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Integrated Approach for Land Surface Temperature Assessment in Different Topography of Iraq

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HIGHLIGHTS

- Analysis of Land Surface Temperature (LST) from ground weather stations in Iraq for various terrains.
- Analysis of the maximum, minimum, and mean LST as long-term series from remote sensing output data (2000 to 2020).
- Statistical Analysis (RMSE, NSE, R^2, and Parson Correlation Coefficient) have been used to evaluate Tmin, Tmax, and Tmean between ground weather stations and MOD11C3 products.

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ABSTRACT

Land Surface Temperature (LST) is a critical parameter for water resources and hydrology investigation. Weather ground stations provide a continuous dataset on the LST. However, some stations rely on discrete events data, which shows limited capabilities to monitor diurnal and annual changes in LST. Remote Sensing technology provided much valid information by using Moderate Resolution Imaging Spectroradiometer (MODIS) to cover LST variations in Iraq. This study aims to analyze LST variation based on MOD11C3 Data with weather ground measurements stations for the different topography periods between 2000-2020. Different statistical parameters were used to validate LST results, including RSME; NSE; R^2, and Parson Correlation. The results indicate agreement between MODIS and ground measurement stations during the winter season. The values ranged: RSME (close to zero); NSE (0 to 1); R^2 (between 0.5 and 1), and Parson Correlation (between 0.51 to 1).In spring, the values ranged: R^2 (between 0.5 and 1) and Parson Correlation (between 0.51 to 1). As the temperature rises during seasonal changes, the congruence in the four statistical indicators begins to decline dramatically. However, Baghdad, Basra, and Mosul stations still appear in good agreement, which is the validity of the data issued by MOD11C3. The finding presented in this research shows that the results of the LST by MOD11C3 are in good agreement and acceptable despite in various topographies of the ground stations.

1. Introduction

Climate and ecosystems are interdependent, with temperature and precipitation being one of the most significant meteorological elements. The distribution of flora, animal habitats, and biodiversity are crucially limited by temperature variations. Recent ecological studies, such as those on vegetation distribution, phenological phases, ecosystem productivity, and population migration in response to global climate change scenarios, have frequently included spatial and temporal climatic patterns as independent variables [1]. For various uses that impact people's lives and livelihoods, the availability of high-quality, long-term temperature records is crucial [2].

Meteorological data, such as air temperature, is critical for society's economic growth since they may anticipate multiple natural phenomena like precipitation patterns, storms, heat waves, or even tourism dynamics. Air temperature is significant because it is commonly employed in climate modeling, global change projections, and modeling of atmospheric, biosphere, and hydrosphere exchange processes. Different scientific disciplines (*e.g.,* Hydrology, agriculture, environmental and ecological evaluations, climate change, and associated social development) require accurate measurement of their spatial and temporal distribution dynamics [3, 4]. The distribution of weather stations has a significant impact on the precision and accuracy of interpolation algorithms. As a result, this strategy is difficult to achieve with few weather stations, specifically in developing nations and isolated areas [5, 6].

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Furthermore, ground-based station data cannot reflect the LST of a region due to rapid and continuous variations in LST on spatial and temporal scales. In other words, the resolution of measured data from stations becomes invalid for broad regions. One of the most promised sources of LST data with high spatial and/or temporal resolution is remotely sensed picture data [5].

Land surface temperature (LST) is the skin temperature of the earth's surface. LST is a crucial parameter in regional and global land-surface processing research. Environmental monitoring, hydrology, urban climate, urban heat island, and agriculture are just a few of the sectors where it's useful [5,7].

For example, the diurnal variation in temperature in Greece in 2008 was investigated using the regional temporal and spatial multi-temporal land surface temperature (LST) MODIS dataset and elevation data [8]. Kenawy et al. have shown a reasonable agreement between remotely sensed daytime and nighttime land surface temperatures (LST) for four seasons (winter, spring, summer, and autumn) obtained from the Aqua (MODIS) sensor and their comparable ground-based data[9]. Lai et al. have used the MODIS data set to obtain LST monthly for Taiwan as a reference to assess the monthly mean data set, so by enlarging the range of the study areas over a wide range to examine the application of MODIS over two continents and different topographical and climate-changing regions [1].

Farahat 2018 has been studied for a period between 2000 and 2015. MISR MODIS and AERONET AOD products are compared across seven AERONET stations in the Middle East and North Africa [10]. A recent report showed that Colombia needs to plan ahead for its productive ecosystems. Still, it presently lacks appropriate geographically dispersed field data for the air temperature at 2-m above ground level. , Therefore, LST from MODIS products is often used for studies in meteorology due to its ability for near real-time evaluations [11].

Similarly, Flores and Lillo 2010 emphasized in the study conducted in the Bío Bío Region, Chile, that the best estimate of air temperature from the atmosphere was obtained with profiles with the proposed modifications. When MODIS surface height was replaced by SRTM, 3.72 °C errors and improved determination were achieved compared to the original methodology [6].

Although research in deducing LST from MODIS is not limited to monthly monitoring, daily monitoring has played a major role in revealing the differences between the results of remote sensing and ground stations in the long term. Establishing a daily monitoring system for LST is quite challenging.

It needs a sufficient number of measuring stations, meteorological parks, and convenient logistics [12]. The urban heat island effect, land-atmosphere energy exchanges, and global climate change all benefit from accurate daily mean LST estimates sensors may deliver up to four instantaneous LSTs from across the world in a single day. However, many studies, such as those on climate change and hydrology, require daily mean LSTs rather than instantaneous values [13, 14]. Based on a long-term MODIS series in the agricultural pastoral ecotone of northern China (2003–2020), Wei et al.2021 evaluated the spatial, temporal, and trend aspects of LST on an annual and seasonal timeframe. Due to the absence of a systematic investigation on the application of MODIS-LST products in arid and semi-arid regions of China, the quality evaluation and reconstruction of LST, as well as the validation of accuracy, were done before [15]. To estimate the daily air temperature by using MOD11A1 product for years ranging from 2011 to 2012. The MODIS LST images used are projected on a sinusoidal grid with a resolution of 1 km (exactly 0.927 km) and were derived from the two thermal infrared bands, band 31 (10.78-11.28 μm) and 32 (11.77-12.27 μm [16,17,18].

Shah et al. studied the possibility of using LST and normalized differential vegetation index (NDVI) products from the (MODIS) sensor, as well as air temperature data from automatic weather stations (AWS) in Gujarat, to derive the spatial distribution of minimum and maximum air temperatures [19].

Lin et al. used MODIS applications to present a gradually linear regression method in many variables (Low-level perceptible water content, solar zenith angle, and vegetation index (NDVI and EVI)) to clarify the factor affecting the temperature mismatch between MODIS and the ground stations [20]. Song et al., 2018 explained a strong correlation between the NDNI and the LST [21].

Recently, the earth's topography is a critical factor that has been studied, highlighting thermal changes from the applications of MODIS. Li et al. used downscaling with machine learning algorithms, including artificial neural networks (ANN), to evaluate the machine learning algorithms in MODIS LST Spatial Downscaling in multiple topography for Beijing city areas. A similar investigation focused on evaluating the temperature on different terrains [22]. Yang et al. used MODIS to monitor air temperature over four seasons.

The results were verified using statistical analysis Findings revealed a good agreement between MODIS results and the real-time data, except for some differences in mountainous areas due to the change in the density of the air layer [23]. Furthermore, topography and station geometry elevation aspects impair interpolation accuracy, particularly in high places [24]. Weather stations are used to measure the minimum and maximum air temperatures. However, these measures lack sufficient spatial density, making them challenging to utilize in real-time applications. Therefore a one-possible solution is satellite imagery can be used to compensate for the absence of information [19].

Moderate-resolution spectroradiometer (MODIS) is a key instrument aboard the Terra and Aqua satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS scan the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands or groups of wavelengths. These data will improve our understanding of global temperature dynamics and processes occurring on the land, in the oceans, and the lower atmosphere. MODIS is playing a potential role in the development of validated, global, interactive ability to predict global change accurately enough to assist policymakers in making sound decisions concerning the protection of our environment; understanding the temporal and geographical fluctuations of land surface temperature (LST) in Iraq is crucial for figuring out how temperature affects agricultural output; remote sensing technologies can swiftly collect information on surface temperature, clouds and rainfall have a significant impact [25]The MODIS observations are an important source for the study of the climate, vegetation, pollution, and various meteorological phenomena. They are stored in a hierarchical data format (HDF) to facilitate sharing of this scientific data on different platforms. Previous studies on LST focused mainly on seasonal or daily studies, with the lack of research that dealt with the monthly aspect and the spatial selection of different topography in Iraq. Therefore, this study will explain LST evaluation's temporal and spatial change from one of the MODIS outputs with the weather ground stations.

This study aims to evaluate the performance of monthly LST with three types (Tmin, Tmax, and Tmean) in different topographical locations in Iraq by comparing them with data records for nineteen selected weather ground measurement stations. To validate LST performance, MOD11C3 was used as one of the outputs of remote sensing, which is also combated with ground weather stations. Temperature estimates are evaluated monthly and validated using four statistical measures for each station and over each month of the year for the long-term period (2000-2020). In addition, RSME, NSE, $R^{2,}$ and Parson Correlation were used to verify the linear best fit between estimated MOD11C3 outputs and the measured data from weather ground stations.

2. Materials and Methods

2.1 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. From the north, Iraq is bordered by Turkey. Iran, Syria, and Syria, from the east, and the west, Saudi Arabia, and Kuwait. Iraq may be classified into four geographical areas based on the type of topographical landscape: Mountain Region, Plateau and Hills Regions, the Mesopotamian plain, and Jazera and Western desert [26], Figure 1.

The topography of the study area was simulated using Digital Elevation Model (DEM), 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). This data has been processed by CIAT to give an actual topography that is smooth surfaces areas where no data in the original SRTM data have been highlighted using interpolation methods described by Reuter et al. [27].

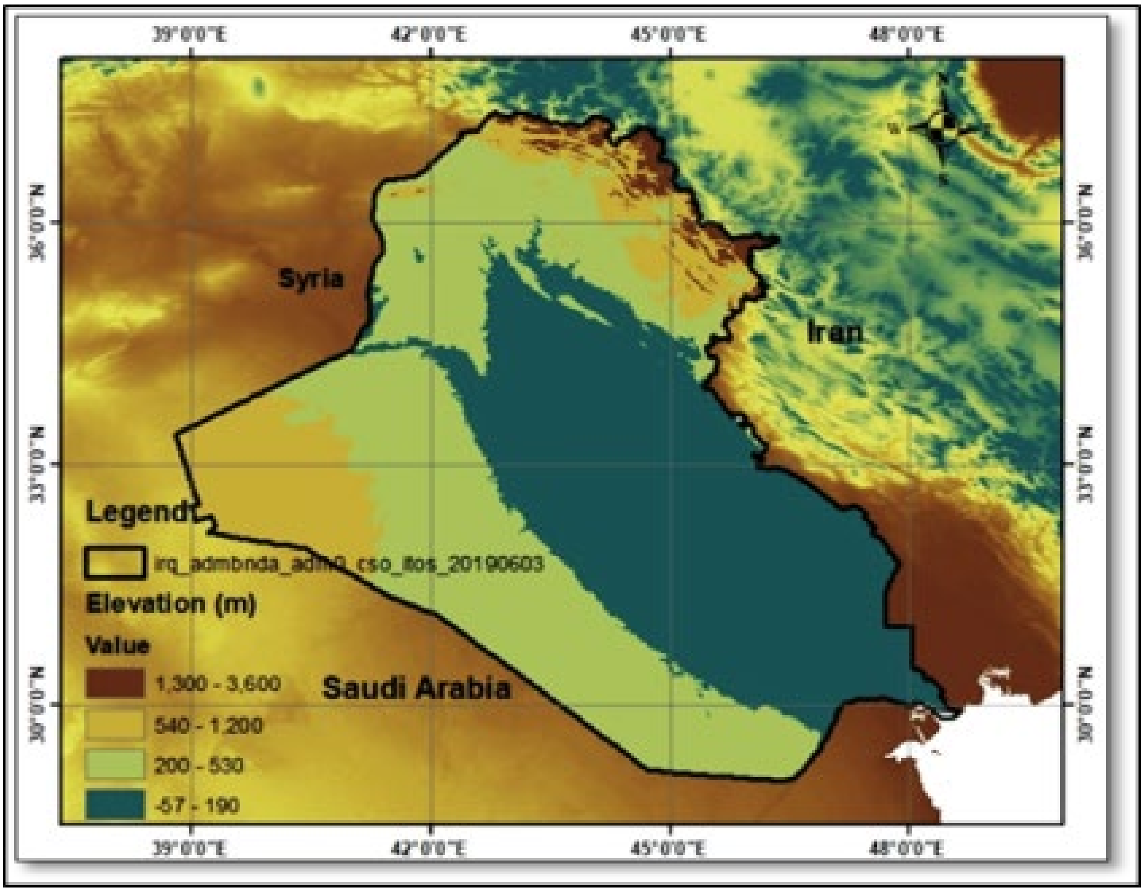


Figure 1: Topography of Iraq and its location within the world

2.2 Data Collection

2.2.1 Meteorological data

The climate of Iraq is predominantly 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 frost potential. On the other hand, the summer season is extremely hot, with an average temperature of above 45°C.In July and August, the temperature drops to 25°C at night [26]. The monthly ground surface temperature and dataset (2000-2020) were obtained from Iraqi Metrological and Organization Seismology [28]. However, Ground weather stations are distributed over all the governorates of Iraq as follows: in the airports, areas of dam reservoirs, some agricultural projects area, some buildings for research lands, and others. Therefore, the random distribution of ground measurement stations is not subjected to the standard spatial distribution that achieves standard climatic information about the study area. However, this could be statistically useful as a random block design to interpret the findings presented in this study. The terrestrial ground stations were classified according to their altitudes within the topographic map of Iraq, Figure 2 and Table 1.

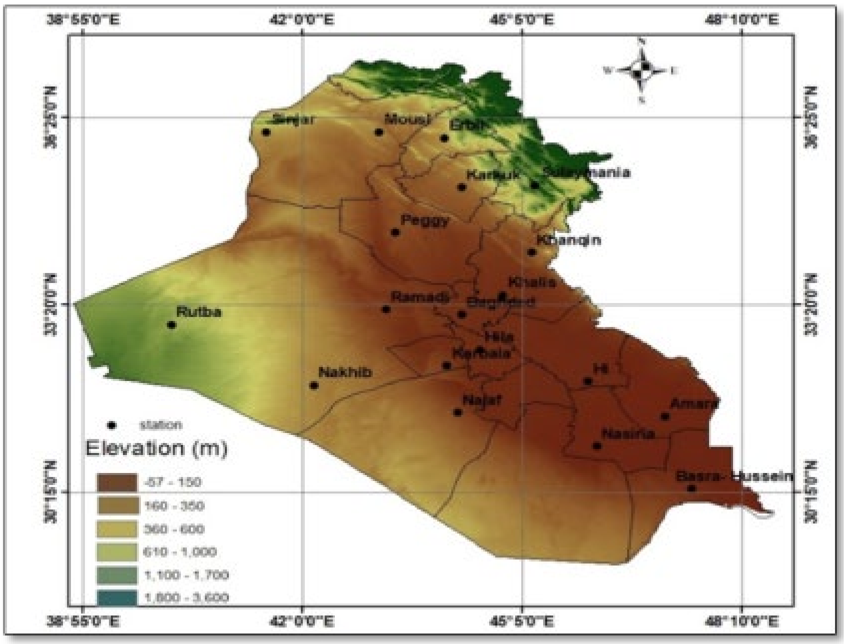


Figure 2: Spatial distribution of weather ground station within this study)

Table 1: Locations of weather stations according to the topography of Iraq

Topography Region-Name	Elevation Topography Region meter above sea level (m.a.s.L)	Station	Station Elevation meter above sea level (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	420
		Kirkuk	331
		Mosul	223
		Nakhib	305
		Sinjar	538
		Khanqin	202
The Mesopotamian plain,	-57-190	Hilla	27
		Najaf	53
		Karbala'	29
		Khalis	44
		Ramadi	48
		Amara	9.5
		Basra- Hussein	2
		Hi	17
		Baghdad	31.5
		Nasiria	5
		Peggy	115.5

2.2.2 Modis data

The monthly MODIS Land Surface Temperature LST dataset (MOD11C3 Monthly CMG LST) from 2000 to 2020 was collected from the MODIS data website [29]. This LST product provides monthly composited and averaged temperature and emissivity values at 0.05-degree latitude/longitude grids (CMG), as well as the averaged observation times and viewing zenith angles for daytime and nighttime LSTs. In a calendar month, the temperature and emissivity values in the MOD11C3 product are simply composited and averaged. The days and nights in clear-sky conditions and with validated LSTs are flagged in each bit of two 32-bit unsigned integers (one for daytime LSTs and another for nighttime LSTs).

The HDF file of MOD11C3 product comprises the following Science Data Set (SDS): layers for daytime and nighttime observations LSTs, quality control assessments, observation times, view zenith angles, clear sky coverage, and bands 31 and 32 of emissivity from land cover types [16].

Three ECS global attributes and 16 product-specific global attributes are stored as metadata. The ECS global attributes, CoreMetadata.0, ArchiveMetadata.0, and StructMetadata.0 are stored as long character strings in PVL format. CoreMetadata.0 contains information about the product during production and is used to populate the EOSDIS database for user support [16].LST retrieved from MAS data using the generalized split-window LST algorithm agrees with field measurement LST values within 1°K. Beta-3 version of the MODIS LST code based on the split-window algorithm was delivered to the MODIS Science Data Support Team [17]. Wind speed and highly reflecting surfaces in the visible and near-infrared domains, as in the case of the region covered by MODIS LST, disturb the accuracy of the MODIS LST output.

This study analyzes both local attributes LST_Day_1km and LST_Night_1km. It involved processing MODIS data and Geographic Information System (GIS) using the following steps:

- Deduction of the study area part from among the countries of the world using (Arc Toolbox /Spatial Analyst Tool/Extraction /Extract by Mask).
- Convert the temperature from Kelvin to Celsius by multiplying it by a coefficient (Raster *0.02-273).
- Adjust formats: color, page settings, and map key, in addition to highlighting contour lines and Legend.

2.3 Statistical Analysis

Four 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[30], Equation (1):

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

where: P is LST predicted value for MOD11C3; O is LST observed value for the ground weather station; i is a numerical census of the years from 2000 to 2020 per month.

2- The Nash–Sutcliffe Efficiency index (NSE) is frequently used to validate statistics for evaluating the goodness of fit of climate data derived from remote sensing applications [31]. However, there is no mechanism for measuring the statistical significance of sample values. Furthermore, the mechanisms contributing to low sample results are poorly understood (a). The (NSE) index is [31]:

$$NSE= \frac{\sum_{i=1}^{n}(o_i - \bar{o})^2 - \sum_{i=1}^{n}(p_i - o_i)^2}{\sum_{i=1}^{n}(o_i - \bar{o})^2} \qquad (2)$$

where: $\bar{o}$ LST is the average observed value for the ground weather station.

3-The coefficient of determination (R^2) 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 [30]:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(o_i - \bar{o})(p_i - \bar{p})}{\sqrt{\sum_{i=1}^{n}(o_i - \bar{o})^2} \sqrt{\sum_{i=1}^{n}(p_i - \bar{p})^2}} \right] \qquad (3)$$

4- Pearson's Correlation Coefficient measures the intensity of the linear association between variables. The term correlation is used in the context of a linear relationship between 2 continuous variables and expressed as Pearson product-moment correlation. The Pearson correlation coefficient is typically used for jointly normally distributed data (data that follow a bivariate normal distribution [32]:

$$r = \frac{\sum(o_i - \bar{o})(p_i - \bar{p})}{\sqrt{\sum(o_i - \bar{o})^2 \sum(p_i - \bar{p})^2}} \qquad (4)$$

The statistical criteria described above differ in the values of good agreement and poor agreement of LST between weather stations and MODIS products. The value of acceptance in RSME is close to zero, NSE is greater or equal to 0.5, and R^2 is greater than 0.5, as in r. Acceptance and unacceptance values are detailed in Table 2. The match between the ground stations and MODIS products is considered good and acceptable when the acceptance rate is achieved for two statistical indicators.

Table 2: Statistical Indexes and Acceptable, Unacceptable Range

Statistical Index	Range	Acceptable Range	Unacceptable Range
Root Mean Square Error(RSME)	0 to 1	Close to 0	Greater value
The Nash–(Sutcliffe Efficiency index (NSE)	-∞ to 1	close to 1	< 0
The coefficient of determination (R^2)	0 to 1	> 0.5	< 0.499
Pearson's Correlation (r)	+1 to -1	Closer to +1	< 0

3. Results and Discussion

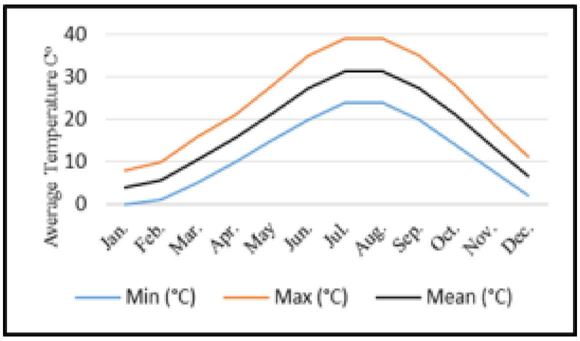
3.1 Meteorological Data

Monthly Land Surface Temperature (LST) was studied in three terms which are: Minimum Temperature (Tmin), Maximum Temperature (Tmax), and Tmean for the period (2000-2020). Ground weather stations provided the study in Tmin Tmax and Tmean data from Iraqi Metrological and Organization Seismology[28].

Tmin at nighttime, Tmax in the daytime, and Tmean average product of minimum and maximum temperature were employed in this study to provide clarification on data on temperatures obtained from ground stations. Due to the lack of data from some stations, a linear approximation method was performed to retrieve missing data on an average monthly for 21 years. The average mothy LST for the period (2000-2020) at weather ground stations of the topography region is shown in Figures (3, 4, 5, and 6), ordered by decreasing latitude.

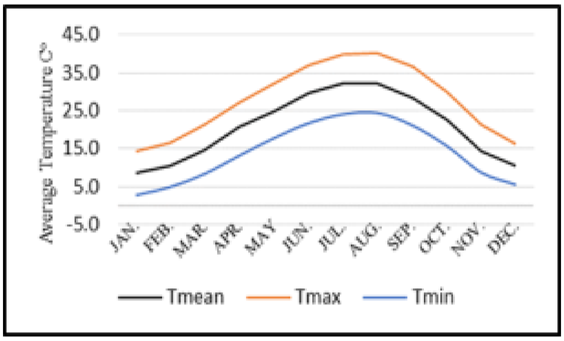
Figure 3 shows the average monthly Tmin Tmax, and Tmean for the mountain Region Sulaymaniyah Station described it. The average temperatures regularly ranged from 6°C in winter to 32 °C in summer; from 15 °C in spring to 17 °C in autumn. Plateau and Hills Region was covered in LST by Rutba Station. The average temperatures ranged around 10 °C in winter and 40 °C in summer; reached 20.5 °C in spring, and reached 22 °C in autumn, Figure 4 .

LST was determined in Jazera and Western Plateau by the isothermal lines of the stations Erbil, Kirkuk, Mosul, Nakhib, Sinjar and Khanqin, Tmin Tmax and Tmean are approximately equal in this region, the following stations: Erbil, Kirkuk, Khanqin, and Mosul are shown in Figure 5. The average temperature in general, Tmean in the Jazera region for the winter, approaches 12.5 °C to 45 °C in summer, 16.8 °C in spring, and Tmean gradually increases significantly in the fall to 25 °C in autumn. While the Tmean rose to 47.5°C in the summer season;12.5°C in winter; 27 °C in spring, and 28 °C in autumn for the Mesopotamian plain, these approximations were obtained from the following stations: Hilla, Najaf, Karbala', Khalis, Ramadi, Amara, Basra- Hussein, Hi, Baghdad, Nasiria and Peggy, their locations are shown in the Figure(2). All details for average Tmin Tmax and Tmean to 21years were explained by selected stations (Ramadi, Basra- Hussein, Hi, and Baghdad)described in Figure 6. From the above, it is understood that the average temperature increases whenever the trend is from the north to the south of Iraq. This expression is caused by the decrease in ground levels and the lack of water bodies and cultivated areas, which causes a reduction in the air temperature.



Sulaymaniyah Station

Figure 3: Average monthly (Maximum, Mean and Minimum) Air Temperature °C in Mountain Region



Rutba Station

Figure 4: Average monthly (Maximum, Mean and Minimum) Air Temperature °C in Plateau and Hills Region

3.2 Land Surface Temperature Analysis From MOD11C3 Product (MODIS Data)

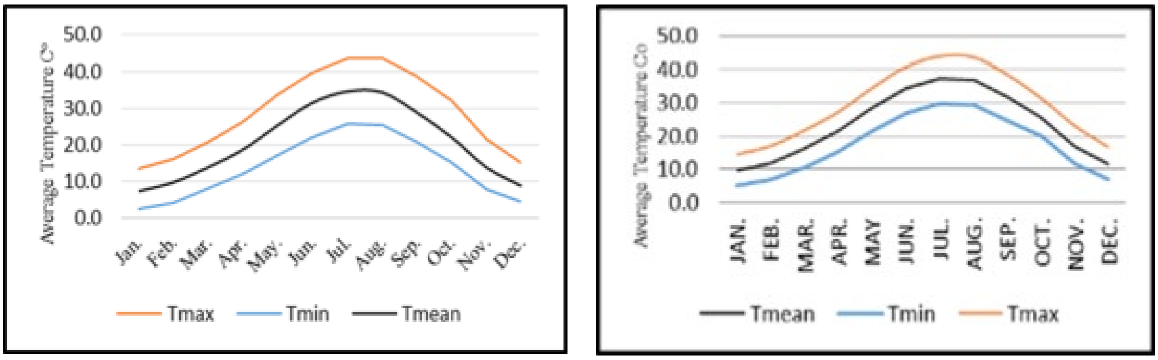
The output HDF file created by MOD11C3 was utilized to use two layers from seventeen layers. The first layer represents the maximum temperature, which represents the temperature during the day; the minimum temperature, which indicates the temperature at night. HDF Files have been processed by Arc GIS software to get a clear monthly temperature change for all study years .

Unfortunately, the number of prepared maps is 252, and it is impossible to include all maps in the research paper due to the limited number of pages. However, the monthly thermal variation of the maximum and minimum temperatures for the year 2020 has been illustrated in Figures (7 and 8).

Figure 7 exposes the observed LST at nighttime which Tmin represents for four seasons. As depicted, the observed Tmin shows a clear spatial gradient from north to south, the lowest temperature recorded in the Sulaymaniyah Station (which is represented in Mountain Region).

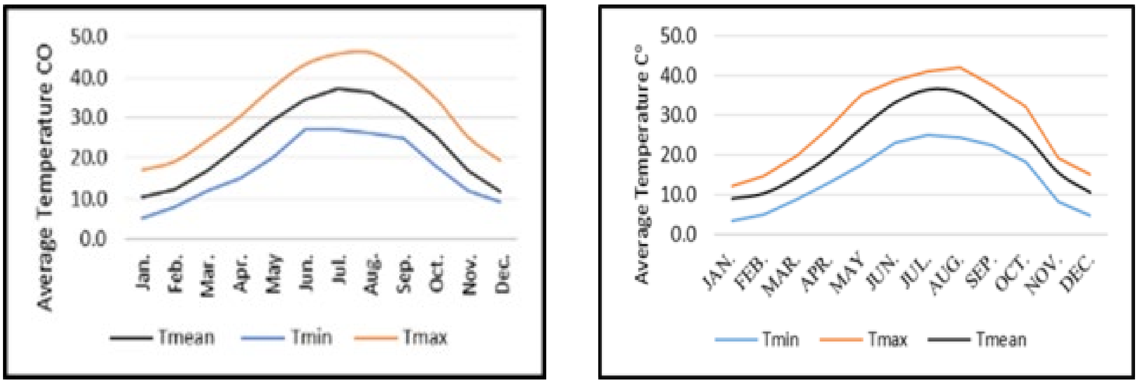
The temperature for the winter months of 2020 reached :(3.5°C in December, -4.5 °C in January, and -1.4 °C in February). Knowing that there is a lower degree Celsius in the region with the highest altitude recorded in the Sulaymaniyah station, as shown in Figure 7.

In contrast, the highest Tmin reached 38 °C in July in the summer season for the Mesopotamian plain. Based on these previous details, LST nighttime extracted from the MOD11C3 was decreased by increasing the elevation of the ground levels.



Mosul

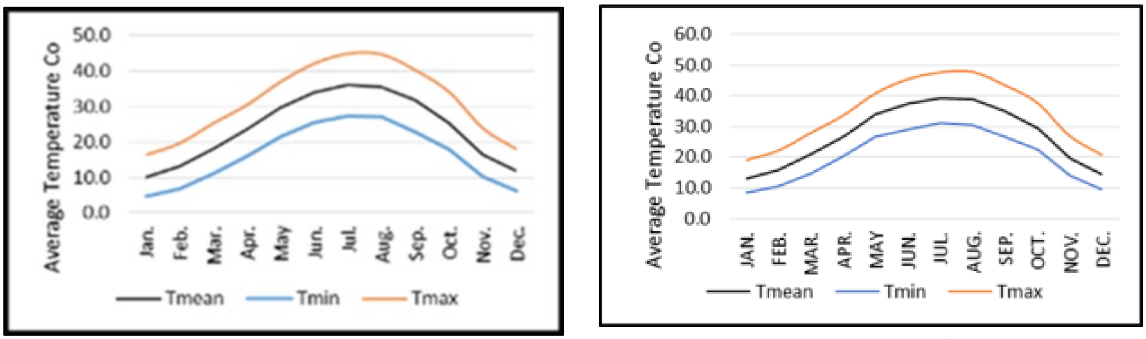
Kirkuk



Khanqin

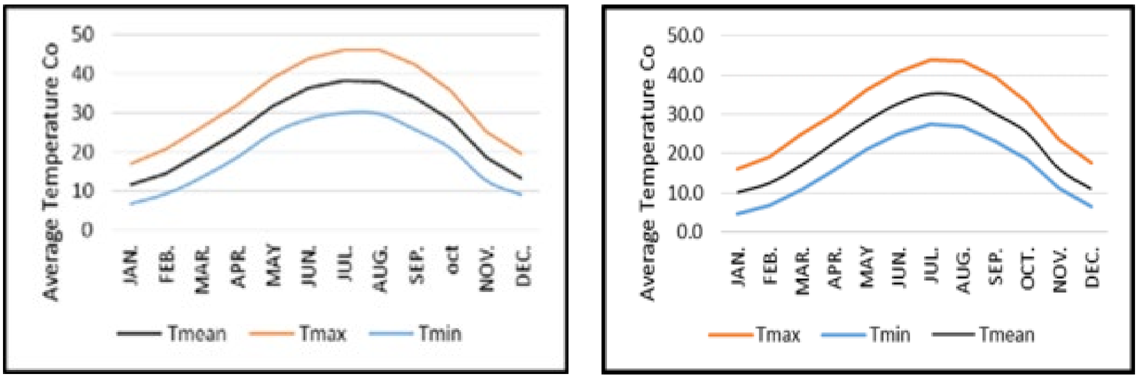
Erbil

Figure 5: Average monthly (Tmin Tmax and Tmean) Air Temperature °C in Jazera and Western Plateau



Baghdad

Basra- Hussein



Hi Ramadi

Figure 6: Average monthly (Tmin Tmax and Tmean) Air Temperature oC in The Mesopotamian plain

Figure 8 illustrates the observed LST daytime, represented by Tmax, the spatial patterns of Tmax captured well, as high LST was seen in the majority of Iraqi territory in all seasons, and the observed Tmax shows a clear spatial gradient from north to south. The highest daytime temperature ever recorded in the summer (>55°C in June, >60°C in July, and 57°C in August) in the Jazera and Western Plateau and the Mesopotamian plain. In the winter season, Tmax decreased dramatically from 17°C to 12.5 °C over the whole of Iraq. However, the highest daytime LST was observed in the south-center region from March to June. This indicates that elevation influences LST and other factors, such as land use/cover. In general, the increase in temperatures in urban areas can be explained by a large number of cars and carbon dioxide emissions, the lack of green spaces in urban areas, and the causes of climate change affecting Iraq.

The daytime and nighttime differences indicate that the topography had a higher influence on the nighttime LSTthan the daytime LST. In addition, the different LST between high and low elevations varied across different months and different times of the day. The region that deviated and did not fall within the calculations is the region with altitudes more than 1300m due to the absence of ground weather stations from the mountainous area, where the lowest LST was recorded in the Tmin and Tmax. After reviewing the maps produced by MODIS, they were organized, and a monthly average was extracted for the period 2000- to 2020, as shown in Figures (9, 10, 11, and 12.)

Figure 9 shows the average monthly Tmin Tmax and Tmean for the Mountain Region in which Sulaymaniyah Station was described by MOD11C3. The average temperatures regularly ranged around 7.8 °C in winter to 33 °C in summer, from 17.5C° in spring to 17.9C° in autumn. Plateau and Hills Region was covered in LST by Rutba Station, as shown in Figure 10. The average temperatures ranged around 11.1 °C in winter, 39.2 °C in summer, 23 °C in spring, and 25 C° in autumn, as shown in Figure 10.LST was determined in Jazera and Western Plateau by the isothermal lines of the stations: Erbil, Kirkuk, Khanqin, and Mosul. Tmean is approximately equal in this region for the winter approach to 10 °C in winter to 39 °C in summer; 20 °C in spring to 27 °C in autumn, Figure 11.

While the Tmean rose to 46.5°C in the summer season and 13.5 °C in winter;25.5 °C in spring and 30 °C in autumn in the Mesopotamian plain, all details for average Tmin Tmax and Tmean to 21years were explained by the selected station (Ramadi, Basra- Hussein, Hi, and Baghdad) described in Figure 12.

Depending on the method of explaining the monthly rates of Tmean extracted from ground weather stations and MOD11C3 outputs in this section, this study gives the differences between ground weather stations and MOD11C3 outputs for the different topography of Iraq in Table 3. As illustrated, nighttime LST exhibited good agreement with the seasonal Tmean. Overall, the Tmean (from the weather ground station) tended to underestimate Tmean (MOD11C3) for most of the year. The differences in Mountain Region reached +1.8 in winter, +1 in summer,+2.5 in spring, and +0.9. This is a good value for high-altitude areas [7]. The difference values continue with the same acceptance for Plateau and Hills Regions ,while negative and positive values appear for the values in Jazera and Western Plateau. This is evident in the summer, with -6°C in summer and +3.5 °C in spring. Whatever the case, the values of the differences in the Mesopotamian plain were good.

3.3 Statistical Measures Analysis for Land Surface Temperature

Statistical Package for the Social Sciences (SPSS) was used to estimate four statistical measures in this study. Below twelve tables for each month showed the change in the values of the selected statistical measures in this study: (RSME), (NSE) and R^2. The results of the three statistical measures for all stations are illustrated with charts in Figures (13, 14, and 15)

Figure 13 illustrates for nineteen ground weather measurement stations the result of statically measuring RSME by three levels of significance: Tmin Tmax and Tmean. As shown in Table 2, the RSME acceptance values must be close to zero, and therefore it is established that values greater than 0.5 are not acceptable. The degrees of admission are divided according to the seasons as follows:

- In winter(December, January, and February), RSME values reached approximately (<0.4 for all stations expects Rutba, Nakhib, Khanqin, Karbala' and Khalis, which are distributed over different topographical regions)
- In spring (March, April, and May), RSME values reached approximately >0.5, as illustrated in Figure 9. However, some stations have achieved compatible values for RSME most stations due to cloud cover and dusty winds because Iraq is one of the arid and semi-arid regions.
- In summer (June, July, and August), RSME values started to stray a lot from the accepted values for Tmax for all stations except some ground stations that violated the non-conformity by giving a good degree of acceptance based on the statistical criteria, which are: Baghdad and Basra– Hussein, fall within the Mesopotamian Plain; Mosul, fall within the Jazera and Western Plateau; Sulaymaniyah fall within Mountain Region.
- In Autumn, RSME values reached approximately >0.5, as illustrated in Figure 9 in Tmax but get good significance in Tmin.

Table 3: The values differences between Tmean (weather Ground station) and Tmean (MOD11C3)

Topography Region-Name	Seasons	Tmean (weather Ground station) (°C)	Tmean (MOD11C3) (°C)	Differences (°C)
Mountain Region,	Winter	6	7.8	+1.8
	Summer	32	33	+1
	Spring	15	17.5	+2.5
	Autumn	17	17.9	+0.9
Plateau and Hills Regions	Winter	10	11.1	+1.1
	Summer	40	39.2	-0.8
	Spring	20.5	23	+2.5
	Autumn	22	25	+3
Jazera and Western Plateau	Winter	12.5	10	-1.5
	Summer	45	39	-6
	Spring	16.8	20	+3.5
	Autumn	25	27	+2
The Mesopotamian plain,	Winter	12.5	13.5	+1
	Summer	47.5	46.5	+1
	Spring	27	25.5	-1.5
	Autumn	28	30	+2

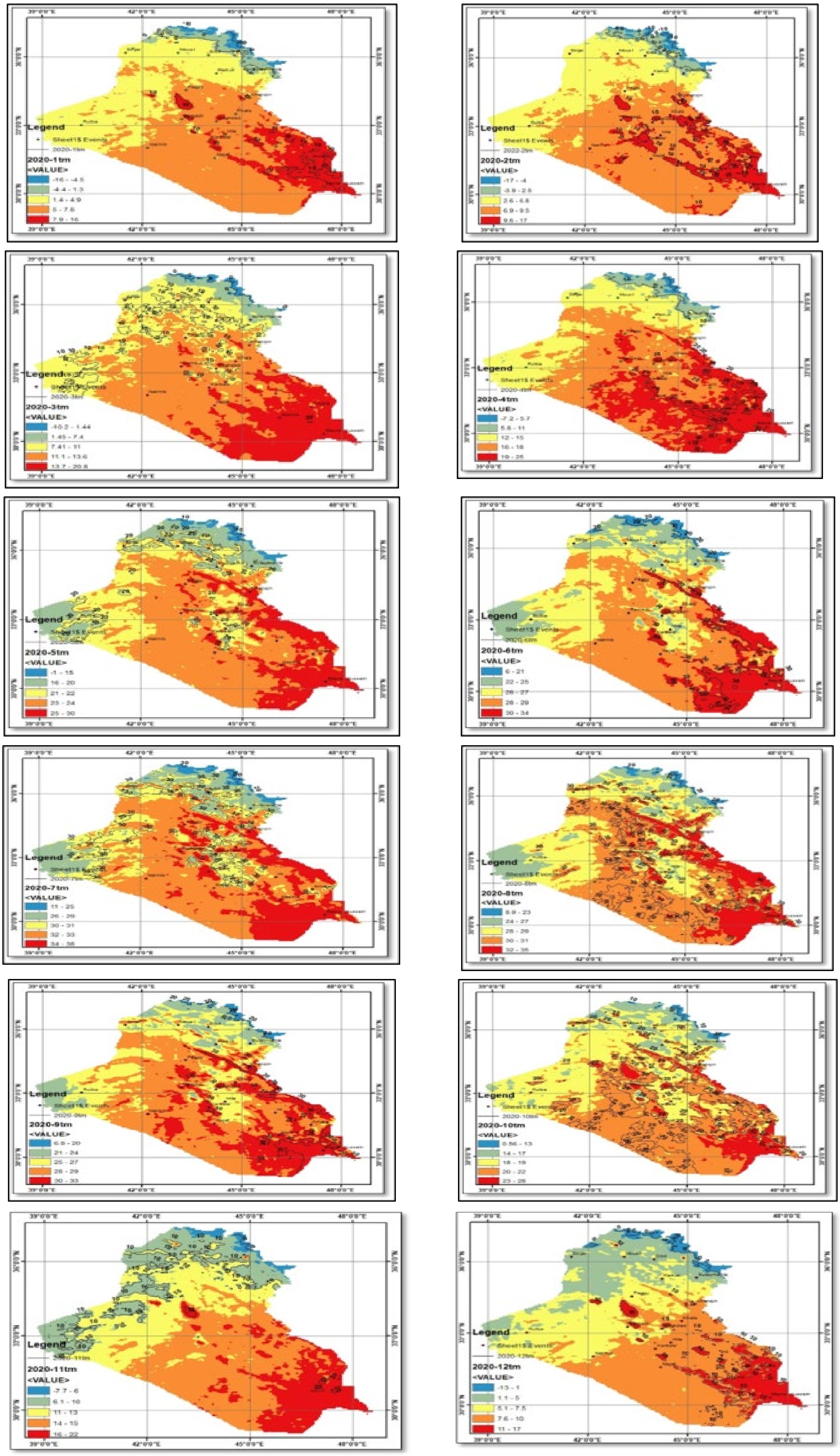


Figure 7: LST (Night) Time- Series illustrate Tmin in MOD11C3 for the year 2020

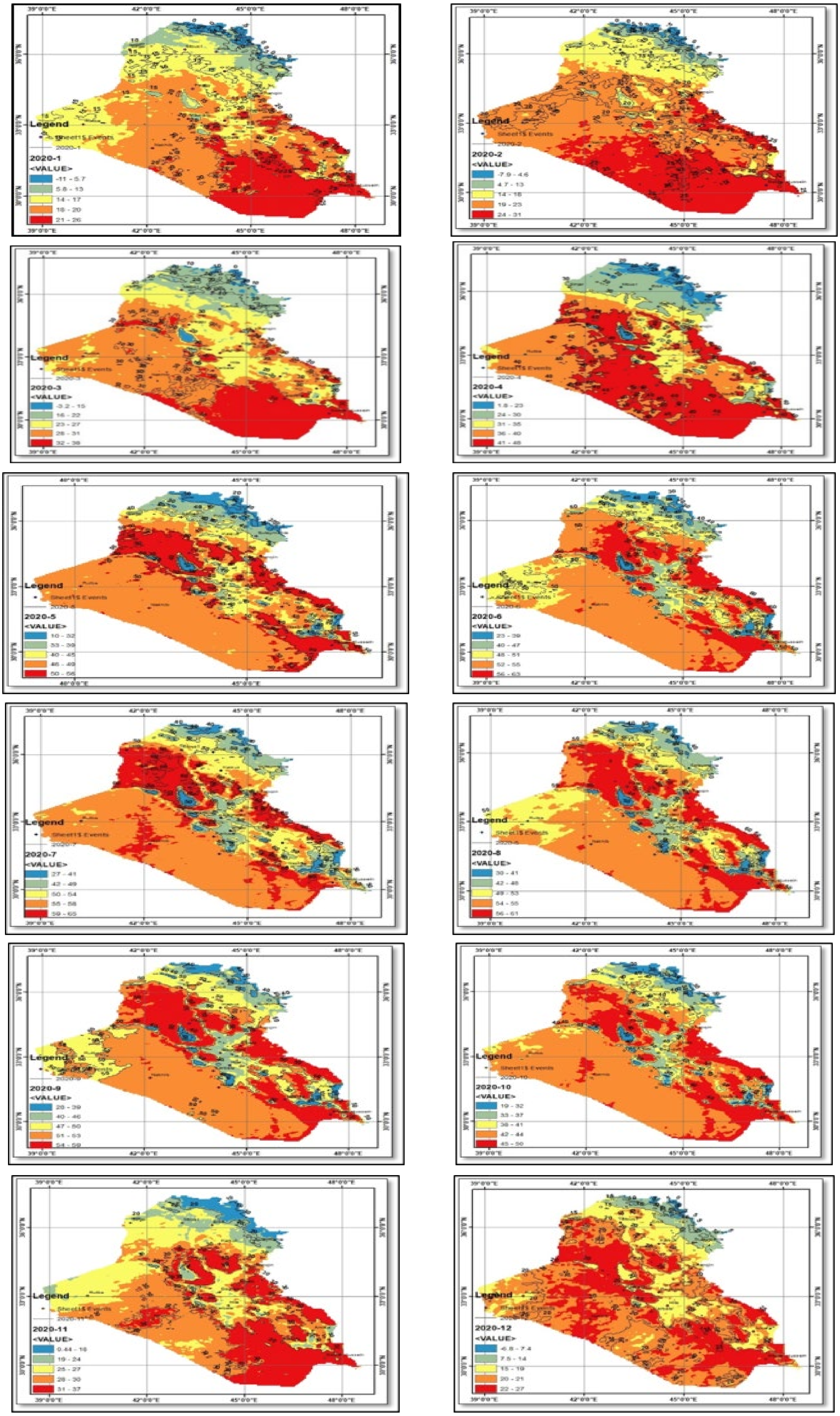
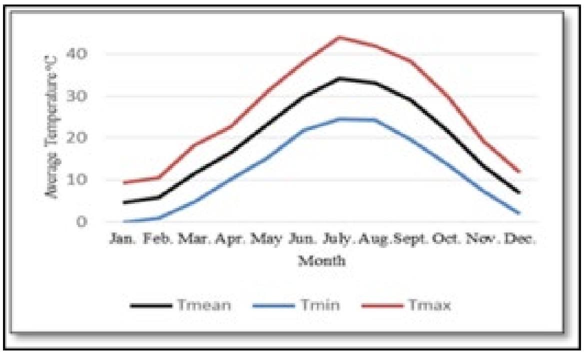
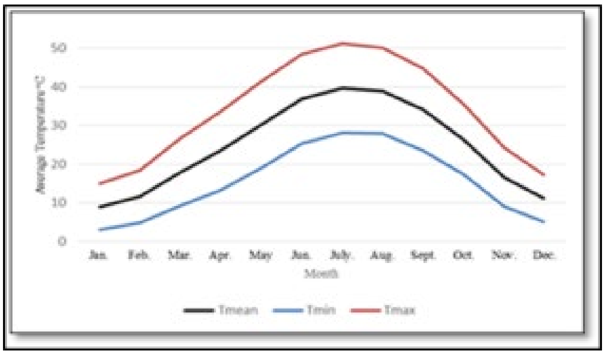


Figure 8: LST (Day) Time- Series illustrate Tmax in MOD11C3 for the year 2020



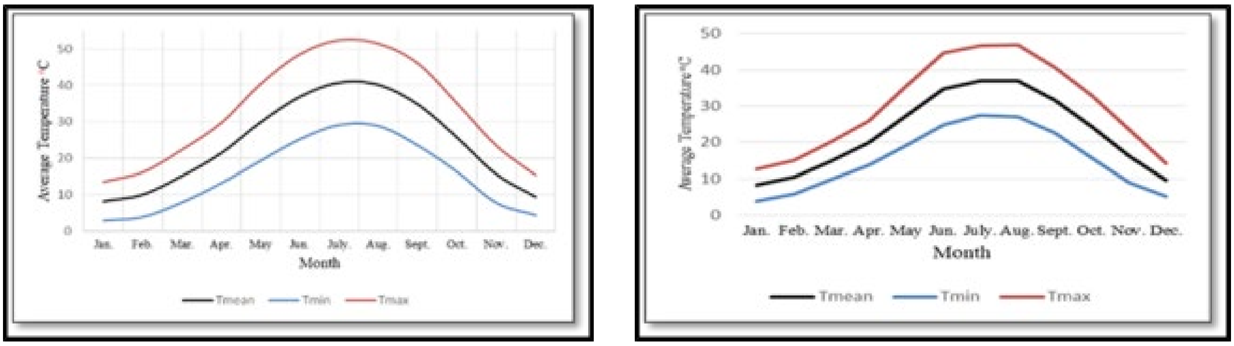
Sulaymaniyah Station

Figure 9: Average Air monthly Temperature (MOD11C3) °C



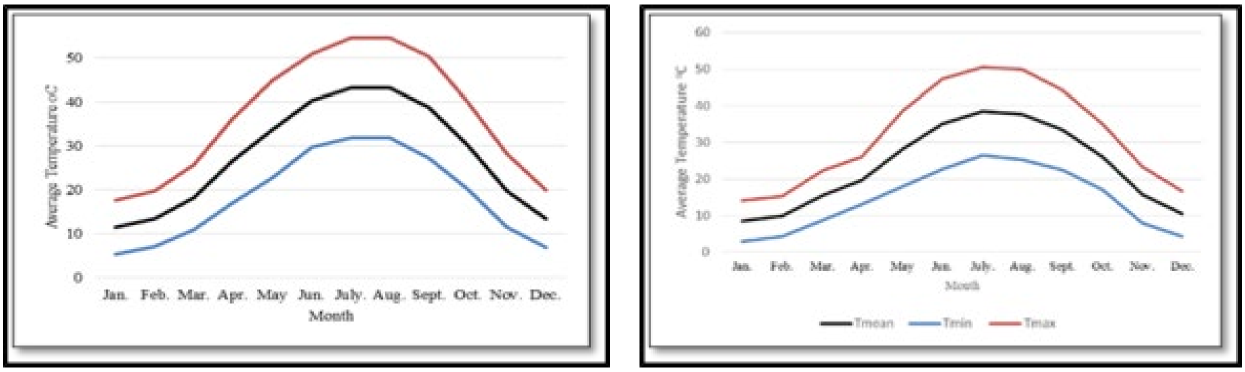
Rutba Station

Figure 10: Average monthly Air Temperature (MOD11C3) °C



Mosul

Kirkuk



Khanqin

Erbil

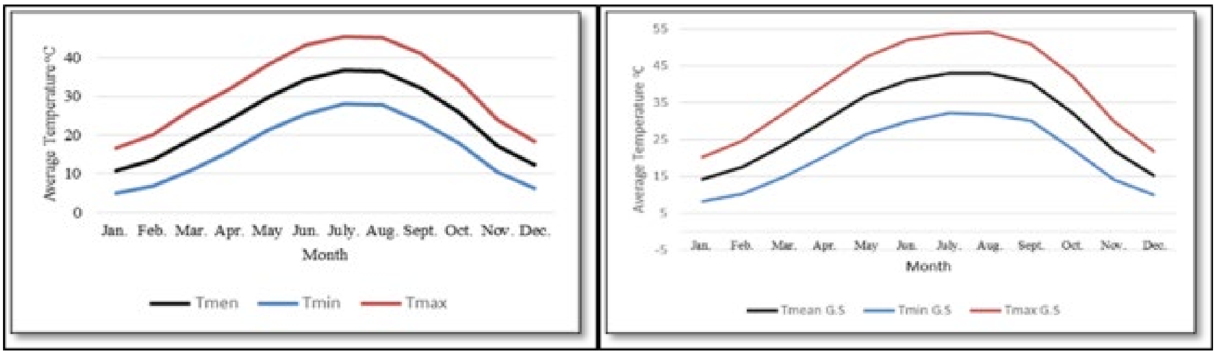
Figure 11: Average monthly Air Temperature (MOD11C3) °C in Jazera and Western Plateau

Figure 14 illustrate for nineteen ground weather station the results of statically measured NSE by three levels of significance: Tmin Tmax and Tmean. As shown in Table 2, the NSE acceptance values must be close to 1, and therefore, values greater than 0.5 are acceptable. The degrees of admission are divided according to the seasons as follows:

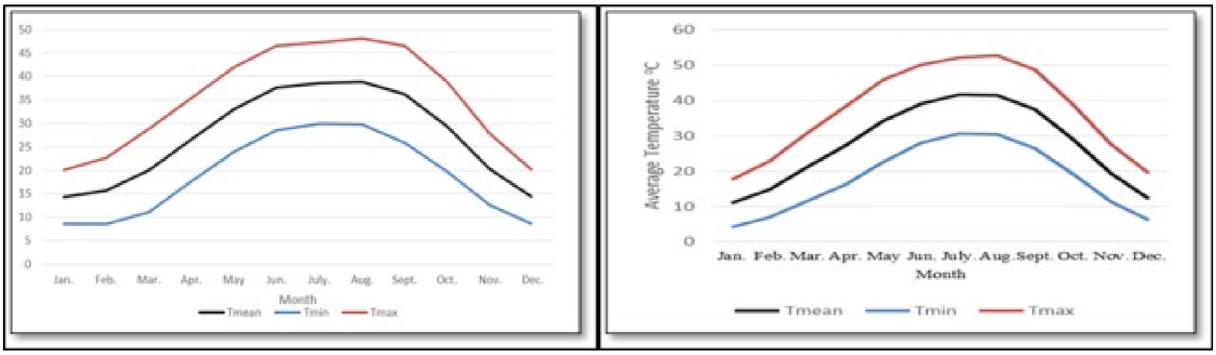
- In winter, Statistical criterion (NSE) for Tmin and Tmax values reached approximately (0.78 to 1) in December ;(0.64 to 1) in January, and (0.54 to 1) in February for all stations except Khanqin, Khalis Nasiria, and Karbala', which they had some negative values, which indicate that the Tmin Tmax
- from MOD11C3 product and the ground stations did not match during these months.
- In spring (March, April, and May), NSE values reached approximately between 0.42to >0.98 in Tmin but Tmax was directed in a negative direction, as illustrated in Figure 10. However, some stations have achieved

compatible values for NSE for most stations due to cloud cover and dusty winds because Iraq is one of the arid and semi-arid regions.

- In summer (June, July, and August), NSE values started to stray a lot from the accepted values for Tmax and Tmin for all stations except some ground stations that violated the non-conformity by giving a good degree of acceptance (RSME in the summer season) based on the statistical criteria, which are: Baghdad and Basra–Hussein, fall within the Mesopotamian Plain; Mosul, fall within the Jazera and Western Plateau; Sulaymaniyah fall within Mountain Region.
- In autumn, NSE values reached approximately RSME values >0.5, as illustrated in Figure 9 in Tmax but get good significance in Tmin.



Baghdad Basra- Hussein



Hi Ramadi

Figure 12: Average monthly (Tmin Tmax and Tmean) Air Temperature °C in The Mesopotamian plain

Figure 15 represents for nineteen ground weather stations the results of statically measured $R^2$by three levels of significance: Tmin Tmax and Tmean. As shown in Table 2, the R^2 acceptance values must be close to 1, and therefore it is established that values greater than 0.5 are acceptable. The degrees of admission are divided according to the seasons as follows:

In winter, Statistical criterion (R^2) for Tmin and Tmax values reached approximately (0.59 to 1) in December ;(0.78 to 1) in January, and (0.67 to 1) in February for all stations except Hilla, Khalis, Nasiria, and Karbala', which they had some negative values, which indicate that the Tmin Tmax from MOD11C3 product and the ground stations did not match during these months. In spring (March, April, and May), R^2 values reached approximately between 0.4 to 0.98 in Tmin, but Tmax was directed in a negative direction, as illustrated in Figure 14.

However, some stations have achieved compatible values for R^2 most stations due to cloud cover and dusty winds because Iraq is one of the arid and semi-arid regions.

In summer (June, July, and August), NSE values started to stray a lot from the accepted values for Tmax and Tmin for all stations except some ground stations that violated the non-conformity by giving a good degree of acceptance (RSME in the summer season) based on the statistical criteria, which are: Baghdad and Basra– Hussein, fall within the Mesopotamian Plain; Mosul, fall within the Jazera and Western Plateau; Sulaymaniyah fall within Mountain Region. In autumn, R^2 values reached approximately RSME values >0.5 as illustrated in Figure 10 in Tmax but get good significance in Tmin.

As direct results from the SPSS program, a relationship was clarified between the measured and practiced data with the result of the R^2 between them for the Baghdad station for a whole year in Figure 16.

The fourth statistical measure (r) is explained as a monthly variation chart in Figure 17. Parsons Correlation(r) shows the compatibility between weather ground stations and MODIS during a monthly average of 21 years. The correlation coefficient increases with the positive direction of the stations, When heading to the northern parts of Iraq (as the ground level rises), and the reason is that the temperatures are naturally concentrated without the intervention of the heat emissions of cars and cities to affect the measured temperature in the plain areas. Pearson's Correlation strongly indicates the extent to which the climatic values of a single station are interconnected in their measurements.

It was found from these statistical measures that the terrestrial weather stations are inaccurate in their measurements due to their lack of continuous maintenance of the temperature-sensing parts, as well as the incorrect measurement times.

Figure 17 shows the monthly change of some weather earth measurement stations through the Monthly Pearson's Correlation values. It is noted that the values were accepted in the Sulaymaniyah station, which confirmed the quality of results in the mountainous region. However, the correlation quality in the plateau region was ineffective, shown every month in the Rutba station.

The rest of the results gave the repeated concept from the previous Figures that the extent of compatibility between the ground measurement stations and MOD11C3 products in the summer months decreased.

Following earlier works [6, 8, 10, 12, 19], this study indicated that MODIS LST, especially for nighttime and daytime, can be trustworthily used for reliable diagnosis of regional climate change in lands similar to the topography of Iraq. In MODIS images, each pixel can be a thermal meteorological station by itself, providing meteorological information at a very detailed spatial scale (1 km). Although, this study contradicts Yang et al. 2017 opinion regarding the stations located in the mountainous region, where the RSME value is less than 0.5.

Moreover, LST is measured at the surface level, and temporal scales often differ from the standard measurements of near-surface air temperatures.

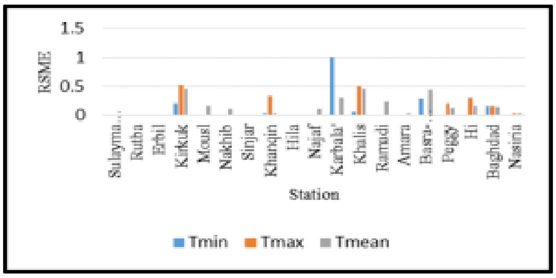
This sometimes makes any attempt to validate LST through a "direct" comparison between ground-based and satellite-based measurements infeasible due to scale mismatch, particularly in regions of complex topography, where the climate is highly variable, even over short distances.

These limitations motivated several previous works to assess the accuracy of LST by using synthetic data as predictors (e.g., land cover, vegetation greening, surface pressure, and solar zenith angle) [22, 2].

At the end of the discussion, the results show complete concordance between MODIS results and the ground stations in different topography in January by credit RSME and on Tmin, Tmax, and Tmean. RSME values coincide with the rest of the indicators during the winter season (December, January, and February).

The values ranged: from RSME (close to zero), NSE (0 to 1), R^2 (between 0.5 and 1), and Parson Correlation (between 0.51 to 1), despite the presence of clouds and rain this month. This is because MODIS eliminates the effect of clouds, with the accuracy required to capture the satellite image in a clear sky.

In the spring season (March, April, and May), the values ranged: R^2 (between 0.5 and 1) and Parson Correlation (between 0.51 to 1).In the summer season(June, July, and August), most of the statistical measures decreased in most stations except for some ground stations that violated the non-conformity by giving a good degree of acceptance based on the statistical criteria, which are: Baghdad and Basra– Hussein, fall within the Mesopotamian Plain; Mosul, fall within the Jazera and Western Plateau; Sulaymaniyah fall within Mountain Region despite the different ground levels of these stations, In autumn season (September, October, and November), The positive regression is due to the variables, and the values ranged of RSME (0.2 to 1)in NSE (0 to 0.4); R^2 (between 0.5 and 1) and Parson Correlation (between 0.271 to 1).4



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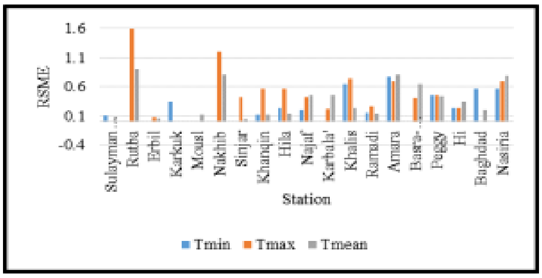

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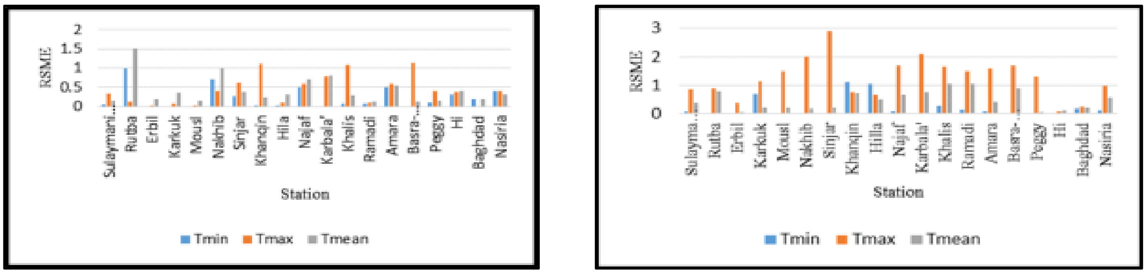

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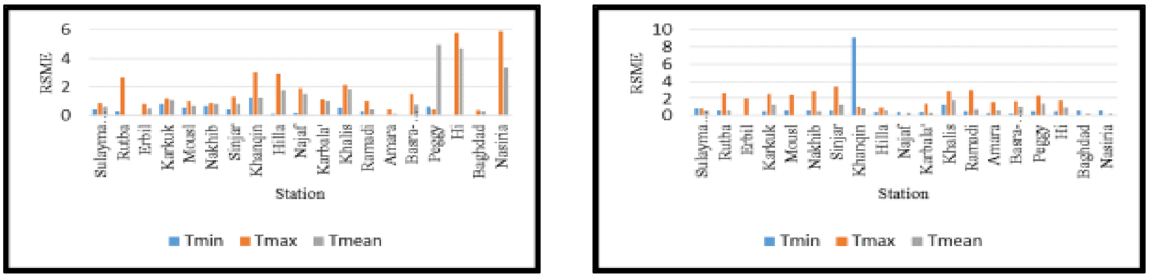

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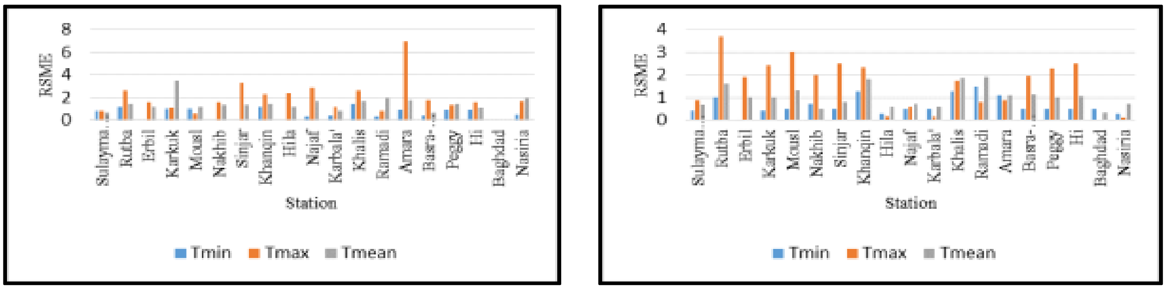

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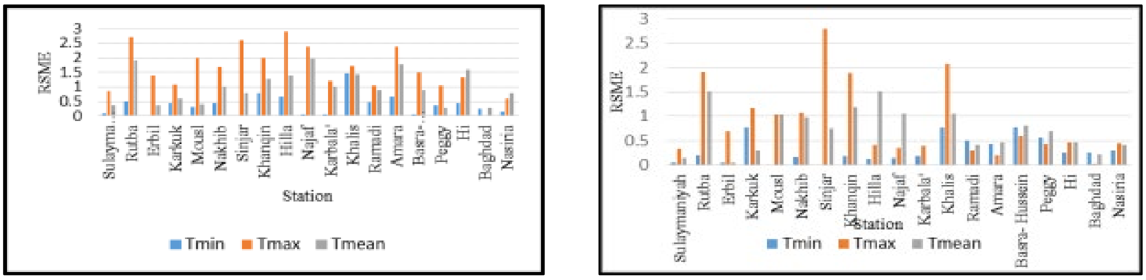
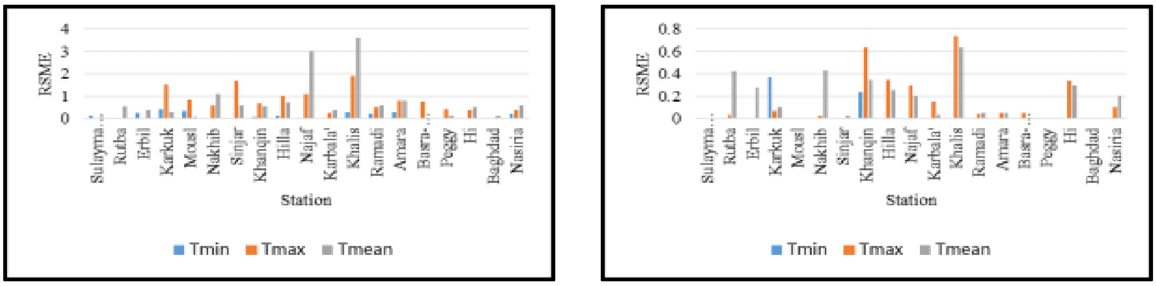
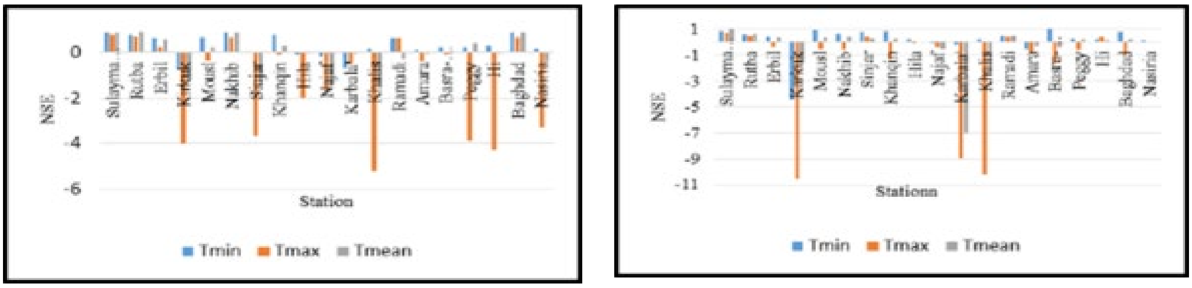


September October



November December

Figure 13: Statistical measure analysis (RSME) for all selected ground weather measurements stations in each month



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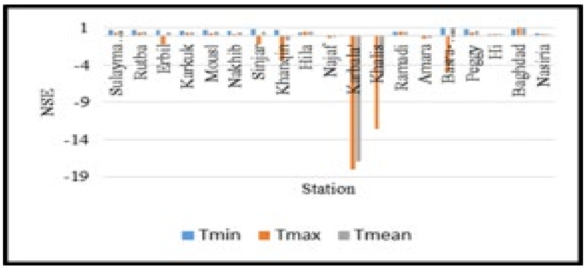

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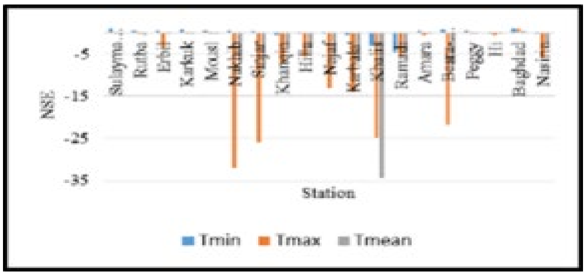

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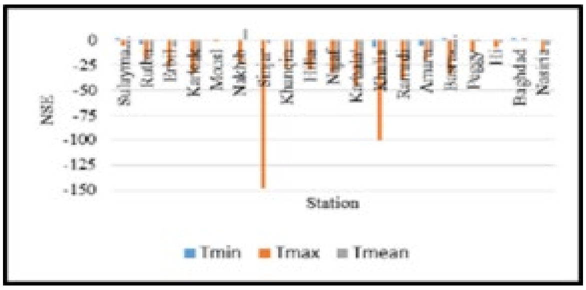

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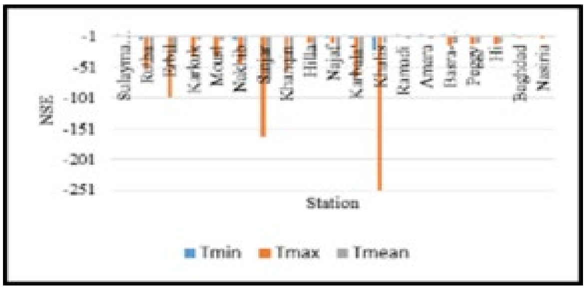
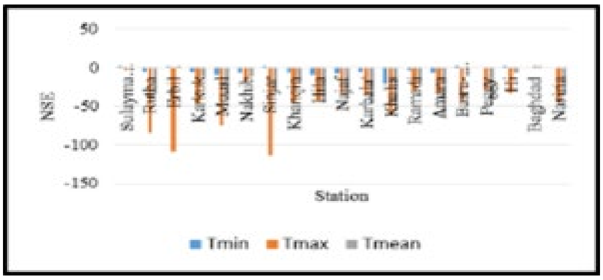


May



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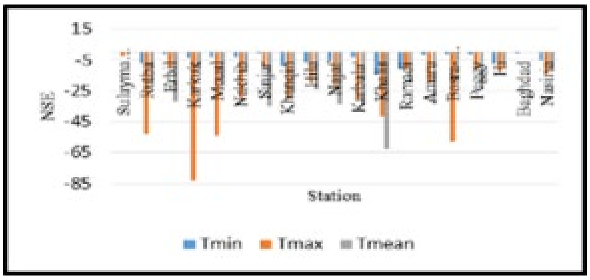

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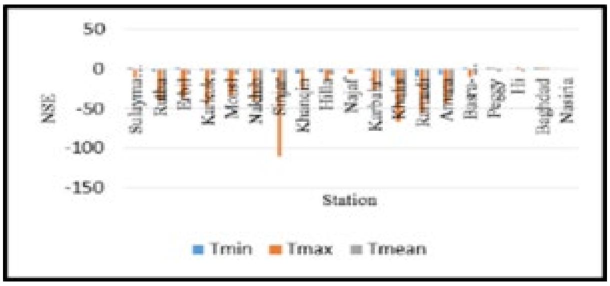
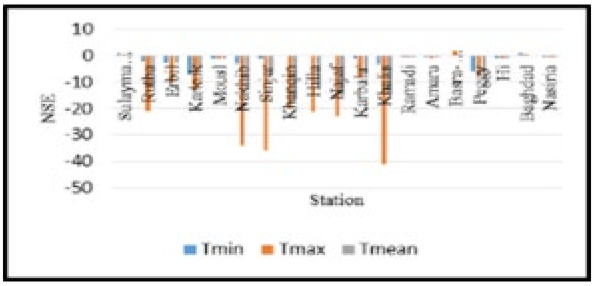
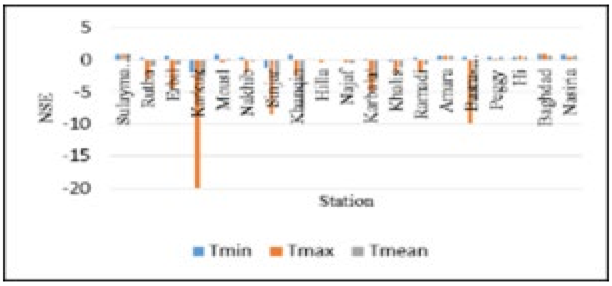


August



September



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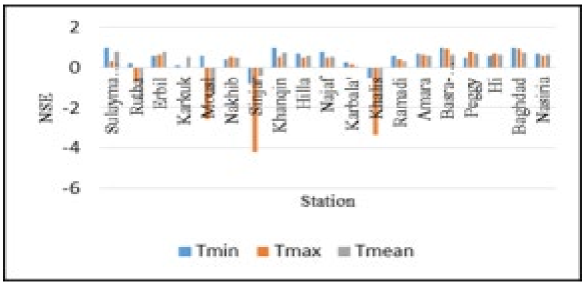
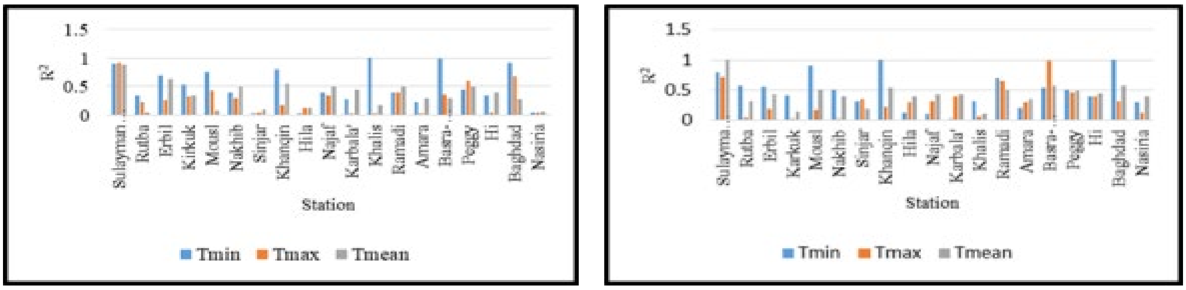


November

December

Figure 14: Statistical measure analysis (NSE) for all selected ground weather measurements stations in each month



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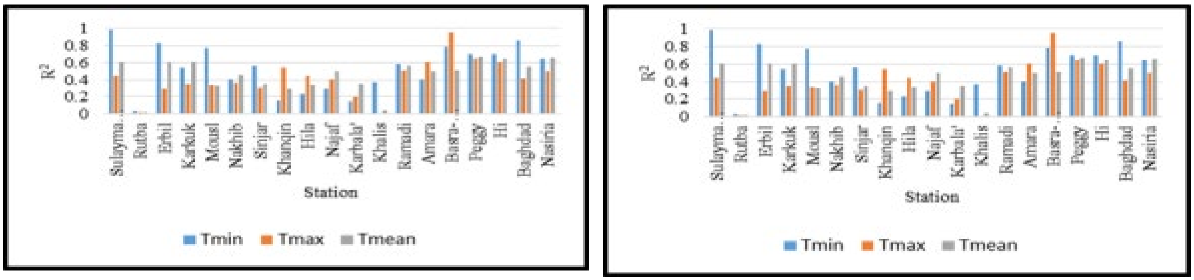

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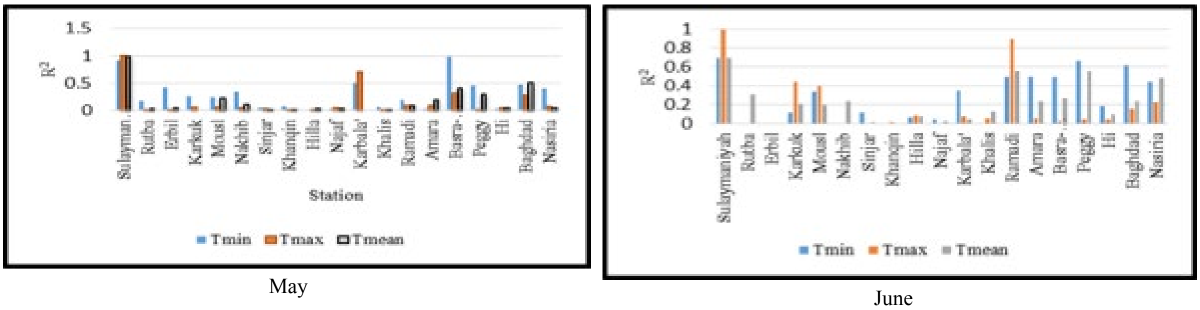

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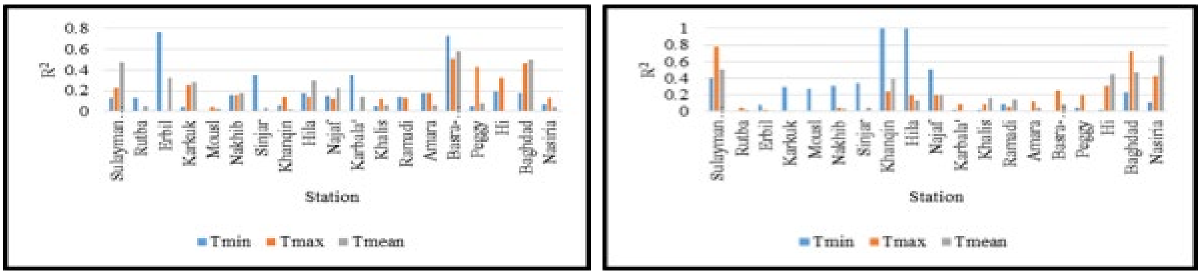

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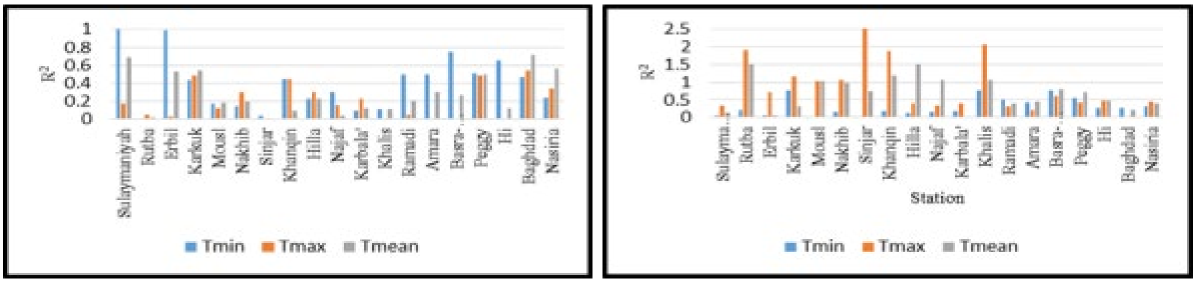

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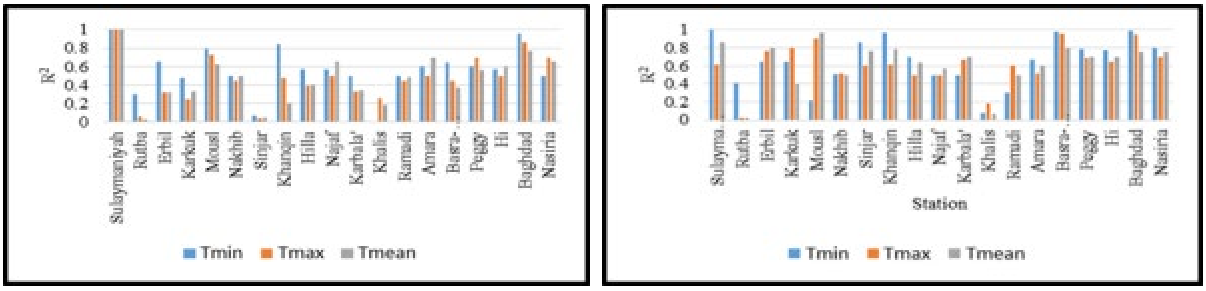
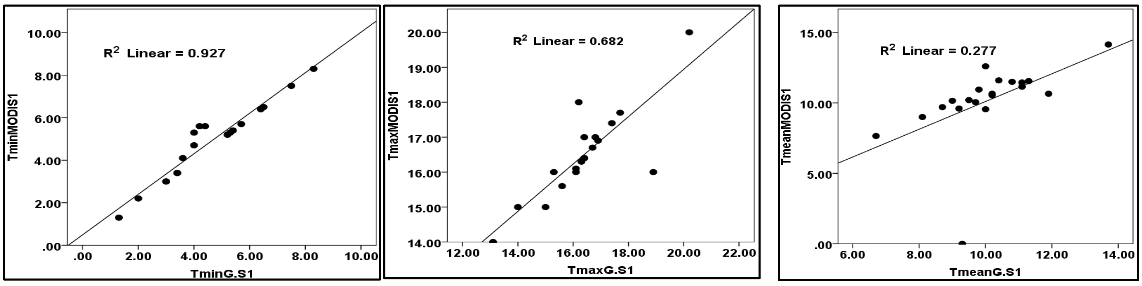
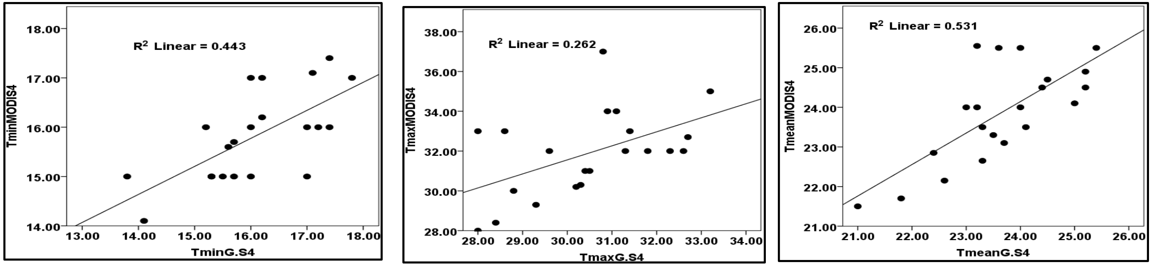


November December

Figure 15: Statistical measure analysis (R^2) for all selected ground weather measurements stations in each month



Jaunary



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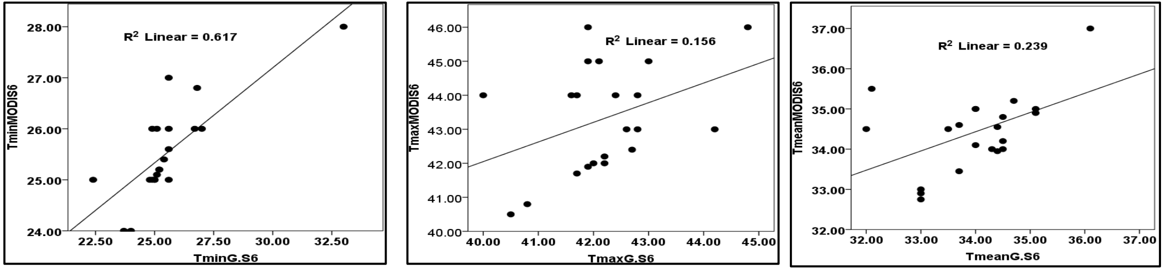

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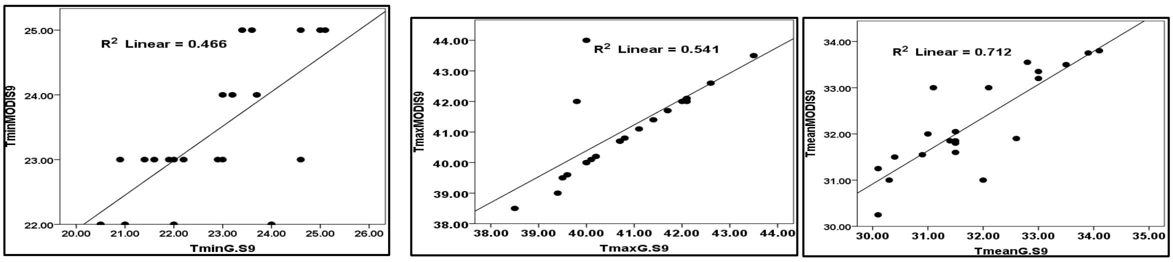

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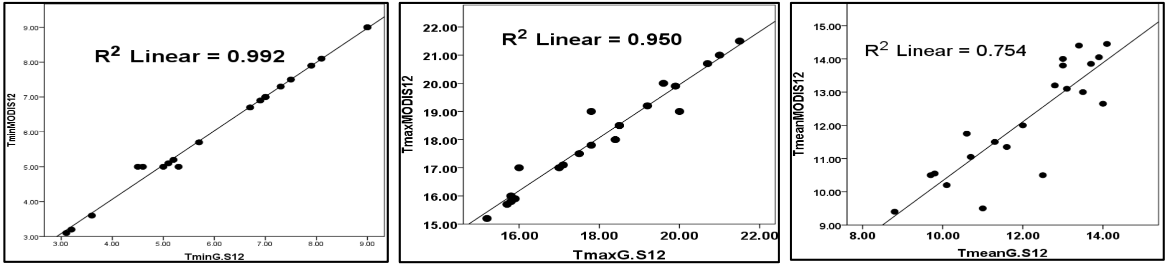
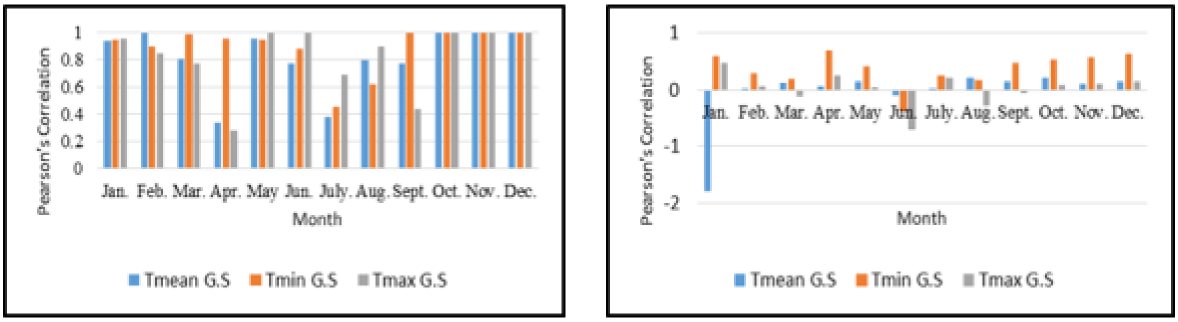


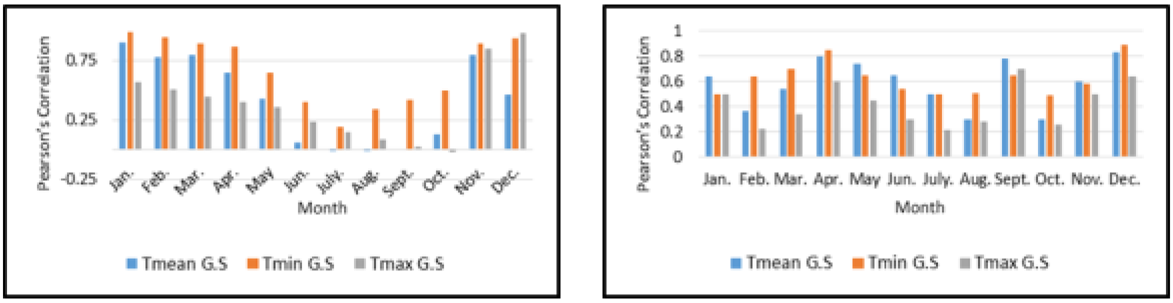
December

Figure 16: Monthly coefficient of determination (R2) in the SPSS Program for Tmin, Tmax, and Tmean between ground measurement station and MODIS Data for Baghdad region



Sulaymaniyah

Rutba



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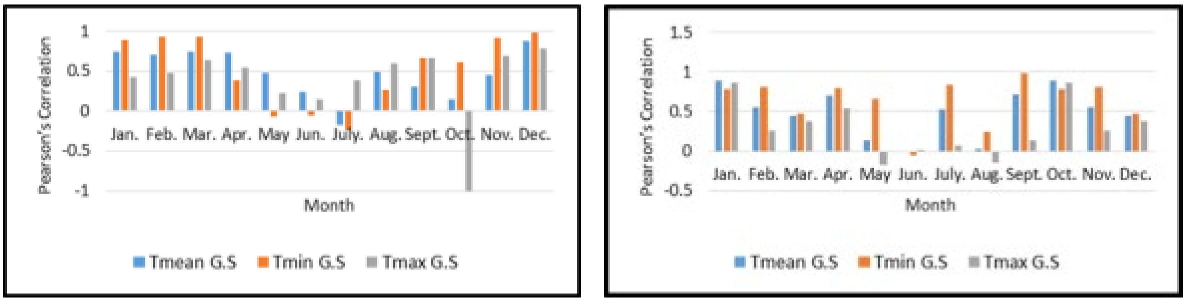
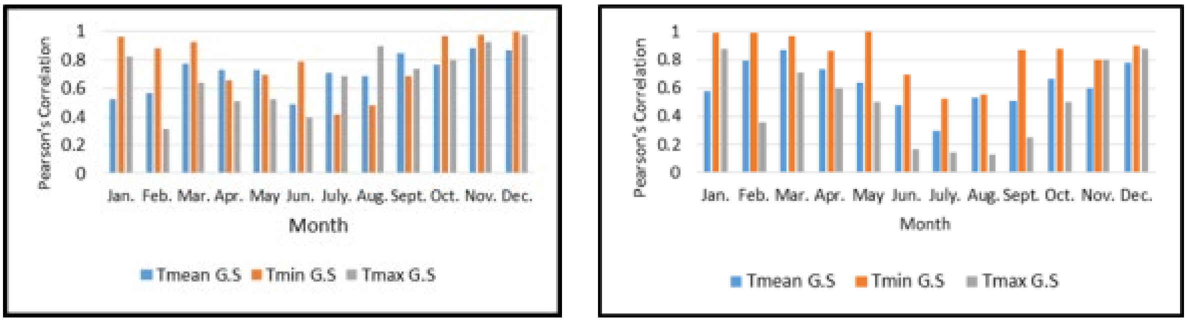


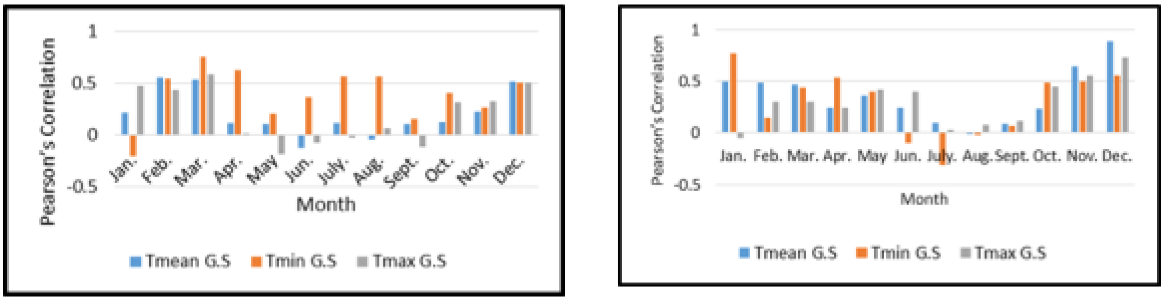
Khanqin

Erbil



Baghdad

Basra- Hussein



Sinjar

Karbala'

Figure 17: Monthly Pearson's Correlation between weather ground measurements stations and MOD11C3 for different topography regions

4. Conclusion

This study developed LST_Day_1km and LST_Night_1km (MOD11C3) a reassessment of the entire Iraq sky based on MODIS Products for all months of the year during the selected period from 2000 to 2020. The statistical processing included four criteria to compare the predicted LST from the outputs of remote sensing and the outputs of weather ground stations, which are as follows: RSME, NSE, $R^{2,}$ and Parson Correlation. The statistical validation included three variables, Tmin, Tmax, and Tmean, for nineteen weather ground stations with different topography of Iraq.

This work highlights the ability of LST to represent the spatial gradient, anomalies, and trends of the Tmin air temperature, Tmax air temperature, and Tmean. In particular, the LST showed better performance in Tmin for all topography of Iraq. Tmin decreases accuracy slightly in the summer and autumn seasons. Despite this, its percentage remains acceptable, depending on the statistical criteria studied in this study. The congruence begins to decrease significantly in the four statistical measures as the temperature increases for the seasonal changes, especially the Tmax that makes a big difference between the ground stations and MODIS outputs. Tmax represented the temperature well in two cold seasons (winter and spring) for different terrains. Still, the daytime LST failed to represent the correct choice in the warm seasons (summer and autumn) except for some stations whose ground heights differed, which are: Baghdad and Basra– Hussein, which fall within the Mesopotamian Plain; Mosul, which falls within the Jazera and Western Plateau; Sulaymaniyah fall within Mountain Region. The reason is due to the presence of these stations at airports and dam reservoirs, characterized by high measurement and control accuracy. The four statistical measures were unanimous on this opinion, RSME, NSE, $R^{2,}$ and Parson Correlation.

The results of this study will play an important role in various applications involving climate monitoring and land-climate interactions, which gives a useful and very important impression in the field of water resources in terms of hydrology, water needs in the field of irrigation and agriculture, and the management of dam reservoirs such as the distribution of water quotas and others. Recent environmental issues in Iraq were brought on by climatic changes. Consequently, keeping an eye on the actual temperature change is crucial. It needs a very extensive ground station network to do this. The MOD11C3 product is a monthly LST. 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 temperature for any region in Iraq. More predictors should be considered for improving the models estimating air temperature. Non-linear models or advanced ensemble models such as boosted regression trees may produce better estimation for LST. Combined with LST data from other thermal infrared sensors or microwave sensors, the monthly mean LST could be obtained for a continuous time series MODIS gave a good evaluation for the assuming LST.

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Author Contributions

Conceptualization, Z.-K.J.,T.-S.K. and I.-A.A. ; methodology, T.-S.K. and I.-A.A.;remote sensing data processing Z.-K.J. and I.-A.A.; climate data analysis, T.-S.K. and Z.-K.J; statistical analysis, Z.-K.J.,T.-S.K. and I.-A.A.; writing—original draft preparation, Z.-K.J.,T.-S.K. and I.-A.A.; writing—review and editing, Z.-K.J.,T.-S.K. and I.-A.A.; visualization, I.-A.A. and T.-S.K. ;supervision ,Z.-K.J. ;project administration, Z.-K.J. ;All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data presented in this study are available in the article.

Conflicts of Interest

The authors declare no conflict of interest.

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