JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **34** No. 1, pp: 159 - 166 (2025 A.D.)
DOI: 10.4197/Met. 34-1.8

Investigation of NASA-POWER Reanalysis Daily Climatic Parameters for Al Madinah Al Munawarah City, Saudi Arabia

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Abstract. Climatic parameters are the main components in meteorological and hydrological studies but their data availability in arid regions like Saudi Arabia is a great problem. Remote sensing and reanalysis dataset can fill this gap and overcome this issue. The objective of this study was to evaluate the accuracy of NASA-POWER reanalysis dataset for the period of three decades (1982-2012) for Al-Madinah Al-Munawarah. Maximum (T_{max}), Minimum (T_{min}), Average (T_{avg}) temperature, Relative humidity (R_h) and wind speed (W_s) were collected and compared with the observational data collected from meteorological station of Al-Madinah Al-Munawarah Airport. The results revealed that the regression (R^2) and Pearson correlation coefficient (r) were found to be highest (0.97, 0.98) for T_{max}, while lowest (0.36, 0.60) for W_s, respectively. Minimum and average temperatures performed very well, presenting performance metrics (R^2 and r) above 0.95. Relative humidity also nicely correlated with observed values having R^2 and r, 0.76 and 0.87, respectively. The maximum percent bias (PBIAS) was found in Ws, indicating an overestimation of 43.32%, while the lowest (0.72) for Tmax. Similarly, R_h presented underestimation (-8.62) while T_{avg} overestimation (8.85) to the observed dataset. However, T_{min} overestimated the values by 17.18%. Mean absolute error (MAE) and Root Mean squared error (RMSE) was found highest (4.95, 6.98) for Rh, while T_{max} was found to be lowest (1.02, 1.37). The error matrix (MAE, RMSE) for T_{min} remains normal (3.76, 4.15) and for W_s (2.61, 3.09) and T_{avg} (2.59, 2.76), it remains low. Overall, NASA-POWER dataset presented very good relationship with observed data for all variables except W_s. However, this study indicates the potential and importance of this reanalysis dataset based on its performance that it can be used for hydrological studies in Al-Madinah region.
Keywords: Al-Madinah Al-Munawarah, Reanalysis dataset, Statistical measures

1. Introduction

Agriculture holds a significant role in the economy of numerous nations worldwide, and its prosperity is heavily impacted by climatic conditions and their variations [1]. Meteorological data is either unavailable or of low quality in numerous places throughout the world. Saudi Arabia is one of those countries that is facing a shortage of observational meteorological data, which is critical for its agriculture, energy, and water management [2-4]. The scarcity of climate data is attributed to various factors, among which the vast size of a country and the scattered distribution of meteorological stations are most notable. Remote sensing and reanalysis of meteorological data have gained great development, which enables it to be used in different hydrological and agricultural studies [5-7]. These methods are regarded as a means of supplementing the shortage of observational datasets [8-10]. The reanalysis products are produced using numerical weather data assimilation systems, which combine a variety of atmospheric and oceanic observations to provide long-term atmospheric and terrestrial variables [11]. There are numerous grided datasets available which cover quite large area around the globe [12-14]. NASA has historically funded satellite systems that provide data for climatic processes and research, such as long-term estimations of atmospheric variables and surface solar energy fluxes [15]. The NASA Prediction of Worldwide Energy Resource (NASA-POWER) is one of the prominent sources of daily metrological reanalysis datasets, including all essential variables like wind speed, relative humidity, solar radiation and air temperature. NASA-POWER is easy to use and provides time series data over a point or region with a spatial resolution of 0.5x 0.5 degree [16].

Numerous studies have been conducted around the globe to compare remote sensing and reanalysis data as an alternative to ground observations. Wu, L. F. (2022) conducted a study to check the effectiveness of China Meteorological Administration Land Data Assimilation System (CLDAS) in estimating reference evapotranspiration (ETo). His findings showed that the temperature data of CLDAS was highly accurate in all regions except for the Qinghai Tibet Plateau. His research highlighted that the accuracy of the global solar radiation data was fair, and the quality of relative humidity and wind speed data was found to be lacking. Despite these limitations, Wu concluded that the overall accuracy of ET_0 estimated from CLDAS reanalysis data was satisfactory [17]. Rodrigues et al. (2021) analyze the performance of NASA-POWER reanalysis products for daily Tmax, Tmin, Rs, R_h, and Ws by observing the data from 14 weather stations. His findings showed that there was a strong agreement between the NASA-POWER reanalysis and the observed data for all parameters except wind speed, with a coefficient of determination greater than 0.82. The aforementioned study also found that the normalized mean bias error (NMBE) ranged from -9 to 26%. Upon application of BIAS correction, the results were further improved and demonstrated a high degree of goodness of fit; therefore, it has been recommended that data be used for climatological and related studies [18]. Raziei et al. (2021) performed a study to calculate reference evapotranspiration using the National Center for Atmospheric Research (NCEP/NCAR) reanalysis dataset and compared it with observed data from 43 stations in Iran. The parameters used in his study were Ws, Tmin, Tmax, Rs and Rh. He found that 95% of stations got $R^2 >= 0.95$ for Tmax and Tmin, and solar radiation gain regression of more than 0.90 for all the stations and some go above this value. However, relative humidity and wind speed were found lower ($R^2 = 0.6\text{-}0.7$) [19]. Different other research on reanalysis data can be seen in these articles [20-25].

Saudi Arabia is a country with large geographical area and shortage of weather stations, creating challenges to accurately predict weather patterns across the country. The lack of comprehensive weather data affects the estimation process of different variables relating to water resources, agriculture and energy, which hinders the decision-making process. Although many studies have been conducted on the use of reanalysis data in different fields around the globe, according to the author, no comprehensive study has been found on Al-Madinah Al-Munawarah. The primary goal of this investigation was to examine the correlation between NASA-POWER reanalysis and observational datasets. The findings will shed light on the capabilities and drawbacks of NASA-POWER data and its compatibility with observational data. This study has the potential to inform a variety of fields and serve as a supplement to observational data with a higher spatial resolution. Moreover, the findings can help improve guiding infrastructure planning, water resource management, and environmental policy.

2. Material and Method

2.1. Study Area

Al-Madinah Al-Munawarah is a city located in the western region of Saudi Arabia and known for its historical significance as the holiest city in Islam. The city has an area of approximately 500 km^2 and is geomorphologically situated in a depression that is surrounded by lava mountains from the north and west. The city experiences a hot and arid desert climate, with temperatures often exceeding 40°C during the summer months and dropping to comfortable levels in the winter. Despite being in a desert region, the city receives occasional rainfall, specifically in the winter season, which results in flash floods. Also, the surroundings of the city have an orchard of Dates, highlighting agricultural demand in this region. The average annual rainfall ranges from 50-100 mm per year. The geographical location of the study area can be seen in Figure. 1.

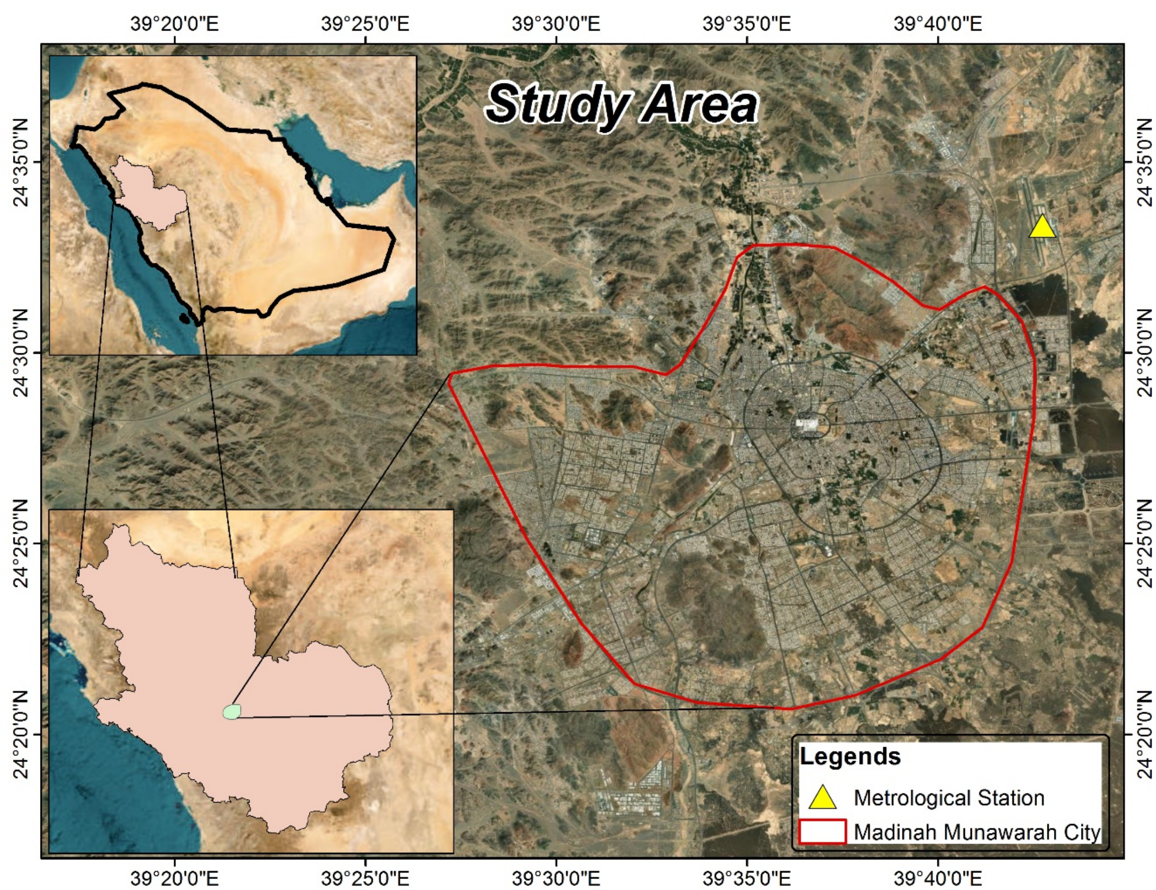

Figure 1. Representing the whole study area including rainfall station

2.2. Methodology

The study utilized daily climatic data from 1982 to 2012 obtained from the Ministry of Environment, Water and Agriculture (MEWA). The data was collected from station located at the airport in Al-Madinah Al-Munawarah. The parameters analyzed included daily minimum temperature (T_{min}), daily maximum temperature (T_{max}), daily average temperature (T_{avg}), wind speed (W_s), and relative humidity (Rh). The aforementioned parameters with same temporal resolution and time period were acquired from NASA-POWER (Assessed on 07-01-2023, http://power.larc.nasa.gov). The spatial resolution for the reanalysis dataset ranges from 0.5° latitude to 0.625° longitude. The datasets were compared on daily time scale to assess their performance by statistical analysis, including coefficient of determination (R^2), Pearson Correlation (r), Percent-BIAS (PBIAS) (%), Mean Absolute Error (MAE), Root Mean Squared Error (RMSE).

2.3. Climatic Data

The climate of the region is hyper-arid, having increasing trend in the middle of the year, from April to August, while less temperature in the winter season. In whole study period, the mean average temperature was found maximum (~40°) in the month of August and minimum (~12°) in January. Relative humidity indicated a reciprocal trend with respect to the temperature, having minimum average value in June and maximum in December. Figure 2 represents the maximum, minimum and average temperature for all months with relative humidity in secondary axis.

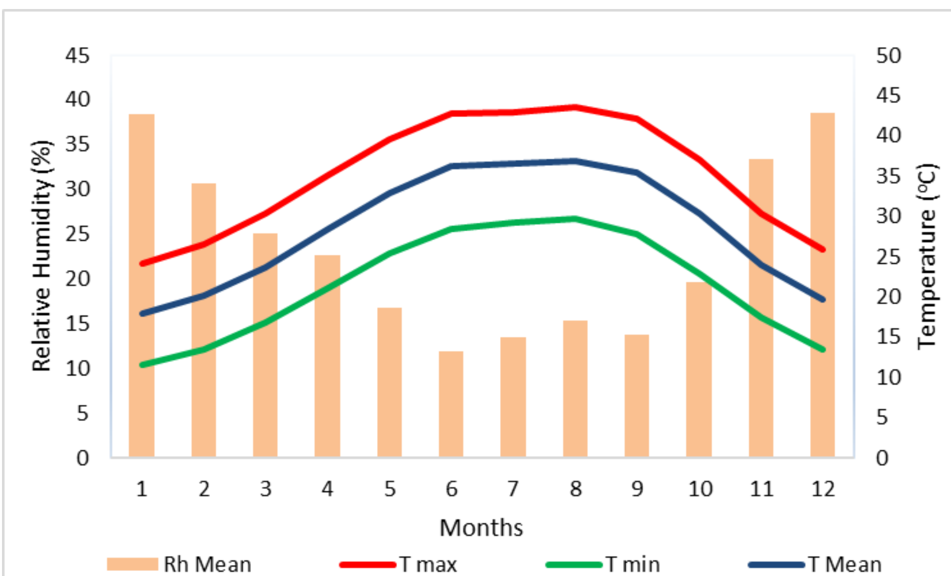

Figure 2. Representing daily maximum, minimum and mean temperature (Line) with relative humidity (Column) for monthly average of whole study period

2.4. Statistical Measures

In this study, datasets were evaluated by different statistical measures such as MAE, RMSE, PBIAS, r, R^2. The RMSE, a commonly used metric in model evaluation, is utilized to gauge the performance of the models, with lower values indicating greater accuracy and vice-versa. The MAE, which stands for the average difference between the model and observed values, was also utilized to gain insight into the model's long-term effectiveness. A lower MAE value suggests better results for long-term predictions. In this research, the Pearson correlation (r) and regression (R^2) were employed as a measure of relationship strength between observed and reanalysis variables. The PBIAS was used to determine whether the model tended to overestimate or underestimate the observations, with values close to zero indicating a good estimation and higher or lower values indicating over or underestimation, respectively. The RMSE, MAE, PBIAS, R^2 and r is given by the following formulas;

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i-1}^{n}|Xi - Yi|} \quad (1)$$

$$\text{MAE} = \frac{1}{n}\sum_{i-1}^{n}|Xi - Yi| \quad (2)$$

$$R^2 = 1 - \frac{RSS}{TSS} \quad (3)$$

$$r = \frac{\frac{1}{n}\sum_{i-1}^{n}(Xi-\overline{X})\,(Yi-\bar{Y})}{\sigma_x\sigma_y} \quad (4)$$

$$\text{PBIAS}\ (\%) = \frac{\frac{1}{n}\sum_{i-1}^{n}(Xi-Yi)}{\sum_{i-1}^{n}Yi}\ X\ 100 \quad (5)$$

Where X_i is observed dataset values, Y_i is reanalysis dataset values, $\bar{X}$ is the mean of observed data set, $\bar{Y}$ is the mean of the reanalysis data set, n is the sample size and $\sigma_{\&}\sigma_y$ are variance for observed and reanalysis data, respectively. RSS = Sum of Squared Regression, TSS = Total Sum of Square.

3. Results and Discussion

The statistical analysis was conducted on the observed and NASA-POWER reanalysis data for whole study period. The results showed that the maximum temperature obtained by NASA-POWER was very close to the measured data. The regression and Pearson correlation were found to be quite high, with values approaching 0.97 and 0.98, respectively. The MAE and RMSE were also found to be very low (1.02, 1.37). The percent bias (PBIAS) indicated 0.72% overestimation for the entire study period. For minimum temperature, the regression and correlation coefficients were 0.93 and 0.96, respectively, indicating a satisfactory fit to the reanalysis values. However, MAE and RMSE were found to be slightly higher (3.76, 4.15), suggesting a larger variation compared to maximum temperature, with a PBIAS of 17.18%, indicating overestimation. The daily average temperature performed well in terms of regression (0.98) and correlation coefficient (0.99) between observed and reanalysis data. The error matrices (MAE, RMSE) were likewise found to be less (2.59, 2.76), which is lower than the minimum and higher than the maximum temperature. The PBIAS rises to 8.85%, indicating that the average temperature is overestimated by reanalysis dataset. Figure 3 depicts regression and time series plots between observed and NASA-POWER data.

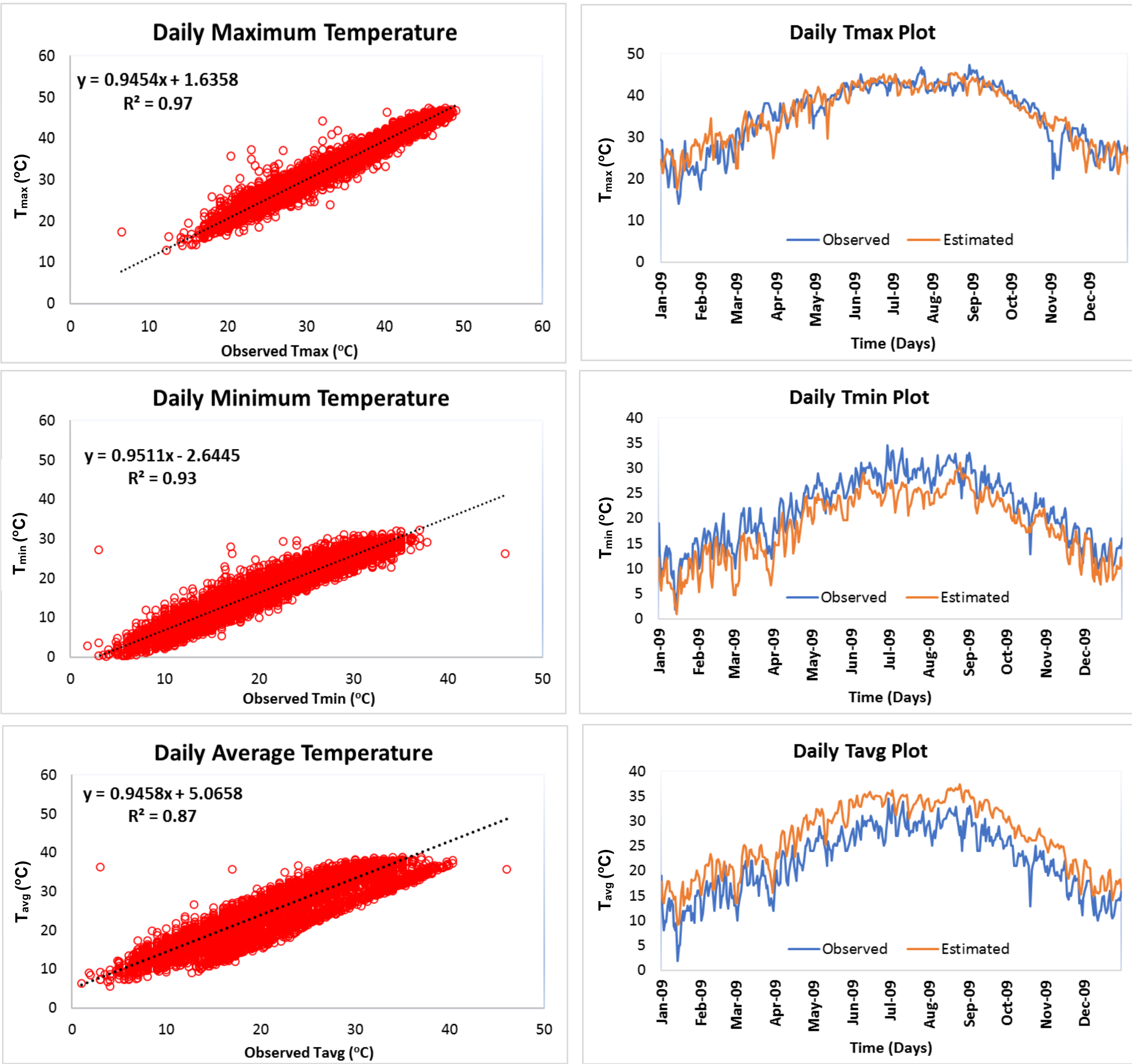

Figure 3. Representing regression and time series data plot of Minimum, Maximum and the average temperature between NASA-POWER and observed dataset on daily time scale.

The results have also shown good relationship between the observed data and the NASA-POWER dataset for relative humidity. The regression and correlation values were found to be 0.76, 0.87, respectively, showing nice goodness of fit. Error matrix (MAE, RMSE) for relative humidity indicated appropriate values (4.95, 6.98) and an underestimation of 8.62% for whole dataset. The regression and time series plot between observed and NASA-POWER for 2009 can be seen in figure 4.

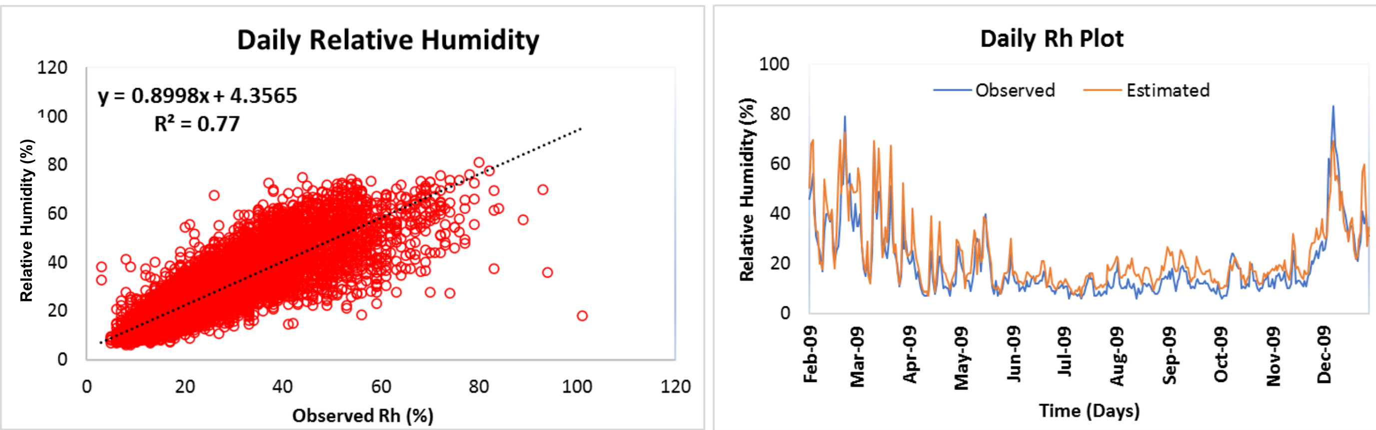

Figure 4. Representing regression and time series data plot of relative humidity for 2009 between NASA-POWER and observed dataset on daily time scale.

The wind speed was also analyzed, and statistical evaluation was performed. The results showed poor agreement matrices (R^2 = 0.36 and r = 0.60) of the reanalysis data observed. The error metrics (MAE = 2.61, RMSE = 3.09) were also found to be high, indicating that this variable has not captured observation accurately. The bias was also found to be the highest (43.32%) among all metrological variables, underscoring significant overestimation. Figure 5 depicts the regression and time series plots of wind speed. Complete statistical measures can be seen in table 1.

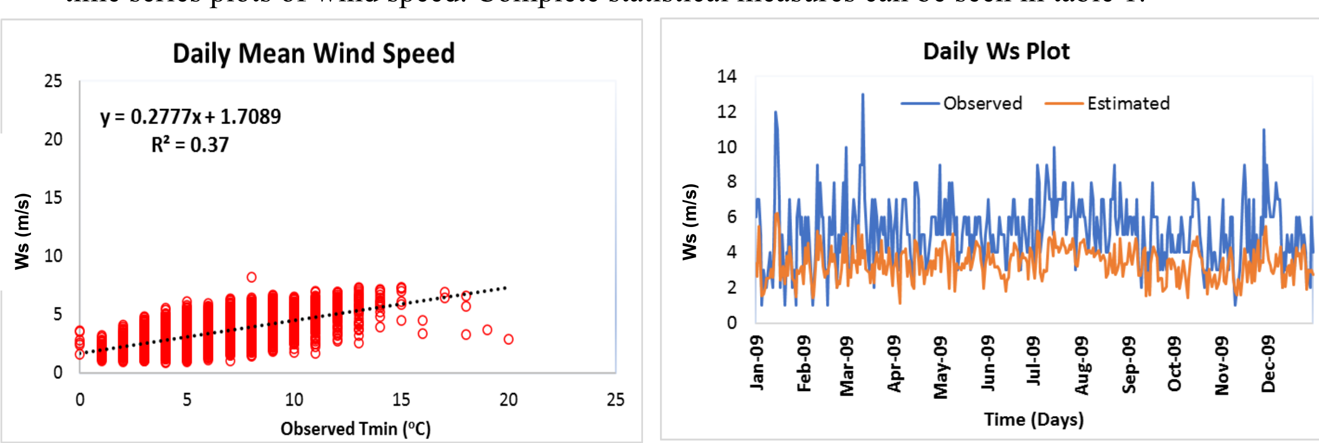

Figure 5. Representing regression and time series data plot of wind speed for 2009 between NASA-POWER and observed dataset on daily time scale.

Overall, maximum temperature had the strongest correlation among all other parameters and was the top performer, while wind speed had the weakest performance. Among the remaining temperature parameters, the average temperature performed better than the minimum temperature. Likewise, relative humidity also showed promising results for the reanalysis dataset of NASA-POWER. All parameters except Ws can be utilized in climatological or hydrological studies when observational data is not available. In future studies, BIAS corrections strategies should be applied to all parameters for better results.

Table 1. Statistical results of metrological variables

Metrices	T_{max}	T_{min}	T_{mean}	W_s	R_h
r	0.98	0.96	0.99	0.60	0.87
R^2	0.97	0.93	0.98	0.36	0.76
PBIAS	0.72	17.18	8.85	43.32	-8.62
RMSE	1.37	4.15	2.76	3.09	6.98
MAE	1.02	3.76	2.59	2.61	4.95

4. Conclusion

This study assessed the accuracy of the NASA-POWER reanalysis dataset against observed climate data for Al-Madinah Al-Munawarah, focusing on maximum, minimum, and average temperatures, relative humidity, and wind speed over a 30-year period (1982–2012). The findings revealed that maximum temperature had the highest correlation and alignment with observed data, demonstrating strong regression ($R^2 = 0.97$) and Pearson correlation ($r = 0.98$), along with low error metrics (MAE = 1.02, RMSE = 1.37), making it the top-performing parameter in this analysis. Daily average temperature also performed well, with satisfactory regression and correlation values ($R^2 = 0.87$, $r = 0.93$) and moderate error values, though it showed a slight overestimation (PBIAS = 17.5%). Minimum temperature displayed reasonable correlation ($R^2 = 0.89$, $r = 0.94$) but presented higher error metrics, indicating greater deviation from observed values and a notable underestimation. Relative humidity showed a good fit with the observed data, reflected by adequate regression and correlation ($R^2 = 0.76$, $r = 0.87$), though it also presented some underestimation. Wind speed, however, was the least reliable parameter, with low regression and correlation values ($R^2 = 0.36$, $r = 0.60$) and high bias (43.32%), indicating poor alignment with observed measurements. Overall, NASA-POWER proved a reasonable source for maximum and average temperatures and, to a lesser extent, relative humidity in the context of arid regions like Al-Madinah. Except for wind speed, these parameters can be effectively used in climatological and hydrological studies where observational data is scarce. To enhance the reliability of reanalysis data for all parameters, future studies should consider implementing bias correction strategies, either regionally or on a point-based scale. These corrections would refine the dataset's accuracy, making it a more robust tool for climate research and resource management in arid environments.

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دراسة إعادة تحليل NASA-POWER للمعاملات المناخية اليومية المدينة المنورة، المملكة العربية السعودية

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مستخلص. تعتبر المعايير المناخية هي المكونات الرئيسية في دراسات الأرصاد الجوية والهيدرولوجية ولكن توافر بياناتها في المناطق القاحلة مثل المملكة العربية السعودية يمثل مشكلة كبيرة. ويمكن لمجموعة بيانات الاستشعار عن بعد وإعادة التحليل أن تسد هذه الفجوة وتتغلب على هذه المشكلة. كان الهدف من هذه الدراسة هو تقييم دقة مجموعة بيانات إعادة تحليل ناسا–باور لفترة ثلاثة عقود (1982–2012) للمدينة المنورة. وقد تم جمع ومقارنة درجات الحرارة القصوى (Tmax) والصغرى (Tmin) ومتوسط درجات الحرارة (Tavg) والرطوبة النسبية (Rh) وسرعة الرياح (Ws) مع بيانات الرصد التي تم جمعها من محطة الأرصاد الجوية في مطار المدينة المنورة. كشفت النتائج أن معامل الانحدار (R2) ومعامل ارتباط بيرسون (r) وجد أن أعلى نسبة (0.97، 0.98) لـ Tmax، بينما كانت أدنى نسبة (0.36، 0.60) لـ Ws، على التوالي. كان أداء درجات الحرارة الصغرى ومتوسط درجات الحرارة جيدًا جدًا، حيث قدم مقاييس أداء (R2 و r) أعلى من 0.95. كما ارتبطت الرطوبة النسبية أيضًا بشكل جيد مع القيم المرصودة مع وجود R2 و r، 0.76 و 0.87 على التوالي. وُجدت النسبة المئوية القصوى للتحيز (PBIAS) في Ws، مما يشير إلى مبالغة في التقدير بنسبة 43.32%، بينما كانت النسبة المئوية القصوى (0.72) في Tmax. وبالمثل، أظهرت نسبة التحيز المئوي (–8.62) أقل من التقدير (–8.62) بينما كانت نسبة المبالغة في تقدير Tavg (8.85) لمجموعة البيانات المرصودة. ومع ذلك، بالغ Tmin في تقدير القيم بنسبة 17.18%. وُجد أن متوسط الخطأ المطلق (MAE) ومتوسط الخطأ الجذري المربّع (RMSE) هو الأعلى (4.95، 6.98) بالنسبة إلى Rh، بينما وُجد أن Tmax هو الأقل (1.02، 1.37). وتبقى مصفوفة الخطأ (MAE، RMSE) بالنسبة لـ Tmin عادية (3.76، 4.15)، وبالنسبة لـ Ws (2.61، 3.09) و Tavg (2.59، 2.76)، تبقى منخفضة. بشكل عام، قدمت مجموعة بيانات NASA–POWER علاقة جيدة جدًا مع البيانات المرصودة لجميع المتغيرات باستثناء Ws. ومع ذلك، تشير هذه الدراسة إلى إمكانات وأهمية مجموعة بيانات إعادة التحليل هذه بناءً على أدائها الذي يمكن استخدامه في الدراسات الهيدرولوجية في منطقة المدينة المنورة.

الكلمات المفتاحية: المدينة المنورة، مجموعة بيانات إعادة التحليل، القياسات الإحصائية