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Research Article

The feasibility of using TRMM satellite data for missing terrestrial stations in Iraq for mapping the rainfall contour lines

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Abstract

Rainfall data are considered an important and critical element of many environmental and hydrological studies such as drought, desertification, climate change and other strategic studies. These studies are mainly based on the rainfall data archive for previous years. During the last two decades, a large number of meteorological stations have been destroyed as a result of wars and internal conflicts, reducing the stations to 16 after the number was more than 30 stations, resulting in a significant lack of meteorological data archive. In addition to the spatial distribution of these stations does not adequately cover Iraq. The research aim to evaluate the feasibility of the TRMM satellite data (3B42 V7 product) to complete the rainfall data archive of the missing terrestrial stations. Several rainfall contour maps of the season 2017-2018 were drawn from data of 16 terrestrial stations, 16 and 30 stations derived from TRMM satellite data, and a hybrid map derived from the TRMM satellite data and available terrestrial stations, afterwards there were compared with the general rainfall contour map. The correlation was made between the satellite data and terrestrial stations data, and the results showed a positive correlation with a strong correlation coefficient reach to 0.91. The results showed that TRMM data could be used as a good alternative to terrestrial station data for its accuracy, wide coverage and ease of availability.

Keywords: Terrestrial stations, TRMM, Rainfall contour map, Drought, Precipitation radar

1. Introduction

The precipitation plays an important role in the hydrological cycle and has obvious repercussions on human life (agriculture, water resources). From a climatic point of view, the intensity and distribution of precipitation are undoubtedly modified in the context of global climate change, known mainly by its aspect of warming temperatures. However, we do not know which way and which regions are likely to be the most affected. Precipitation measurements are essential to improve our understanding of the mechanisms of climate change [1]. To do that, climate-related studies need extensive data to cover events and arrive at the best conclusions. In addition, updating the rainfall contour map is an important pillar in strategic studies.

Satellite measurements began in the 1970s, with equipment measuring in the infrared domain. Infrared imagers measure the temperature at the top of the clouds to relate it indirectly to the precipitation they generate. A second frequency domain useful in measuring precipitation is the microwave domain. Microwave measurements are direct measurements of the absorption and emission or diffusion of radiation by water drops and ice crystals contained in clouds [2].

The meteorological data obtained from the terrestrial stations are no longer sufficient for conducting regional studies, especially in developing countries, but are restricted to local studies with small areas. Therefore, many researchers e.g. [3-6] turned to the use of data that obtaining from the meteorological space radar of Airborne via satellite. Iraq is one of these countries that owns a few earth stations. Moreover, several stations have been destroyed as a result of the military operations against ISIS gangs that have occurred since 2014 and until now. Where it became the number of terrestrial stations at the present time is 16 after the number was more than 30 stations. Thus, it was necessary to use an alternative resource that provides a solution to the problem of the lack of the meteorological data, and the most prominent of these data are from the TRMM (Tropical Rainfall Measuring Mission) satellite [7]. The study aims to produce an updated the rainfall contour map by integration the meteorological data of the terrestrial stations and TRMM satellite as one of the meteorological and agricultural droughts indicators.

2. Materials and Methods

2.1. TRMM Overview

The TRMM satellite constitutes the first space mission dedicated to the measurement of precipitation in the tropics and sub-tropics. It is a joint mission of the American agency NASA (National Aeronautics and Space Administration) and the Japanese agency NASDA (National Space Development Agency of Japan) now called JAXA (Japan Aerospace and Exploration Agency), whose objectives are to measure precipitation as well as energy exchanges (latent heat) in tropical regions [8]. The satellite was launched on November 27, 1997 for an expected duration of three years. In August 2001, the satellite's altitude was increased from 350 to 403 km to extend its lifespan by a few years. In 2010, the satellite was still active [9].

The idea of measuring precipitation using a combination of passive and active microwave space instruments was introduced in the early 1980s. The start of the reflection on the TRMM mission took place in 1984. After preliminary studies, the inclined orbit between 35° N and 35° S at an altitude of 350 km was chosen. The orbit chosen is such that the satellite flies over a place at a different time each day with a

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cycle of about 42 days. This non-helio-synchronous orbit makes it possible to document the large daily variation in tropical precipitation. The low altitude of 350 km is chosen according to the needs of the radar measurement (backscattered radiation strong enough to be measured by the radar receiver).

The TRMM satellite carries five instruments (Fig. 1), three of which are specifically dedicated to the observation and estimation of precipitation:

1- The VIRS (Visible and Infrared Scanner). It is a Visible-Infrared radiometer with 5 channels at wavelengths 0.63 μm, 1.6 μm, 3.75 μm, 10.8 μm and 12 μm.

2- The TMI instrument (TRMM Microwave Imager) is a multi-frequency microwave radiometer comprising 8 channels polarized horizontally and vertically at frequencies 10.7 GHz, 19.3 GHz, 37 GHz and 85.5 GHz, and a vertically polarized 21.3 GHz channel.

3- PR radar (Precipitation Radar). It is a radar operating at a frequency of 13.8 GHz and allowing the measurement of vertical rain profiles.

4- The CERES instrument (Cloud and Earth's Radiant Energy System) is a wide-band VISIR radiometer dedicated to the study of the radiation balance. It comprises three radiometric sensors, which measure the solar radiation reflected by the Earth in the interval 0.3 - 0.5 μm, the radiation reflected and emitted by the Earth in the interval 0.3 -100 μm, and the wave radiation long emitted by the Earth in the interval 8 - 12 μm with a spatial resolution of 10 km at nadir. Coupled with latent heat estimates derived from precipitation estimates, the radiation budget estimates obtained from CERES measurements describe the entire energy balance of the Earth's atmosphere. However, the instrument only worked during the months of January to August 1998 and during the month of March 2000.

5- The LIS (Lightning Imaging Sensor) is an imager dedicated to the observation of lightning [9].

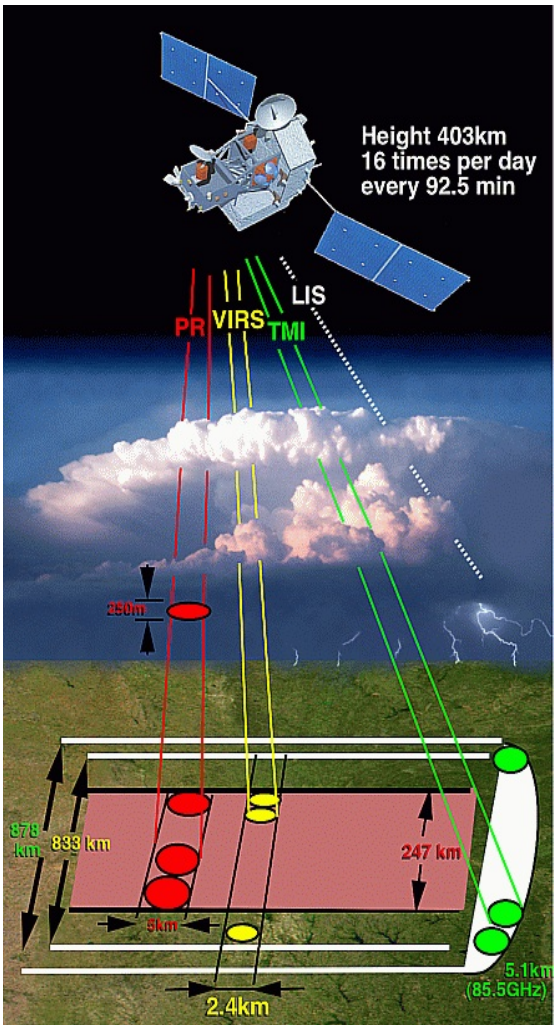

Figure 1. Schematic view of the scanning geometries of the TMI, VIRS and PR instruments of TRMM [10]

2.2. TRMM TMPA 3B42 RT and V7 products

The TRMM-TMPA 3B42 (TRMM Multi-satellite Precipitation Analysis) algorithm, developed by NASA, is a precipitation estimation product from the TRMM which combines satellite data and data on the ground [11-13]. The infrared sources for TRMM-TMPA 3B42 V7 come from the operational geostationary environmental study satellites (GOES) West and East, the geostationary meteorological satellite (GMS), the METEOSAT-5 and METEOSAT-7 satellites and the NOAA-12 polar orbit (National Oceanic and Atmospheric Administration). PMW sources come from radiometers present in low-orbiting satellites TMI, SSMI (Special Sensor Microwave Imager), AMSU (Advanced Microwave Sounding Unit), and AMSR (Advanced Microwave Scanning Radiometer).

There are two datasets from the TRMM-TMPA 3B42 algorithm: the first is TRMM-TMPA 3B42 V7, which is the research version, available approximately two months after the observation. The second is TRMM-TMPA 3B42 RT which is the real-time version, available approximately 6 to 9 hours after the observation, but which does not take into account the data on the ground. Over the past 10 years, the TRMM-TMPA 3B42 algorithm has undergone three major updates due to the new sensors used by the algorithm [12].

The data output from the TRMM-TMPA 3B42 algorithm has a time resolution of 3 hours with precipitation rate values in mm / h. The geographic area covered extends from latitude 50 ° S to 50 ° N for 3B42 V7 (Fig. 2) and from 60 ° S to 60 ° N for 3BR42 RT for a spatial resolution grid of 0.25 ° x 0.25 °. Product data is available from January 1, 1998 to date for 3B42 V7 and from March 1, 2000 to today for 3B42 RT [14].

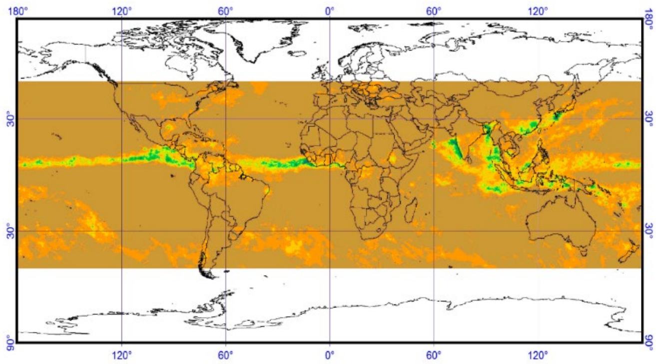

Figure 2. The coverage area of TRMM-TMPA 3B42 V7 [15]

2.3. Data collection

In this study, data from terrestrial stations and satellite-derived were used for the period 2017–2018. The period starts from 1 September and ends on April 31, which is considered the rainy season in Iraq. 16 terrestrial stations data (Table 1) were available out of 30 stations (Fig. 3). On the other hand, 16 and 30 stations data were derived from TRMM satellite data as a terrestrial station equal to ground stations. These stations were chosen on the basis of their proximity to the missing terrestrial stations with a distance of no more than 50 km. In order to represent it as much as possible. TRMM-TMPA 3B42 V7 product is used in this study, with a spatial resolution of 0.25° × 0.25° which downloading from TOVAS system. Firstly, the area of interest is defined, and selecting the time interval, then the data are visualized. Four format data types can download it, including HDF, NetCDF, ASCII, and Google Earth KMZ [16]. The TRMM data were downloaded as a NetCDF format to operate it in ArcGIS software for mapping the rainfall contour lines using Kriging interpolation method to estimate the rainfall distribution in Iraq.

Table 1. The available and missing data of the terrestrial stations [17] and TRMM data [18] for the season of 2017–2018.

No	Terrestrial stations data				TRMM data		
	Station Name	Lat.	Long.	Rainfall (mm)	Lat.	Long.	Rainfall (mm)
1	Mosul	36.375	43.125	290	36.125	43.125	304.751
2	Kirkuk	35.375	44.375	253	35.375	44.125	338.3469
3	Tuz	34.875	44.625	252	34.875	44.375	295.3835
4	Khanaqin	34.375	45.375	295	34.375	45.125	371.6543
5	Khales	33.833	43.533	203	33.875	43.625	199.0592
6	Baghdad	33.375	44.375	183	33.375	44.125	198.9865
7	Kerbela	32.625	44.125	111	32.375	44.125	184.3744
8	Hilla	32.45	44.45	118	32.125	44.375	140.4296
9	Aziziyah	32.91	45.066	155	32.875	45.125	242.9573
10	Kut	32.5	45.816	126	32.375	45.875	164.6396
11	Najaf	31.875	44.375	91	31.875	44.375	106.034
12	Diwaniya	31.875	44.875	82	31.625	45.125	96.83266
13	Samawa	31.375	45.375	72	31.375	45.375	80.27095
14	Nasiriya	31.125	46.125	58	31.125	46.125	71.5834
15	Amara	31.875	47.125	103	31.875	46.875	114.5546
16	Basra	30.625	47.875	66	30.625	47.875	103.7755
17	Tel-Afar	36.375	42.375	-	36.375	42.375	332.5606
18	Sulamaniya	35.375	45.375	-	35.375	45.375	756.343
19	Arbil	36.125	43.875	-	36.125	43.875	463.1895
20	Samarra	34.125	43.875	-	34.125	43.875	208.8148
21	Hai	32.125	45.875	-	32.125	45.875	124.4244
22	Ana	34.375	41.875	-	34.625	41.875	73.91969
23	Rutba	32.875	40.375	-	32.875	40.375	56.17239
24	Baiji	34.875	43.375	-	34.875	43.125	194.5393
25	Ain Al Tamur	32.58	43.46	-	32.625	43.125	117.9774
26	Al Misiab	32.71	44.12	-	32.875	44.125	187.0971
27	Al Qa'im	34.30	41.09	-	34.375	41.375	70.52767
28	Ar Ramadi	33.32	43.34	-	33.375	43.125	142.7511
29	Shamiya	31.89	44.49	-	31.875	44.625	122.5724
30	Hit	33.59	42.78	-	33.375	42.625	114.0135

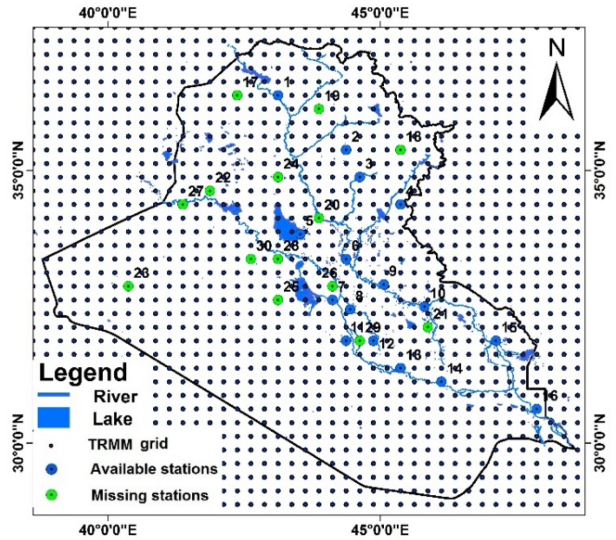

Figure 3. The distribution of the available and missing terrestrial stations in Iraq

3. Results and Discussion

The knowing of the trend of changes in rainfall and temperature rates is extremely important in knowing possible future environmental changes, and their impact on the national economy, and constitute one of the most important factors guiding the planning of the national economy, and the stability of agricultural production in Iraq depends on securing irrigation water on schedule.

The rainfall in Iraq was characterized in general by its irregular distribution in terms of place and time, as the amount of rain recorded in the terrestrial stations varies from place to another according to the height of the sea surface and the geographical location of the station, as it increases in high places in general. The main source that supplies Earth with water is the rainfall that can be studied in two terms: the spatial distribution and the temporal distribution.

Figure 4a shows clearly deformed rainfall lines due to the few number of terrestrial stations and their poor geographical distribution. Likewise, in Figure 4b for the same reasons, compared to the last rainfall contour map (Fig. 5) produced by Jassim et al (2012) [19]. On the other hand, Figure 6 shows a good distribution of rainfall lines, due to the increase in the number of TRMM stations. While the hybrid map derived from the TRMM satellite data and terrestrial stations (Fig. 7) showed a very good matching.

Rainfall contour maps have a great importance for production the areas suitable for permaculture and the most area vulnerable to drought. Through observing the 100 mm contour line (which is the critical line for drought), we notice that the southern and southwestern part of Iraq is the most vulnerable to drought. However, this is difficult to guess from the maps drawn from 16 stations.

In Figure 4a and b, the data is not uniformly distributed along the study-area. This is of course very usual for hydrological studies under the current circumstances. The problem is that the extend the area of interest to cover the whole country, and disregarding the fact that the estimations in areas where the data network is dense are much more accurate than in areas where the observation network is less dense or does not even exist. In this case, the results would be is not accurate and not applicable.

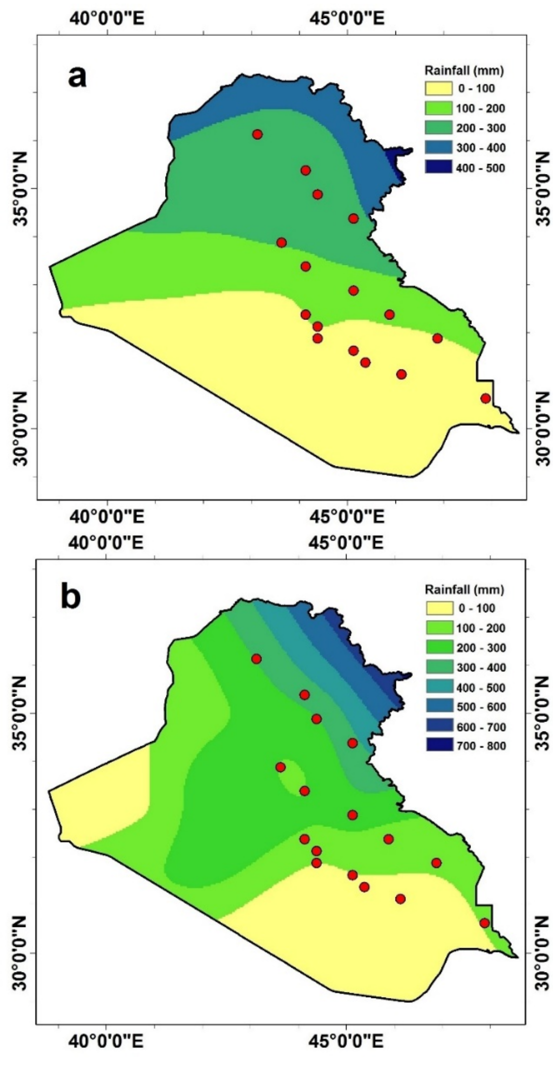

Figure 4. The rainfall contour map for the season of 2017–2018, a- based on 16 terrestrial stations, b- based on 16 stations derived from TRMM data

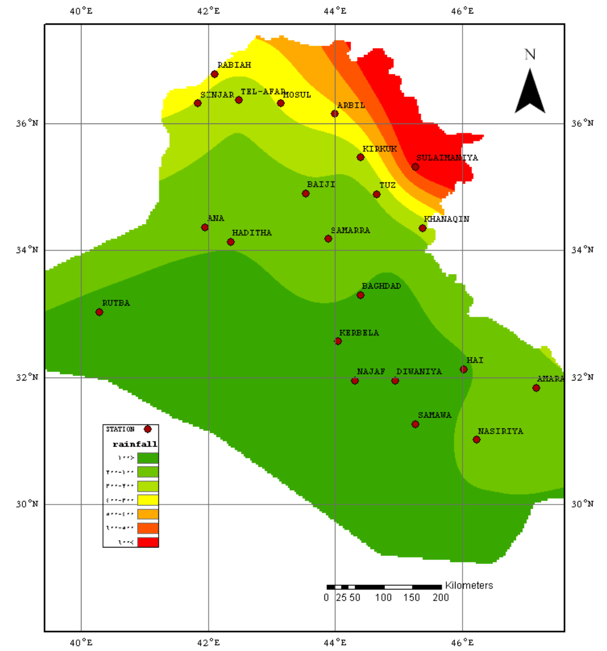

Figure 5. The rainfall contour map for the season of 2010–2011 based on 23 terrestrial stations [18]

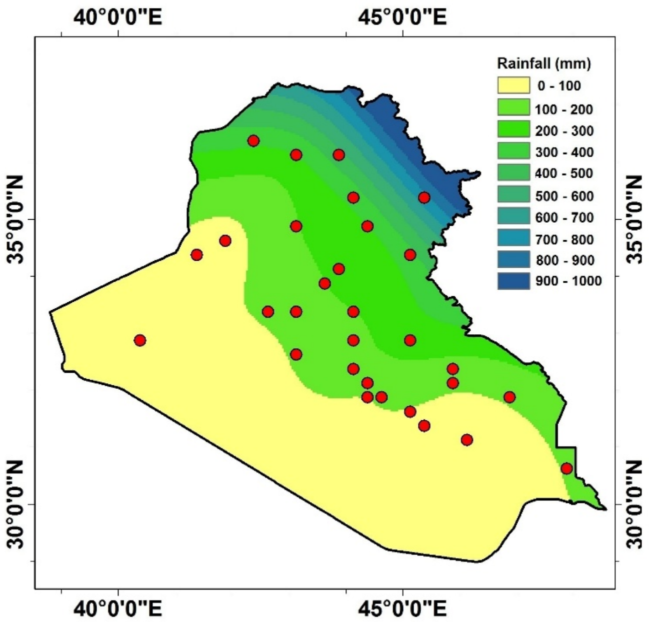

Figure 6. The rainfall contour map for the season of 2017–2018 based on 30 stations derived from TRMM data

Regression analysis was made between terrestrial stations and TRMM data (Fig. 8) to validate the TRMM data, where the relationship was normal and linear with 0.91 R-squared (the correlation coefficient). Where the correlation coefficient gives evidence of the appropriateness of the data when it approaches the value of 1 [20].

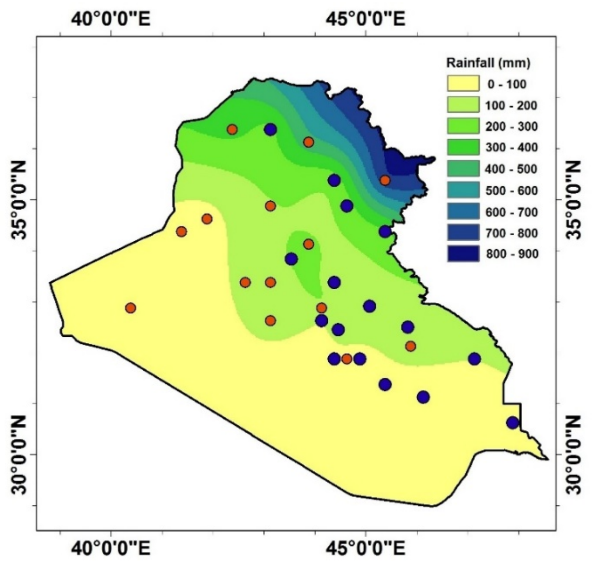

Figure 7. Hybrid rainfall contour map for the season of 2017–2018 based on 16 terrestrial stations and 14 stations derived from TRMM data

No.	TRMM station	Terrestrial station
1	304.751	290
2	338.347	253
3	295.384	252
4	371.654	295
5	199.059	203
6	198.987	183
7	184.374	111
8	140.43	118
9	242.957	155
10	164.64	126
11	106.034	91
12	96.8327	82
13	80.271	72
14	71.5834	58
15	114.555	103
16	103.776	66

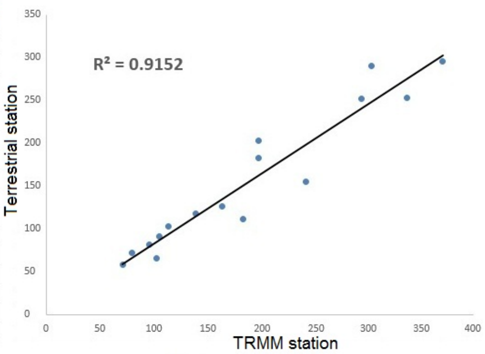

Figure 8. Regression analysis between terrestrial and TRMM rainfall data.

TRMM data have some limitations, as some systematic errors can result in them. One of these limitations is the presence of land water-bodies (e.g. lake and marsh) [21], where measurements are inaccurate over or near these water bodies. This is due to the fact that the radar sensor will calculate the evaporated water vapor from the water bodies as a rain precipitation. Another limitation is the existence of topography that may cause terrain-induced errors on remote sensing retrievals [22, 23].

As indicated in Figure 8 the correlation is higher for the rainfall values less than 150-200 mm. According to this data and the positions of the missing stations, those are generally located in this range. While the data with less correlation are more likely to be near water bodies or areas with high topography. This can be seen clearly when we used the whole accumulated rainfall grid values as shown in Figure 9. The closed areas are associated with water bodies (see Fig. 3), whereas irregular contour lines are noticed in the northern region, which is associated with topographic areas. Therefore, the data that generates systematic errors must be reduced or ignored when need to using the whole TRMM grid data.

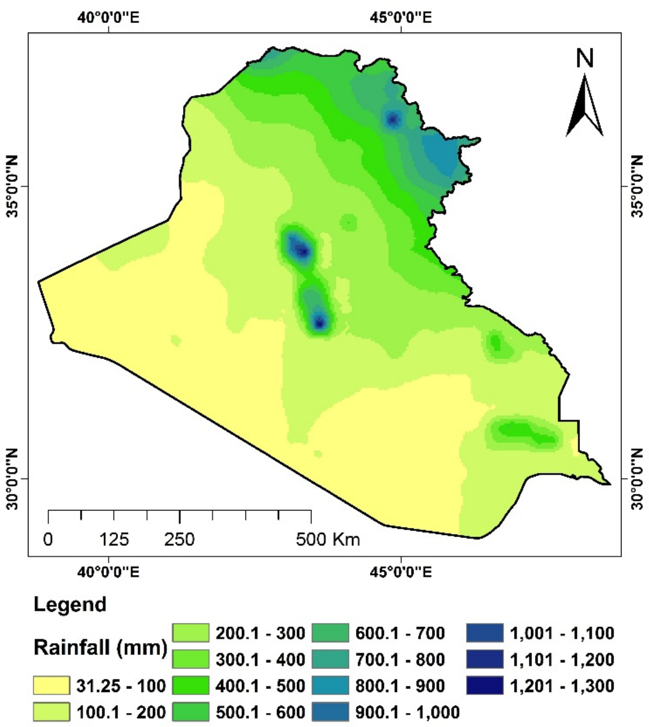

Figure 9. The rainfall contour map for the season of 2017–2018 based on the whole TRMM grid data

4. Conclusions

TRMM is a research satellite designed to improve knowledge of the distribution and variability of precipitation, as part of the water cycle in the climate system. In the present study, the accuracy of TRMM satellite precipitation data for the season of 2017–2018 was evaluated. The results indicate that there is a high correlation between satellite precipitation data and terrestrial data and, it has a correlation coefficient 0.91, which is a high accuracy. Therefore, it is suitable to use it in meteorological and hydrological studies, and rainfall contour maps. In addition, TRMM data can be used to compensate for the lack of archival data for previous years due to its good and realistic results. Besides, the choose of TRMM stations should considering the existence of the topography and water bodies that may cause errors on remote sensing retrievals. Finally, the large number of stations may not produce good results in contour mapping if they are not well distributed.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest.

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