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Estimation of the Validity of Remote Sensed Rainfall Data over Selected Regions in Iraq

Zahraa N. Al-Montaser

Department of Atmospheric Sciences, College of Science, Mustansiriyah University

zahraanasir@uomustansiriyah.edu

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Abstract

Rainfall is a major The most changeable and fluctuating atmospheric element. Existing rain gauge networks lack the temporal and geographical coverage required for adequate monitoring. Satellite measurements offer the benefit of producing spatially homogeneous data across broad regions. The main objective of the present study is to investigate rainfall over Iraq using TRMM Rainfall data. The daily rainfall observations were collected by ground stations at different locations in Iraq and compared to rainfall estimates obtained from TRMM data to calibrate the acquired rainfall data.

The results showed that during the months of January, April and December, Iraq is influenced by the Mediterranean low-pressure systems where during winter, the prevailing westerly winds may bring moist air from the Mediterranean Sea, leading to increased chances of rainfall. Generally, the highest rainfall pattern is observed in the southeastern boundary, also during April, the pattern shifts in around of Sulaymaniyah province, from the south-east border to the near north-east sections. Additionally, the precipitation weather system in Iraq is influenced by the Red Sea Convergence Zone as a meteorological feature which can contribute to winter rainfall over Iraq where the convergence of air masses from the Red Sea and the Mediterranean can lead to the lifting of moist air and subsequent precipitation. Finally, Daily rainfall

measurements for all evaluated stations were compared with TRMM-estimated rainfall values, and the results were very acceptable. These results show that rainfall estimations using TRMM data may be valuable in various applications, including agriculture and water resources.

Keywords: Atmospheric Science, Rainfall, Iraq, TRMM, Calibration.

Introduction

Precipitation is one of the elements controlling the atmospheric cycle, due to its complicated geographical and temporal distributions. Many applications, particularly agriculture and water resources, require knowing the amount of rainfall in a certain location. The water cycle largely depends on rainfall, which helps with weather and climate predictions. [1, 2]. Therefore, monitoring rainfall quantities across the world is critical. Rainfall data is only accessible on land and in heavily populated regions. [3]. Remote sensing techniques such as radars and satellites can determine the amount of precipitation. Radar is a powerful remote sensing technology that delivers impulses of electromagnetic radiation with wavelengths ranging from 1 to 10 cm and observes target resonance (eg rain drops)[4] [5]. The radar's greatest range is 300 kilometers, which limits its use in coastal areas. This is why satellite data are commonly used to estimate rainfall across large portions of the Earth's land and seas. [6]. The majority of rain research in Iraq has concentrated on statistics and prediction [7, 8], with several recent Studies on satellite rainfall estimations. Satellite data was used to study and evaluate convective rain by. [9, 10] investigated the features of precipitation systems measured by TRMM Radar across Iraq. The main objective of the present work is to investigate the spatiotemporal rainfall over whole of Iraq and calibrate TRMM Rainfall observations employing Iraqi meteorological station rain gauges.

Material and methods

Study Area, Climate situation and TRMM Data Acquisition

Iraq is bounded to the north by Turkey, to the east by the Islamic Republic of Iran, to the southeast by the Arabian Gulf, to the south by Saudi Arabia and Kuwait, and to the west by Jordan and the Syrian Arab Republic. Iraq is situated like a basin, the with Tigris and Euphrates rivers creating the Great Mesopotamian alluvial plain (Mesopotamia is the area between two rivers). This plain is bounded by mountains in the north and east, which may reach 3550 meters above sea level in mountain parts in east norther border regions with Iran, and desert areas in the south and west, which account for more than 40% of the entire area [11]. Iraq has a continental, subtropical semi-arid climate with Mediterranean influences in the north and northeastern mountainous regions. Rainfall is seasonal, falling from December to February, especially in the north and northeast of the country, where it falls from November to April. The average annual rainfall is 216 millimeters; however, it varies from 1200 mm in the northeast to less than 100 mm across 60% of the nation in the south. Winters are cool to chilly, with daytime temperatures about 16 °C dropping to 2 °C at night, with the chance of frost. Summers are dry and hot to extremely hot, with shade temperatures exceeding 43 °C. [12].

The Iraqi Meteorological Organization and Seismology (IMOS) provided the rainfall data (2000-2013) used in the present research. Figure 1 shows meteorological stations located throughout Iraq. The essential descriptive statistical measures of the annual rainfall data and the missing data for the selected stations are tabulated in Table 1. The average yearly precipitation in Iraq is 247 millimeters. The high standard deviation values are easily connected with the high rainfall range (northern area), as northern stations have high rainfall values. The skewness was calculated to see if the annual rainfall data had a normal distribution.

TRMM is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the Japan Aerospace Exploration Agency (JAXA) of Japan. The satellite was launched in November 27, 1997 and is currently continuing to operate. The objectives of TRMM are to measure rainfall and energy (i.e., latent heat of condensation) exchange of tropical and subtropical regions of the world from the space. The data used in this study was downloaded from University of Utah TRMM database for whole of Iraq. The data set covers the period from 2000 to 2013 [13].

The illustrated spatiotemporal maps in present study has been plotted by Surfer 13.3 which considered a suitable software for mapping atmospheric element data also the statistical evaluation considered the Root Mean Square Error (RMSE), error function, mean-squared error (MAE) and correlation coefficient (R) are employed. The following equation describes how MAE, RMSE and R which represent the accuracy in terms of performance [14].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(estimated - actual)^2}{N}} \quad \text{---------------(1)}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|estimated - actual| \text{---------------(2)}$$

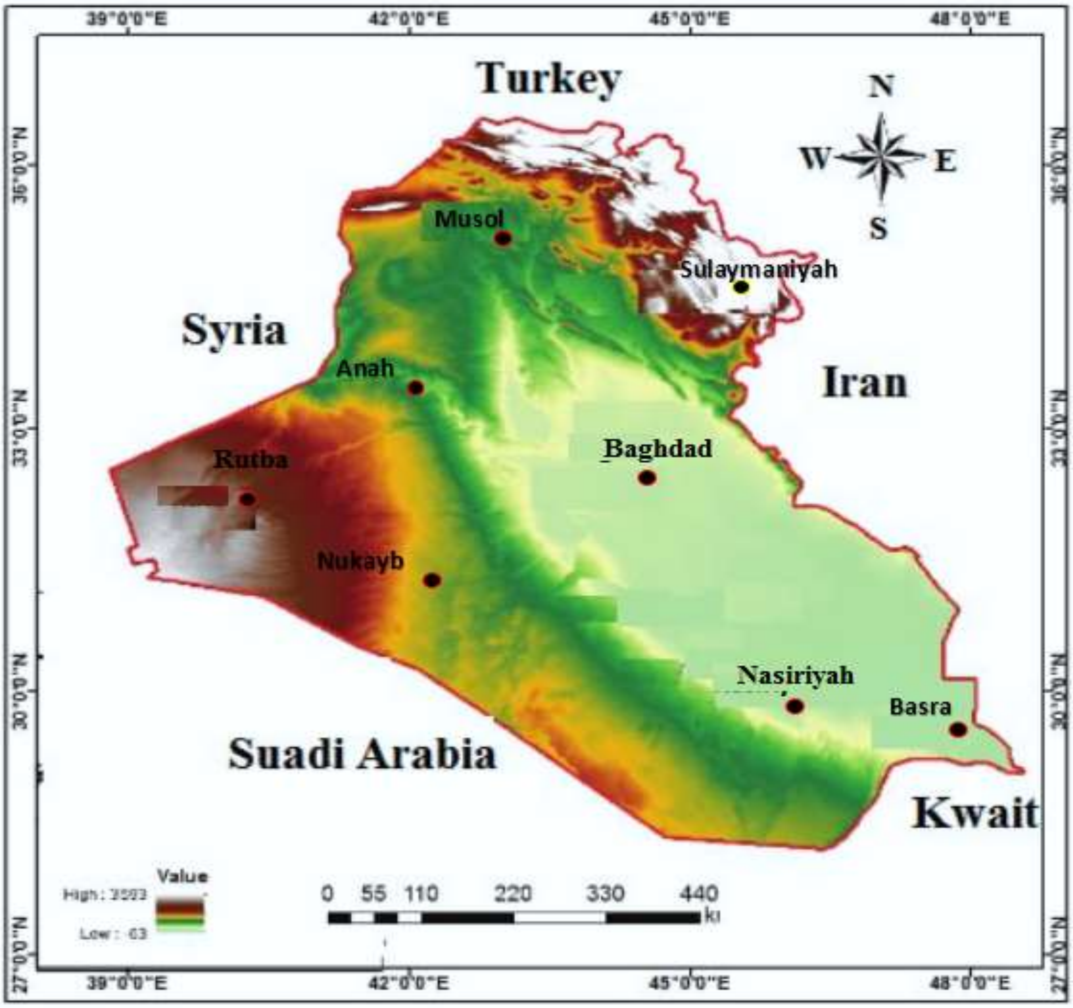

Figure 1: Meteorological Station locations (circle marks) over Iraq.

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Table 1: provides the Station list with elevation and rainfall per year and geographical coordinates (latitude, longitude).

No.	Station	Latitude (N)	Longitude (E)	Elevation (m)	Rainfall / year (mm)
1	Mosul	36.25	43.08	223	**342**
2	Sulaymaniya	35.58	45.48	832	670
3	Anah	34.42	42.00	**150**	**159**
4	Baghdad	33.33	44.39	**32**	**205**
5	Rutba	33.00	40.42	**615**	**120**
6	Nukayb	32.07	42.05	**305**	**117**
7	Nasiriyah	31.00	46.25	**5**	**181**
8	Basra	**30.50**	47.83	**2**	**193**

Results

Spatial and Temporal Variation of Rainfall in Iraq and Surrounding Regions

The spatial characteristics of monthly mean rainfall (mm) over Iraq and surrounding regions are presented in Table 2 and in figure 1.a and b, the rainfall observations during 2000-2013 acquired from TRMM database.

The maps of monthly rainfall distribution show that the major rainfall patterns are generally located from the eastern part in January and northeast to southwest of Iraq as illustrated in Fig. 1.a and b. During the months of January, April and December over Iraq and surrounding regions as a result of especially the northern and western regions, can be influenced by the Mediterranean low pressure systems where during winter, the prevailing westerly winds may bring moist air from the Mediterranean Sea, leading to increased chances of rainfall. Generally, the highest rainfall (up to 100 mm) pattern is observed in the southeastern boundary of the study area during December and January. However, in the months of April, the pattern changes from southeastern boundary to extreme north eastern parts near Sulaymaniyah province of the study area. This seasonal shift of rainfall maxima zones could be clearly identified from the maps (Fig. 1.a and b). Overall, the month of June, July, and August experience lower amount of rainfall thus known as dry season also the precipitation weather system in Iraq influenced by the Red Sea Convergence Zone as a meteorological feature that can contribute to winter rainfall over Iraq where the convergence of air masses from the Red Sea and the Mediterranean can lead to the lifting of moist air and subsequent precipitation.

The average annual rainfall over Iraq and surrounding regions during the period from 2000 to 2013 is 194.1 mm with a standard deviation of 129.1 mm. The coefficient of variation of annual rainfall is 66.5 % presenting evidence that the precipitation system over the study area has obvious variation. During late Autumn, Winter season and mid spring (November, December, January, February and April) have high values (26.5, 27.70,27.72 , 20.82 and 32.7 mm) respectively and contributes 13.6, 14.2, 14.4,10.6 and 16.8 % of annual rainfall (194.1 mm), followed by March (9.9 %), May (8.9 %) and October (7.8 %) with approximately no rainfall because of the height levels of the air temperature and the lowest values of relative humidity during summer months.

Table 2: Mean monthly, annual rainfall statistics of Iraq (2000–2013).

Month	Rainfall (mm)	Standard deviation	Coefficient of Variation (%)	% Contribution to annual rainfall
January	27.72	24.92	89.87	14.29
February	20.82	17.05	81.90	10.73
March	19.39	17.01	87.73	9.99
April	32.71	25.89	79.15	16.85
May	17.44	13.64	78.18	08.99
June	1.61	2.97	184.45	0.008
July	1.29	3.11	240.66	0.006
August	1.42	2.47	174.25	0.007
September	2.13	4.47	209.97	1.10
October	15.31	12.29	80.28	7.89
November	26.53	17.27	65.09	13.67
December	27.70	28.13	101.55	14.27
Annual	194.12	129.13	66.52	**100**

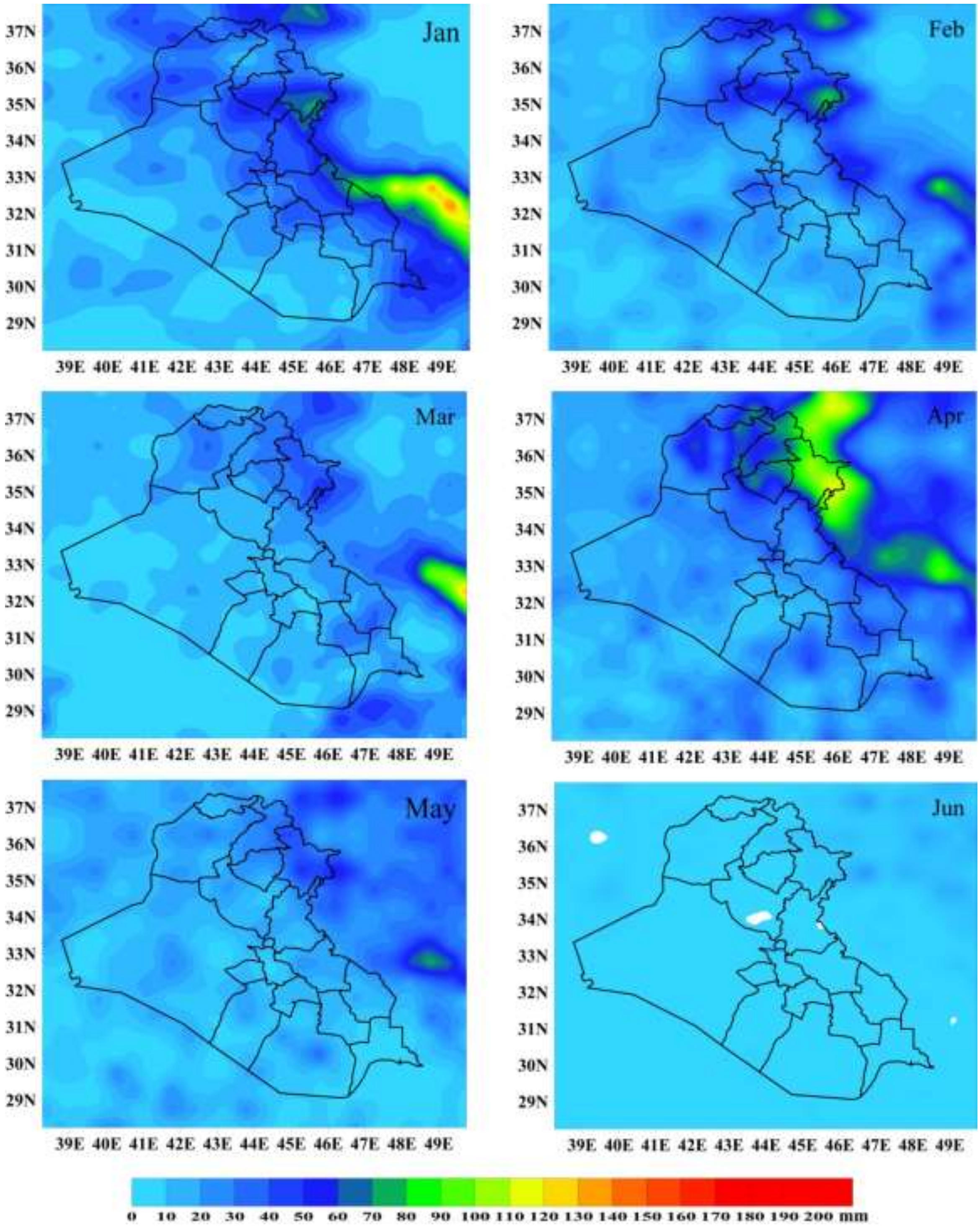

Figure 2:.a Regional dispersion of TRMM monthly precipitation (mm) data averaged during months (January–June) from 2000 to 2013.

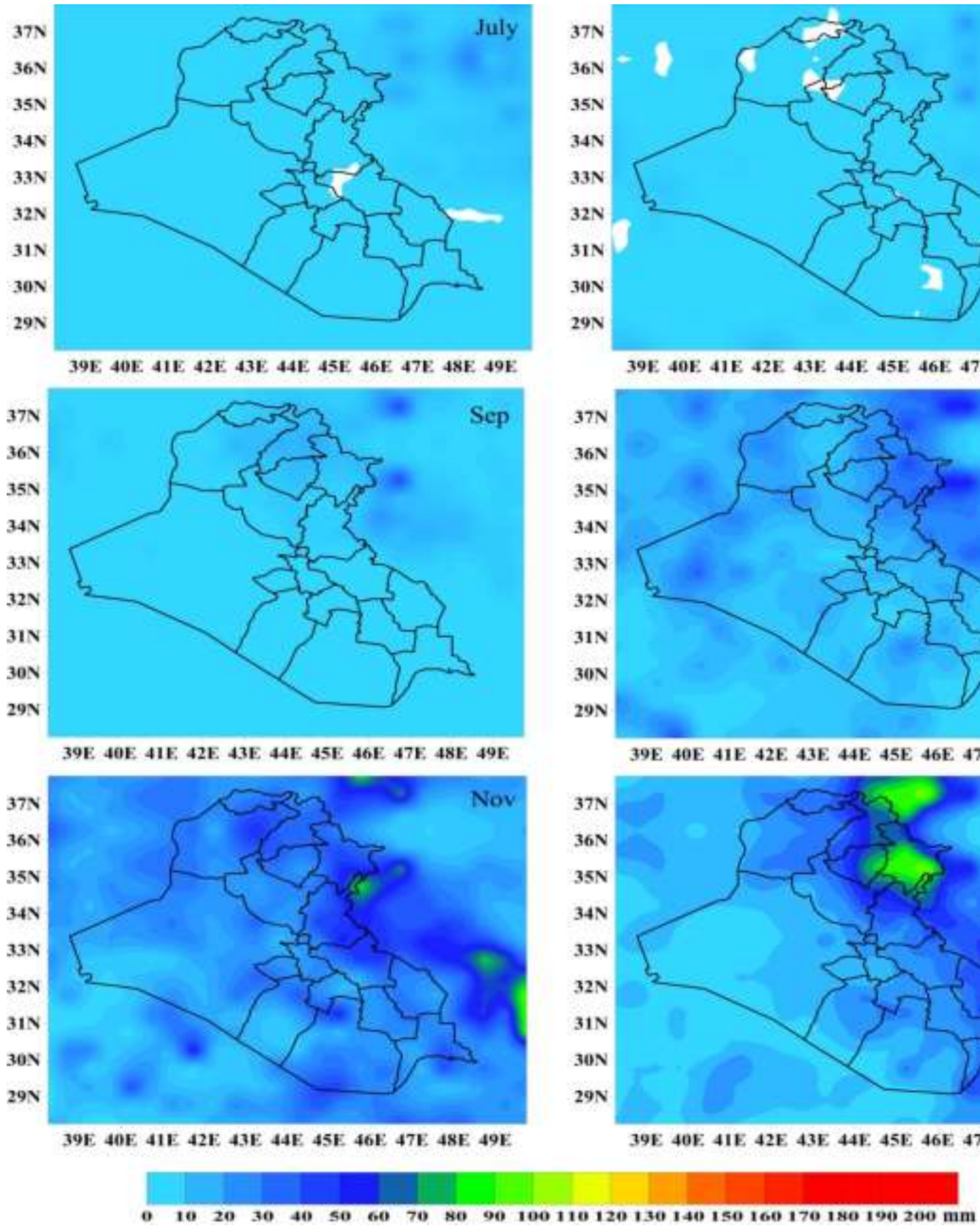

Figure 2: b Regional dispersion of TRMM monthly precipitation (mm) data averaged during months (July–December) from 2000 to 2013.

Seasonally Spatial and Temporal variation of rainfall over Iraq

The seasonal distribution of rainfall in the wet, dry, winter, spring, summer and autumn seasons is shown in Figure 3. There are several similarities between the summer and dry seasons. Except

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for the northeast of the country, which is close to the Caspian shore, where there is some amount of precipitation, there is none over Iraq. In much of the nation, rainfall falls in the winter, spring, and autumn. The northeast and southeast of Iraq get a lot of rainfall, which helps to maintain the pattern of precipitation during the rainy season. The moisture from the Arabian Sea and the Red Sea contributes with a large amount of cold and humid air masses to the season's higher rainfall totals. system with low pressure as shown in figure 4 which illustrate the dry and humid seasons in Iraq shows the highest levels of rainfall over Iraq especially in north regions (Mosul and Sulymaniyah) and the border regions with Turkey from other hand the north eastern region parts the border region with Iran presented a severe values of rain as illustrated in figure 4

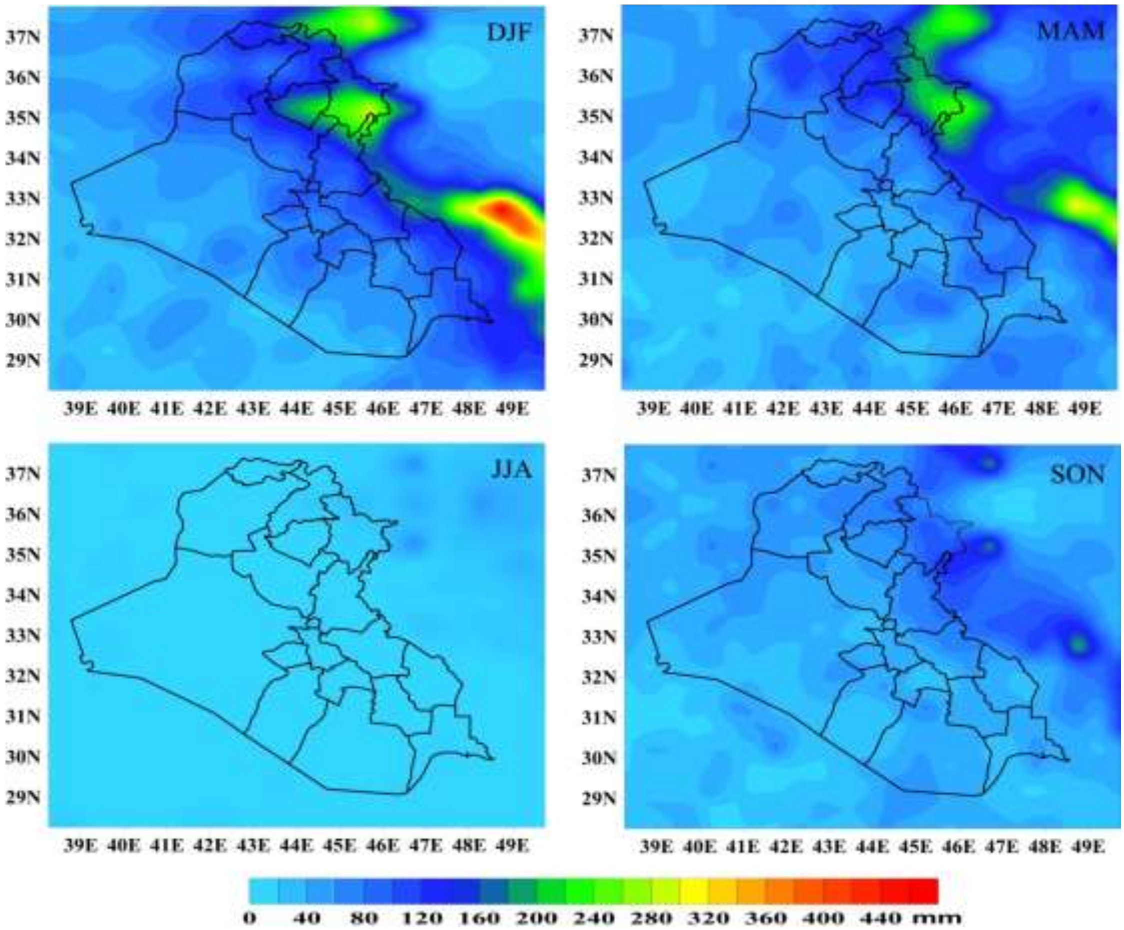

Figure 3: The winter (DJF), spring (MAM), and summer (JJA) and Autumn (SON) seasons' averaged regional pattern of TRMM seasonal rainfall (mm) data is shown in the left to right panels for the years 2000–2013.

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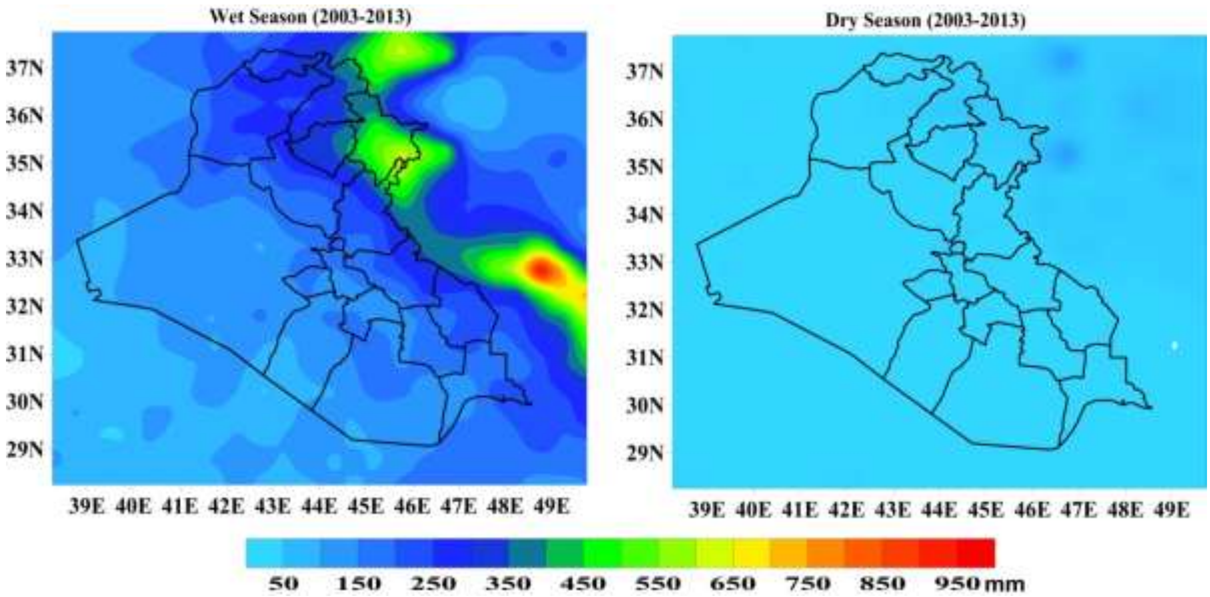

Figure 4: Regional dispersion of TRMM rainfall (mm) data for the wet and dry seasons, averaged for the period 2000–2013.

Annual Spatial and Temporal variation of rainfall over Iraq

The Annual mean of rainfall over Iraq were calculated on the basis for 14 years during the period was from 2000 to 2013. Figure (5) shows the mean of annual rainfall rate for this period. Its seen that the northeastern and southeastern parts of Iraq is characterized by the highest (more than 640 mm/year) mean of annual rainfall while the desert region of the country, which covers the western and southwestern parts of Iraq, is characterized by the lowest mean of annual rainfall (less than140 mm/year).The annual amount of rainfall over Iraq and surrounding regions differs from year to year and from location to other, because of the different topography and meteorological conditions . The results show that, values of rainfall were characterized by a decrease of mean in most regions for some years especially during the year 2008, which characterized by the evident decrease of rainfall for most of the regions over Iraq and also surrounding regions, whereas the year of 2006 was characterized by extreme increase of rainfall in most of the regions particularly in the north eastern regions represented by sulymaniyah province and line border extended from the north to north eastern regions of Iraq. as illustrated in figure (5).

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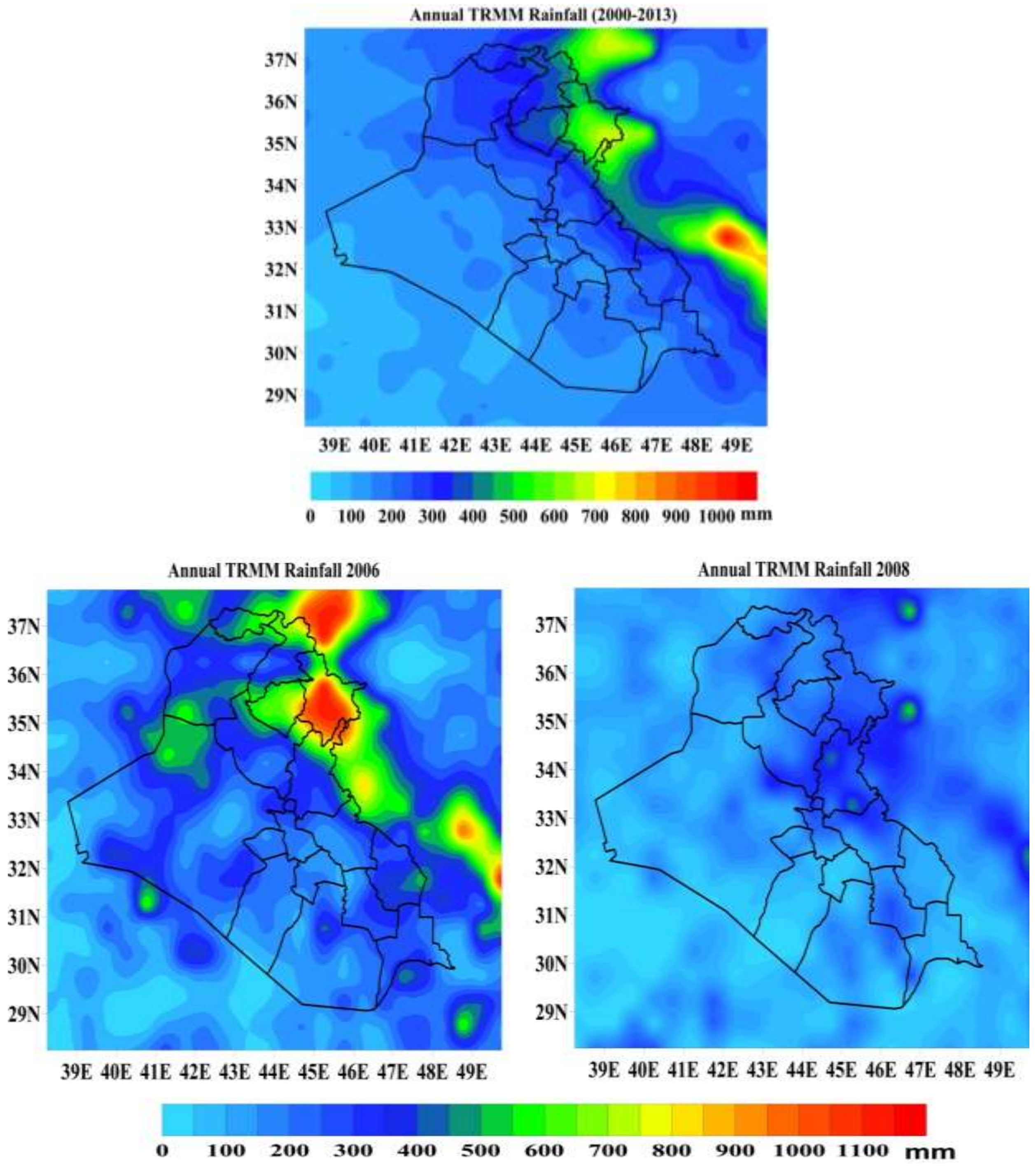

Figure 5: Regional dispersion of TRMM annual rainfall (mm) averaged for the period 2000–2013 and Regional dispersion of TRMM annual rainfall (mm) data for the years 2006 and 2008.

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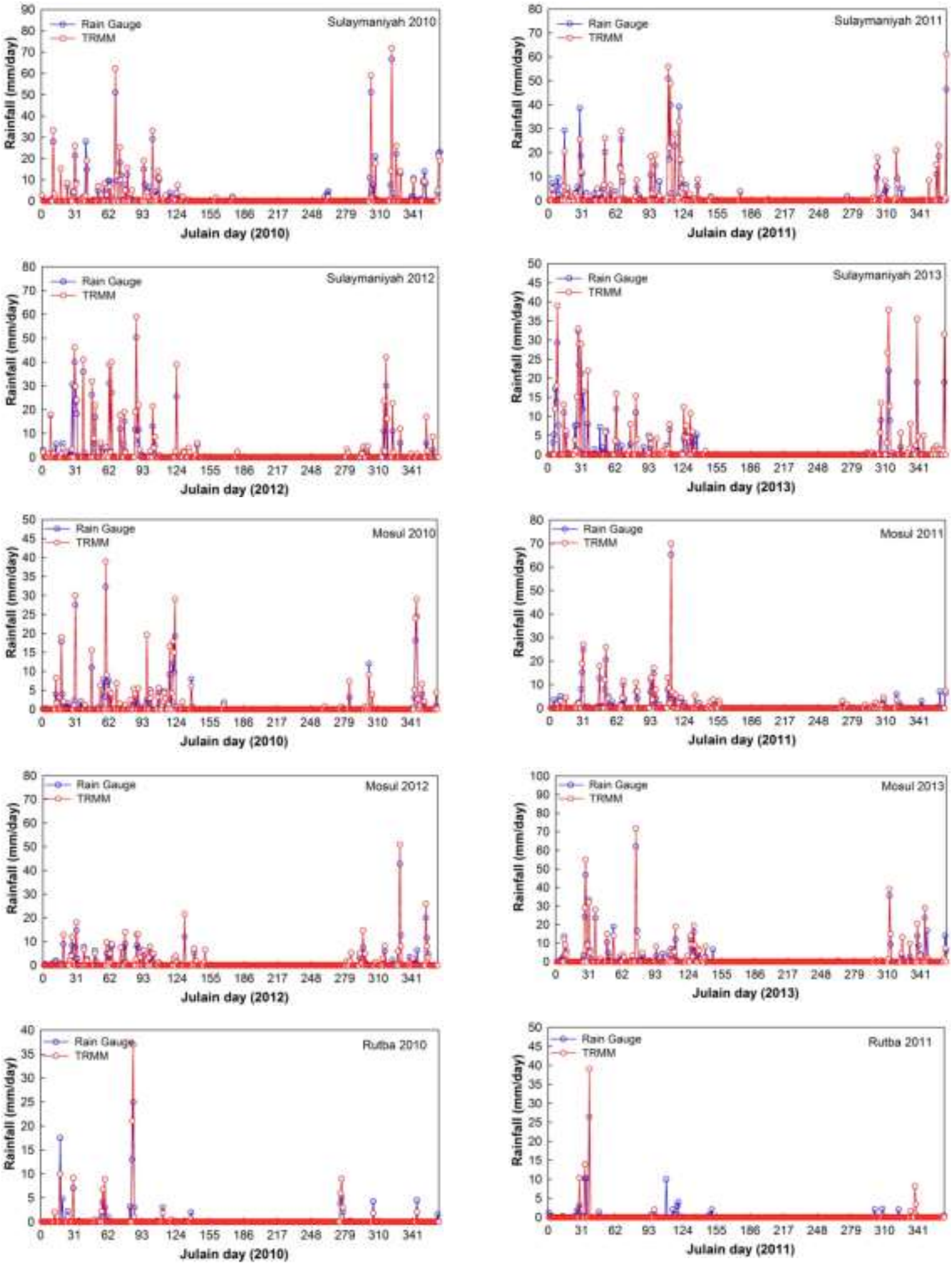
TRMM measurement calibration of rainfall over Iraq

In order to evaluate day-to-day rainfall comparison acquired from TRMM and rain-gauge at diverse geographic locations and elevations across Iraq, the records of the stations are tabulated in Table 1. Are employed in the present section. The rainfall patterns are well identified with each other, in spite of underestimated and overestimated of TRMM observations in some periods and overestimated on others.

Four pairs of stations are considered: Mosul and Sulaymaniya in the Northern region, Baghdad and Nukayb in the central region, Anah and Rutba in the western region and Nasiriyah and Basra in southern region of the country for four years of each station during the period 2010 - 2013. In each pair one station is located at high elevation compared to another except Nasiriyah and Basra stations have relatively close elevations.

Sulaymaniyah (Table 1; Fig. 1) is located in northern Iraq and a strip along the eastern borders with Iran at 823 meters above mean sea level (msl) is the elevation. It receives more than 670 mm of rainfall per year. The annual precipitation decreases gradually as one moves from the north and north-east to the west and south-west, or from mountains to deserts. Desserts are caused by a lack of rain. It is observed that the maximum amount of precipitation, more than 583 mm/year, occurs in two distinct areas, one in the north-east of Iraq near the city of Sulaymaniyah and the other in Iran near the Iranian city of Kermanshah.

Rain gauges at the Sulaymaniyah station recorded 290 precipitation events between 2010 and 2013. Of those days, 217 received rainfall greater than or equal to 1 mm/day, and 73 had less than 1 mm/day (Fig.6). In the same time frame, there were 198 days with rainfall of at least 1 mm per day and 81 days with less than that amount **.**While actual measured rain data on the generality of the rain related days and the TRMM's detection of rainy days coincide, the latter was unable to ascertain the noteworthy amount of rainfall on 1, 2, 3, December 2010, 10, 30, January 2012, and 11 February, 8 April, 3 November 2013.


Sulaymaniyah 2010
Sulaymaniyah 2011
Sulaymaniyah 2012
Sulaymaniyah 2013
Mosul 2010
Mosul 2011
Mosul 2012
Mosul 2013
Rutba 2010
Rutba 2011
Rain Gauge
TRMM
Rainfall (mm/day)
Julain day (2010)
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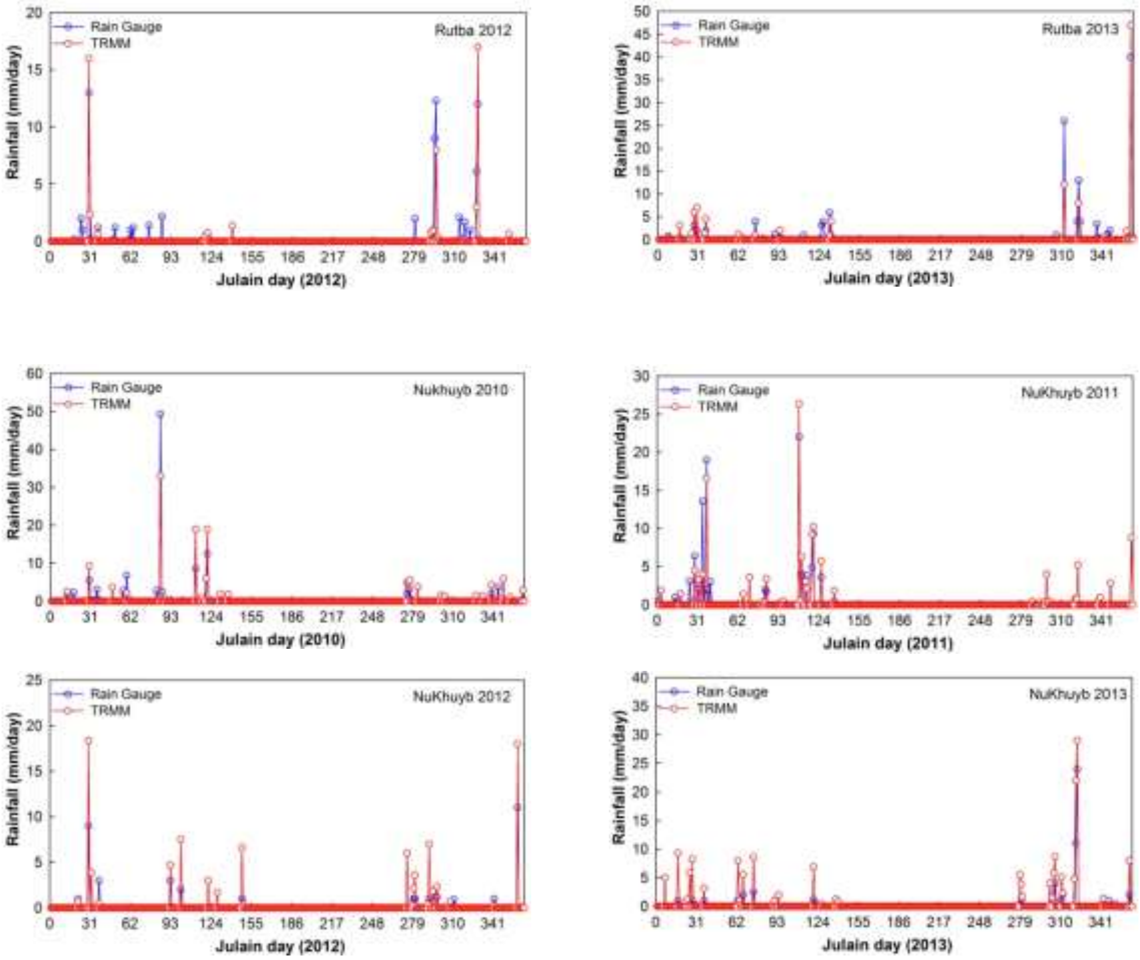
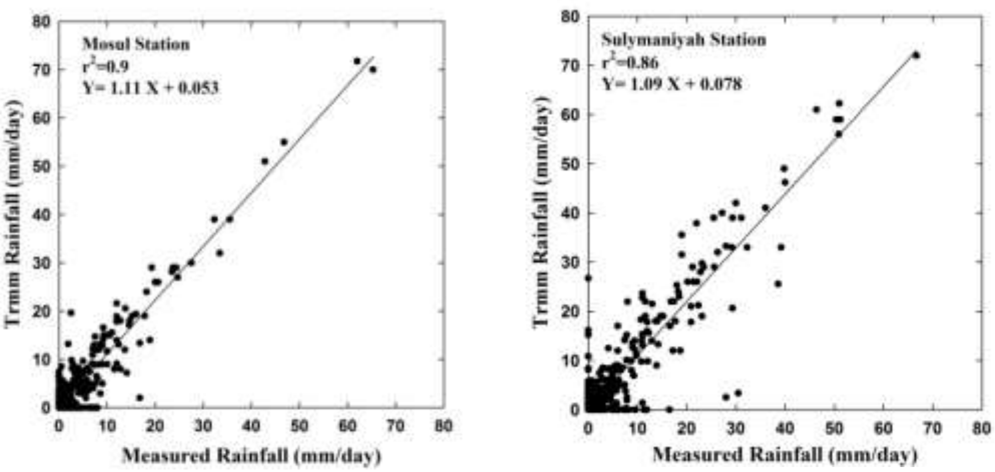


Figure 6: The comparison of the recorded daily rainfall (mm/d) at Mosul, Sulymaniyah, Rutba and Nukuyb during the years 2010, 2011, 2012 and 2013. The TRMM rainfall observed at the selected sites are used in present comparison.



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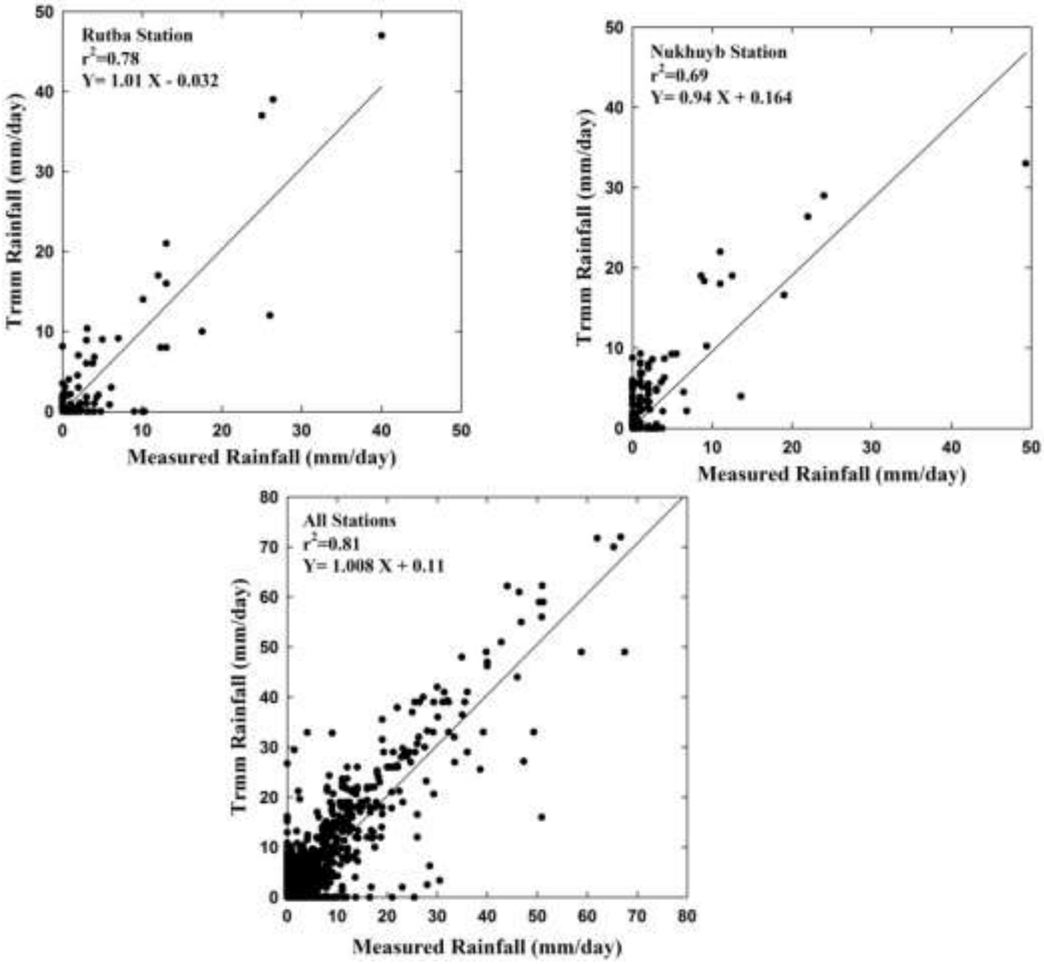

Figure 5: A scatter graph of the daily rainfall averaged over 2000–2013 from all 8 stations in a single 365 days, as well as the recorded rainfall (mm/d) and TRMM data on a (a, b, c, and d) daily basis for Mosul, Sulymaniyah, Rutba, and Nukuyb. The linear relationship is shown by a solid line.

The records of all considered stations in the present work calibrated of TRMM with the rain gauge over Iraq for the period (2010 – 2013) by employing the statistical criteria includes (R, RMSE and MAE) as tabulated in table 3 , the tabulated results shows that the station give the best operation performance where Baghdad (2012) , Basra (2010,2012) where the statistical indication of calibration achieved the highest correlation coefficient (R) and lowest root mean square error (RMSE) and mean absolute error (MAE) . Where the correlations ranged between (0.976 – 0.950) and the RMSE (0.283 – 0.693) and (0.129 – 0.282) for Baghdad (2012) and

Basra (2012), Where the station showed the worst operation performance where Sulimaniah , Nasryiah and Anah which reduce the low correlations between TRMM , rain gauge cross region as tabulated in table 3 . Finally figure 7 shows the scatter plots between TRMM and reengaged for the considered stations where the correlation coefficient was 0.81 with RMSE and MAE where 1.47, 0.425 respectively.

Table 3: Statistical criteria of rain gauge-TRMM evaluation of Iraq (2010–2013).

	2010			**2011**		
Station	R	RMSE	MAE	R	RMSE	MAE
Mosul	0.935	0.923	0.310	0.967	1.798	0.512
Sulaymaniya	0.919	1.528	0.386	0.842	1.747	0.415
Anah	0.910	1.305	0.370	0.921	1.784	0.657
Baghdad	0.918	1.199	0.384	0.842	2.283	0.633
Rutba	0.919	1.528	0.386	0.954	2.613	0.741
Nukayb	0.872	1.872	0.458	0.869	1.188	0.385
Nasiriyah	0.902	1.477	0.465	0.909	1.448	0.310
Basra	0.954	0.693	0.255	0.830	2.195	0.744
	2012			2013		
Station	R	RMSE	MAE	R	RMSE	MAE
Mosul	0.928	1.901	0.403	0.960	0.559	0.673
Sulaymaniya	0.853	0.456	0.123	0.857	2.138	0.856
Anah	0.886	1.421	0.395	0.785	1.230	0.398
Baghdad	0.976	0.429	0.129	0.804	2.342	0.721
Rutba	0.853	1.456	0.123	0.891	1.528	0.386
Nukayb	0.898	1.091	0.217	0.871	1.444	0.376
Nasiriyah	0.841	0.675	0.250	0.796	2.660	0.298
Basra	0.950	0.283	0.282	0.898	1.806	0.624

Conclusion

In the present paper, the tropical rain full measuring mission (TRMM) 3B42 dataset has been analyzed and investigated for the period 2000-2013, where the analysis based on monthly, seasonally and finally annual spatiotemporal variation crosses the country. The rain full data of TRMM shows rain full patterns on daily bases are similar in most stations across Iraq to those considered by actual measurements. The calibration procedures implemented on TRMM rain full data have a clear matching between TRMM and rain gauges' data in most seasons. Finally, these mentioned results and validation statics leads to result which indicates that the TRMM rain full data can be considered as a powerful tool to employ in spatiotemporal rain full estimations.

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