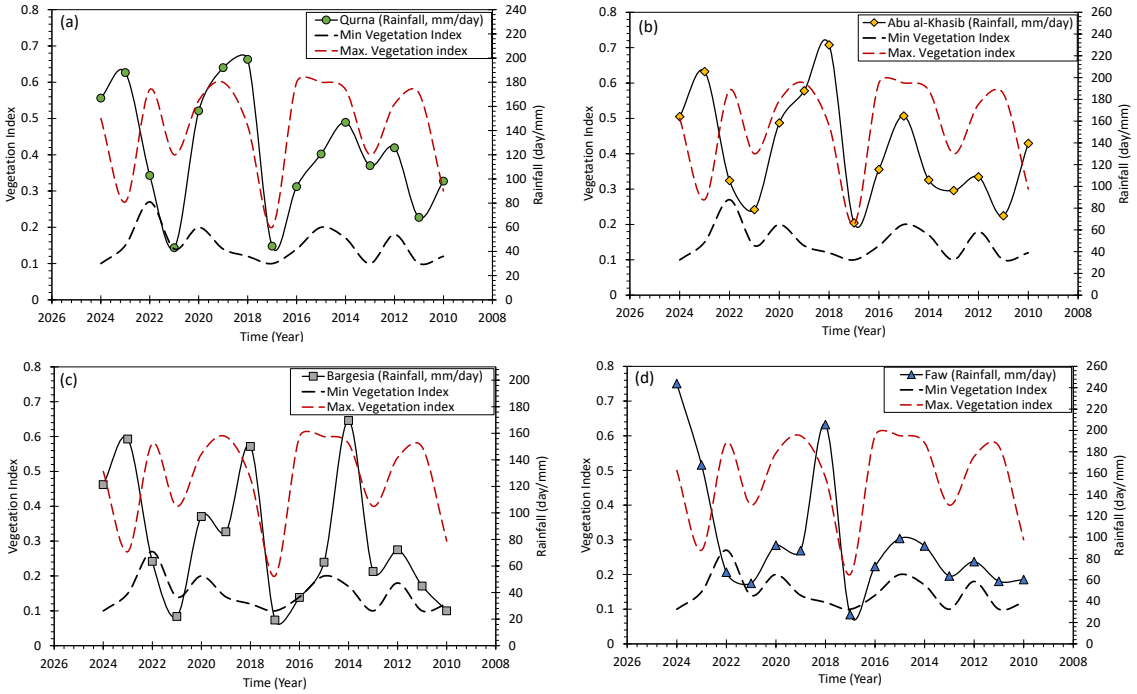


Fig 10: Vegetation response for rainfalls during the 15years (2010-2025), where (a), (b), (c), and (d) at Qurna, Abu al-Kasib, Barjesia, and Faw location, respectively.

Vegetation Response analysis:

To investigate the vegetation response to rainfall variability in Basra, the average NDVI values were compared with rainfall observations recorded at Bargesia, Abu Al-Khasib, Faw, and Qurna stations during the period 2010-2024. Fig 11 illustrates the temporal variation of average rainfall and vegetation conditions (NDVI) in Basra during 2010-2024 under both current and antecedent moisture conditions. The average annual rainfall exhibited substantial interannual variability, ranging from approximately 39 mm in 2017 to more than 196 mm in 2018. Average NDVI values varied between 0.15 and 0.43 over the same period.

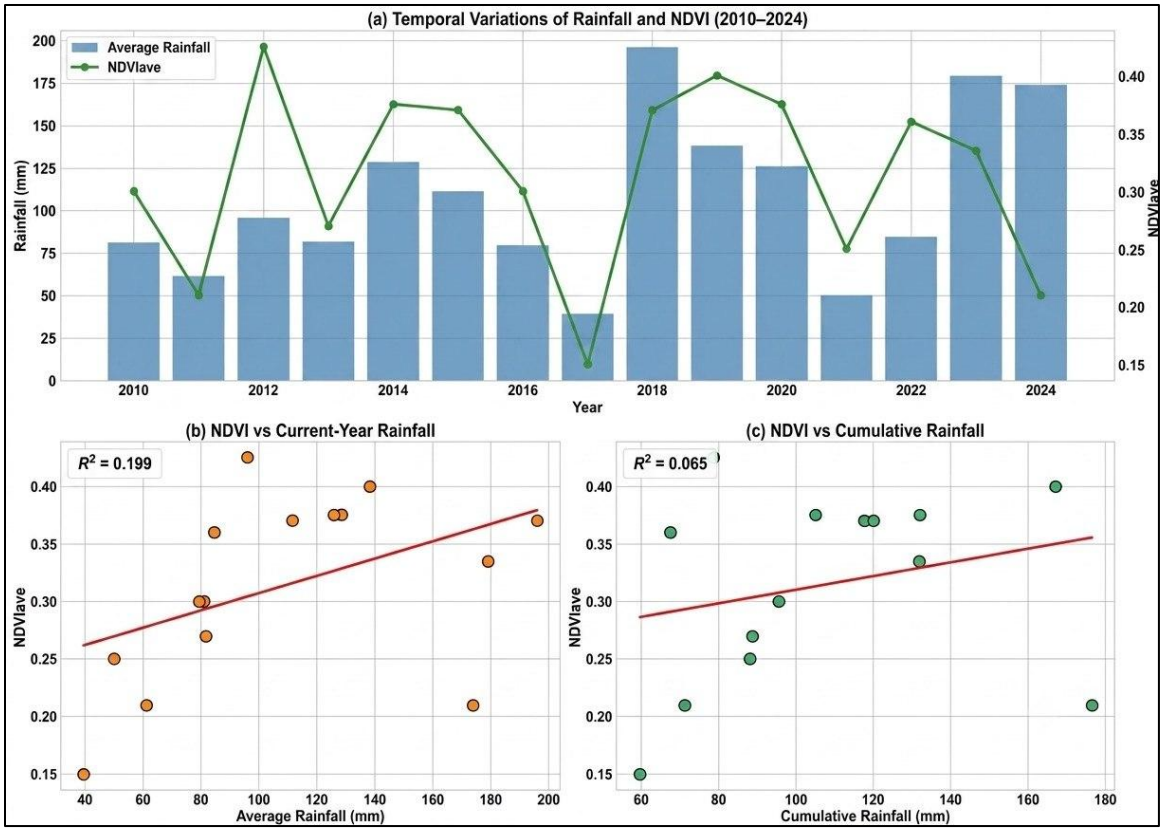


Fig 11: Vegetation response to rainfall variability in Basra during 2010-2024. (a) Temporal variations of average annual rainfall and NDVIave. (b) Scatter plot showing the relationship between NDVIave and current-year rainfall (R^2 = 0.199). (c) showing the relationship between NDVIave and cumulative rainfall conditions, where R^2 = 0.065.

As shown in Fig 11a, the drought years of 2017 and 2021 were characterized by low rainfall (39.39 and 50.11 mm, respectively) and relatively low NDVI values (0.15 and 0.25). whereas the wetter years such as 2018, 2019, and 2020 exhibited higher NDVI values ranging between 0.37 and 0.40. However, the rainfall-vegetation relationship is not strictly proportional. For example, although rainfall remained exceptionally high during 2023 and 2024 (179.18 and 174.02 mm), NDVI values declined from 0.335 in 2023 to only 0.21 in 2024. Similarly, the highest NDVI value observed during the study period (0.425 in 2012) occurred under moderate rainfall conditions rather than during the wettest years.

Fig. 11b illustrates the direct weak positive relationship, $R^2 = 0.199$ between NDVI and current-year rainfall. This result indicates that only about 20% of the observed NDVI variability can be explained by annual rainfall alone. This outcome aligns with recent geospatial investigations in comparable semi-arid and watershed systems, which emphasize that vegetation dynamics and hydrological drought are dictated by a complex interplay of multi-factorial drivers rather than direct precipitation inputs alone [15,25]. Specifically, biophysical characterisation and drought modeling in semi-arid zones reveal that antecedent soil moisture, soil salinity, soil texture, groundwater depth, and anthropogenic land-management practices significantly modulate how vegetation responds to climatic anomalies [15,16, 25]

. Consequently, assessing ecosystem vulnerability and vegetation health in southern Iraq requires holistic, multi-criteria frameworks that integrate soil-water interactions alongside atmospheric precipitation. Fig. 11c evaluates vegetation response against cumulative rainfall conditions. Interestingly, the cumulative rainfall model yielded an even weaker relationship; $R^2 = 0.065$. The very low R^2 indicates that a simple accumulation of rainfall from consecutive years does not adequately explain NDVI variability. Several years with similar cumulative rainfall exhibited markedly different vegetation conditions, suggesting that rainfall effects are not transferred directly into vegetation growth over annual time scales.

Conclusions

1. Analysis of the 2010-2024 rainfall record revealed substantial interannual variability across the Basra region, with alternating dry and wet periods. Although annual rainfall fluctuated significantly, there is no evidence of a consistent long-term decline was identified during the study period (2010-2024).
2. Comparison between satellite-derived rainfall estimates and ground-station observations showed a moderate overall agreement ($R^2 = 0.42$). However, K-means clustering revealed that the dataset comprises three distinct rainfall regimes (dry, moderate, and heavy rainfall). The moderate-rainfall regime exhibited the strongest correspondence between satellite and ground observations, while discrepancies increased during heavy rainfall events. This finding demonstrates that the performance of satellite rainfall datasets should be evaluated according to rainfall intensity rather than by a single general correlation model.
3. The statistical relationship between rainfall and NDVI was weak ($R^2 = 0.199$), and cumulative rainfall produced an even weaker relationship ($R^2 = 0.065$), meaning that rainfall is an important but insufficient predictor of vegetation dynamics in Basra.
4. The vegetation-rainfall relationship in Basra is best interpreted as a nonlinear response rather than a direct cause-and-effect relationship. Vegetation growth is likely controlled by the combined other influencing environmental parameters such as, soil type, moisture content, and land-management practices, which required more future studies to determine the most affecting ones.

Conflict of interest statement:

The authors declare that there is no conflict of interest.

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