Research Article

An Assessment of the Rainfall Change Scenarios Projection Until 2050 -A Case Study of Iraq

Fadia W. Al-Azawi[1*] , Huda M. Hamid[2], Husam Jasim Mohammed[1] and Jan Muhammad[3]

[1]Al-Karkh University of Science, Baghdad, Iraq; [2]Soil and Water Resources Department, College of Agriculture, Al-Qasim Green University, Babylon, Iraq; [3]Institute of Space Technology, Karachi Campus, Pakistan.

Abstract | The decrease in precipitation is the foremost noteworthy perspective within the period of climate inconstancy. Information was utilized for surveying precipitation alter scenarios in the whole of Iraq amid the period (1951-2020), at that point predicate, the alter until 2050. The PRECIS Regional Climate Model (RCM) is utilized to simulate the current time period from 1951 to 2020, as well as a future time period from 2021 to 2050. The model operates at a spatial resolution of 25 x 25 km. The RCM can provide timely and appropriate forecasts for usage in rainfall scenarios. The study aim to prepare maps to predicate rainfall changes in the twenty-two stations over a wide range of Iraq. Rainfall data for 100 years from 1951-2050 were analyzed and annual rainfall amounts predicated to measure the amount of rainfall in the Region of Interest (ROI) in the next years. The data and extraction process runs through various techniques by analyzing data statistically using SPSS and interpolation techniques using GIS. In this study, IDW estimated the rainfall distribution in the ROI. Furthermore, to obtain optimal interpolation rainfall data, root mean squared error value for Kriging, and IDW was measured. The results showed that IDW interpolation for rainfall data can obtain more accurate results; a smaller RMSE is due to an accurate method; and the better kriging method should produce a smaller value. It is used for evaluating the goodness of a prediction interpolation task. To obtain a more precise picture of the scenarios for changing rainfall, the analysis was performed in most districts of Iraq. Dry seasons yield more reliable results than flood seasons. High correlation coefficients above 0.95 validated IDW for spatial interpolation to predict ROI rainfall data.

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***Correspondence** | Fadia W. Al-Azawi, Al-Karkh University of Science, Baghdad, Iraq; **Email:** fadia.alazawi@kus.edu.iq
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Introduction

In recent decades, there has been a conspicuous alteration in global precipitation patterns, which possesses the capability to exert substantial impacts on the realms of societal dynamics, environmental conditions, and economic viability (Solomon *et al*., 2007; Stocker *et al*., 2013; UNISDR, 2015). These changes increase weather extremes and hydrological cycle variability, it is necessary to investigate following changes in variables of hydro climatic in order to understand regional effects of changing rainfall (Houghton *et al*., 1996; Easterling *et al*., 2000).

Studies over Iraq have focused on analyzing regional temperature, relative humidity, and rainfall trends and variability e.g., (Ansam and Taymoor, 2020; Samira, 2021; Luis *et al*., 2002; Al-Quraishi and Negm, 2019; De Lima *et al*., 2010; Al-Arazah, 2017; Thair *et al*., 2019) to name a very small number of contributions.

According to previous researches, long-term increases in rainfall and temperature (more than 30 years) are regarded useful factor to gauge the possibility of climate change in a location of interest. ROI (Almazroui *et al*., 2012; Lazaro *et al*., 2001; Liebmann *et al*., 2010). Iraq is located between latitudes 29.000 and 37.220 N and 38.450 and 48.300 E, and its climate is typically subtropical semiarid. It is distinguished by having a short, cold winter and a long, hot summer, as well as a wide range in annual temperatures (Al-Sudani, 2019). The study of (Al-Waeli *et al*., 2020) showed that lack of rain is what causes drought, which leads to disruption of agricultural ecosystems by increasing soil salinity, which leads to chemical decomposition of the soil and reducing the soil content of organic matter, which causes poor fertility and unsuitability of economic plants, and thus deterioration of the quality index.

Al-Waeli (2020) also explained the negative impact of the absence of rain on the agricultural reality in the Iraqi Babylon Governorate, as it contributes to a decrease in the soil's organic matter content, which accelerates the possibility of soil loss due to erosion.

Al-Waeli *et al*. (2021) indicated that the decrease in rainfall forced farmers to use groundwater that had not been laboratory-tested, and in their study they concluded that it would have a negative impact in the future on the soils of western Karbala, Iraq. Al-Waeli *et al*. (2024) indicated that the Evaluation of the sensitivity of Al-Husseiniya soils in Karbala to erosion using Landsat sensors.

For the management of water resources, rainfall variability and its trends are crucial (Lei *et al*., 2011; Mahmud *et al*., 2014).

The annual rainfall be 30-35 years in length and be calculated as the average of the daily amounts. The selection of this time period was made to reflect the local climate. The climate is the average state of the weather over a long period of time, with little variation.

In order to develop trends that would later demonstrate the absence or existence of a change in rainfall in the ROI, the research set out to collect and evaluate annual rainfall measurements for a period of 70 years (1951-2020) and predict the likelihood of rain-fall for 29 subsequent years (2021-2050). The community would gain from this since rainy weather makes it possible to modify farming methods and boost livelihoods.

Materials and Methods

Study area

Iraq is located between longitudes and latitudes (38° 45' and 48° 45' east , 29° 5' and 37° 22' north), respectievely. Figure 1 illustrates the 435052 square kilometers that make up Iraq.

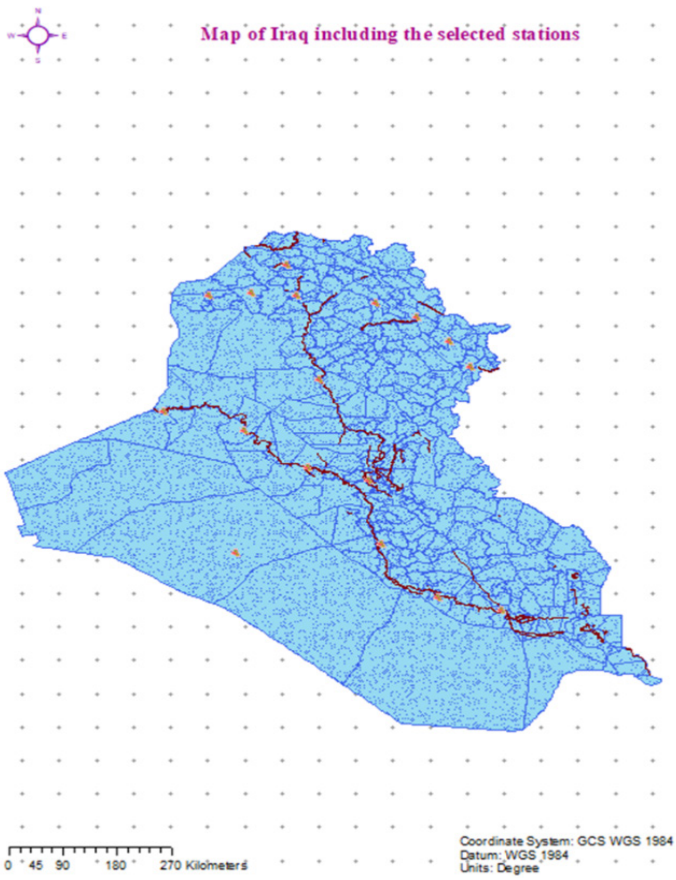

Figure 1: *Distribution map of Iraqi meteorological stations.*

Iraq's population in 2020 was 0.52% of the world's population, according to the most recent United Nations estimations. Iraq has a population density of 240 persons per square mile. There are 167,692 square miles of land in all. In this study, rainfall data are gathered and evaluated for the chosen region of interest (ROI) from 22 stations spread throughout a large area of Iraq from 1951 to 2020. The following statistical tests were used, and GIS maps were created for these stations' yearly rainfall and the quantity of rainfall predicted for them until 2050 as shown in Table 1.

Table 1: *Metrological stations in Iraq.*

Station	Longitude (D)	Latitude (D)	Elevation (m)
Nukheb	42.25	32.033	305
Samawa	45.266	31.3	6
Hilla	44.433	32.183	25
Rutba	40.283	33.033	615.5
Ramadi	43.316	33.45	48
Baghdad	44.233	33.233	32
Nasiriya	46.233	31.0833	3
Qaim	41.166	34.383	178
Hadithah	42.366	34.066	140
Hai	46.05	32.1666	14.9
Basra	47.716	30.516	2.4
Baiji	43.483	34.916	115
Khanqin	45.433	34.3	202.2
Tel-Afer	42.483	36.366	200
Kirkuk	44.4	35.466	330.8
Sinjar	41.833	36.316	538
Mosul	43.15	36.316	223
Erbil	44.333	36.183	426
Duhok	43	36.833	536
Dar-bandikhan	45.75	35.133	400
Sulaymaniyah	45.45	35.55	853
Dukan	44.95	35.95	490

Methodology

The methodology of this research depended upon three phases:

Phase 1 (Date Collection): The data is the backbone of every research and/or study. Initially, various types of data were very helpful to compile this study namely Satellite Data, and Climate Model Data.

Phase 2 (Data Processing, Extraction and Developing Maps): After getting data from various sources as mentioned above in the data collection section, the data and extraction process run through the various helping tools and techniques by analyzing statistical parameters, statistical interpolation. Through algorithms to analyze past and present rainfall events and compare these events with actual available data met. Observatories of Iraq meteorological department. On the base of these past and present rainfall events to predict the future scenarios using various geospatial techniques.

Phase 3 (Comparisons, Analyzing and Assessing Risk): These all analyzing maps, statistically compared to each other during this phase and identified low and high-risk areas and/or sectors of Iraq due to predicted rainfall events till 2050. Through mapping is clarified which areas and/or sectors of Iraq are under high risk due to torrential rainfall events and low risk due to normal rainfall events. Using mapping resources to save the rainfall water for the agricultural sector and other water shortage issues. The various climate models data and Iraq data in the format of an excel sheet is used for processing with help of the many tools such as, Geo-statistical analytical tools, Geo-referencing data, and geospatial interpolation techniques (Robinson and Metternicht, 2006). There are many estimation methods that can be used with ArcGIS to analyze upcoming meteorological events, including IDW, GPI, RBF, and conventional kriging.

On the base of the past and present rainfall events to predict the future scenarios using different geo-spatial techniques. The following analyzing maps, statistically compared to each other during this phase and identified (low and high) risk sectors of Iraq due to predicted rainfall events till 2050. Through mapping that is clarified which sectors and/or area of Iraq under high risk due to different amount of annual rainfall. The various climate models data used for processing with help of the different tools such as Geo-referencing, geo-spatial interpolation methods, and Geo-statistical analytical. Since the 1950s, Iraq's annual rainfall totals have decreased, but in the late 1990s, they have increased. Most studies ending before the mid-1990s concur that annual totals increased from the 1960s. Later research confirm the mid-1990s decrease in annual rainfall (Ansam and Taymoor, 2020).

Statistical studies (Altman and Bland, 2005)

The calculated statistical parameters as in the following. Equation 1 calculates the mean (the average of all data set numbers).

$$\text{Mean} = \frac{\text{Sum of all data values}}{\text{Number of data values}} \quad \dots(1)$$

The variance computes the dispersion of group members within the data set relative to the arithmetic mean (σ^2), as represented by Equation 2.

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n} \quad \dots(2)$$

Where; μ: Population mean; X_i: Elements in the data set.

Step 1: The above formula subtracts each population element from the data set mean. Then, sum all values. Step 2: Divide Step 1's sum by the total elements. The results is postive value.

As in Equation 3, standard deviation (Ali *et al*., 2013) represents the difference between data set observations from its mean in the same unit as the dataset values.

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}} \quad \dots(3)$$

The interquartile range shows where the middle fifty is in a data collection. Where a range measures the starting and finish of a set, an interquartile range measures the majority of values. Reporters prefer it above other spread measures. As seen in Equation 4, the interquartile formula range is the first quartile minus the third.

$$\text{IQR} = Q_3 - Q_1 \quad \dots(4)$$

95% Confidence interval for mean

A range of values, based on the sample mean, that with a designed likelihood, include the population mean. The arithmetic mean estimated when the largest and the smallest is 5% of the cases have been eliminated. Variance is defined as the total of squared departures from the mean divided by one less than the number of cases, and it measures dispersion around the mean.

Range of interquartile

A data spread measure. Third-quartile (75th percentile) to first-quartile (25th percentile) distance.

Skewness

A distribution symmetry measure. Symmetric normal distributions with Skewness zero. Significant plus Skewness distributions have lengthy right tails. Distributions with strong negative Skewness have extended left tails.

Negative Kurtosis means that observations have thicker tails than a normal distribution and cluster less until the distribution's extreme values, at which point the tails are thinner.

Here, the techniques of interpolation and kriging were employed for mapping annual data of rainfall. Also, deterministic interpolation methods, include four methods: IDW, Radial Basis Functions (RBF), Global Polynomial Interpolation (GPI), and Kriging.

According to the inverse distance weighted (IDW) the resemblance rate as well as the connection between adjoining points is proportionate to distance between the points. The weight assigned to each interpolated point is equivalent to the distance inverse from that point. In IDW method, an unknown point's value is estimated as in the equation 5 (Robinson and Metternicht, 2006; Setianto and Triandini, 2013; Bhunia *et al*., 2018).

Where's ß is weighting power, n is the values of total sample data, (xi: h_{ij}) the separation distance between sample data value and interpolated value, and x_0 is interpolated value.

Creating a surface grid that traverses all measured points is the objective of the precise radial basis function (RBF) method. The predictions may vary in magnitude below and above highest and lowest values observed (Pham *et al*., 2020; Li *et al*., 2011). The generated values are comparable to those measured at the same location. If there is a significant value shift across small distances the RBF is an inappropriate method (Johnston, 2001). This technique bears resemblance to IDW, except for the predicated value fluctuation. Additionally, a smoothening parameter is incorporated to regulate the degree of smoothness in the resultant surface (Biancolini, 2018). In the context under investigation, the optimal kernel parameter is 0.41.

The global polynomial interpolation (GP) applies multiple regression on entire set of data, GPI is a rapid method (Johnston *et al*., 2001). At both edge and border the points can impact on resulted surface, in this interpolation technique. In the GPI orders allowed are ten (Johnston *et al*., 2001). 1st is utilised in this research due to its compatibility with a single data plane, as indicated by the equation:

$$Z\ (x0) = \frac{\sum_{i=0}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum \frac{1}{h_{ij}^{\beta}}} \quad ...(5)$$

Where; ε (xi , yi): the random error , βi (xi, yi) : the parameters, z (xi, yi): the datum at location.

$$Z\ (x_i, y_i) = \beta_0 + \beta_1 x_i + \beta_2 y_i + \varepsilon\ (x_i, y_i) \quad ...(6)$$

A technique that integrates the data's measurable statistical features is ordinary kriging (O.K.). When considering the strength of statistical connection in this manner, it is important to note that the correlation is a function of distance. O.K estimates $Z^*(x_0)$ and error estimation Variance $\sigma^2_k(x_0)$ at any individual point x_0 , respectively, calculated as follows:

$$Z^*(x_0) = \sum_{i=1}^{n} \gamma_i Z\ (x_i) \quad ...(7)$$

$$\sigma_k^2(x_0) = \mu + \sum_{n=1}^{n} \lambda_2 \gamma\ (x_0 - x_i) \quad ...(8)$$

Where; $(x_0 - x_i)$ is distance semivariogram value between ×0 and xi, and ki :The weights. l is the lag range constant (Mohammadi, 2019; Gia Pham *et al*., 2019; Zeng *et al*., 2020).

Results and Discussion

Throughout the entire period and on 22 different weather stations, the assessment was carried out to thoroughly investigate the changes in rainfall and the patterns that emerged from them. The annual rainfall maps for the period of this study are shown in the following Figures 2-11.

Comparison study between (increase and decrease) trend of rainfall (%) in 1st (50 and 100) years respectively as shown in Figure 12. This predication is important to all of the life joints; it is very important to make relation between these results and the groundwater studies like (Ali *et al*., 2013; Muhammad *et al*., 2016; Al-Waeli and Al-Azawi, 2018).

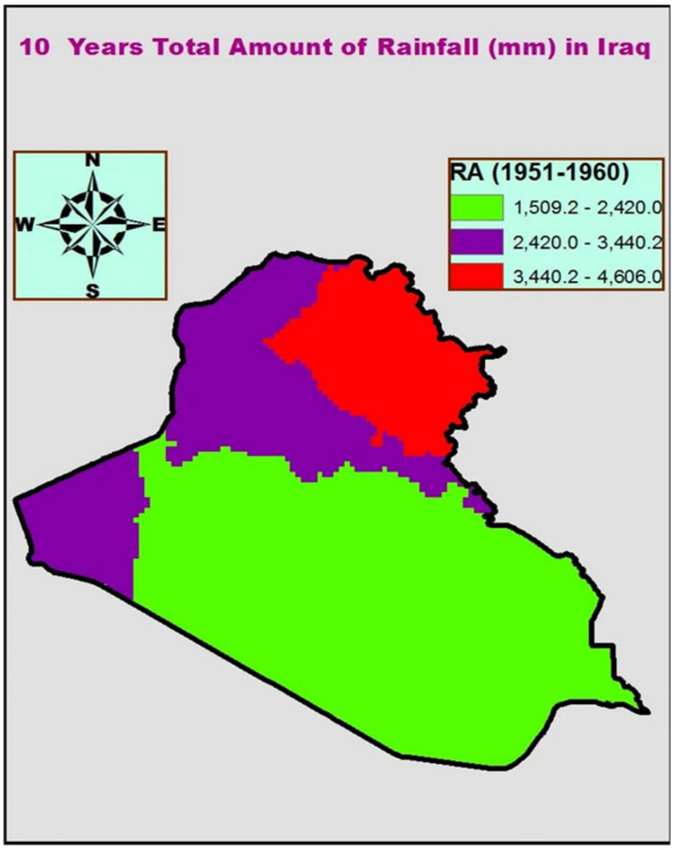

Figure 2: *Total Rainfall (in millimetres) from 1951 to 1960.*

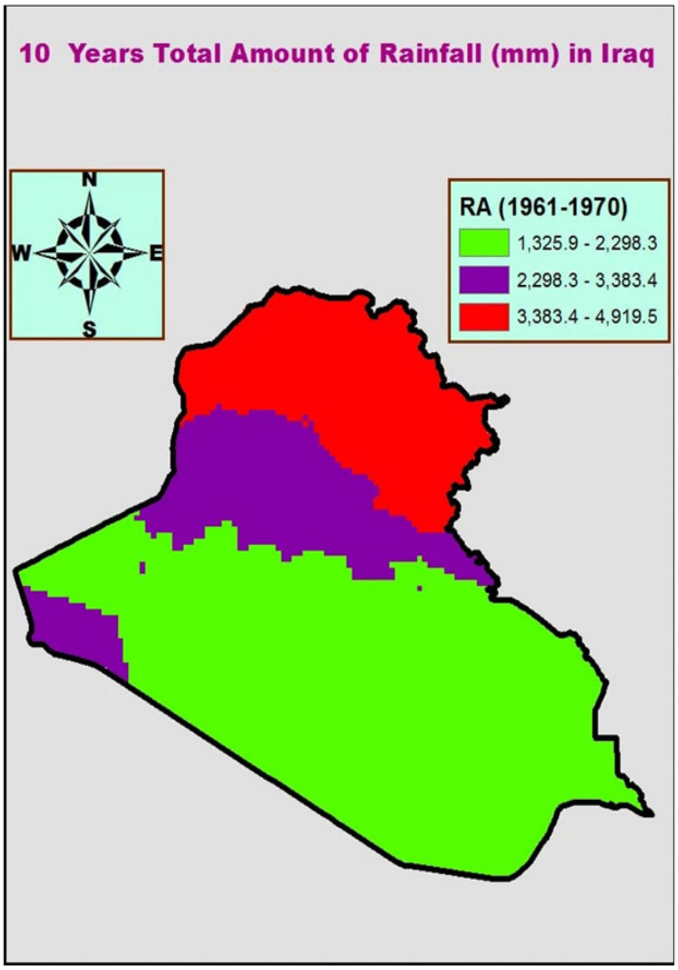

Figure 3: *Total Rainfall (in millimetres) from 1961 to 1970.*

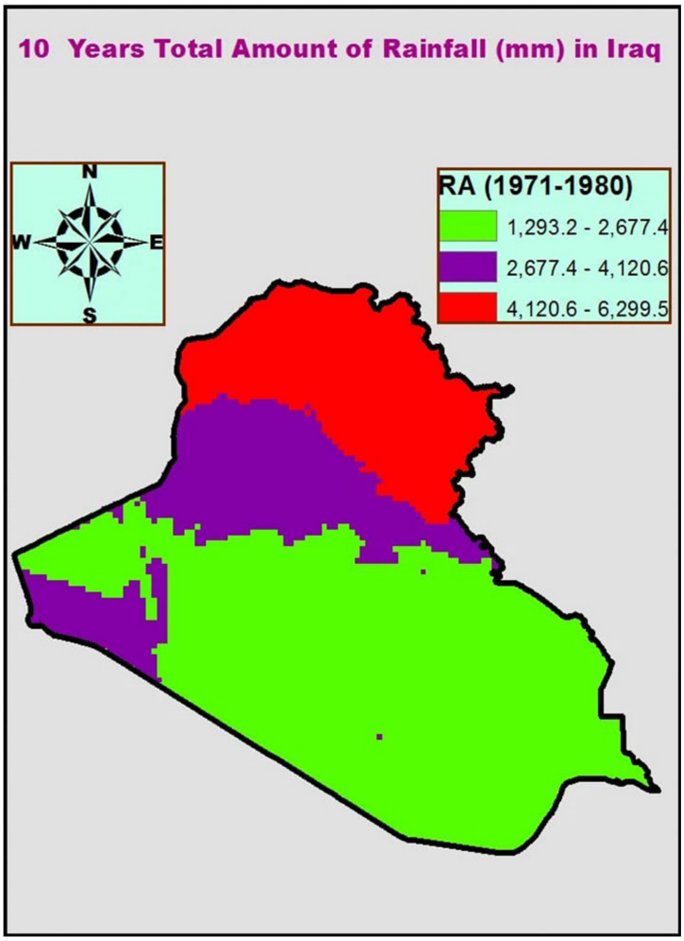

Figure 4: *Total Rainfall (in millimetres) from1971 to 1980.*

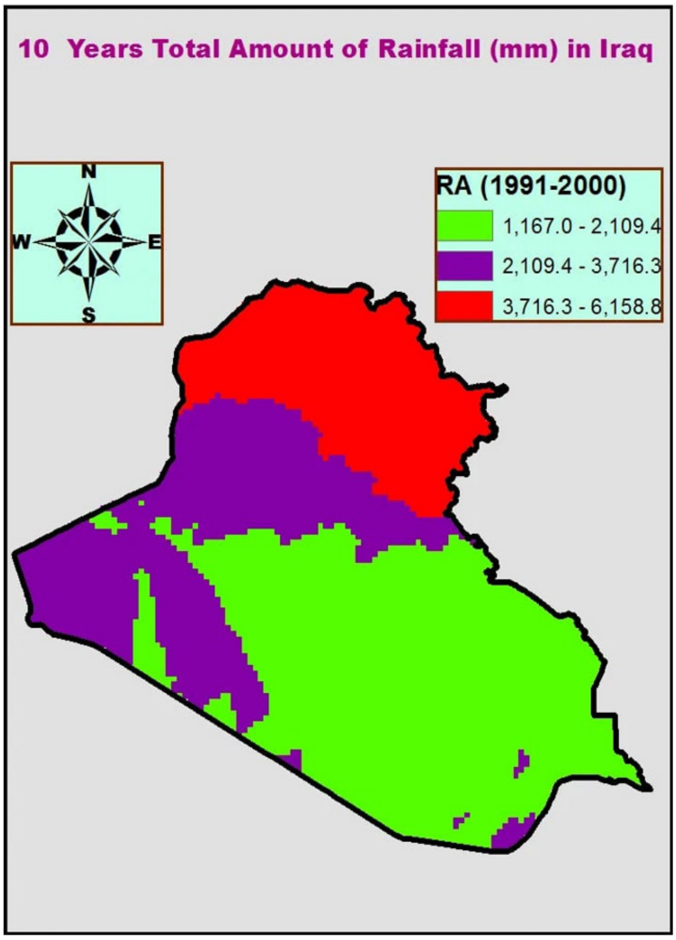

Figure 6: *Total Rainfall (in millimetres) from 1991 to 2000.*

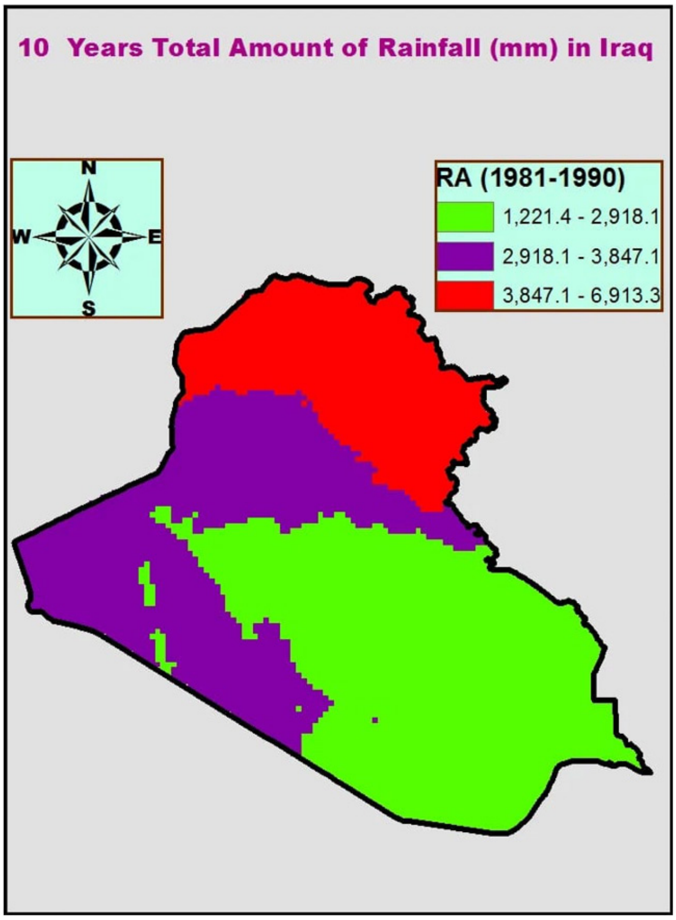

Figure 5: *Total Rainfall (in millimetres) from1981to1990.*

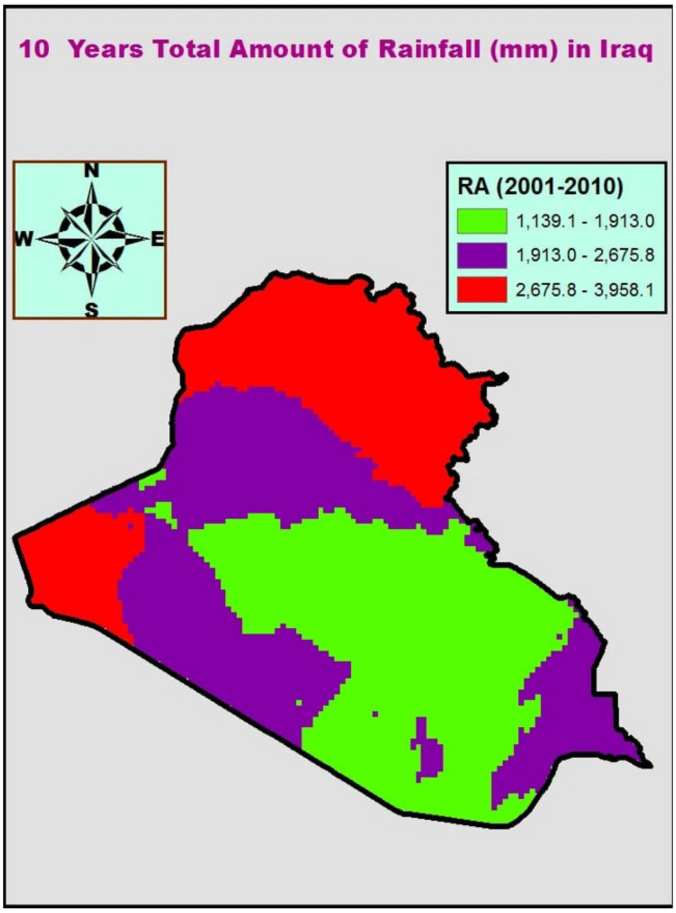

Figure 7: *Total Rainfall (in millimetres) from 2001 to 2010.*

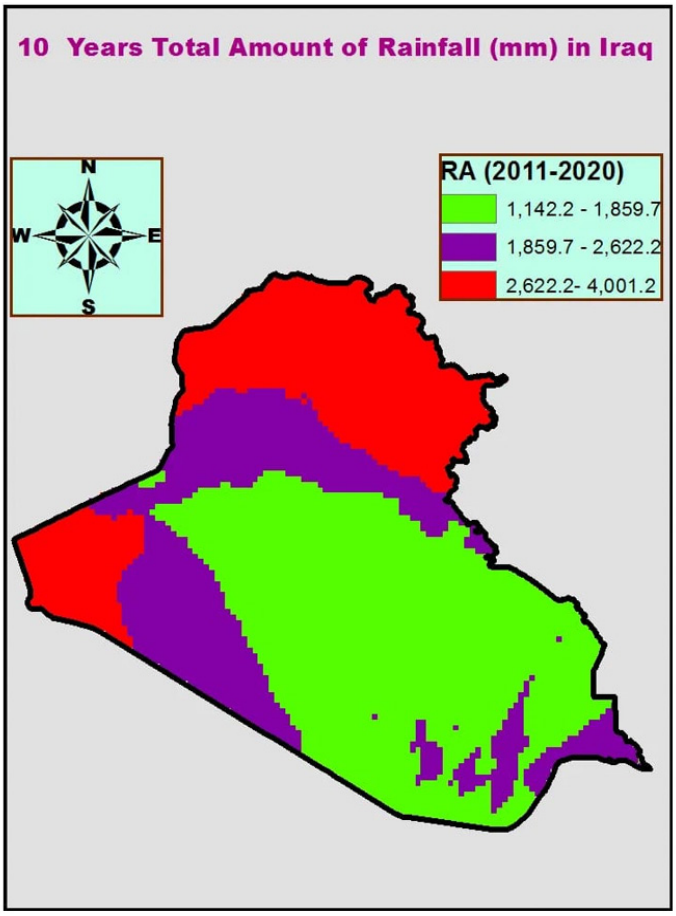

Figure 8: *Total Rainfall (in millimetres) from 2011 to 2020.*

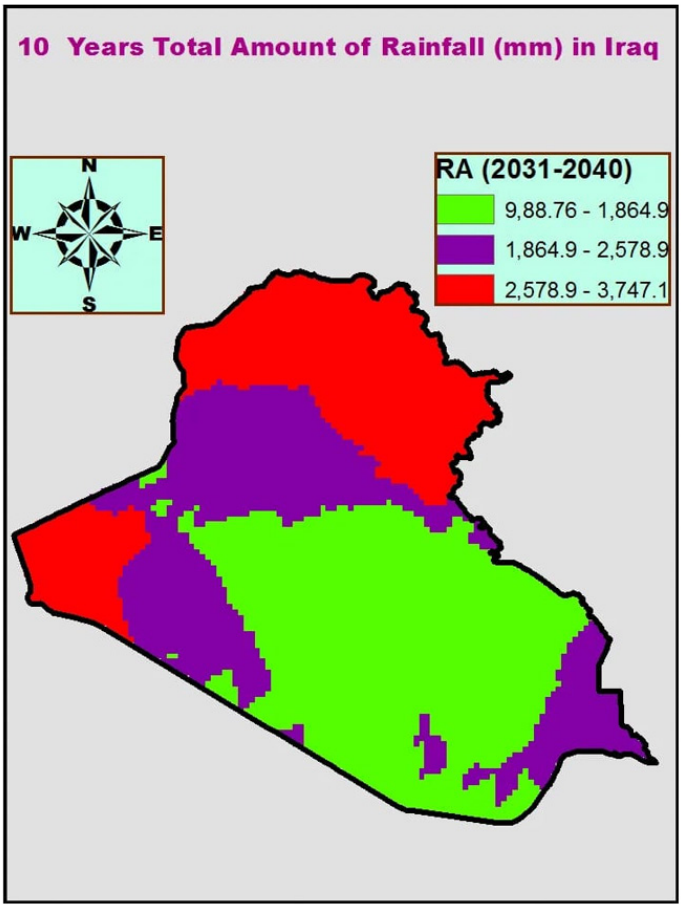

Figure 10: *Total Rainfall (in millimetres) from 2031 to 2040.*

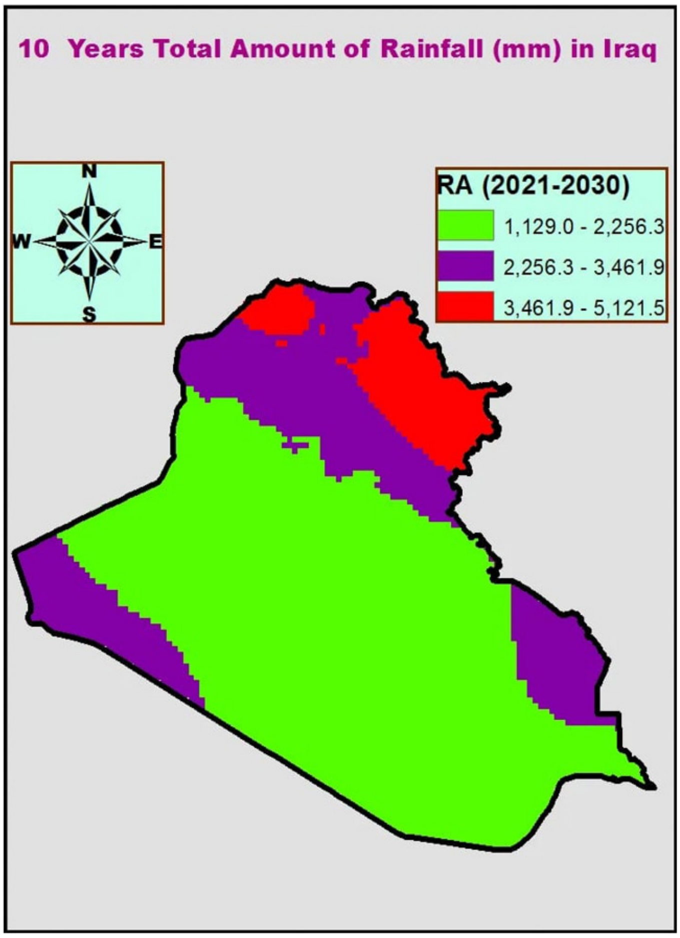

Figure 9: *Total Rainfall (in millimetres) from 2021to 2030.*

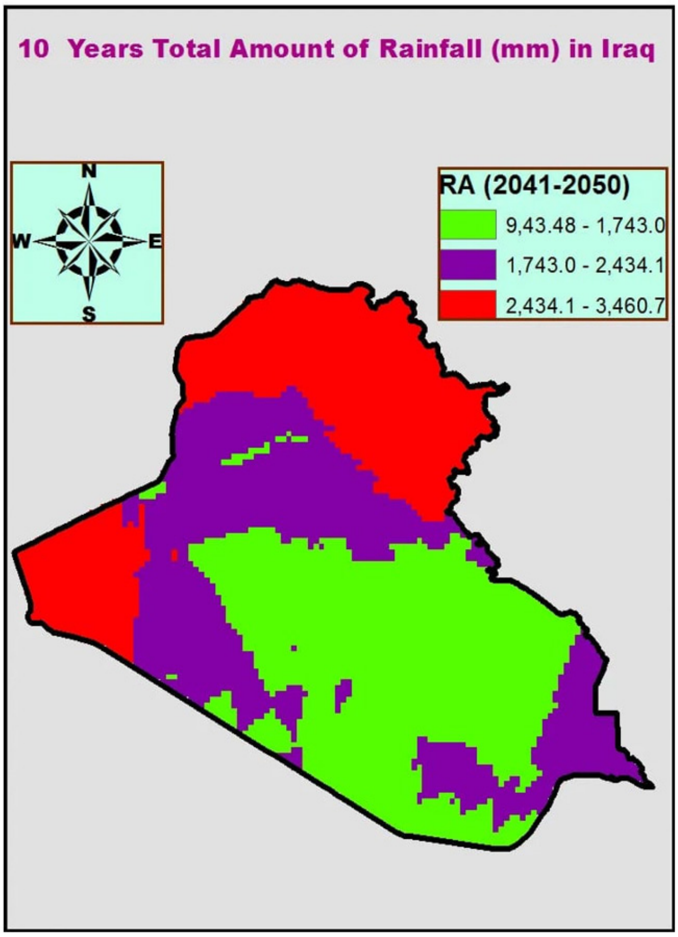

Figure 11: *Total Rainfall (in millimetres) from 2041 to 2050.*

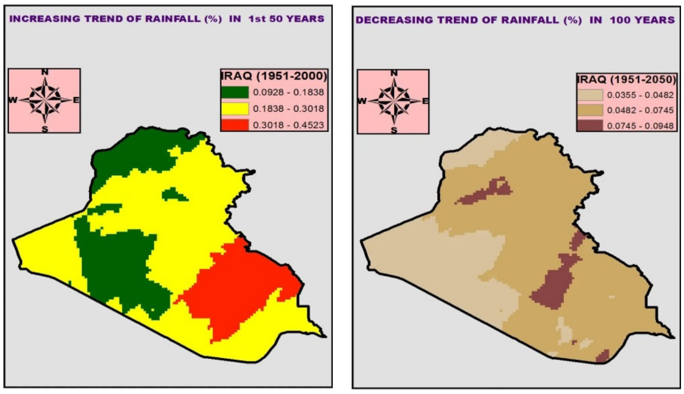

Figure 12: *Study between (increase and decrease) trend of rainfall (%) in 1st (50 and 100) years respectively using annual values.*

Table 2 provides the standard deviation, average (mean), maximum value, and minimum value of each variable for descriptive statistics.

Table 2: *Descriptive analysis result.*

		Statistic	Std. Error
Mean		4036.9959	549.35875
95% confidence interval for mean	Lower bound	2812.9483	
	Upper bound	5261.0434	
5% trimmed mean		4031.1757	
Median		3385.6273	
Variance		3319745.340	
Std. Deviation		1822.01683	
Minimum		1292.48	
Maximum		6886.27	
Range		5593.79	
Interquartile Range		3583.19	
Skewness		0.439	0.661
Kurtosis		-0.981	1.279

The above results showed that Negative Kurtosis shows that observations cluster less and thicker tails than a normal distribution until the extreme values, while Skewness has a lengthy right tail because its value is positive.

Tests of normality

A test of normality on the absolute of maximum difference between(observed and expected) cumulative distribution based on the assumption of normality. Two tests for annual rainfall are done as in the following Table 3. df used in determining the observed significance level.

Table 3: *Normality tests.*

Shapiro-wilk			Kolmogorov-Smirnova		
Statistic	Df	Sig.	Statistic	Df	Sig.
0.906	11	0.219	0.247	11	0.59

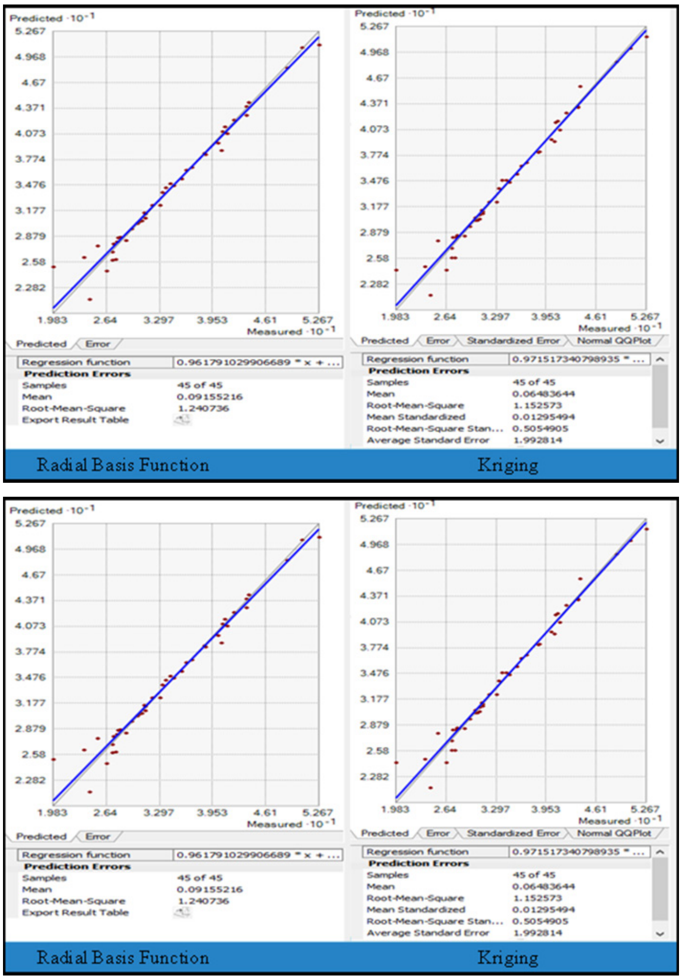

Figure 13: Geostatistical Wizard- RBF and Kriging.

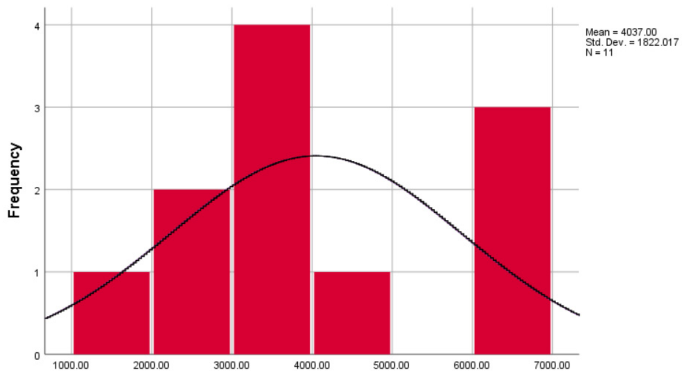

Figure 14: *Histogram of the mean annual maximum rainfall.*

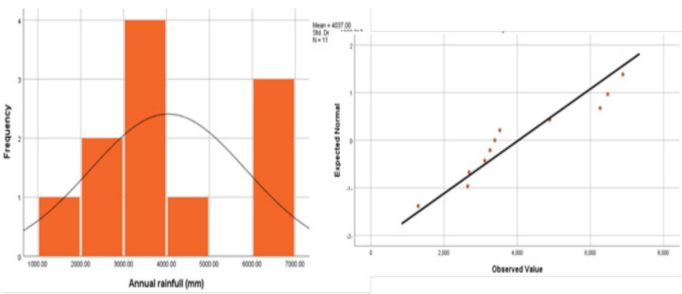

Figure 15: *Detrended normal Q-Q- plots of annual rainfall (mm).*

The conditional probability of the existence of a association as strong as the one seen in the data. If the null hypothesis (p-value) were true. A result of less than 0.05 is usually regarded as noteworthy. While other Shapiro-Wilk tests the hypothesis that the sample is from a normal population.

Conclusions and Recommendations

Spatial Interpolation of annual rainfall data contributes useful maps to understand the spatial distribution and for sustainable management. Such techniques also require continuous, evenly and widespread data to obtain consistent results. In this study, various interpolation techniques (IDW, RBF, GPI, and Kriging) were considered to estimate the values of the annual rainfall over a wide range of Iraq. Accuracy Assessment was done using statistical calculations. Spline, Global Polynomial Interpolation is considered to be the best method of interpolation for this study.

The kriging technique is more useful for this study area as compared to other techniques. For this purpose, selected data points of climate models to verify which Geo-Statistical analytical technique is the best and most accurate to detect the future scenarios of meteorological events compared with the previous studies (Ali *et al.*, 2013; Muhammed *et al.*, 2016; Al-Waeli and Al-Azawi, 2018).

After thoroughly studying on above figures, the kriging technique was considered the best technique on applied climate model data sets for the study area as compared with other geostatistical techniques. That's the main reason was that kriging used as the fundamental tool to analyze the results of this study.

IDW was shown to be a suitable spatial interpolation approach for predicting rainfall data over Iraq with high correlation coefficients of above 0.95.

Because the normality test results were more than 0.05; it can be concluded that all variables in the hypothesis met the normality assumption with a significance value > 0.05. There is a clarity decrease in the amount of annual rainfall in the next decades until 2050.

Novelty Statement

This study is very important for Iraq and the region because the predication of rainfall help in the following:

1. help inform strategies and water resource management policies to ensure the sustainable use of water resources in Iraq.
2. this study related to predict healthy crop yields and sustaining ecosystems.

Author's Contribution

Fadia W. Al-Azawi: Investigation, writing, project administeration.
Huda M. Hamid: Data curation, formal analysis, visualization
Husam Jasim Mohammed: Resources, present concept.
Jan Muhammad: Reviewed the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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