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GIS-Based Rainfall Analysis using Remotely Sensed Data in Kirkuk Province, Iraq

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ABSTRACT

This research aims to calculate the rainfall rate for two consecutive years, 2018 and 2019, to study and analyze the drought periods during these years. The research was conducted in Kirkuk province, north of Iraq. The study area was divided into five regions based on the five stations of rainfall records. Two types of data were used in investigations; remotely sensed daily precipitations from integrated multi-satellite retrievals and monthly precipitations average rate from NASA power application. The methodology involved the rainfall rates calculation using three methods, i.e., Mean, Thiessen's polygons, and the Isohyetal technique. The obtained data were analyzed, and final maps were produced using Geographic Information Systems based on data from 2011 to 2021. In 2018, the average annual rainfall rate produced by Mean, Thiessen's polygons, and Isohyetal technique were 495.36, 482.76, and 483.48, respectively. However, in 2019, the average annual rainfall rate produced by Mean, Thiessen's polygons, and Isohyetal technique were 347.76, 335.52, and 317.52, respectively. The results showed water scarcity and rainfall lack during the study years. While in 2018, the rainfall increased, then again decreased in 2019 up to 2021. Therefore, the studied region was under a significant impact of exposure to drought, represented by the drying up of rivers.

تحليل هطول الأمطار القائم على نظم المعلومات الجغرافية باستخدام بيانات الاستشعار عن بعد في محافظة كركوك، العراق

ارزو محمد وحدت محمدهادي1، اكرم خلف محمد2، هدى جمال جمعه1، محمد هاشم امين2، بهاري كلنتار3، حسين مجددي رضائي4، زينب طالب الشريفي5
1 قسم هندسة البيئة والتلوث/ كلية التقنية الهندسية كركوك/ الجامعة التقنية الشمالية / العراق. 2 قسم الهندسة البيئة/ كلية الهندسة / جامعة تكريت / تكريت ـ العراق. 3 مركز ريكين لمشروع الذكاء المتقدم ، مجموعة أبحاث تكنولوجيا الهدف الموجه، فريق علوم المرونة في الكوارث، طوكيو، اليابان. 4 مركز النمذجة المتقدمة ونظم المعلومات الجغرافية المكانية (CAMGIS) ، كلية الهندسة وتكنولوجيا المعلومات ، جامعة التكنولوجيا ، سيدني ، نيو ساوث ويلز ، أستراليا. 5 قسم الهندسة الكيمياوية، جامعة برمنغهام، المملكة المتحدة.

الخلاصة

يهدف هذا البحث إلى حساب معدل هطول الأمطار لعامين متتاليين 2018 و2019 لدراسة وتحليل فترات الجفاف خلال هذه السنوات. تم إجراء البحث في محافظة كركوك شمال العراق، من خلال تقسيم منطقة الدراسة إلى خمس مناطق بناءً على خمس محطات لسجلات الأمطار. نوعان من البيانات تم استخدامها في الدراسة: بيانات الاستشعار عن بعد للأمطار اليومية من الأقمار الصناعية ومعدل الامطار الشهرية من تطبيق Power التابع لوكالة ناسا. تضمنت المنهجية حساب معدل سقوط الأمطار بثلاث طرق؛ المتوسط، ومضلعات ثيسين، وتقنية Isohyet. م تحليل البيانات، وتم إنتاج الخرائط النهائية باستخدام نظم المعلومات الجغرافية بناءً على البيانات من عام 2011 إلى عام 2021. بالنسبة لعام 2018، كان متوسط معدل هطول الأمطار السنوي الناتج عن طريق المتوسط، ومضلعات ثيسين، وتقنية Isohyet؛ 495.36و 482.76 و483.48 على التوالي. ولكن، بالنسبة لعام 2019، كان متوسط معدل هطول الأمطار السنوي الناتج عن طريق المتوسط، ومضلعات ثيسين، وتقنية Isohyet؛ 347.76 و335.52 و317.52 على التوالي. وأظهرت النتائج ندرة المياه وقلة هطول الأمطار خلال سنوات الدراسة بينما ارتفعت في عام 2018 لتتراجع مرة أخرى في عام 2019 حتى 2021 مما كان له تأثير كبير على تعرض المنطقة للجفاف المتمثل في جفاف الأنهار.

الكلمات الدالة: جفاف، تقنية ايزوهيتال، معدل هطول الأمطار، مضلعات ثيسن. نظم المعلومات الجغرافية.

1.INTRODUCTION

Rainfall is one of the hydrological cycle components, and it is considered the primary water source on earth [1]. The total precipitation received in a specific period in a region dramatically varies from year to year due to rainfall variation geographically, temporally, and seasonally [2]. The variability is based on the climate type and the length of the rainfall period [3]. Seasonal and annual changes in precipitation significantly affect runoff, evaporation, ecosystem responsibility, stream discharge, and flood forecasting [4]. The rainfall average provides information about the region's expected precipitation quantity [5]. One of the significant problems in managing water resources is the forecasting of precipitation [6]. Rare rainfall causes drought, considered a natural hazard [7], that virtually impacts all regions in the world [8]. Water resources are constantly decreasing due to the increased demand for various purposes, promoting researchers to conduct hydrogeological investigations [6]. With the impact of precipitation on water resources as an inevitable consequence, a more accurate precipitation prediction would enable more efficient use of water resources [5]. The Geographical Information Systems GIS technique allows the incorporation of numerous datasets and investigations with deep understanding [9, 10]. Also, GIS implements practical tools in info integration besides statistical analysis [11, 12]. In addition, hydro-meteorological rainfall estimates using remote sensors provide high-resolution space-time rainfall info [13, 14]. Al-Kubaisi and Rasheed, concluded that the percentage of precipitation feeding groundwater from Kirkuk station was 26.07% with 90.4 mm/year, i.e., a small percentage [15]. Besides, Jasim and Awchi, analyzed the regional drought in Iraq using 22 meteorological stations for monthly precipitation. It was concluded that there was a high drought rate in the northeastern part of Iraq [16]. Moreover, Sh et al. used satellite rainfall data as an alternative to ground station data, indicating that satellite data is considered accurate input for the hydrological models [17]. Every year, apparent variations appear in the amounts of rainfall throughout Iraq. Sometimes, rainfall measured rates are increasing, providing a suitable environment for the success of agriculture, while at other times, they decline below their natural levels. The decline reaches a real danger and a definite threat to agricultural production, especially in areas that depend on rain for their cultivation. Percentages of their oscillations and precipitation rate investigations are essential for advancing the country's agricultural situation and overcoming water scarcity. To observe rainfall rate, the utilized processes in the study used spatially distributed estimations and Geographic Information Systems GIS (e.g., Thiessen's polygons, Isohyetal technique, two-dimensional minimum curvature spline technique, besides average mean statistical calculations and satellite remote sensing). Most professional devices for this purpose nowadays rely on electronic systems; however, anyone can design a gauge to measure the amount of precipitation. Calculating the rainfall rate is important in many fields, such as agriculture. Also, the construction sector requires rainfall rate calculation to design roads, bridges, and urban infrastructure. At this point, the main aims of the present study are determining the rainfall rate in the study area using GIS and measurement techniques, presenting spatial distribution maps of daily rains in the study area adopting remote sensing images, and analyzing and detecting drought periods.

2.METHODOLOGY

2.1.Rainfall Data

The data in this study was based on satellite images and remotely sensed records of rainfall information from NASA. The data represent the period from 01/01/2018 to 31/12/2019. Precipitation rates in millimeters per hour were estimated by the Integrated Multi satellite/Retrievals and (IMERG) for Global Precipitation Measurement (GPM), which was downloaded from Worldview via NASA Worldview application. Besides, monthly precipitations rate in millimeters were downloaded from the NASA Prediction of Worldwide Renewable Energy Resources (POWER) via power data access viewer.

2.2.Study Area

The study area is Kirkuk Province (Fig. 1), located in the north of Iraq and occupies 9679 km². It lies between latitudes 34° 35' - 35° 50' North and longitudes 43° 10' - 46° 00' East. The weather is characterized as hot semi-arid, very hot, and dry in summer and cold in winter [18]. The average annual temperature ranged between 43.2°C and -3°C [5]. The rainy period in the year was almost from October to May, and the cumulative average annual rainfall was 342.7 mm, while the evapotranspiration extended to 1662.9 mm [19].

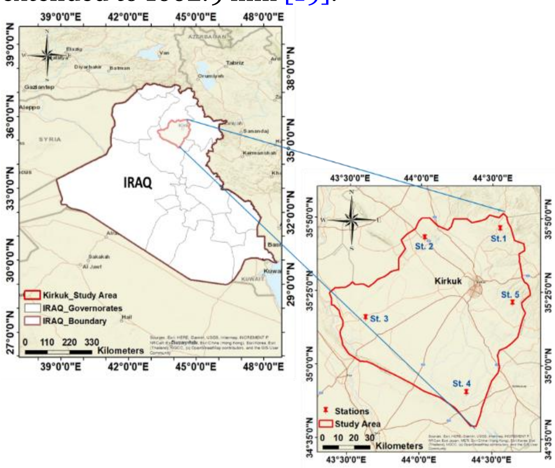


Fig. 1 The study area Kirkuk province with rainfall recording stations.

2.3.Data Processing

Different statistical processes report the spatial distribution aspect; however, with advances in Geographical Information Systems (GIS), applying calculations is frequently a quite minor manner [20]. Three methods were utilized in the present work: Mean observations, Thiessen's polygons, and the Isohyetal technique. Based on Mean observations, the average spatial rainfall (R) can be calculated from Eq. (1) [20]:

$$R = \sum_{i=1}^{n} \left(\frac{ri}{n}\right) \quad (1)$$

where R is the rainfall rate (Mean), ri is the average annual precipitation at i location, i is the rainfall station, and n is the number of stations. Basically, Thiessen's polygons attribute a representative station area to each rain station. The extent of the representative area was related to how close each station was to its surrounding area. The polygons were drawn on the map; the borders of the polygon were central from each station and strained orthogonal to an imaginary line between two stations. After drawing the polygons, the area of each polygon surrounding the rainfall station was calculated. The average spatial rainfall (R) can be calculated using Eq. (2) [20]:

$$R = \sum_{i=1}^{n} \left(\frac{ri * ai}{A}\right) \quad (2)$$

where R is the rainfall rate (Thiessen's polygons), ri is the monthly rainfall at i location, i is the rainfall station, ai is the station area (the polygon surrounding each rainfall station), and A is the total region area. Each drawn Thiessen polygon held only a single rainfall station as a point input feature. Any position within the specific Thiessen polygon was nearer to its linked station than any other station. When there are more rainfall stations within the study area, the most understandable weighting to apply to a mean was based on recorded rainfall distribution rather than on alternate measures, as explained above. In this case, the rainfall distribution map of the study area was drawn by interpolating between the precipitation values, creating a smoothed rainfall surface. The traditional Isohyetal technique was convoluted, drawing isohyets (lines of equal rainfall) on the map and calculating the area between each isohyet. The spatial average rainfall can be calculated from Eq. (3):

$$R = \sum_{i=1}^{n} \left(\frac{ri * ci}{A}\right) \quad (3)$$

where R is the rainfall rate (Isohyetal technique), ri is the average rainfall between the isohyets, ci is the area between each isohyet (area between two counters), and A is the total region area. The interpolation divided the study area into small grid cells and then allocated the rainfall value for each grid cell, representing the smooth rainfall surface. The more straightforward interpolating technique used the nearest neighbor analysis, so the allocated point value for the grid square was proportionate to the nearest point station [21]. The more complex method was kriging, so the value that was interpolated for each cell resulted in an understanding of how closely correlated the nearby station were to each other in their covariance [20].

2.4. Final Maps Production

ArcGIS10.3 was used to process and produce the final rainfall maps, including legends and rainfall rate info. With the advent of Geographical Information Systems, creating Thiessen polygons, interpolating of Isohyets, and drawing related maps can be organized easily. GIS Arc Toolbox involves tools that can be used in this matter. For example, it creates Thiessen polygons from point features, interpolates a raster surface from points using a two-dimensional minimum curvature spline technique, and creates a line feature class of contours (isolines) from a raster surface. Moreover, all remotely sensed daily rainfall layer images were arranged for each full rainy day in the study area from 01/01/2018 to 31/12/2019, and the maps were created.

3. RESULTS AND DISCUSSION

Based on NASA satellite data and the present GIS graph analysis, the average annual precipitations during the study period are represented in Fig. 2. During 2018, the average precipitation ranged from 388.8 mm to 565.2 mm. While in 2019, the average precipitation was about 248.4 mm to 414 mm. During these two years, northern parts of Kirkuk received a high range of rain, comprising stations 1, 2, and 5 (Fig. 1). Otherwise, less rainfall during this period was in the southern parts, which involved stations 3 and 4. The fluctuating rain was the first characteristic of the city of Kirkuk's rains, as it varied from one month to another. Also, the difference in terrain from sea level and climate change affected the variation or lack of rain from one station to another. Moreover, the average monthly precipitations during the study period were analyzed and represented in Fig. 3 for stations 1, 2, 3, 4, and 5, respectively. Based on Eq. (1), the result of mean observations was 495.36 mm and 347.76 mm in 2018 and 2019, respectively. Based on Eq. (2), the result of Thiessen's polygons was reported in Table 1. The average rainfall rate was 482.76 mm and 335.52 mm in 2018 and 2019, respectively. Based on Eq. (3), the results of the Isohyetal technique during 2018 and 2019 are reported in Table 2 and Table 3, respectively. The average rainfall rate was 483.48 mm and 317.52 mm in 2018 and 2019, respectively. Moreover, the result of the average annual rainfall rate outputs from 2011 to 2021 is reported in Table 4.

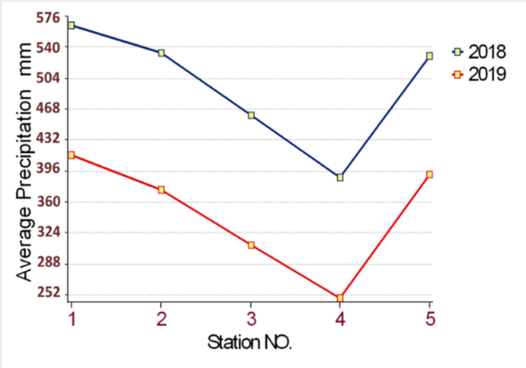


Fig. 2 Average annual precipitations during the study period.

Table.1 Thiessen polygons measurements and outputs.

Station NO.	Station Area km²	Average Annual Precipitation mm	
		2018	2019
1	989.3285	565.2	414
2	1755.385	532.8	374.4
3	2784.579	460.8	309.6
4	2129.159	388.8	248.4
5	2020.549	529.2	392.4
Total Area (km²)	9679		
Average Rate		482.76	335.52

Table.2 Isohyetal technique measurements and outputs for 2018.

Station NO.	Contour Area km²	2018 Average Annual Precipitation mm
1 and 5	2022.970547	547.2
2	3210.811315	532.8
3	1901.130681	460.8
4	2544.087457	388.8
Total Area km²	9679	
Average Rate mm		483.48

Table.3 Isohyetal technique measurements and outputs for 2019.

Station NO.	Contour Area km²	2019 Average Annual Precipitation mm
1 and 2	1939.282742	392.4
3	1693.025408	374.4
4	2837.959929	309.6
5	3208.73192	248.4
Total Area km²	9679	
Average Rate mm		317.52

Table.4 Average annual rainfall rate outputs from 2011 to 2021.

Year	Average Annual Rainfall Rate mm		
	Mean observations	Thiessen polygons	Isohyetal technique
2011	189.36	183.24	182.52
2012	237.60	233.64	235.44
2013	301.68	298.80	297.72
2014	240.48	233.28	236.16
2015	343.44	336.24	339.48
2016	227.52	210.96	145.80
2017	221.04	215.64	219.96
2018	495.36	482.76	483.48
2019	347.76	335.52	317.52
2020	231.12	224.46	197.70
2021	136.80	131.16	131.42

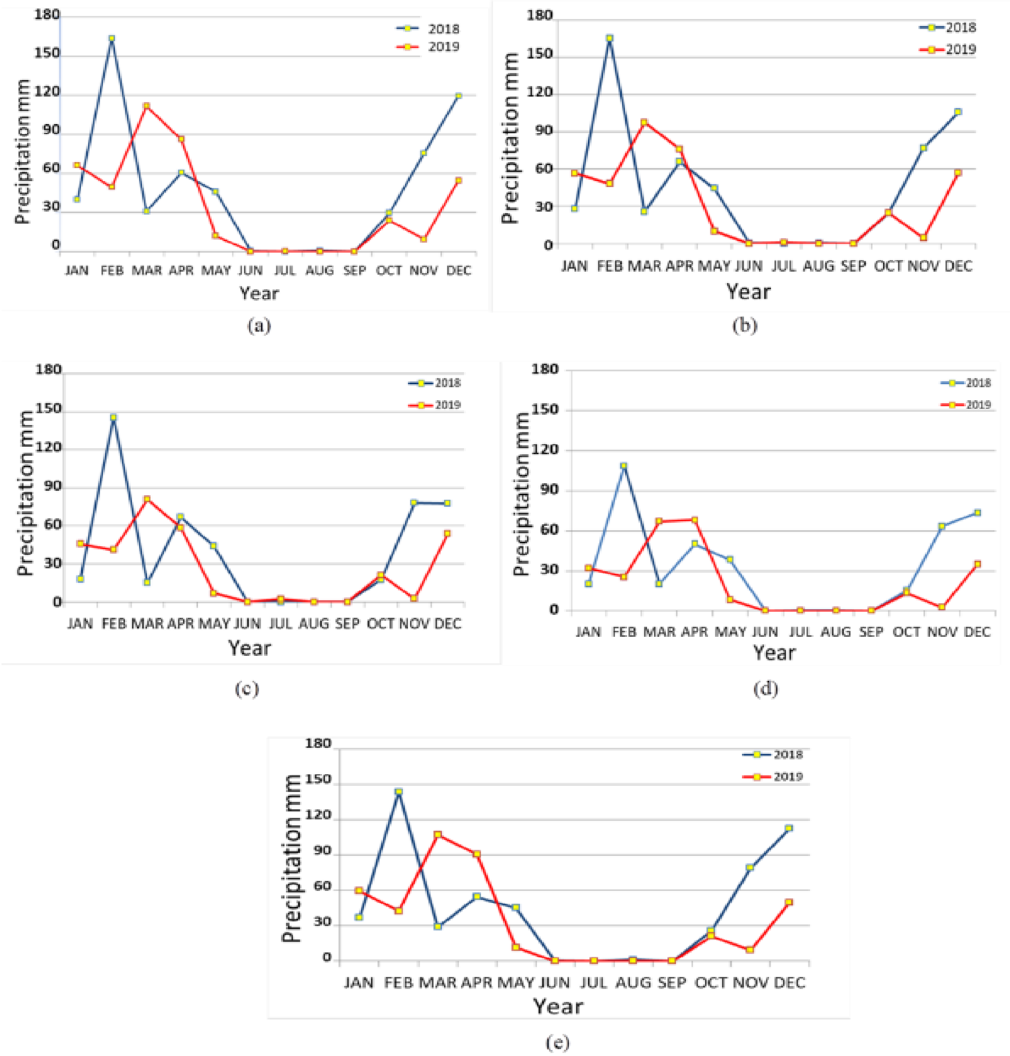


Fig. 3 Average monthly precipitations during the study period in; (a) station 1, (b) station 2, (c) station 3, (d) station 4, and (e) station 5.

Based on Figs. (2, 3), the rainfall during 2018 was concentrated in February, November, and December, while it was at lower rates in the other months. The maximum average monthly rainfall values ranged as 163.8mm, 165mm, 145.5mm, 108.6mm, and 143.7 mm in stations 1, 2, 3, 4, and 5, respectively. While rainfall during 2019 was concentrated in March and April. The maximum average monthly rainfall values ranged as 111.6 mm, 97.2 mm, 80.7 mm, 68.1 mm, and 107.4 mm in stations 1, 2, 3, 4, and 5, respectively. The average rainfall values ranged between (0 – 2.1) mm in the two seasons, especially from June to September. The results of Thiessen's polygons method are shown in Fig. 4. The results of the Isohyetal technique are shown in Fig. 5, representing the areal rainfall maps using the Isohyetal technique in 2018 and 2019. The three rainfall rate determination methods used in this study showed different results; however, they were almost close in all results' values. Otherwise, satellite image outputs of full rainy days in 2018 and 2019 are shown in Fig. 6 (a) and (b), respectively. Based on the daily rainfall satellite image in 2018, the data recorded rainfall ranged between (0 to 3.1) mm/hr, and the precipitation was concentrated in February. The maximum precipitation was on February 16 and 17, shown on the map, Fig. 6(a), in the central and northern parts of the province. In 2019, the data ranged from (0 to 3.7) mm/hour, and the rain was concentrated in January, February, and March. The maximum precipitation was on January 28 and February 15, shown on the map, Fig. 6(b), in the northwestern parts of the province. The data collected by remote sensing were similar to precipitation's measured and observed data. Low rainfall is a forecast for dry periods. Although many explanations for drought have been presented, the essential factor for drought is the amount of precipitation the area receives compared to the regular rate [22]. The lack of rainfall has led to changes in the availability of water resources in Iraq [23, 24], and the resulting rates were within very low values compared to previous years.

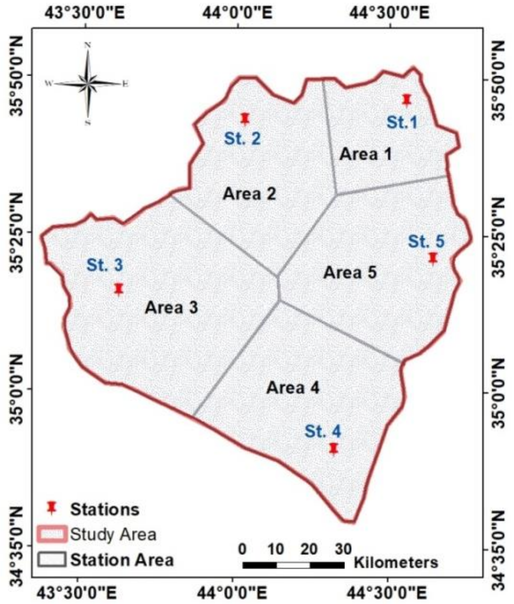
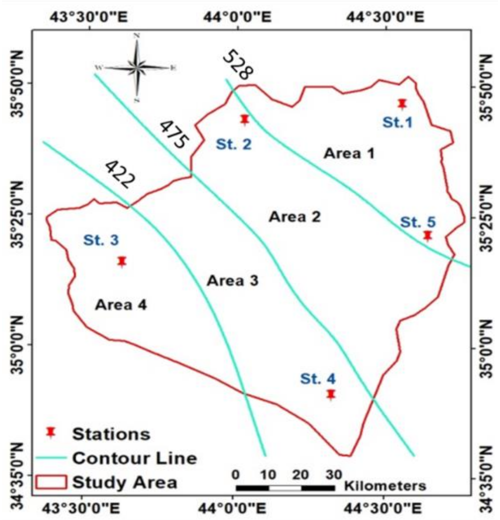
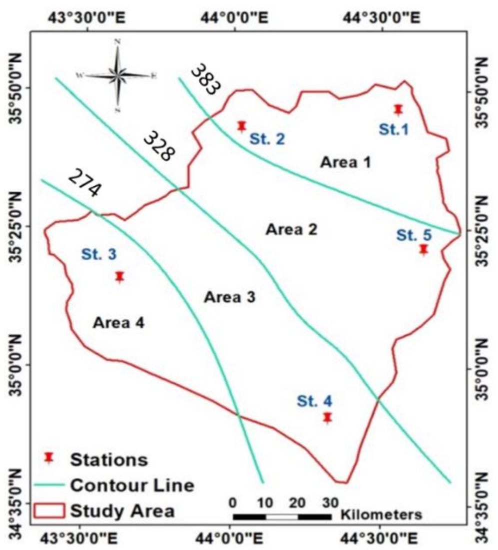


Fig. 4 Thiessen's polygons maps for specific rain stations.

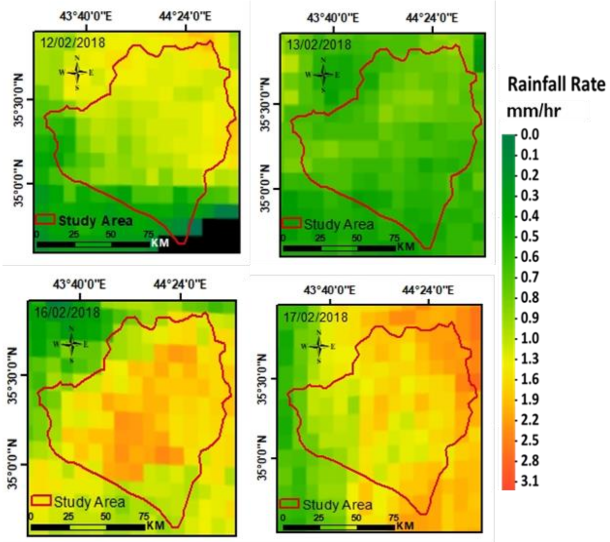


(a)

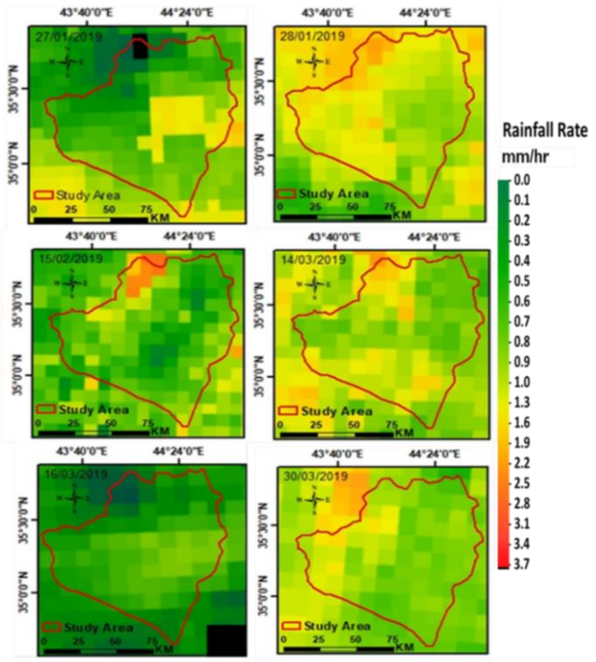


(b)

Fig. 5 Areal rainfall maps using Isohyetal technique of; (a) 2018, (b) 2019.



(a)



(b)

Fig. 6 Rainfall rate of full rainy days based on satellite images in (a) 2018 and (b) 2019.

4.CONCLUSIONS

The present study investigated the rainfall rate in Kirkuk province, Iraq, from 1-1-2018 to 31-12-2019. Data from (2011 to 2021) was also used to compare changes. Three methods were used to analyze the rainfall amounts based on GIS and remote sensing. The results showed that the rainfall rate for the two years mentioned in the study all agree with the negative trends. Also, the objective precipitation estimations and GIS mapping methods elected in this study were beneficial for operational and research purposes. Moreover, the analysis and resulting maps were essential for service works, mainly nowadays with the increasing activities in the hydro-meteorology field.

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