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Remote Sensing- Based Assessment of Climatic Decades in Baghdad City Using Statistical Trend Analysis and Variance Testing (ANOVA)

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Abstract
This study analyzes long-term trends in temporal data from 1980 to 2020 in Baghdad's city, spanning four decades, to assess the impacts of climate change on the environment and ecosystems. The National Aeronautics and Space Administration (NASA) provided us with data on wind, temperature, solar radiation, atmospheric pressure, precipitation, and humidity. The study used statistical analysis methods, such as trend analysis and ANOVA, to assess the differences between the decades of time. Linear regression models were employed to conduct trend analysis for each decade, assessing changes in climate parameters. Key findings indicated that the P-values were high. The findings demonstrated no statistically significant differences in the examined climate parameters during the decades. However, trend analysis of average monthly data over the four decades indicated that local climates have changed in recent years. The monthly analysis of six parameters indicated an increase in wind speed, temperature, and pressure, whereas solar radiation, humidity, and precipitation consistently decreased.

Article Info.

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1. Introduction

Climate changes, from changes in weather patterns to increased environmental threats, are the biggest challenges facing the world these days [1]. Remote sensing plays a prominent role in studying and monitoring these changes [2, 3]. Weather comprises various types of climates, daily and seasonal, which fluctuate throughout the year, as well as climatic conditions that persist over years or decades, which known as climate change [4]. Climate refers to the long-term trend of weather patterns in a specific region. It encompasses mean temperatures, precipitation, humidity, and wind velocity [5, 6]. Climate assessments cover the acquisition and evaluation of meteorological and climatic data via observation stations or reanalyzed datasets, as well as the application of climate models to project future variations and their impacts [7, 8]. Information on climate can be assessed through reviewing past trends in relation to current weather trends, or by employing mathematical equations and computerized simulations that consider various factors, such as temperature, humidity, wind speed, and atmospheric pressure to generate precise weather forecasts. Climate statistical analysis entails the collection, processing, and interpretation of data from diverse sources to obtain insights into present and prospective weather patterns [9, 10]. The tracking and evaluation of long-term changes in the climate is essential for formulating strategies to adapt to and mitigate its adverse impacts on the natural world and society [11, 12]. The effects of climate changes are being felt across all continents, impacting agriculture, water supplies, and the environment [13-16]. Trend analysis is crucial for understanding long-term climate patterns, detecting changes, and predicting future conditions. It is crucial to detect changes in climatic factors by monitoring gradual variations in climate variables throughout time [13]. Trend analysis involves looking at trends in a phenomenon over a defined timeframe, whether it be short-term in nature or over the long term [14, 15]. Analysis of Variance (ANOVA) is a form of statistics employed to investigate variations between and within groups. It assists in ascertaining whether the disparities between groups are sufficiently substantial to be statistically significant or merely attributable to chance [16, 17]. ANOVA is utilized in various domains, including health studies, research in the agriculture industry, quality control, and climate purposes [18].

The present study relies on remote sensing climate data to look into and evaluate climate trends and variations over a four-decade period for the city of Baghdad. This study is of utmost importance for monitoring climate change and developing strategies for adaptation and mitigation by decision-makers or those interested in climate science.

2. Data Collection and Study Area

The NASA power Data Access Viewer (DAV) offers a platform for retrieving worldwide meteorological data, including temperature, wind speed, solar radiation, and more variables. The site enables users to investigate and get data for various geographies and temporal spans, which is very beneficial for climate research [19, 20]. Data encompassing information from 1980 to 2020 was obtained and organized. The file storage was in CSV format. The period from 1980 to 2020 was segmented into four distinct periods (or decades): 1980-1990, 1990-2000, 2000-2010, and 2010-2020, with the monthly averages for each year chosen for exploration.

The research region is located between latitudes 33.452°N and 33.184°N and longitudes 44.189°E to 44.576°E in the Baghdad district, the capital of Iraq. Figure 1 illustrates the research area.

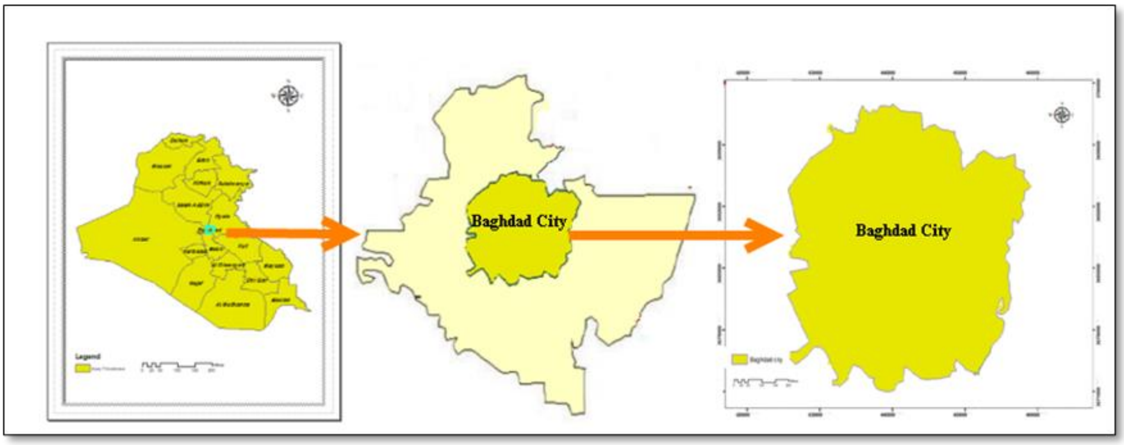

Figure 1: Study area.

3. Methodology

The study focused on analyzing historical or temporal data spanning from 1980 to 2020, segmented into four decades. The desired region and time range were selected on the interactive map to download data from the NASA Power Data Access Viewer [21,22]. The study defined the first decade as the period from 1980 to 1990, the second decade as the period from 1990 to 2000, the third decade as the period from 2000 to 2010, and the fourth and final decade as the period from 2010 to 2020. The study focused on various climatic factors associated with climate change, including wind speed, temperature, solar radiation, relative humidity, atmospheric pressure, and rainfall. Statistical analysis was employed through trend analysis and variance analysis ANOVA to study the climatic elements. Excel was used to analyze the trend of data through the built-in Trendline tool. Variance analysis was employed to show the differences between the climate factors averages of the groups (the decades in this study) within the study period.

3.1. ANOVA Procedure

ANOVA consists of several essential steps: first, the null hypothesis, which suggests that there is no difference between the groups, and the alternative hypothesis, which suggests that at least one group exhibits a difference are tested. Subsequently, the group means and the overall mean are computed and the sums of squares for between and within the groups are calculated. The mean squares are calculated by dividing the sum of squares by the corresponding degrees of freedom. The F-statistic is computed and evaluated against the critical value to determine whether to reject or fail to reject the null hypothesis.

1. Sum of Squares Between the Decades (SS_B)

The disparities in averages among different demographics or decades were assessed. The process involved squaring the difference between the mean and the overall mean of each group, and multiplying the result by the number of observations in each group [23]

$$SS_B \sum_{i=1}^{k} n_i \left(\overline{x_i} - \bar{x}\right)^2 \qquad \textbf{(1)}$$

where k is the number of groups, n_i is the size of group i, $\bar{x}_i$ is the mean of group i, and $\bar{x}$ is the overall mean.

2. Sum of Squares Within the Decade (SS_W)

SS_W demonstrates the differences that exist within each decade or group [23]:

$$SS_W = \sum_{i=1}^{k} (n_i - 1) {S_i}^2 \qquad \textbf{(2)}$$

where ${S_i}^2$ refers to the variance of the i^th^ group.

3. Total Sum of Squares (SS_T)

It denotes the overall variation that is present in the data. It is the sum of the squares within the decades (SS_W) and that between the decades (SS_B) [23]

$$SS_T = SS_B + SS_W \qquad \textbf{(3)}$$

4. Mean Square Between Groups (MS_B)

It is calculated by dividing (SS_B) by the related degrees of freedom. The statistic is indicative of the average variation among the group means, which helps to assess whether there are substantial disparities between the group means [23]

$$MS_B = \frac{SS_B}{k-1} \qquad \textbf{(4)}$$

where k is the degrees of freedom for the between groups (decades) variations, typically the number of groups minus one (here 4 decades).

5. Mean Square Within Groups (MS_W)

The measurement reflects the average variation present within each group [23]. The equation for MS_W is

$$MS_W = \frac{SS_W}{N-K} \qquad \textbf{(5)}$$

where N is the total number of observations.

6. F-Test Statistic

The F-statistic in ANOVA represents the ratio of the mean square between groups (MS_B) to the mean square within each group (MS_W). This method is employed to assess whether there are notable differences among the means of the groups. The equation for the F-statistic is

$$F = \frac{MS_B}{MS_W} \tag{6}$$

7. P-Value

The p-value in ANOVA quantifies the likelihood that the differences observed between the groups means is due to random variation. The derivation comes from the F-statistic and is evaluated against a significance level (e.g. 0.05) to check whether to reject the null hypothesis or not. The null hypothesis is rejected for a p-value below 0.05, suggesting a notable difference between the groups involved. If the value exceeds 0.05, the null hypothesis should be taken into consideration, indicating that there is no significant difference observed. The p-value can be derived using an F-distribution table or through statistical software, such as Excel, Statistical Package for the Social Sciences (SPSS), or Python.

The p-value in ANOVA is calculated from the F-distribution using the Cumulative Distribution Function (CDF) given by

$$P = P(F > F_{observed}) = 1 - F_{cdf}(F_{observed}, d_{fB}, d_{fW}) \tag{7}$$

where $F_{observed}$ is the computed F-statistic, $F_{cdf}(F, d_{fB}, d_{fW})$ is the cumulative distribution function (CDF) of the F-distribution, $d_{fB}=k-1$ is the degrees of freedom for between-group variance, and $d_{fW}=N-k$ is the degrees of freedom for within the group variation.

4. Results and Discussions

4.1. Wind Speed

Wind speed trends, as shown in Fig. 2, may indicate fluctuations in atmospheric circulation patterns, affected by evolving global and regional climatic conditions. The overall rise during the first three decades may be linked to escalating temperature gradients or altering pressure systems that influence wind velocities. Nonetheless, the decrease observed in the last decade (2010 to 2020) may suggest a deterioration of these driving forces or alterations in local land use, vegetation, or urbanization that affect wind flow patterns; All patterns have the same trend. This reversal necessitates further examination to ascertain its causes, which may impact wind energy potential and climate variability research in the region.

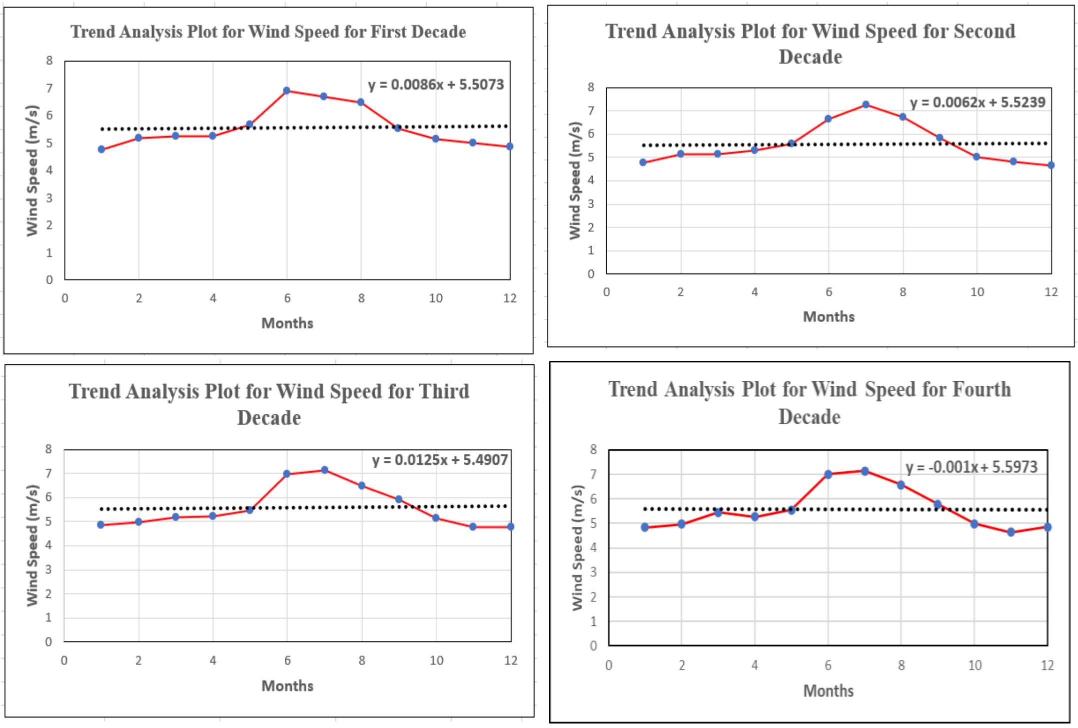

Figure 2: Trend analysis of wind speed during the four decades.

4.2. Temperature

Temperature trends indicated the warming during the four decades, as shown in Fig. 3. The most significant rate of increase was noted in the second and third decades. The minor deceleration in the fourth decade may suggest regional climatic fluctuations or the impact of mitigation strategies. The ongoing increase in baseline temperatures indicates that the long-term warming trend is continuing. This aligns with global climate change observations, highlighting the necessity for additional research into the fundamental causes and consequences on ecosystems, energy requirements, and human health in the area.

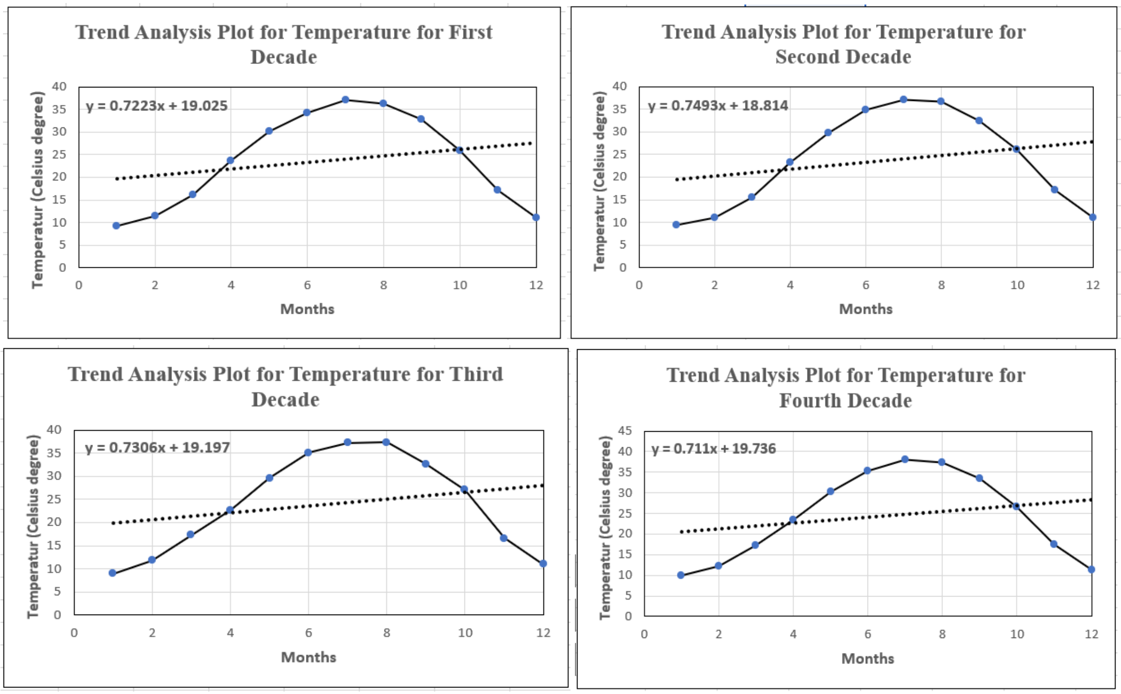

Figure 3: Trend analysis of temperature during the four decades.

4.3. Solar radiation

Fig. 4 depicts the trend analysis plots for solar radiation during the four decades of the time period (1980–2020) revealing a consistent downward trend in solar radiation levels over time. Each decade shows a linear regression line with a negative slope, indicating a gradual decrease in solar radiation. The slight decline trends over the decades may be linked to rising atmospheric particulates, fluctuations in cloud cover, or global dimming effects resulting from anthropogenic emissions. Nonetheless, the comparatively stable indicate that the availability of solar energy has predominantly remained constant over time. Additional analysis, encompassing regional aerosol concentrations, alterations in cloud fraction, and global radiation patterns, is required to ascertain whether this trend constitutes a broader climatic shift or is merely a manifestation of localized atmospheric variability.

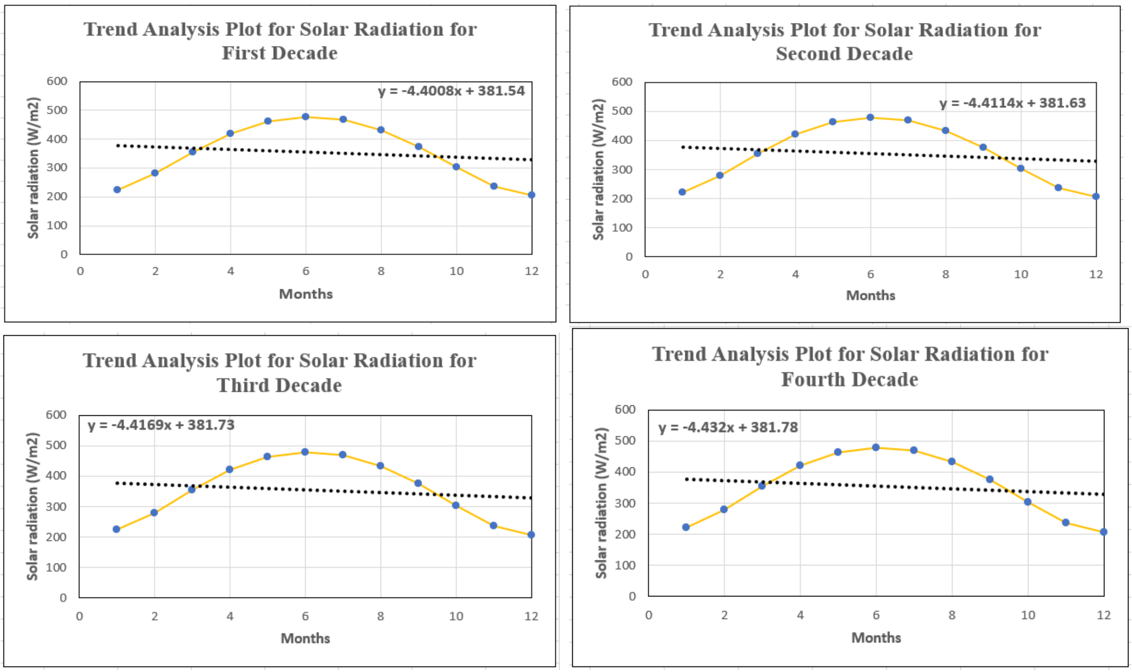

Figure 4: Trend analysis of solar radiation during the four decades.

4.4. Atmospheric Pressure

Fig. 5 illustrates the trend analysis plots for atmospheric pressure during the four decades of the time period (1980–2020). The pressure analysis plots exhibited a clear seasonal pattern, diminishing from the start of the year, attaining a lowest point approximately mid-year (June–July), and subsequently rising towards the end of the year. Pressure typically decreased during warmer months and increased during cooler months. This seasonal behavior is influenced by temperature-induced changes in atmospheric circulation, which causes lower pressure in the summer and higher pressure in the winter.

This pattern remained consistent throughout all four decades, indicating a stable seasonal pressure variation. Seasonal pressure fluctuations are likely influenced by temperature-induced alterations in atmospheric circulation, exhibiting lower pressure in warmer months and higher pressure in cooler months. The minor discrepancies in slopes may be ascribed to alterations in atmospheric dynamics, possibly driven by climate change, regional warming, or changes in wind patterns. The consistent intercept values indicate that no significant long-term pressure fluctuations have transpired.

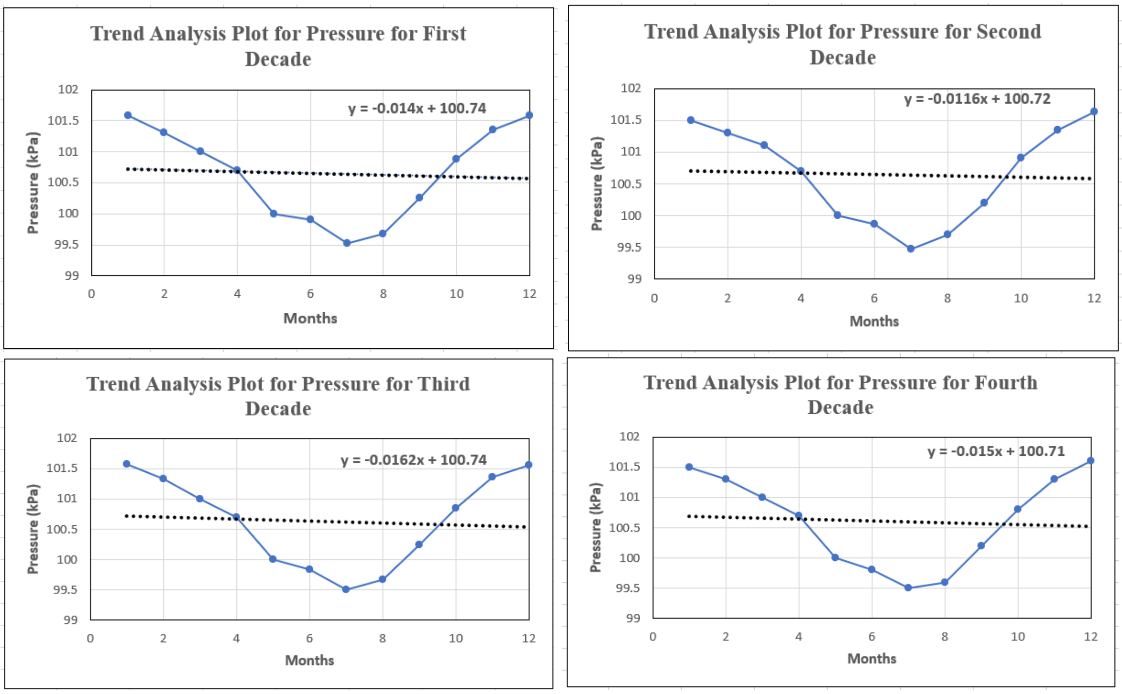

Figure 5: Trend analysis of atmospheric pressure during the four decades.

4.5. Precipitation

Precipitation rates were declining steadily, as demonstrated in Fig. 6. The last two decades demonstrated the most significant decrease. This indicates that precipitation has diminished more swiftly in recent decades, which is potentially associated with the impacts of climate change, including rising temperatures.

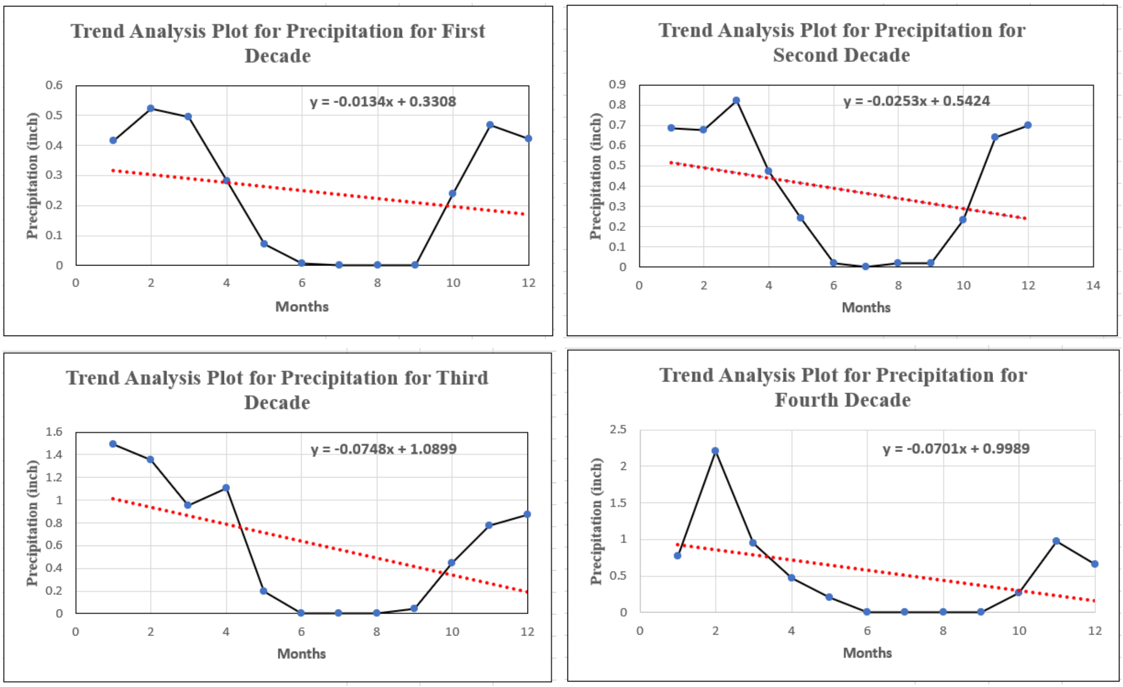

Figure 6: Trend analysis of Precipitation during the four decades.

4.6. Humidity

The humidity trend analysis demonstrated a steady decrease in levels, as depicted in Fig. 7. A reduction in humidity can result in significant consequences, including increased evapotranspiration, reduced soil moisture, and heightened drought risks, all of which can negatively affect agriculture, water resources, and ecosystem stability.

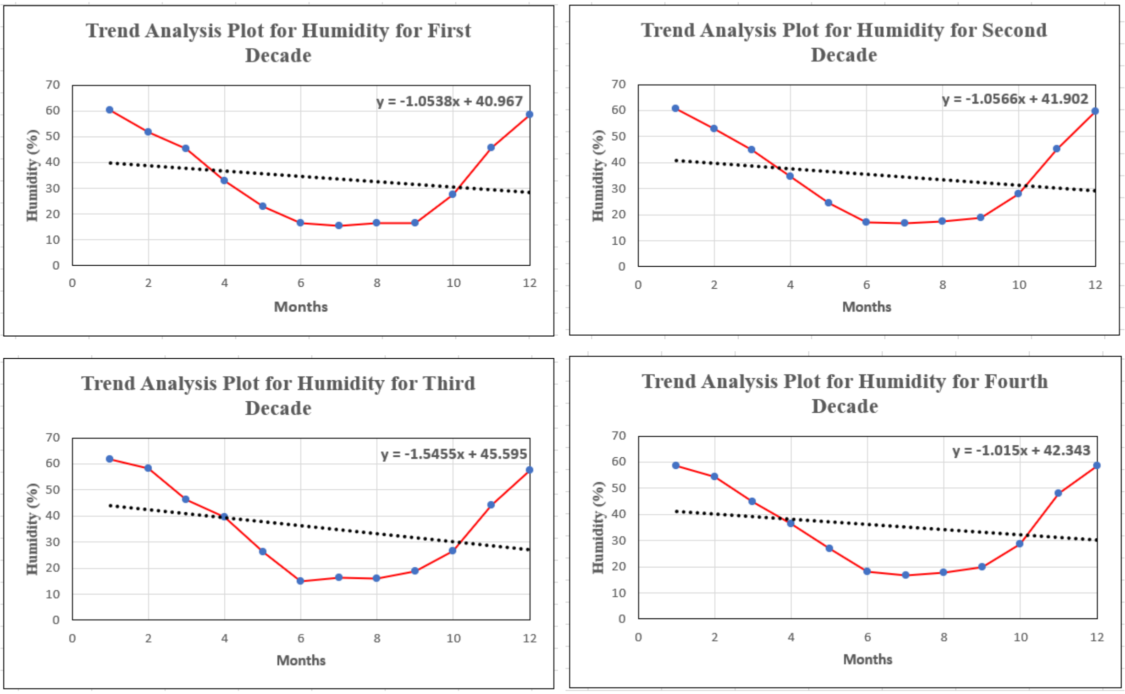

Figure 7: Trend analysis of humidity during the four decades.

Table 1 depicts the ANOVA analysis summary for the climate parameters. This ANOVA table summarizes the statistical comparison of various climate parameters (wind, temperature, solar radiation, atmospheric pressure, precipitation, and humidity) during the four decades of the time period (1980–2010).

Table 1: ANOVA analysis results of various climate parameters

Parameters		**SS**	**MS**	**F-stat**	**P-value**
Wind	Between decades	0.006	0	0.003	0.99977
	Within a decade	30.12	0.69		
Temperature	Between decades	12.88	4.29	0.04	0.98957
	Within a decade	4792.34	108.92		
Solar radiation	Between decades	0.02	0.005	0	1
	Within a decade	446956	10158		
Atmospheric Pressure	Between decades	0.01	0.004	0.007	0.99918
	Within a decade	25.28	0.574		
Precipitation	Between decades	0.94	0.312	1.444	0.24288
	Within a decade	9.52	0.22		
Humidity	Between decades	19.07	6.36	0.02	0.99551
	Within a decade	12995.9	295.36		

The results showed high p-values (> 0.05), indicating that there are no statistically significant differences in the analyzed climate parameters throughout the decades. This suggests that these parameters have remained relatively stable over time, at least within the sampled dataset. For all parameters, the sum of squares between decades (SS_B) is very small compared to the sum of squares within decades (SS_W), meaning that variations within each decade are larger than variations across decades.

Although the ANOVA results indicated no significant differences during the decades, trend analysis for each average month in the four decades suggested that local climates have experienced shifts in the past decades. The monthly analysis of the six parameters indicated that wind speed increased by 1% in the second decade, 8% in the third decade, and 4% in the fourth decade. The temperature rose at monthly rates, particularly during the study period, with a notable increase of 1.7% from 2010 to 2020. Solar radiation diminished by 0.0003% from 2000 to 2020, potentially attributed to pollution, as Baghdad is an urban area characterized by significant industrial activity and a high population density. The pressure increased over the four decades, with the highest percentage occurring between 2010 and 2020, reflecting a change rate of 5.3%. The distinguished long-term increase in pressure that reflects changes in atmospheric dynamics, possibly influenced by regional warming, shifts in circulation patterns, or the effects of climate change. The humidity decreased during the study period, with change ratios from 2.6% for the first decade to 0.5%, for the fourth decade.

5. Conclusions

This study studied climate transition processes during the period from 1980 to 2020 amidst changed climate conditions using remote sensing. The analysis showed that all p-values were greater than 0.05, suggesting that there were no statistically significant differences in the climate parameters studied over the decades. Although the ANOVA results showed no significant differences among the decades, an analysis of trends in average monthly data during the over four decades suggested that local climates have experienced changes in recent years. Trend analysis proves to be more effective in identifying gradual alterations in climate parameters, while ANOVA is more appropriate for assessing significant changes between time intervals. Combining ANOVA with time series trend analysis and remote sensing data analysis would provide a deeper understanding of climate changes over decades.

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Conflict of interest

Author declares that they have no conflict of interest.

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التقييم القائم على الاستشعار عن بعد للعقود المناخية في بغداد باستخدام تحليل الاتجاه الإحصائي واختبار التباين (ANOVA)

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الخلاصة

تحلل هذه الدراسة الانماط طويلة المدى للبيانات الزمنية للفترة من عام 1980 إلى عام 2020 لمدينة بغداد والتي تشمل أربعة عقود لتقييم آثار تغير المناخ على البيئة والنظم البيئية. تم الحصول على البيانات من وكالة ناسا، وتشمل الرياح ودرجة الحرارة والإشعاع الشمسي والضغط الجوي وهطول الأمطار والرطوبة. تم استخدام طرق التحليل الإحصائي، بما في ذلك تحليل الانماط وتحليل التباين ANOVA لتقييم التفاوتات بين الدورات الزمنية. تم استخدام نماذج الانحدار الخطي لإجراء تحليل الانماط لكل عقد، وتقييم التغيرات في معايير المناخ. أشارت النتائج الرئيسية إلى أن قيم P كانت عالية. وضحت النتائج أنه لا توجد فروق ذات دلالة إحصائية في معايير المناخ المدروسة على مدى العقود. ومع ذلك، يشير تحليل الأنماط لمعدلات البيانات الشهرية على مدى أربعة عقود إلى أن المناخات المحلية خضعت لتغييرات في السنوات الأخيرة. أشار التحليل الشهري لستة معايير إلى زيادة في سرعة الرياح ودرجة الحرارة والضغط، في حين أن الإشعاع الشمسي والرطوبة وهطول الأمطار يتناقصان باستمرار.

الكلمات المفتاحيه: الاستشعار عن بعد، تغير المناخ، تحليل الاتجاهات، تحليل التباين (ANOVA).