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Integrated Approach for Precipitation Assessment in Different Topography of Iraq

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Abstract

Remote sensing precipitation data is a significant tool for solving the issue of precipitation forecasting at ground weather stations since it offers the benefits of extensive spatial coverage and high spatial and temporal precision; Providing data on precipitation that is necessary for agricultural projects important in the production of crops, especially those involved in food security, because Iraq is one of the countries affected by climate change, according to the Intergovernmental Panel on Climate Change (IPCC) report. The weather ground stations provide data on the precipitation, but some stations have incomplete data and are subjected to maintenance and shutdown at multiple intervals, which causes gaps in the data which affects the studies when observing a change in precipitation. The aim of this study is an analysis of precipitation based on Global Precipitation Measurement (GPM) data variations with weather ground stations for the different topography for the period (2000-2020) for the months of precipitation. Two statistical criteria were used in this study to obtain an appropriate evaluation that links the results of precipitation and these statistical criteria are: RSME and R2. The results indicate full agreement between GPM and ground stations which is similar to those obtained in this study. The annual accumulated correlation values ranged (from 0.51 to 0.875) for different topography between ground weather stations and GPM. The GPM data ability to detect precipitation is influenced by its height and intensity. This paper offers recommendations for using GPM IMERG precipitation products in hydrological research and managing Iraq's water resources.

Keywords: GPM, IMERG, Remote Sensing, Ground Weather Station, Topography

النهج المتكامل لتقييم هطول الأمطار في تضاريس مختلفة من العراق

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الخلاصة

بيانات هطول الأمطار بالاستشعار عن بعد هي أداة مهمة لحل مشكلة التنبؤ بالسقيط المطري في المحطات المناخية الارضية لأنها توفر فوائد التغطية المكانية الواسعة والدقة المكانية والزمانية العالية ؛ توفير البيانات الخاصة بسقوط الأمطار التي تعتبر ضرورية في المشاريع الزراعية المهمة في إنتاج المحاصيل ، وخاصة تلك المعنية بالأمن الغذائي ، لأن العراق من الدول المتأثرة بالتغير المناخي ، بحسب تقرير الهيئة الحكومية الدولية المعنية (IPCC) بتغير المناخ توفر محطات الطقس الأرضية بيانات عن هطول الأمطار ، لكن بعض المحطات بها بيانات غير كاملة وتخضع للصيانة والإغلاق على فترات متعددة ، مما يجعل البيانات معرضة لفجوة ، مما يؤثر على الانطباعات المأخوذة عند ملاحظة تغير في هطول الأمطار. الهدف من هذه الدراسة هو تحليل هطول الأمطار بناءً على تغيرات بيانات القياس العالمي للهطول (GPM) مع محطات الطقس الأرضية للطبوغرافيا المختلفة للفترة (2000-2020) لأشهر هطول الأمطار. تم استخدام معيارين إحصائيين في هذه الدراسة للحصول على التقييم المناسب الذي يربط نتائج GPM وهذه المعايير الإحصائية هي RSME :و تراوحت قيم الارتباط التراكمية السنوية (0.51 إلى 0.875) لمختلف التضاريس بين محطات الطقس الأرضية و GPM. تتأثر قدرة بيانات GPM على اكتشاف هطول الأمطار بارتفاعها وشدتها. .R2.تشير النتائج إلى اتفاق كامل بين GPM والمحطات الأرضية في. تتأثر قدرة بيانات GPM على اكتشاف هطول الأمطار بارتفاعها وشدتها. تقدم هذه الورقة توصيات لاستخدام منتجات GPM IMERG لهطول الأمطار في البحث الهيدرولوجي وإدارة موارد المياه في العراق.

الكلمات المفتاحية : عمليات الاسترجاع متعددة الأقمار الصناعية المتكاملة (IMERG), القياس العالمي للهطول (GPM) ,الاستشعار عن بعد ، محطة الطقس الأرضية ، الطبوغرافية

Introduction

The Integrated Multi-Satellite Retrievals (IMERG) for Global Precipitation Measurement (GPM) uses data from the satellite constellation to predict precipitation throughout the majority of the Earth's surface, which is devoid of precipitation-measuring sensors. The technique used in IMERG's Version 06 release combines earlier precipitation estimates collected between 2000 and 2015 during the operation of the Tropical Rainfall Measuring Mission (TRMM) satellite with more recent estimates gained during the operation of the GPM satellite (2014 - present). As academics and application developers confirm, the longer the record, the more useful it is. Researchers are better informed to make climate and weather models more accurate, better understand normal and extreme rain and snowfall around the world, and strengthen applications for current and future disasters, disease, resource management, energy production, and food security by being able to compare and contrast past and present data (https://gpm.nasa.gov/data/imerg). GPM Core Observatory serves as both calibration and an assessment tool for all passive microwave and infrared-based precipitation products incorporated in IMERG in their respective periods. Both the TRMM and GPM satellites include active scanning radars and multi-channel dual-polarization Passive Microwave (PMW) sensors. The orbital inclination of GPM has been extended from 35° to 65°, allowing coverage of crucial extra climatic zones; the radar has been updated to two frequencies; the spacecraft has been improved. (Huffman , et.al.,2019)

Ordouni , et.al.,2020 compared half-hourly daily satellite data with ground-based observational data (stabilizer and ordinary). GPM-IMERG satellite data has spatial (0.1o*0.1o) and temporal (daily and half-hourly) resolutions. Some statistical metrics such as Critical Success Index (CSI), Probability of Detection (POD), Relative bias, and other validation indicators were utilized to examine the accuracy of GPM data in rainfall estimation. The IMERG algorithm for the GPM satellite was found to be generally consistent with the daily ground station readings as well. The Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Bias Error (MBE) statistical criteria were used to validate GPM satellite rainfall data, and the results were found to be accurate. Given the error warning ratio values for all stations, it can be concluded that satellite data and observed data from ground stations are in close proximity. IMERG products are accessible in the form of near-instant data, i.e. IMERG early and late, and real-time post-research data, i.e. IMERG Final. The analysis has been received and is being considered every half hour, IMERG early, late, and final. Sungmin , et.al.,2017 evaluated GPM half-hour on two 0.1o × 0.1o grid cells

Wegener Net Feldbach Highland of the climate station network in southeastern Austria, Fully covered with 40 and 39 WEGN stations each, with data during the summer season.

Evaluation of the climatic remote sensing elements with the ground stations according to its accuracy was used in comparing the ground stations with the results of the remote sensing elements. Therefore, to increase this accuracy, the influence of topographical characteristics and the intensity of precipitation estimated precipitation values were taken. Safa , et.al.,2020 thoroughly assessed the three GPM IMERG products (near and post-real-time). Different seasons, rainfall intensities, topographical characteristics, and hydrological areas were evaluated across a very dry and semiarid nation like Saudi Arabia between March 2014 and June 2018. Also, Tang et al.,2018 have investigated the correlations between precipitation and topography for 17 years of (TRMM) Precipitation Radar (PR) data and 2 years of (GPM) Dual-Frequency Precipitation Radar (DPR) data of the Tibetan Plateau using spaceborne precipitation radars. Ramadhan et al.2022 confirmed a good connection to (GPM-IMERG) multi-satellite, which evaluate the following elements: utilizing gauge data from yearly, monthly, daily, and hourly data for three types of IMERG: Early, Late, and Final , from 2016 to 2020 over Indonesian Maritime Continent.

The accuracy of the (GPM IMERG) recalls in China, including IMERG Early, Late, and Final, was compared and evaluated using eight statistics and detection indices. Precipitation detection capacity in east China is good, according to the correlation coefficient between GPM IMERG products precipitation and precipitation measurement (Nan , et.al.,2021). Accurate remote-sensed precipitation data are essential for flood and climate change monitoring and analysis. Sun et al .2018 compared the applicability of GPM IMERG products to ground-measured data at various temporal resolutions. GPM products were studied in three schedules based on precipitation data from 107 meteorological stations in the Beijing-Tianjin-Hebei region: half-hour, daily and monthly As a result, the ground station data is closely connected to the GPM-M product in five evaluation indicators were use.

Verifying the validity of GPM data is not limited to comparing it with ground stations, but there are many regional, international and global remote sensing sources. Popovych and Dunaieva ,2021 obtained good correlation results when comparing GPM IMERG with Famine Early Warning System Network FEWS NET service in addition to stabilizing the results with the ground stations in the steppe region of the Crimea in order to evaluate the spatial representation of the spatial distribution of precipitation and the applicability of data sets for water balance calculations and agricultural yields dynamic modeling for the period (January 2017 - July 2020).

This study aims to evaluate the precipitation based on (GPM) data variations with the weather ground stations for different topography for each month of Iraq. Two statistical criteria were used in this study to obtain an appropriate evaluation which link that results of precipitation and these statistical criteria are: RSME and R2.

Research Methodology

Study Area

Iraq is located between the geographic coordinates (37°23' N- 29°04' N) and (48°32' E- 38°50' E), it has a surface area of 437,072 Km^2. Iraq may be classified into four areas based on the type of the physical landscape: Mountain Region, Plateau and Hills Regions, The Mesopotamian plain, and Jazera and Western Plateau (Al-Ansari, 2021), Figure (1). The topography of the study area was simulated using Digital Elevation Model (DEM) which is provided by the Shuttle Radar Topography Mission (SRTM). The data is available in ARC GRID, ARC ASCII, and Geotiff formats, using decimal degrees and WGS84 datum. SRTM data are obtained from the USGS and NASA (USA) (Reuter , et.al.,2007).

Meteorological Data

The climate of Iraq is continental, subtropical, and semi-arid. The climate in the mountains is the Mediterranean. Rainfall in the mountains is most common from December to February or November to April. During the winter, the temperature is around 16°C during the day, decreasing to 2°C at night, with the potential of frost. On the other hand, the summer season is extremely hot,

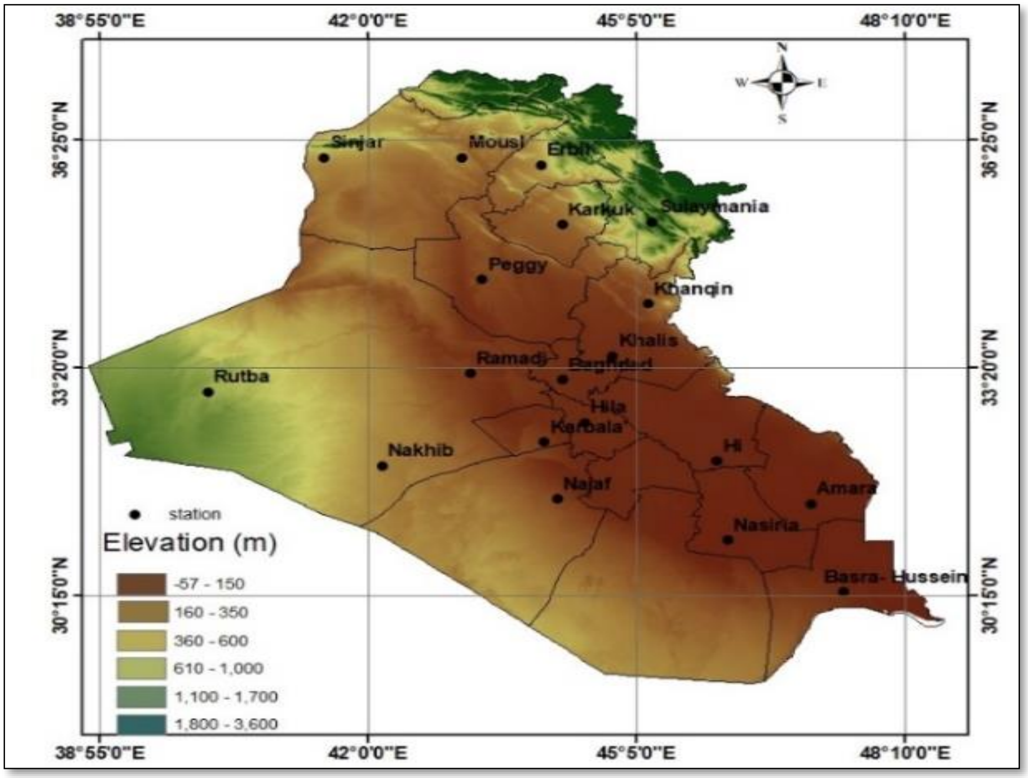


Figure (1): Spatial distribution of weather ground station in the different topography of Iraq

with an average temperature of above 45°C.In July and August, the temperature drops to 25°C at night (Al-Ansari ,2021). Ground weather stations are distributed over all the governorates of Iraq as follows: in the airports, area of dam reservoirs, some agricultural projects area, some buildings for research lands, and others. Therefore, the distribution of ground stations is not subject to the correct spatial distribution that achieves climatic information about the study area. The terrestrial ground stations were classified according to their altitudes within the topographic map of Iraq, Figure (1) and Table (1).

Table (1) : Geographical locations of ground weather stations in Iraq.

Topography Region-Name	Elevation Topography Region (m.a.s.L)	Station	Station Elevation (m.a.s.L)
Mountain Region,	1300-3600	Sulaymaniyah	1300
Plateau and Hills Regions	540-1200	Rutba	630.8
Jazera and Western Plateau	200-530	Erbil Karkuk Mousl Nakhib Sinjar Khanqin	420 331 223 305 538 202
The Mesopotamian plain,	-57-190	Hilla Najaf Karbala' Khalis Ramadi Amara Basra- Hussein Hi Baghdad Nasiria Peggy	27 53 29 44 48 9.5 2 17 31.5 5 115.5

GPM Data

The monthly GPM dataset (IMERG_ATBD_V06) from (2000 to 2020) was collected from the GPM data website. The TIF file of GPM product comprises the following Science Data Set: Time interval: 60 min; Resolution: 0.1°; Spatial domain: global; Sensor precipitation products intercalibrated to CORRA; Precipitation phase estimates; probability of liquid precipitation; Instantaneous accumulated Snapshot for hour, accumulation for monthly (Huffman,2019).

1. Deduction of the study area part from among the countries of the whole world using a (Arc Toolbox /Spatial Analyst Tool/Extraction /Extract by Mask).
2. Convert the value in any point by multiplying by the coefficient (Raster *24*No. Day of the month) to get the average monthly in-station study.
3. Adjust formats: color, page settings, and map key, in addition to highlighting contour lines and Legend.

Statistical Analysis

The collecting and evaluation of data in order to find patterns and trends is known as statistical analysis. It's a part of the data analytics process. Statistical analysis is useful for obtaining research interpretations, statistical modeling, and survey and study design, among other things. It, also be useful for searches that deal with huge amounts of data. In this study, two statistical indexes were used to evaluate the land surface temperature with weather ground stations, these statistical indexes are shown below:

1. Root Mean Square Error (RSME) indicates a perfect match between observed and predicted values (Chicco 2021) get Equation (1) as follows:

$$\text{RSME}=\sqrt{\frac{\sum_{i=1}^{n}(p_i-o_i)^2}{n}} \quad (1)$$

where: P is precipitation predict a value for GPM; O is LST precipitation value for ground weather station; is a numerical census of the years from 2000 to 2020 per month.

2. The coefficient of determination R^2

The coefficient of determination is a statistical measurement that assesses how variations in one variable may be explained by changes in another one. In other words, while doing trend analysis, researchers mainly rely on this coefficient to judge how strong the linear relationship between two variables is (Chicco 2021).

$$R^2 = \left[\frac{\sum_{i=1}^{n}(o_i-\bar{o})(p_i-\bar{p})}{\sqrt{\sum_{i=1}^{n}(o_i-\bar{o})^2}\ \sqrt{\sum_{i=1}^{n}(p_i-\bar{p})^2}}\right] \quad (2)$$

The statistical criteria described above differ in the values of acceptance and unacceptance of precipitation between weather stations and GPM products. The value of acceptance in RSME is close to zero and R^2 is greater than 0. The match between the ground stations and GPM products is considered good and acceptable when the acceptance rate is achieved for two statistical indicators.

Uncertainty Analysis

In order to evaluate and forecast the performance of complex engineering systems, uncertainty quantification is crucial, especially when there is insufficient experimental or real-world data The uncertainties are major obstacles to the predictive capability and the reliability of simulations (Xiao & Cinnella, 2019). Different uncertainties may present in a given problem and interact with each other, affecting almost all aspects of engineering modeling and design. Hence, it is important to quantify the errors in order to be able to interpret the results (Absil , et.al.,2016). Inferential statistics are used by researchers because they enable us to evaluate behavior in samples to understand the behavior in populations that are frequently too vast or difficult to access, Figure (2). So, the Hypotheses theory was used in this study.

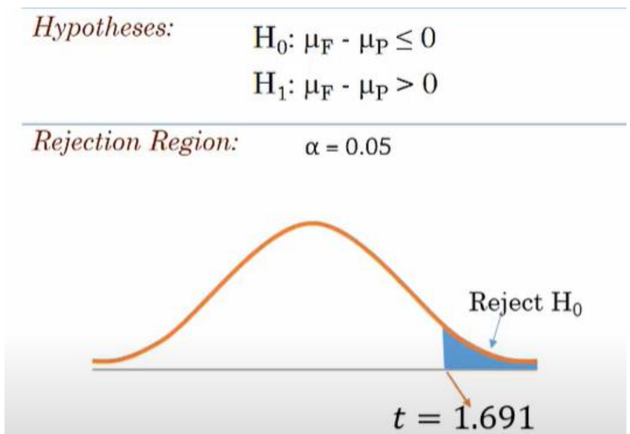


Figure (2) : Hypotheses Theory Concepts

The null hypothesis (Ho), stated as the null, is a statement about a population parameter, such as the population mean, that is assumed to be true. An alternative hypothesis (H1) is a statement that directly contradicts a null hypothesis by stating that the actual value of a population parameter is less than, greater than, or not equal to the value stated in the null hypothesis.

Results and Discussion

Meteorological Data

Monthly Precipitation was selected in three seasons which are: winter, spring, and autumn for the period (2000-2020). Precipitation data was provided by the ground weather station from the Ministry of Transportation, Iraqi Metrological and Organization Seismology. The data of some stations were not integrated and had a shortage of several years as a result of the wars in the locations of those stations, which lead to work an approximate way to compensate for the monthly lost data in the Precipitation as an average monthly for 21 years. The average monthly precipitation for the period (2000-2020) at some weather ground stations of the topography region are shown in Figure (3). The stations which have been selected for each Topography Region, are Sulaymaniyah for Mountain Region; Rutba for Plateau and Hills Regions; Erbil and Mosul for Jazera and Western Plateau; Baghdad and Basra- Hussein for the Mesopotamian plain. The winter season includes December, January and February; Spring season (March and April) and autumn season includes October and November. These months were chosen based on the months of Precipitation distribution in Iraq, which are determined by the rainfall rates by Iraqi Metrological and Organization Seismology.

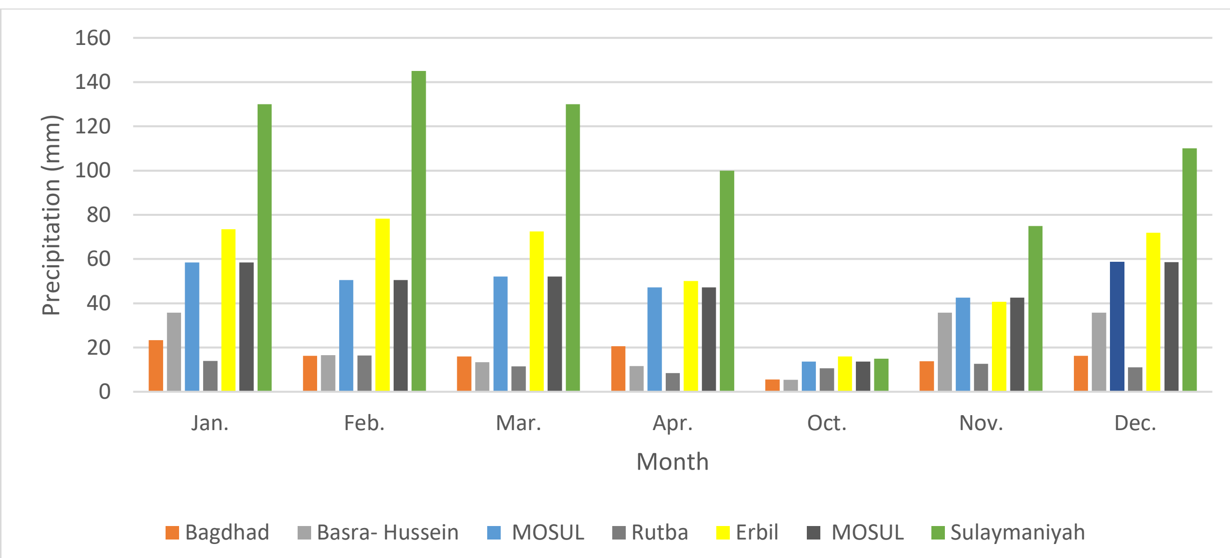


Figure (3) : Monthly average Precipitation for some selected ground stations with different topography in Iraq

GPM Data

The data produced from GPM per hour are processed as a monthly average of precipitation were shown in Figures (4, 5, and 6). The monthly variation of the precipitation for the years 2001 and 2020 has been illustrated in Figures (4, 5, and 6). The data extracted from GPM maps are formatted for each month in mm. The values of the rainfall are obtained in the form of numbers and entered into tables to know the temporal and quantitative variation within each station and for each month over the period of 21 years. The maps produced by GPM express the reality that the precipitation of Iraq will be affected by the impact of climate change, the effect of climate change on the rainfall is clearly visible by noting the difference between 2001 and 2020. Climate change is explained by the amounts of precipitation between the years 2001-2020 in December and February of the winter season. Where the values of change ranged (170-220) mm in 2001 to (9.2 -22) mm in 2020.

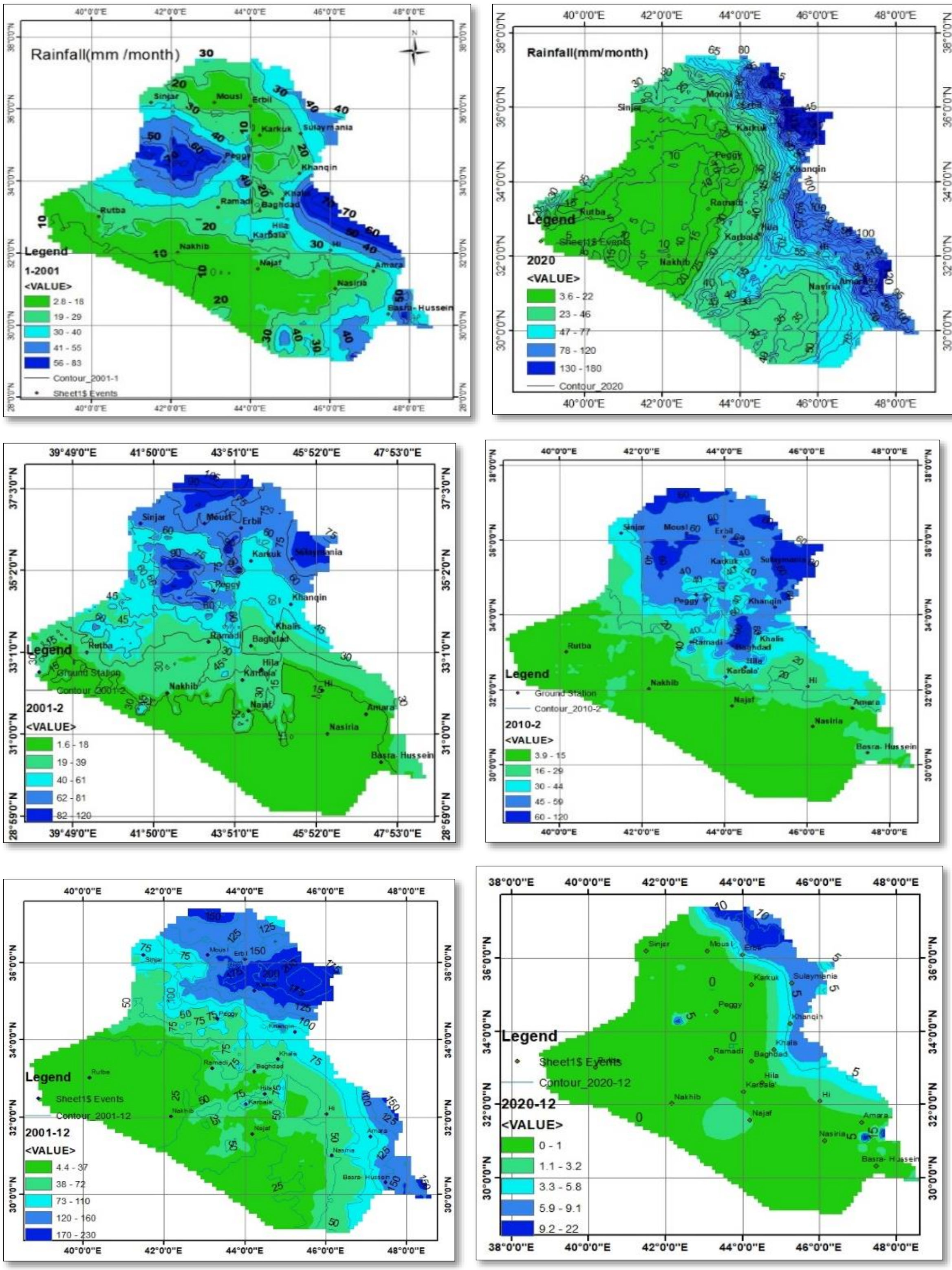


Figure (4) :Average monthly of precipitation in the winter for (December, Jaunary and February).

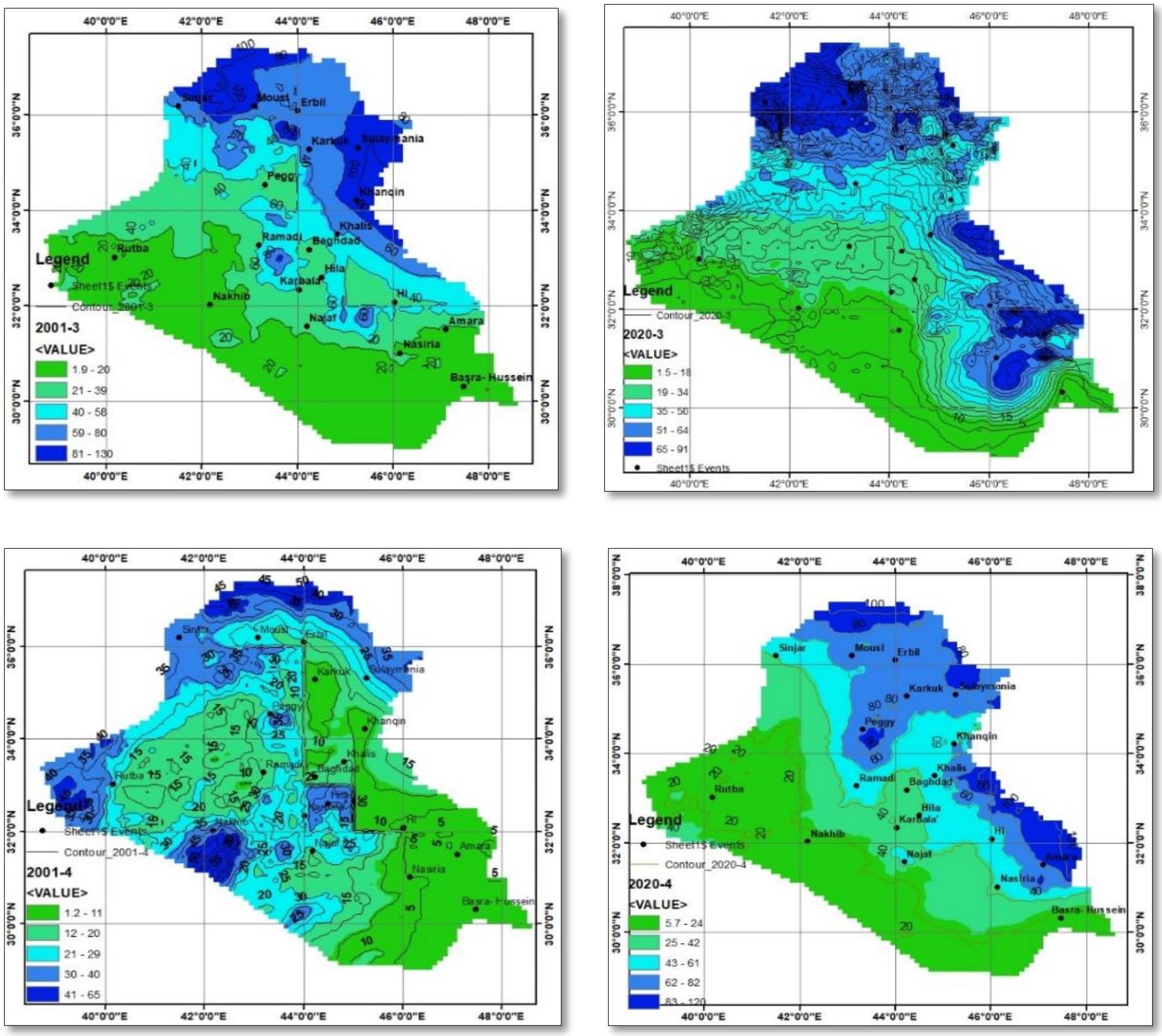


Figure (5) :Average monthly of precipitation in the Spring for (March and April).

The variables defined in the statistical evaluation within the SPSS program are the monthly averages for each station according to the pre-defined months and the values extracted from GPM maps as two columns in the SPSS program. Then, the SPSS program performs the statistical analysis according to equations 1 or 2, and the values of RSME and R^2 are graduated.

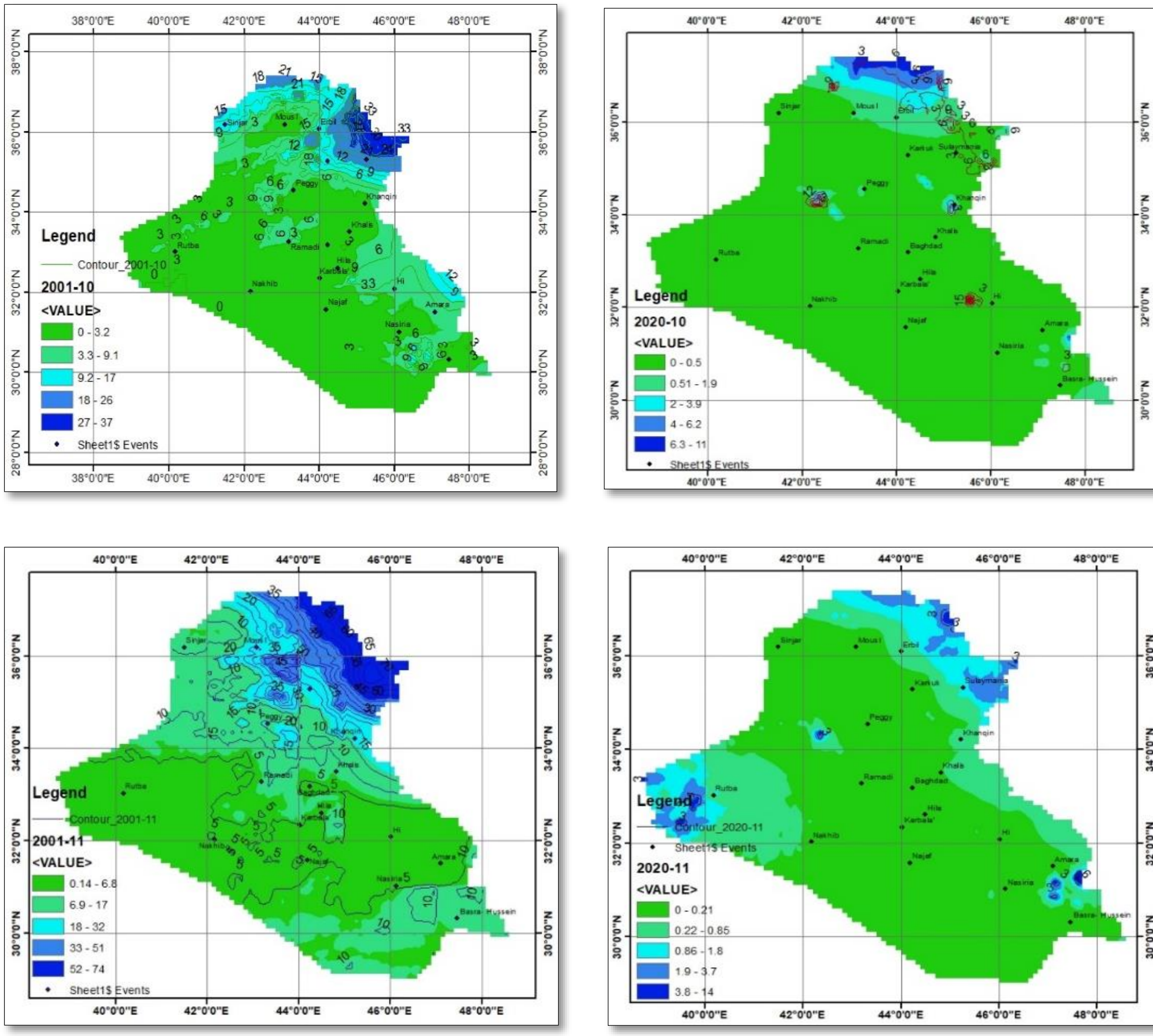


Figure (6) :Average monthly of precipitation in the Autumn for (October and November)

Statistical Analysis Indexes for Precipitation

Statistical Package for the Social Sciences (SPSS) was used to extract two statistical measures in this study. Figures (7) and (8) showed the change in the values of the selected statistical indicators in this study, these indicators: RSME and R^2. The maps in Figures (7 and 8) were obtained after extracting the statistical figures from Equations (1 and 2) , then entering them into the GIS program to link the results of all-weather earth stations into a single map to express the value of the statistic measures RSME in Figure 6 and R^2 in Figure (8). Figure (7) demonstrates the spatial distribution of the RMSE from 2000-2020. The spatial distributions, show an increasing trend in the Mountain stations in January, February March and

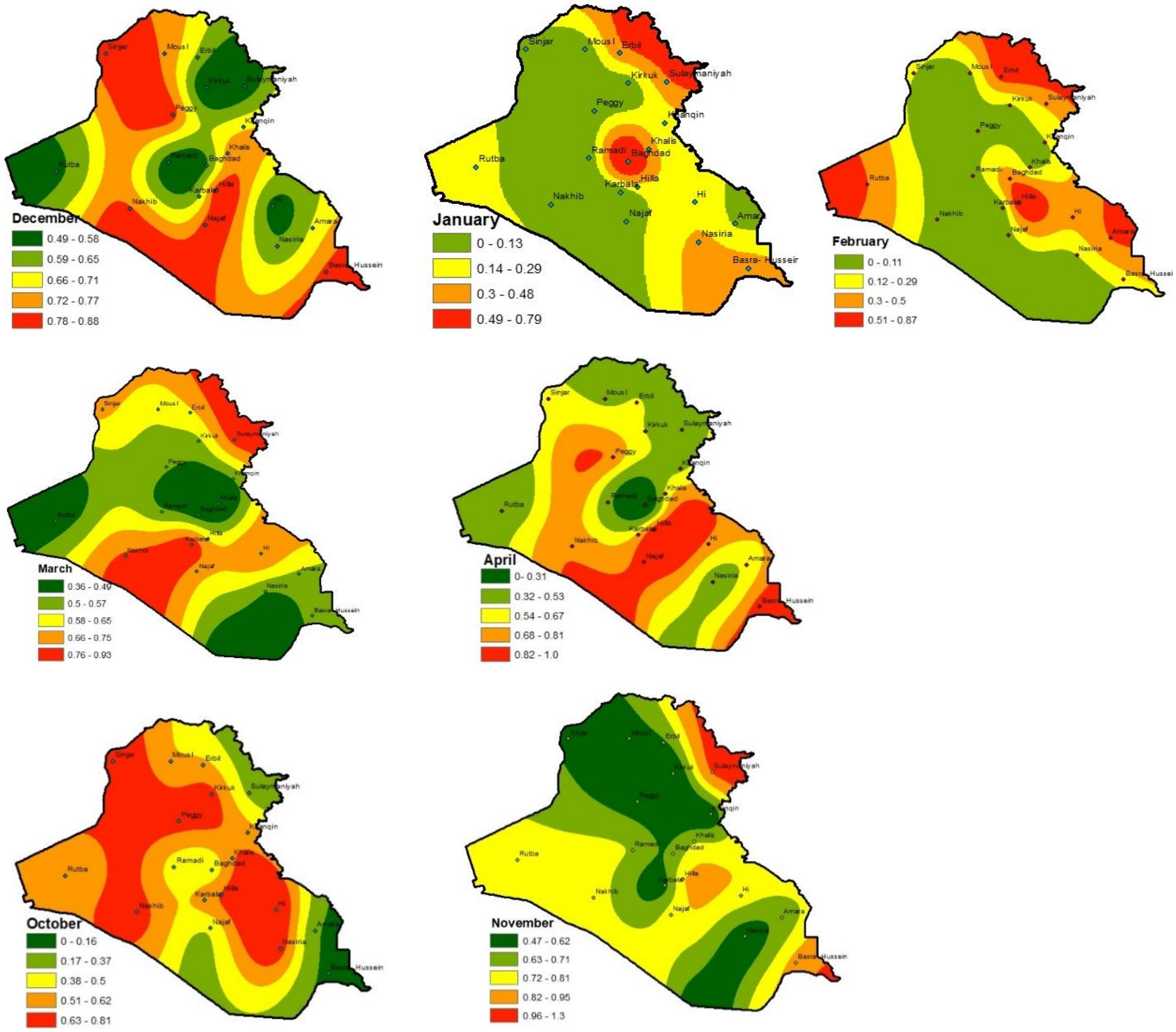


Figure (7) : Statistical measure analysis (RSME) for all selected ground weather stations in each month

November. The reflects the inconsistency with RSME values, which determines the acceptable statistical results for the evaluation when the values approach to 0 .While RSME values were (0.49 -1.3) except for the months of December, April and October, which gave acceptable values for statistical measure RSME (0 to 0.49). To differentiate between precipitation and non-precipitation events, satellites often categorize clouds based on the cloud top infra - red temperature. While RSME values for the rest of the topographical regions of Iraq were acceptable .These values were 0 to 0.48. However, the RSME values gave a high performance and the acceptance opinion applies to the weather earth stations that fall within the Plateau and Hills Regions, Jazera and Western Plateau and the Mesopotamian plain.

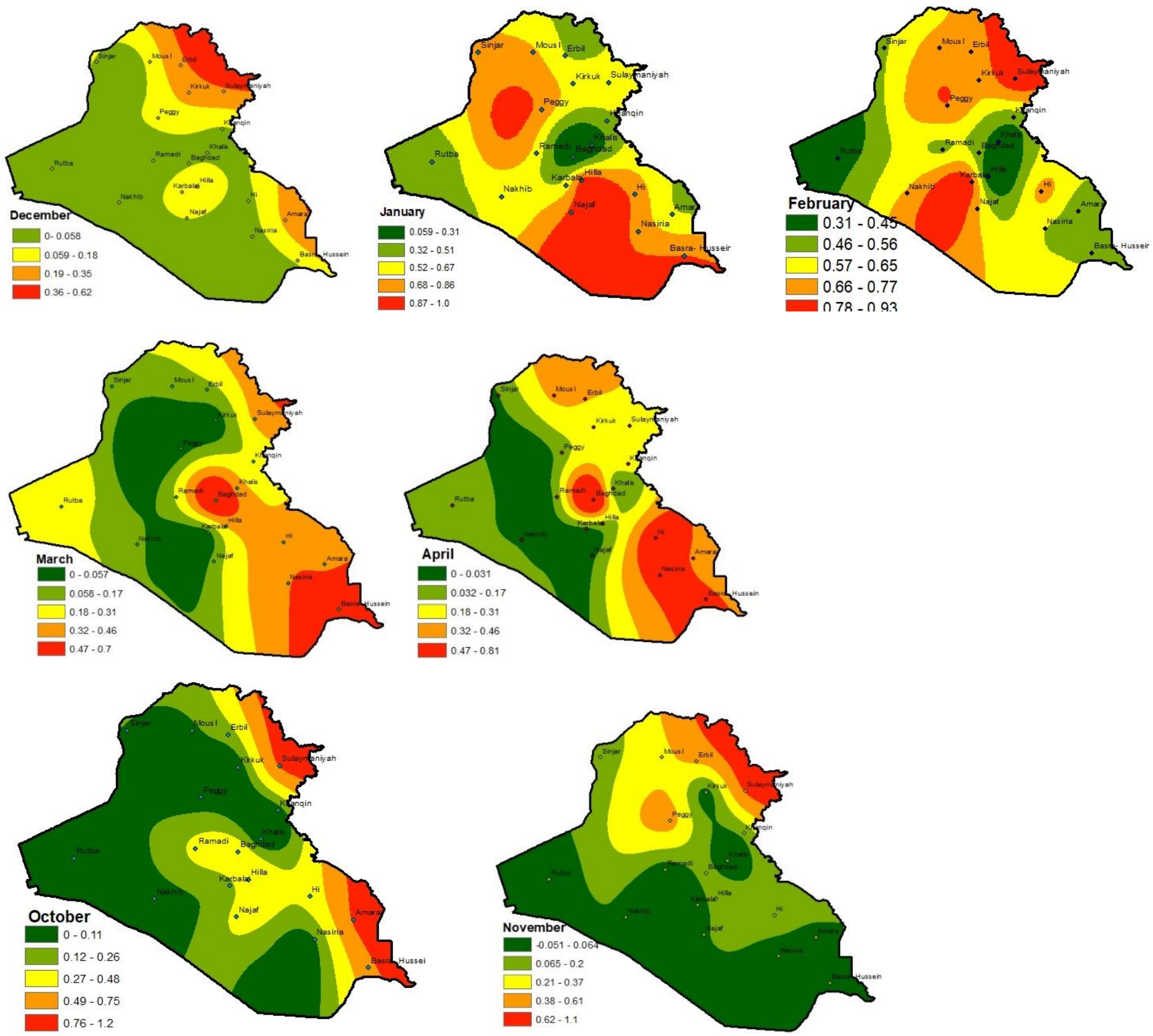
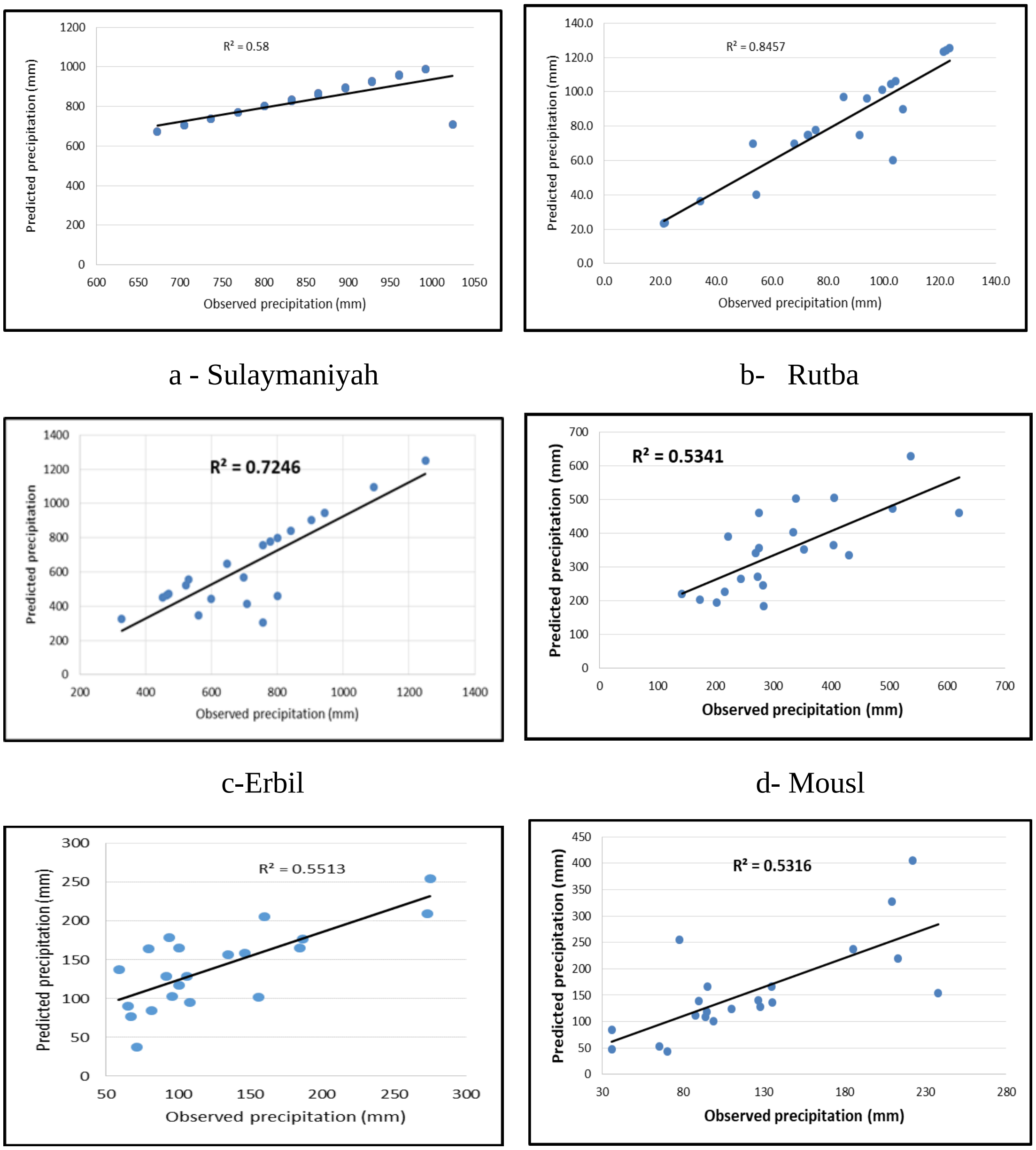


Figure (8): Statistical measure analysis (R^2) for all selected ground weather stations in each month

In Figure (8) , Statistical measure analysis (R^2) values ranged between 0.31 to 1 at January and February; 0.1 to 0.81 in March and April; on different terrains. While the results of admission in the fall season moved away in various terrains. This is due to a large number of clouds and dusty winds in the autumn season.

For the purpose of showing the extent of convergence of the values of precipitation between ground weather stations (Annual accumulated observed precipitation) and GPM (Annual accumulated predicted precipitation), statistical R^2 was determined within the acceptance value for some weather ground stations which represents a different topography, R^2 values were values ranged from (0.51 to 0.875), Figure (9) .



a - Sulaymaniyah b- Rutba

c-Erbil d- Mousl

e- Baghdad f- Basra- Hussein

Figure (9) : Relationship between observed precipitation and predicted precipitation.

In general, this study discovers that the GPM-IMERG data's accuracy rises when the average time scales are lengthened. This is comparable to what was discovered in other areas (Ramadhan , et.al.,2022). All recent researches demonstrate that IMERG data, both monthly and annually, have the highest accuracy, with correlations between (0.5 to 0.7), which is similar to those obtained in this study. The annual correlation values ranged (from 0.51 to 0.875). Another element that influences the accuracy is the distribution of weather ground stations in Iraq when data is utilized to calibrate IMERG data.

Uncertainty Analysis

The uncertainty analysis results are shown in Table (2), which shows the accumulated average of precipitation for the measured and predicted data with the difference between them.

Table (2) : Uncertainty Analysis between accumulated precipitation observed from Ground Stations and Accumulated precipitation predict from GPM

Ground Stations	Sulaymaniyah	Rutba	Erbil	Mosul	Baghdad	Basra-Hussein
Accumulated precipitation observed from Ground Stations	842.142	83.4	710	323.20	125.60	121.224
Accumulated precipitation predict from GPM	825.66	81.82	635	351.66	139.842	155.609
Differences (mm)	16.476	1.6	74.50	-28.45	-14.24	-34.38
Uncertainty Analysis						
t Stat	0.563	0.205	0.872	-0.756	-0.807	-1.449
P(T<=t) one-tail	0.28	0.419	0.194	0.227	0.212	0.078
t Critical one-tail	1.68	1.68	1.687	1.686	1.684	1.69
P(T<=t) two-tail	0.576	0.838	0.389	0.454	0.424	0.156
t Critical two-tail	2.024	2.02	2.026	2.024	2.021	2.034

With the results shown in Table 2, the decision is to accept the hypotheses theory, because the test values are within the acceptance region for all stations despite some different numerical differences between the measured and predicted data.

Conclusions

Estimating the amount of precipitation when using the applications of remote sensing sources is one of the important studies in providing data for terrestrial metrological systems. GPM satellite is considered one of the effective remote sensing products in estimating the amounts of precipitation, especially in Iraq. Ground weather stations are reliable sources in providing climatic data in the short and long term, but due to some exceptional circumstances that occur in those stations, they are closed for maintenance, which causes gaps in the data and alters perceptions of a shift in precipitation.

The statistical processing included two criteria to compare the predicted precipitation from the outputs of remote sensing and the outputs of weather ground stations, which are as follows: RSME and R2. The statistical validation included nineteen weather ground stations with different topography of Iraq. Based on the GPM -IMERG evaluation, the following conclusions can be summed up: the RMSE of the northern mountainous area was high, which may be related to the local complex terrain. Mountainous regions with complicated topography make satellite detection more challenging. Sometimes, the temperature and albedo of rough surfaces in mountainous places are similar to the albedo produced by precipitation, which causes confusion between the clouds that will rain and clouds that will not rain.

The findings of this study will be crucial for a number of applications involving climate monitoring and land-climate interactions. These applications include the hydrology of water resources, water needs for irrigation and agriculture, and the management of dam reservoirs, including the allocation of water quotas and others. Iraq has experienced recent environmental problems as a result of climate change. So it's important to monitor the real precipitation change. To do this, a sizable ground station network is required. The GPM IMERG product is a monthly precipitation. It indicates good compatibility with high-resolution earth stations, as indicated above in the results field. With the help of this connection, it is possible to obtain a more accurate estimate of the average daily true precipitation for any region in Iraq. . Future studies should be assessed for the GPM IMERG 60 min precipitation data using additional indices to obtain conclusions which are more complete, non-linear models or advanced ensemble models such as boosted regression trees may produce better estimation for precipitation.

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