Available online at https://sanad.iau.ir/journal/jrors

Publisher: Yazd Branch, Islamic Azad University

Journal of Radar and Optical Remote Sensing and GIS

ISSN: ***2645-5161***

Validation of MODIS Land Surface Temperature Products with Ground-Based Measurements: A Case Study in the Bajestan Desert, Iran

Morteza Kaffash [a*], Seyed Hoseyn Sanaei Nejad [b]

[a,b]*Department of Water Engineering, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran*

A R T I C L E I N F O

Research Type:
Case study

Article history:
Received 22 Sep 2020
Accepted 29 Oct 2020
Published 10 Dec 2024

Keywords:
LST,
SMT160,
Satellite,
Validation,
MODIS

A B S T R A C T

Objective: Land surface temperature (LST) is a critical parameter for environmental studies, including climate change analysis, soil moisture monitoring, evapotranspiration estimation, and surface energy balance evaluation. This study aims to validate the accuracy of MODIS LST products (MOD11A1 and MYD11A1) from Terra and Aqua satellites in the Bajestan Desert, Iran, by comparing them with ground-based measurements.
Methods: Ground-based LST measurements were conducted using six thermometers equipped with SMT160 temperature sensors over 15 clear-sky days and nights. MODIS LST products were validated using two approaches: (1) comparison with pixel-level ground-based data and (2) comparison with the average LST values of image windows larger than the pixel size (e.g., 3×3, 5×5). Statistical parameters, including root mean square error (RMSE), coefficient of determination (R^2), and standard deviation, were calculated to assess the accuracy of satellite-derived LST.
Results: The results indicate that MODIS LST products systematically underestimate LST in the barren study area. Nocturnal LST exhibited higher accuracy (RMSE = 1.1) compared to diurnal measurements (RMSE = 3.38). Increasing the size of the window used for averaging resulted in higher standard deviations of pixel temperatures, while RMSE and R^2 values showed negligible changes, demonstrating the homogeneity of the selected study area.
Conclusion: This study validates the applicability of MODIS LST products in arid environments despite their systematic underestimation. The findings highlight the importance of incorporating homogeneous sampling areas and suggest the need for further improvements in MODIS algorithms for arid regions. The methodologies applied in this study provide a robust framework for LST validation in other arid and semi-arid environments.

1. Introduction

Thermal Infrared Remote Sensing serves as a crucial tool for retrieving land surface temperature (LST) over large spatial extents and various temporal scales. It offers unparalleled advantages in applications such as vegetation monitoring (Guillevic et al., 2013), climate change assessments (Maimaitiyiming et al., 2014), drought monitoring (Orhan et al., 2014; Son et al., 2012; Wan et al., 2004), urban heat island studies (Zakšek & Oštir, 2012; Bokaie et al., 2016), and geological and hydrological

* *Corresponding author.* Tel.: 0098- 9129536614
E-mail address: kaffash67@gmail.com

Peer review under responsibility of Yazd Branch, Islamic Azad University

DOI: https://doi.org/10.30495/xxxxx.2023.1963135.xxxx

investigations (Srivastava et al., 2013; Olivera-Guerra et al., 2017). However, ensuring the accuracy of LST estimations across varying spatial and temporal scales remains a significant challenge (Ermida et al., 2017; Alavipanah, 2006; Azizi et al., 2007). Algorithms for LST estimation, when validated against ground-based measurements, become both effective and reliable (Wan et al., 2002; Pahlevani & Mobasheri, 2009).

Ground-based validation of satellite-derived LST requires that measurement stations be located in areas with uniform surface emissivity and temperature over regions larger than the satellite pixel size. Such conditions are commonly met in homogeneous environments such as dense vegetation, bare land, or desert areas (Wang et al., 2016). Validation processes compare satellite products against ground-based measurements to evaluate their accuracy (Justice et al., 2000). For instance, Wan et al. (2002) validated MODIS LST by comparing 11 cloudless daytime datasets from 2000 and 2001 with field measurements. Their findings revealed that MODIS-derived LST often underestimated actual surface temperatures by a few degrees due to emissivity overestimations in arid and semi-arid regions.

Similarly, Coll et al. (2005) assessed the LST data from ASTER and MODIS using a homogeneous paddy field. By validating the split-window algorithms of AATSR (Prata, 2002) and MODIS (Wan and Dozier, 1996), along with a quadratic emissivity-based algorithm (Coll and Caselles, 1997), they reported LST variations between 25°C and 32°C with uncertainties ranging from ±0.5°C to ±0.9°C. These uncertainties were largely attributed to spatial variability in surface temperatures. Notably, MODIS-derived LST demonstrated superior accuracy compared to AATSR (Coll et al., 2005).

Wang et al. (2008) validated MODIS daily LST products, MOD11_L2 and MOD07_L2, against long-term field measurements across eight vegetated stations. Their results indicated that MOD11_L2 had a lower root mean square error (RMSE) than MOD07_L2. Furthermore, Wan and Li (2008) suggested a validation method for MODIS LST data based on surface emissivity. Their findings showed RMSE values below 0.7°C and overall accuracy within 1 Kelvin across diverse clear-sky cases, including vegetation, soil, and lake sites.

MODIS LST products are particularly appealing due to their global daily coverage, high radiometric resolution across 36 spectral bands, and detailed grading in visible, near-infrared, and thermal infrared bands (Davies et al., 2008). These features make MODIS data a preferred choice for many remote sensing studies. In this research, ground-based surface temperature measurements were utilized to validate MODIS LST products in the arid environment of the Bajestan desert. High-accuracy thermometers were employed to provide reliable reference data for assessing errors in satellite-derived LST values (Wang et al., 2007).

The objectives of this study are threefold:

- Validation of MODIS LST products, including MOD11A1 and MYD11A1 (Terra and Aqua), using field-collected surface temperature data in arid regions.
- Comparison of diurnal and nocturnal MODIS LST data with ground-based measurements.
- Evaluation of MODIS LST accuracy in homogeneous areas with spatial extents larger than MODIS pixel size.

In order to assess the accuracy of MODIS Land Surface Temperature (LST) products in arid environments, this study aims to explore the performance of MOD11A1 and MYD11A1 products through comparison with ground-based temperature measurements. Based on the objectives and the methodology, the following hypotheses are proposed:

Hypothesis 1:

The accuracy of MODIS Land Surface Temperature (LST) products (MOD11A1 and MYD11A1) will be higher for nocturnal measurements than diurnal measurements in arid regions, due to the reduced influence of solar radiation and more homogeneous surface conditions during the night.

Hypothesis 2:

MODIS LST products will systematically underestimate the actual land surface temperature in barren, arid regions, with the degree of underestimation being more pronounced in diurnal measurements compared to nocturnal measurements, due to higher surface temperature variability during the day.

This study contributes to improving the reliability of satellite-derived LST products for applications in arid and semi-arid environments, providing insights for enhancing algorithm performance in similar climatic zones.

2. Materials and Methods

2.1. Study Area

The Bajestan Desert, situated within the central desert region of Iran, was selected as the study area due to its highly uniform land surface and minimal vegetation cover, which are ideal for validating satellite-derived LST products. This desert lies in the southwestern part of Khorasan Razavi Province, between 34°55'–34°57' N latitude and 58°6'–58°8' E longitude. The area is predominantly flat, characterized by clay soil texture and sparse vegetation, making it an excellent natural laboratory for remote sensing studies focused on arid and semi-arid regions (Davari et al., 2017).

The geographical and physical attributes of the Bajestan Desert provide homogeneity in surface emissivity and temperature over spatial extents larger than the MODIS pixel size, ensuring that ground-based measurements accurately represent satellite observations. The uniformity of these conditions minimizes the uncertainties often associated with surface heterogeneity, such as mixed land cover types, and enhances the reliability of validation results (Fig. 1).

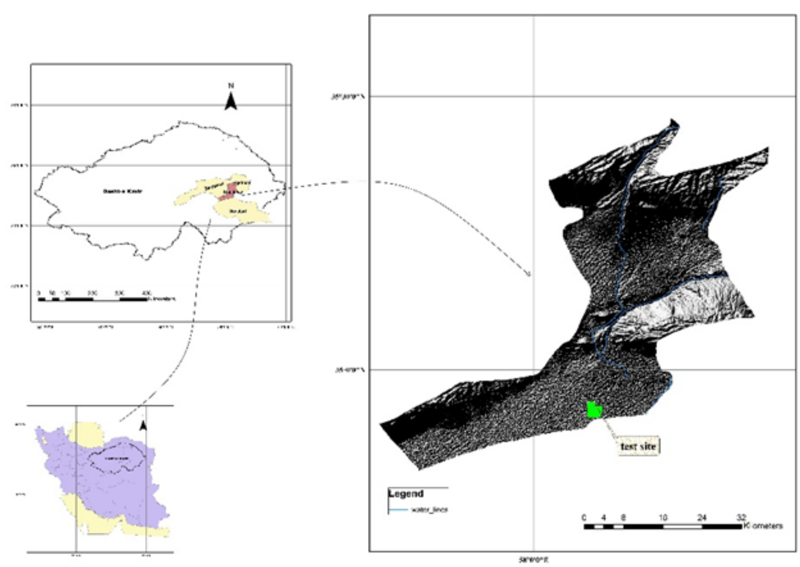

Fig. 1- Location of the study area in Khorasan Razavi province of Iran

2.2. Fieldwork for Measuring Land Surface Temperature

Land surface temperature (LST) in the Bajestan Desert was measured using thermometers equipped with SMT160 temperature sensors. These sensors, known for their high reliability and accuracy, operate within a temperature range of -45°C to 130°C (Ghalamchi et al., 2015). Key features of the SMT160 temperature sensors include:

- Absolute accuracy: ±0.7°C.
- Measurement range: Up to 175°C.
- Low power consumption: Ideal for prolonged field deployment.

Before field deployment, the sensors were calibrated at the Mashhad Synoptic Station (36°16' N, 59°38' E) to ensure measurement precision. Calibration results demonstrated an accuracy better than ±0.5°C, confirming the reliability of the temperature estimates obtained by these sensors.

In the field, the SMT160 thermometers were set to record temperature measurements every 10 minutes, with the data automatically stored in their internal memory for subsequent analysis. To capture accurate LST values, the thermometers were partially buried in the soil, ensuring that they were exposed to representative surface conditions while minimizing external disturbances (Fig. 2).

This meticulous field measurement protocol ensured the collection of high-quality, continuous LST data, forming a robust basis for validating the MODIS-derived LST products in the study area.

Fig. 2 - photograph of the thermometer used to measure LST and study area

In this study, field measurements of land surface temperature (LST) were conducted using six SMT160 thermometers. These thermometers were distributed randomly across a 2 × 2 km area within the Bajestan Desert to ensure a representative sampling of surface conditions. The random placement of the thermometers minimized potential biases in data collection and accounted for any microvariations within the study area.

Fig. 3 illustrates the specific locations of the thermometers within the selected area, highlighting their spatial distribution. This arrangement ensured that the collected LST data adequately represented the uniform surface characteristics of the region and provided a reliable basis for validating MODIS-derived LST products.

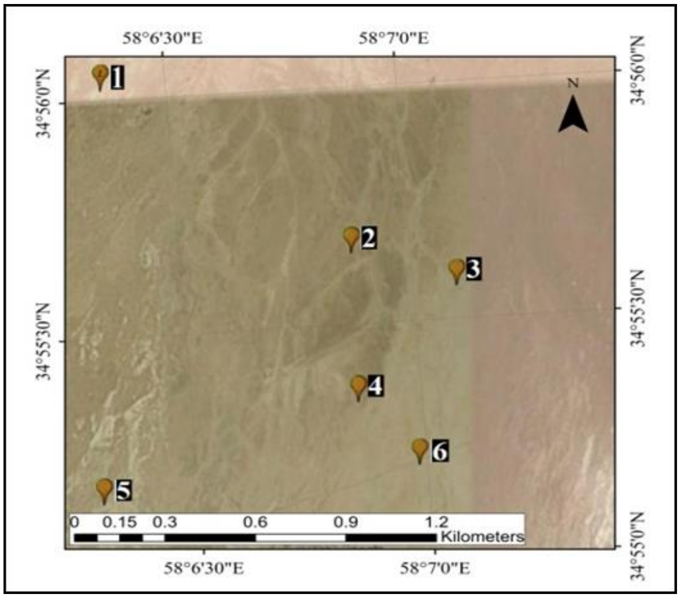

Fig. 3 - Field measurement points of the land surface temperature in the study area

2.3. Satellite products

This study utilized the MOD11A1 and MYD11A1 products, derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra and Aqua satellites, respectively. These are daily Level-3 land surface temperature (LST) products generated using the generalized split-window algorithm, offering a spatial resolution of 1 km and gridded in the Sinusoidal projection (Wan, 2014).

Both MOD11A1 and MYD11A1 datasets provide comprehensive information through several data layers, including:

- Land surface temperature (LST): Measured during both daytime and nighttime.
- Quality control: Indicators for assessing data reliability.
- Satellite overpass times: Precise timing of data acquisition.
- Viewing angles: Geometric information of satellite observation.
- Surface emissivity: Derived for bands 31 and 32, essential for accurate LST calculations.

These products are widely used for various applications due to their global daily coverage and reliability (Wan, 2008). By incorporating both day and night observations, MOD11A1 (Terra) and MYD11A1 (Aqua) provide a robust dataset for assessing diurnal temperature variations, which is critical for validating satellite-derived LST in the arid conditions of the Bajestan Desert.

3. Results

3.1. Validation by Ground Truth Measurements

Ground-based land surface temperature (LST) data were collected using thermometers equipped with SMT160 temperature sensors during June 2013. The temperatures recorded by the thermometers were compared with the average LST values obtained from MODIS pixels corresponding to the study area.

Field measurements were conducted 30 times in total, with 15 measurements taken during the daytime and 15 during the nighttime, all under clear-sky conditions. This design allowed for a thorough comparison of both diurnal and nocturnal LST, ensuring a comprehensive validation of the satellite-derived data. The thermometers were placed at various locations within the study area, capturing spatial variations in surface temperature across the region.

A detailed statistical analysis of the measured LST and MODIS data was performed to assess the accuracy of the satellite products. Table 1 presents the results of the measurements collected in June 2013, specifically focusing on the 15 daytime measurements under cloudless sky conditions. This data serves as the foundation for further evaluation of the MODIS LST products' reliability and their ability to represent ground conditions in arid environments.

Table 1:The diurnal field measurements and land surface temperature data of MODIS sensor

Date	Time of satellite's overpass	Ground LST (K)	Product Name	MODIS LST (K)	Difference between MODIS and ground LST (K)
09 June	11:36	318	MOD11A1	312.74	5.26
10 June	10:42	316	MOD11A1	316.8	-0.8
12 June	10:30	313	MOD11A1	313.42	-0.42
13 June	11:12	318	MOD11A1	320.18	-2.18
14 June	10:18	316	MOD11A1	320.5	-4.5
22 June	11:00	324.9	MOD11A1	322.3	2.6
24 June	10:54	322.1	MOD11A1	320.4	1.7
09 June	13:12	324	MYD11A1	323.3	0.7
10 June	13:54	322	MYD11A1	317.92	4.08
11 June	13:00	320.3	MYD11A1	322.85	-2.55
13 June	12:48	322.5	MYD11A1	323.84	-1.34
14 June	13:30	326	MYD11A1	330	-4
23 June	13:24	328.1	MYD11A1	323.32	4.78
24 June	12:30	326.2	MYD11A1	318.34	7.85
25 June	13:12	326.5	MYD11A1	323.22	3.29

3.2. Comparison of Ground-Based LST Measurements and MODIS Derived Land Surface Temperature

According to the data presented in Table 1 and Fig. 3, the comparison results between the field-based LST measurements and the MODIS-derived land surface temperature are illustrated in Fig. 4. This figure visually demonstrates the agreement (or discrepancies) between the ground truth data collected with the SMT160 thermometers and the satellite-derived LST products from MODIS.

The analysis focuses on the temporal and spatial variations of LST, emphasizing both the diurnal and nocturnal temperature measurements under clear-sky conditions. Fig. 4 provides a direct comparison, showcasing how well the MODIS LST estimates align with the ground-based measurements and highlighting any potential biases or errors in the satellite data. This comparison is crucial for assessing the accuracy and reliability of MODIS LST products in representing the true surface temperatures of the study area.

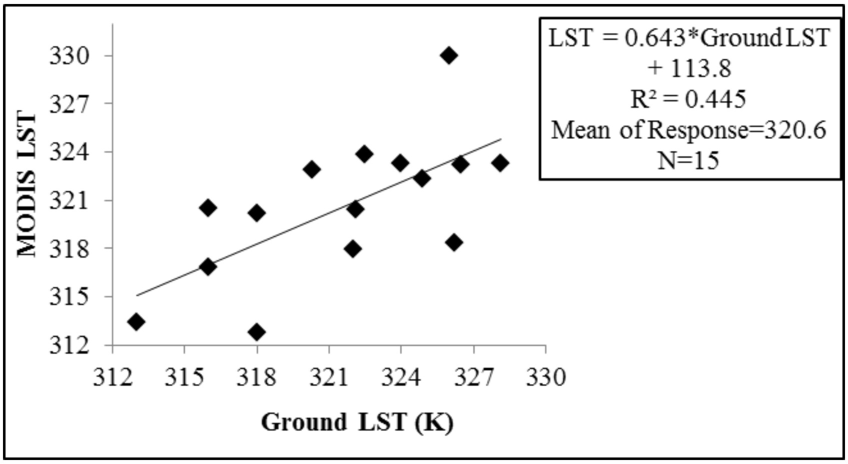

Fig. 4 - Comparison of field-based LST measurements and MODIS LST values (diurnal and nocturnal) from June 2013 under clear-sky conditions

3.3. MODIS-Detected LST for the Study Area

Fig. 5 presents the land surface temperature (LST) data retrieved from the MODIS sensor for the study area at 13:54 on June 10, 2013. The image illustrates the spatial distribution of LST across the Bajestan Desert, showcasing the variation in surface temperature at a 1 km spatial resolution, as captured by the MODIS sensor on the Terra satellite.

The data in Fig. 5 reveal notable temperature gradients across the study area, reflecting the homogeneous, yet variable surface characteristics of the desert environment. The highest temperatures are observed in regions with minimal vegetation cover, while slightly cooler areas are associated with slight surface variations. The MODIS LST data provides a clear view of the diurnal temperature profile, highlighting the impact of solar radiation at midday.

This figure not only enhances our understanding of the thermal characteristics of the Bajestan Desert but also provides a visual representation of how MODIS captures the large-scale surface temperature dynamics. The comparison of these MODIS-derived temperatures with the ground-based measurements, as presented in the previous section, offers critical insights into the accuracy and reliability of satellite-derived LST in arid regions.

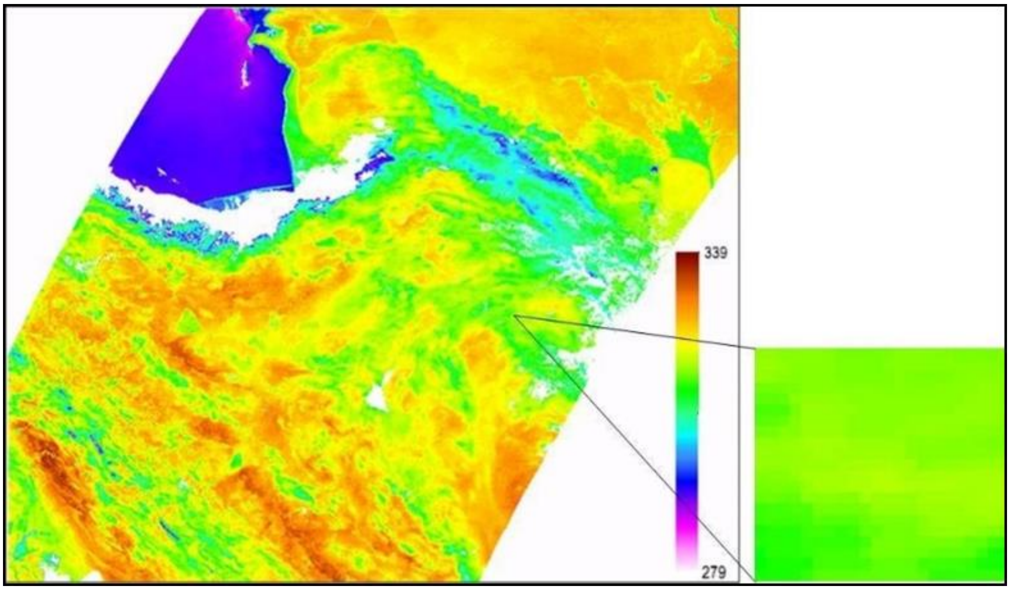

Fig. 5 - Land surface temperature retrieved from MODIS sensor for the study area at 13:54 on June 10, 2013

The results of the measurements collected in June 2013, specifically for the 15 nocturnal times during clear-sky conditions, are presented in Table 2. This table provides a detailed comparison of the land surface temperature (LST) values measured by the field thermometers and the corresponding MODIS-derived LST values for nighttime conditions. The data in Table 2 will be used to evaluate the accuracy of the MODIS LST products during the night, which is crucial for understanding the full diurnal temperature cycle in the study area. Statistical analysis will also be performed to assess the agreement between the field measurements and satellite data, further supporting the validation of MODIS LST in arid environments.

Table 2. Comparison of ground-based LST measurements and MODIS LST during nocturnal clear-sky conditions, June 2013

Date	Time of satellite's overpass	Ground LST (K)	Product name	MODIS LST(K)	Difference between MODIS and ground LST (K)
10 June	21:42	302	MOD11A1	296.2	5.8
12 June	21:30	304	MOD11A1	296.2	7.8
13 June	22:12	301	MOD11A1	297.2	3.8
14 June	22:54	298	MOD11A1	294.2	3.8
15 June	22:00	297	MOD11A1	293.5	2.5
22 June	22:06	303.8	MOD11A1	300	3.8
24 June	21:54	303	MOD11A1	299.8	3.2
10 June	02:00	298.3	MYD11A1	293.2	5.1
12 June	01:48	299	MYD11A1	294.3	4.7
13 June	02:30	298.2	MYD11A1	293.1	5.1
14 June	01:36	296	MYD11A1	291.4	4.6
15 June	02:18	293	MYD11A1	288.6	4.4

23 June	01:30	299	MYD11A1	293.6	5.4
24 June	02:18	298	MYD11A1	295	3
25 June	01:18	299	MYD11A1	295.6	3.4

According to the data presented in Table 2, Fig. 6 displays the linear relationship between MODIS-derived land surface temperature (LST) and the ground-based LST measurements. This graph illustrates how well the satellite-observed LST values correlate with the field measurements taken during nocturnal, clear-sky conditions in June 2013.

In addition to the linear regression graph, statistical parameters such as the coefficient of determination (R^2), slope, and intercept are provided to quantify the strength and accuracy of the relationship between the two datasets. These parameters offer insights into the level of agreement between the MODIS LST data and the ground truth measurements, helping to assess the reliability of the MODIS products during nighttime observations. The comparison of the data further contributes to validating the MODIS LST in arid regions and supports the evaluation of the accuracy of remote sensing technologies in representing real-world surface temperatures.

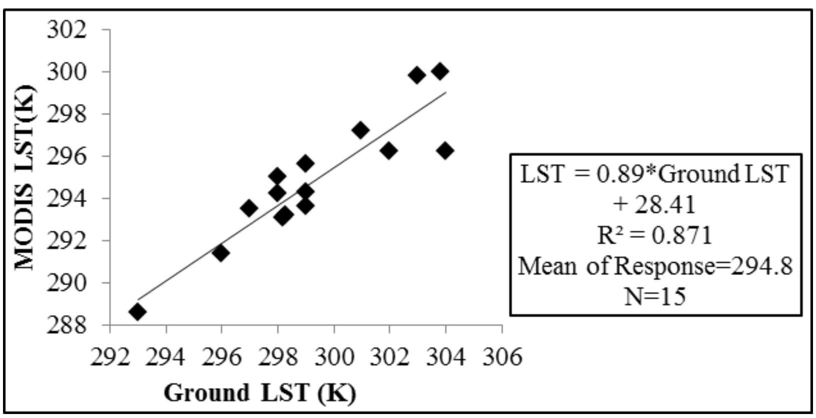

Fig. 6 - Linear relationship between MODIS LST and ground-based LST measurements during nocturnal clear-sky conditions, with statistical parameters

3.4. Diurnal vs. Nocturnal LST Validation

The results of the comparison between ground-based measurements and MODIS-derived LST products revealed that the diurnal measurements exhibited a lower coefficient of determination (R^2) compared to the nocturnal measurements. This discrepancy can be attributed to the inherent differences between day and night thermal dynamics. During the nighttime, the absence of solar radiation results in a more homogeneous and isothermal land surface, which makes it easier for the MODIS LST products to match the ground-based measurements. In contrast, during the day, the surface temperature varies significantly between areas exposed to direct sunlight and those in shadow. In some cases, this temperature difference can be as high as 20°C (Wan and Dozier, 1996). Such spatial heterogeneity during the day increases the difficulty for MODIS to accurately capture the true surface temperature.

Additionally, the MODIS LST products (MOD11A1 and MYD11A1) generally underestimated the surface temperature, especially during the daytime. This underestimation is attributed to the overestimation of surface emissivity by the split-window algorithm used in these satellite products, which tends to result in a lower temperature estimation.

Fig. 7 illustrates the LST data retrieved from the MODIS sensor at 22:45 on June 14, 2013, providing a visual representation of the temperature distribution in the study area during the nighttime. This further reinforces the more consistent and reliable temperature retrievals at night as compared to the daytime.

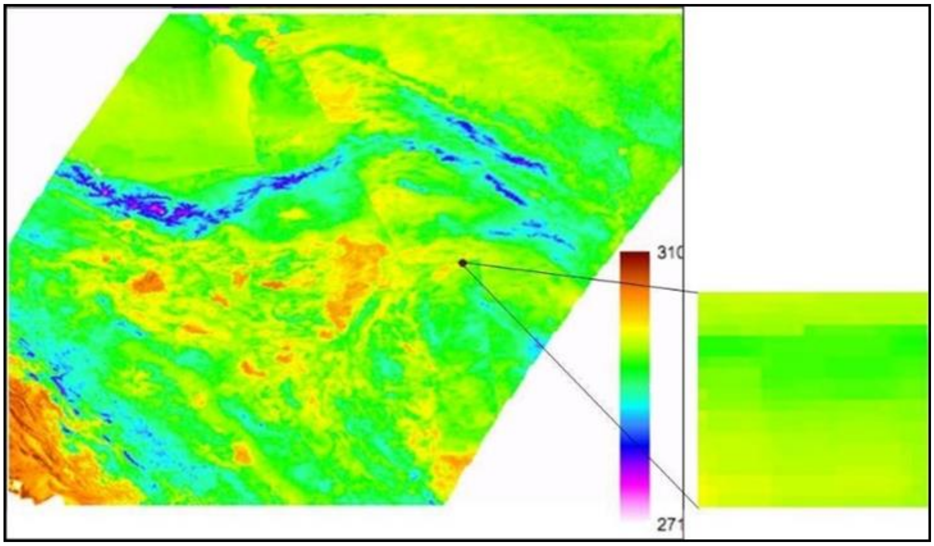

Fig. 7 - Land surface temperature retrieved from MODIS sensor at 22:45 on June 14, 2013

3.5. Comparison of Aqua and Terra Satellite LST Data with Ground-Based Measurements

The land surface temperature (LST) data retrieved from the Aqua and Terra satellites were compared with ground-based measurements to evaluate the accuracy of the satellite-derived products. This comparison provided insights into the performance of MODIS LST data under varying conditions and times of observation.

The analysis specifically focused on the data obtained from the Aqua satellite (MYD11A1 product). The results of this analysis, including the statistical relationship between Aqua-derived LST and ground-based measurements, are presented in Fig. 8. This figure illustrates the correlation and any systematic deviations observed in the Aqua satellite data when compared to field measurements.

The findings highlight the accuracy and limitations of MODIS products, providing a basis for improving their application in arid and semi-arid environments.

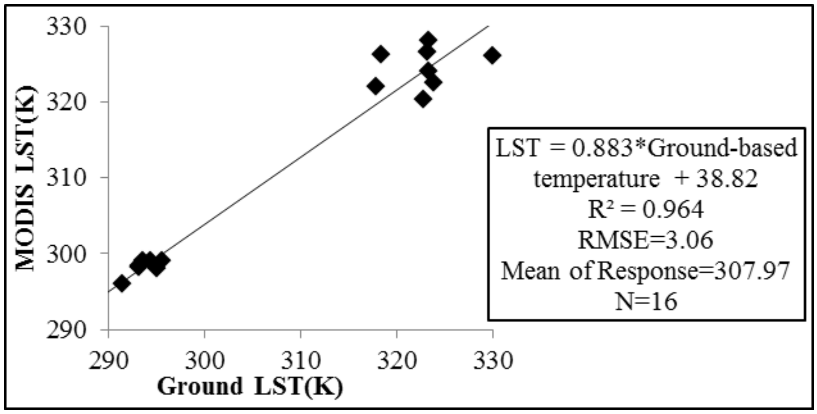

Fig. 8 - Linear relationship between LST data of Aqua satellite and ground-based measurements

3.6. MODIS Aqua Satellite Imagery

Fig. 9 presents an example of the MODIS sensor images captured aboard the Aqua satellite on June 25, 2013. These images illustrate the spatial distribution of land surface temperature (LST) within the study area, as observed by the Aqua satellite.

The imagery provides a visual representation of the thermal variations across the Bajestan Desert, highlighting the high-resolution capabilities of the MODIS sensor to detect temperature patterns. Such images are crucial for understanding the diurnal and nocturnal thermal behavior of the land surface and for validating satellite-derived LST data against ground-based measurements.

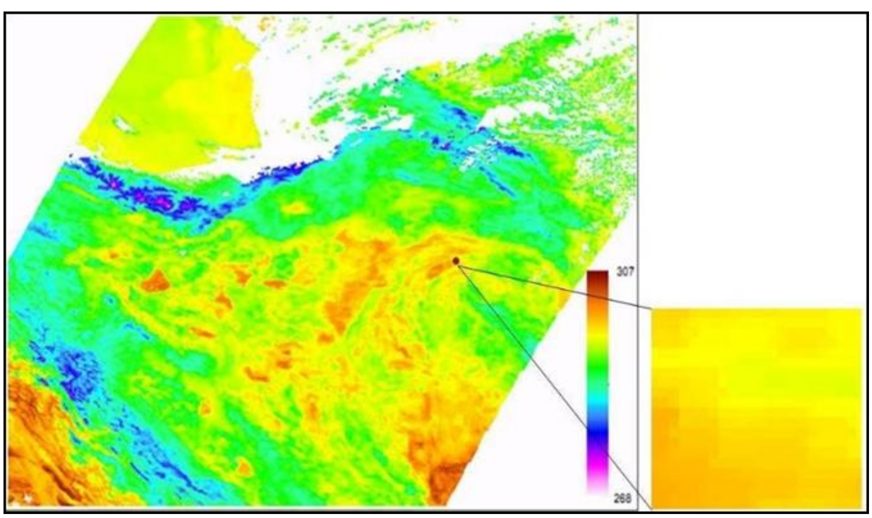

Fig. 9 - MODIS Aqua satellite imagery showing land surface temperature distribution on June 25, 2013.Analysis of Terra Satellite LST Data

The land surface temperature (LST) data retrieved from the Terra satellite (MOD11A1 product) were analyzed and compared with ground-based measurements to assess its accuracy. The results of this analysis are depicted in Fig. 10, which highlights the relationship between Terra-derived LST and the measured surface temperatures in the study area.

Fig. 10 provides a detailed statistical comparison, showcasing the correlation and any potential biases present in the Terra satellite data. This analysis is essential for understanding the performance of MODIS Terra LST products, particularly under the arid conditions of the Bajestan Desert.

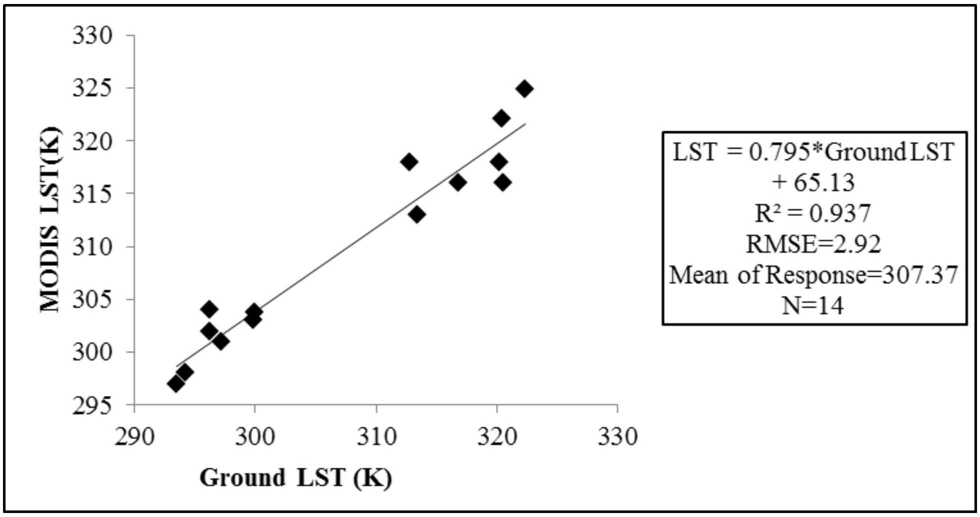

Fig. 10 - Linear relationship between LST data of Terra satellite and ground-based temperature measurements.

3.7. MODIS Terra Satellite Imagery

Fig. 11 provides an example of the images captured by the MODIS sensor aboard the Terra satellite at 10:18 on June 14, 2013. This imagery highlights the spatial distribution of land surface temperature (LST) across the study area during the daytime, showcasing the thermal variations observed under clear-sky conditions. The Terra satellite imagery offers valuable insights into the daytime thermal dynamics of the Bajestan Desert. The observed patterns in Fig. 11 underscore the influence of solar radiation and surface characteristics on temperature distribution, providing a visual representation that complements the statistical analyses of Terra LST accuracy.

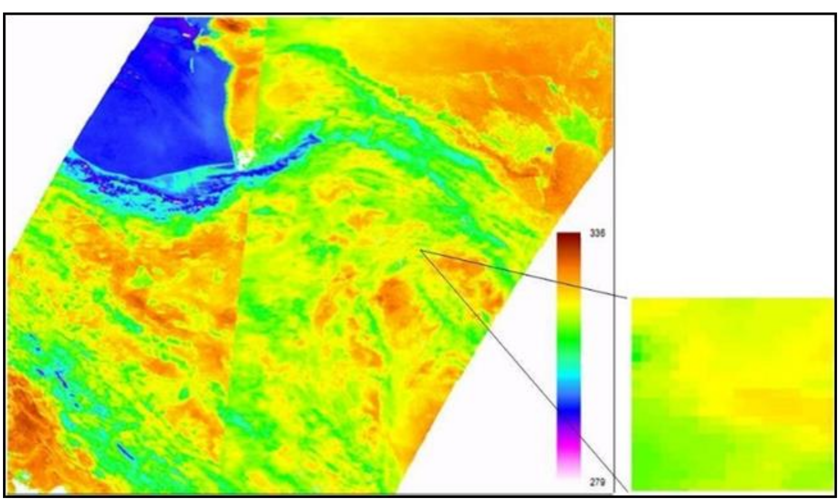

Fig. 11- MODIS Terra satellite imagery showing land surface temperature distribution at 10:18 on June 14, 2013

3.8. Summary of Validation Results and Practical Application

The validation results demonstrate that the land surface temperature (LST) values derived from Terra and Aqua satellite data exhibit a coefficient of determination (R^2) exceeding 95% and a root mean square error (RMSE) of approximately 3°C. These findings confirm the reliability of MODIS LST products for representing surface temperatures in arid regions like the Bajestan Desert. The derived regression equations from the analysis can be effectively applied to estimate the actual surface temperature using MODIS images from both Terra and Aqua satellites.

However, a consistent underestimation of the land surface temperature by MODIS was observed, with values ranging from 1.5°C to 4°C below the actual ground-based measurements. This bias is likely attributed to the overestimation of surface emissivity by the split-window algorithm used in the MODIS products.

The results of the comparison between 30 diurnal and nocturnal ground-based surface temperature measurements and MODIS-derived LST values from both Terra and Aqua satellites are summarized in Fig. 12. This figure provides a comprehensive overview of the relationship between the satellite data and field measurements, highlighting the strong agreement while also reflecting the observed systematic bias.

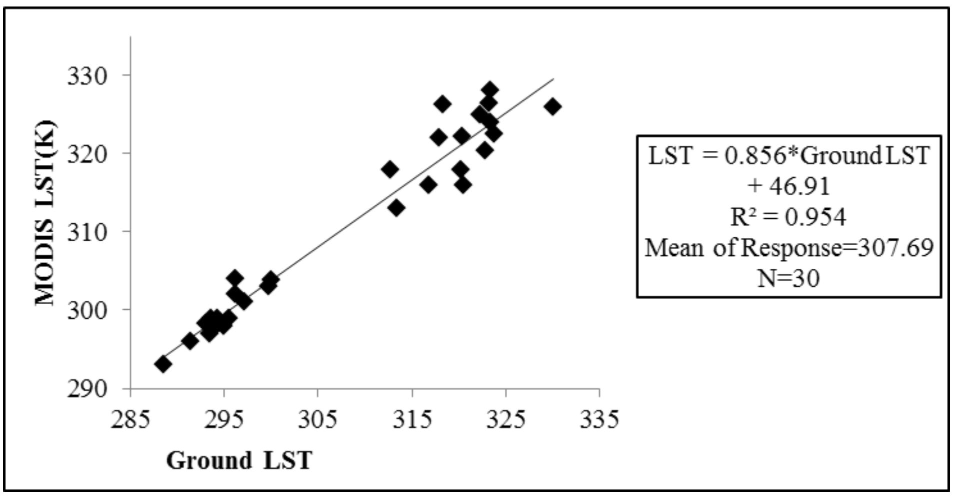

Fig. 12- Linear relationship between LST data of MODIS sensor and ground-based temperature measurements.

3.9. Validation Using Homogeneous Areas Larger than MODIS Pixel Size

An effective approach for validating MODIS LST products involves selecting homogeneous areas that are larger than the size of MODIS pixels and analyzing image windows (e.g., 7×7 pixels) to derive mean temperature values. This method ensures that the sampling points are located in regions with minimal surface variability, enhancing the reliability of the validation process.

In the present study, windows of varying sizes—3×3, 5×5, 7×7, 9×9, and 11×11 pixels (kilometers on the ground)—were selected as sampling areas. The mean LST values of these pixel windows were compared with ground-based surface temperature measurements. This multiscale approach helped to identify the influence of window size on the agreement between MODIS-derived temperatures and field observations. For each selected window, the mean surface temperature was calculated and compared against the corresponding field measurements. Fig. 13 illustrates the results obtained from analyzing temperature within different windows of the MODIS image captured on June 13, 2013. This figure highlights the impact of window size on the accuracy of MODIS LST products and their consistency with ground-based measurements, providing further insights into the validation process.

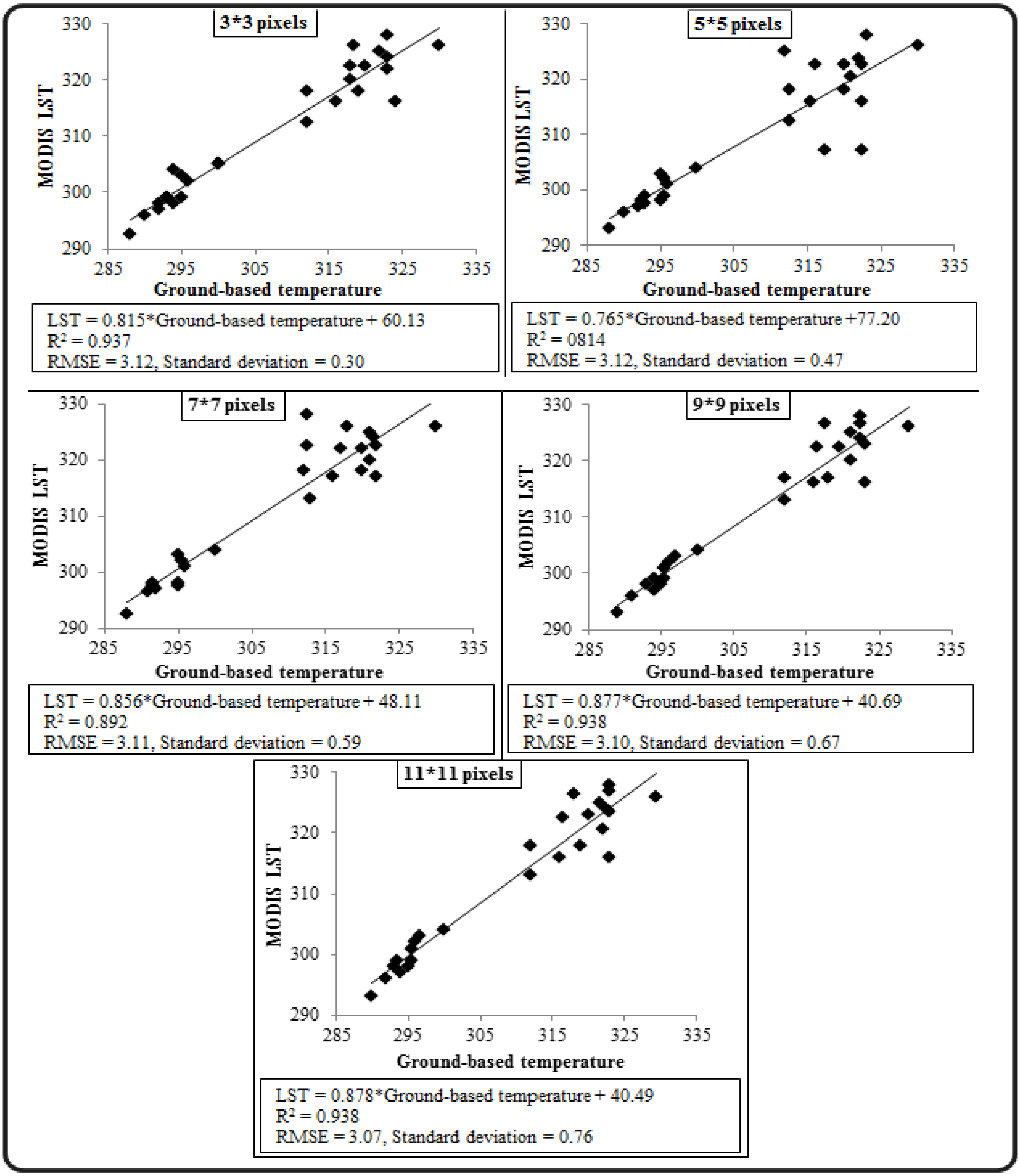

Fig. 13- Analysis of LST derived from MODIS image on June 13, 2013, using various window sizes compared with ground-based measurements

3.10. Influence of Window Size on Validation Results

The results of the analysis indicate that increasing the window size leads to an increase in the maximum temperature and a decrease in the minimum temperature, resulting in greater temperature variation and higher standard deviation. A low standard deviation reflects minimal variation in the temperatures of image pixels, indicating a more uniform surface temperature. Despite the observed increase in the standard deviation of pixel temperatures with larger window sizes, the root mean square error (RMSE) and the coefficient of determination (R^2) exhibited only minor changes. This consistency suggests that the MODIS LST data maintain high reliability across varying window sizes. The high R^2 and low RMSE values across all window sizes demonstrate that the MODIS LST products are effective in representing surface temperatures, even in cases of low surface temperature variability. These findings highlight the robustness of MODIS LST products for temperature estimation in homogeneous areas, making them a valuable tool for environmental and climatic studies.

4. Discussion

Land surface temperature (LST) is a critical parameter in understanding and monitoring climatic and environmental processes. Its accurate retrieval from remote sensing data, particularly MODIS (Moderate Resolution Imaging Spectroradiometer) products, has been extensively studied due to its wide applicability in areas such as climate modeling, drought monitoring, and urban studies (Wan and Dozier, 1996; Coll et al., 2005; Wang et al., 2008). However, validating satellite-derived LST with ground-based measurements is essential to ensure reliability, especially in challenging environments like arid and semi-arid regions.

This study utilized a robust approach to validate MODIS LST products (MOD11A1 from Terra and MYD11A1 from Aqua) in the Bajestan Desert, Iran, an area with homogeneous land cover and minimal vegetation. Two complementary validation methods were employed:

Direct comparison of ground-based temperature measurements with corresponding pixels in MODIS images. Validation by averaging temperatures over larger homogeneous windows (3×3 to 11×11 pixels) within MODIS images to account for spatial variability. The study analyzed diurnal and nocturnal measurements under clear-sky conditions, leveraging statistical metrics such as the coefficient of determination (R^2) and root mean square error (RMSE) to evaluate accuracy.

The results highlighted that nocturnal LST data exhibited higher correlations with ground-based measurements compared to diurnal data. This distinction can be attributed to the absence of solar radiation at night, resulting in a more isothermal and homogeneous land surface. During the day, the effects of direct solar radiation and shadows introduce spatial variability, reducing the correlation between satellite and ground measurements. This phenomenon is consistent with earlier studies, which reported significant temperature differences due to varying surface emissivity and radiative effects during daytime (Wan et al., 2002; Zakšek and Oštir, 2012).

A systematic underestimation of LST by MODIS products was observed, with Terra and Aqua data underestimating ground-based temperatures by 1.5°C to 4°C. This underestimation aligns with findings from previous research, which suggested that the split-window algorithm used in MODIS LST products often overestimates surface emissivity, particularly in arid and semi-arid regions (Coll et al., 2005; Wan and Li, 2008).

The statistical metrics demonstrated the reliability of the validation methods. Coefficient of determination values exceeding 90% and RMSE below 4°C across all cases affirm the suitability of the selected homogeneous windows and validation methodology. Low standard deviation values (less than 1°C) further confirmed the appropriateness of the study area, as homogeneous and uniform surfaces are critical for accurate satellite data validation (Wang et al., 2016).

The study underscores the importance of validating satellite-derived LST products using robust methodologies and appropriate sampling areas. The results highlight the necessity of incorporating larger homogeneous areas in validation studies to reduce the influence of spatial variability and ensure more reliable comparisons.

Given the observed underestimation of LST by MODIS products in arid regions, long-term validation studies are recommended. Automatic temperature measurement stations strategically located in representative areas can provide continuous and precise ground-based data, enhancing the reliability of satellite product validation.

Future research could extend this study by examining seasonal and interannual variations in LST accuracy, as well as exploring the impact of atmospheric corrections on MODIS products. Addressing these factors will improve the usability of MODIS LST products in arid and semi-arid environments, where accurate temperature data are essential for various environmental and climate-related applications.

This study validates the accuracy of MODIS LST products (MOD11A1 and MYD11A1) in the Bajestan Desert, demonstrating their applicability despite systematic underestimations in arid regions. The high R^2 values and low RMSE obtained confirm the robustness of the employed methodologies and the suitability of the study area. However, ongoing efforts to refine algorithms and validation techniques are crucial for achieving higher accuracy in satellite-derived LST products, particularly in challenging environments.

5. Conclusion

This study emphasizes the critical importance of validating satellite-derived land surface temperature (LST) products using robust methodologies and carefully selected sampling areas. The findings highlight the necessity of incorporating larger homogeneous areas in validation studies to mitigate the effects of spatial variability and ensure reliable comparisons. The observed underestimation of LST by MODIS products in arid regions underscores the need for long-term validation efforts. Establishing automatic temperature measurement stations in representative areas will enable continuous and precise ground-based data collection, enhancing the accuracy and reliability of satellite product validation.

Future research should explore seasonal and interannual variations in LST accuracy and investigate the influence of atmospheric corrections on MODIS products. These efforts will further improve the applicability of MODIS LST products, particularly in arid and semi-arid regions where precise temperature data are vital for environmental and climate-related studies. The results of this study validate the accuracy of MODIS LST products (MOD11A1 and MYD11A1) in the Bajestan Desert, demonstrating their applicability despite systematic underestimations. The high coefficient of determination (R^2) and low root mean square error (RMSE) values obtained confirm the robustness of the employed methodologies and the appropriateness of the study area. Nonetheless, continuous refinement of algorithms and validation techniques remains essential to achieve higher accuracy and broader applicability of satellite-derived LST products in complex environments.

Acknowledgements

The authors express their sincere gratitude to all individuals and institutions that supported this research.

Declarations

Funding Information (Private funding by authors)

Conflict of Interest /Competing interests (None)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Authors consent to publishing)

Authors Contributions (All co-authors contributed to the manuscript)

Code availability (Not applicable)

REFERENCES

Alavipanah, S. K. (2006). Thermal remote sensing and its application in earth sciences. *University of Tehran press, ISBN*, 964-903.

AZIZI, G., Alavipanah, S. K., Goudarzi, N., & Kazemi, M. (2007). An estimation of the temperature of Lut desert using MODIS sensor data.

Bokaie, M., Zarkesh, M. K., Arasteh, P. D., & Hosseini, A. (2016). Assessment of urban heat island based on the relationship between land surface temperature and land use/land cover in Tehran. *Sustainable Cities and Society*, *23*, 94-104. https://doi.org/10.1016/j.scs.2016.03.009

Coll, C., Caselles, V., Galve, J. M., Valor, E., Niclos, R., Sánchez, J. M., & Rivas, R. (2005). Ground measurements for the validation of land surface temperatures derived from AATSR and MODIS data. *Remote sensing of Environment*, *97*(3), 288-300. https://doi.org/10.1016/j.rse.2005.05.007

Coll, C., & Caselles, V. (1997). A split‐window algorithm for land surface temperature from advanced very high resolution radiometer data: validation and algorithm comparison. *Journal of Geophysical Research: Atmospheres*, *102*(D14), 16697-16713. https://doi.org/10.1029/97JD00929

Davari, S., Rashki, A., Akbari, M., & Talebanfard, A. (2017). Assessing intensity and risk of desertification and management programs (Case study: Ghasemabad plain of Bajestan, Khorasan Razavi Province). *Desert Management*, *5*(9), 91-106. https://doi.org/10.22034/jdmal.2017.27855

Davies, D. K., Ilavajhala, S., Wong, M. M., & Justice, C. O. (2008). Fire information for resource management system: archiving and distributing MODIS active fire data. *IEEE Transactions on Geoscience and Remote Sensing*, *47*(1), 72-79. https://doi.org/10.1109/TGRS.2008.2002076

Ermida, S. L., Jiménez, C., Prigent, C., Trigo, I. F., & DaCamara, C. C. (2017). Inversion of AMSR‐E observations for land surface temperature estimation: 2. Global comparison with infrared satellite temperature. *Journal of Geophysical Research: Atmospheres*, *122*(6), 3348-3360. https://doi.org/10.1002/2016JD026148

Ghalamchi, M., Kasaeian, A., & Ghalamchi, M. (2015). Experimental study of geometrical and climate effects on the performance of a small solar chimney. *Renewable and Sustainable Energy Reviews*, *43*, 425-431. https://doi.org/10.1016/j.rser.2014.11.068

Guillevic, P. C., Bork-Unkelbach, A., Göttsche, F. M., Hulley, G., Gastellu-Etchegorry, J. P., Olesen, F. S., & Privette, J. L. (2013). Directional viewing effects on satellite land surface temperature products over sparse vegetation canopies—A multisensor analysis. *IEEE Geoscience and Remote Sensing Letters*, *10*(6), 1464-1468. https://doi.org/10.1109/LGRS.2013.2260319

Justice, C., Belward, A., Morisette, J., Lewis, P., Privette, J., & Baret, F. (2000). Developments in the'validation'of satellite sensor products for the study of the land surface. *International Journal of Remote Sensing*, *21*(17), 3383-3390. https://doi.org/10.1080/014311600750020000

Maimaitiyiming, M., Ghulam, A., Tiyip, T., Pla, F., Latorre-Carmona, P., Halik, Ü., ... & Caetano, M. (2014). Effects of green space spatial pattern on land surface temperature: Implications for sustainable urban planning and climate change adaptation. *ISPRS Journal of Photogrammetry and Remote Sensing*, *89*, 59-66. https://doi.org/10.1016/j.isprsjprs.2013.12.010

Olivera-Guerra, L., Mattar, C., Merlin, O., Durán-Alarcón, C., Santamaría-Artigas, A., & Fuster, R. (2017). An operational method for the disaggregation of land surface temperature to estimate actual evapotranspiration in the arid region of Chile. *ISPRS Journal of Photogrammetry and Remote Sensing*, *128*, 170-181. https://doi.org/10.1016/j.isprsjprs.2017.03.014

Orhan, O., Ekercin, S., & Dadaser-Celik, F. (2014). Use of landsat land surface temperature and vegetation indices for monitoring drought in the Salt Lake Basin Area, Turkey. *The Scientific World Journal*, *2014*(1), 142939. https://doi.org/10.1155/2014/142939

Pahlevani, M., & Mobasheri, M. R. (2009). An Improvement on Land Surface Temperature Determination by Producing Surface Emissivity Maps. *Desert*, *14*(2), 171-184. https://doi.org/10.1080/01431160600702665

Prata, A. J. (2002). Land surface temperature measurement from space: AATSR algorithm theoretical basis document. *Contract Report to ESA, CSIRO Atmospheric Research, Aspendale, Victoria, Australia*, *2002*, 1-34.

Son, N. T., Chen, C. F., Chen, C. R., Chang, L. Y., & Minh, V. Q. (2012). Monitoring agricultural drought in the Lower Mekong Basin using MODIS NDVI and land surface temperature data. *International Journal of Applied Earth Observation and Geoinformation*, *18*, 417-427. https://doi.org/10.1016/j.jag.2012.03.014

Srivastava, P. K., Han, D., Ramirez, M. R., & Islam, T. (2013). Machine learning techniques for downscaling SMOS satellite soil moisture using MODIS land surface temperature for hydrological application. *Water resources management*, *27*, 3127-3144. https://doi.org/10.1007/s11269-013-0337-9

Wan, Z., & Li, Z. L. (2008). Radiance-based validation of the V5 MODIS land-surface temperature product. *International Journal of Remote Sensing*, *29*(17-18), 5373-5395. https://doi.org/10.1080/01431160802036565

Wang, K., Wan, Z., Wang, P., Sparrow, M., Liu, J., & Haginoya, S. (2007). Evaluation and improvement of the MODIS land surface temperature/emissivity products using ground-based measurements at a semi-desert site on the western Tibetan Plateau. *International Journal of Remote Sensing*, *28*(11), 2549-2565. https://doi.org/10.1080/01431160600702665

Wang, W., Liang, S., & Meyers, T. (2008). Validating MODIS land surface temperature products using long-term nighttime ground measurements. *Remote Sensing of Environment*, *112*(3), 623-635. https://doi.org/10.1016/j.rse.2007.05.024

Wan, Z. (2014). New refinements and validation of the collection-6 MODIS land-surface temperature/emissivity product. *Remote sensing of Environment*, *140*, 36-45. https://doi.org/10.1016/j.rse.2013.08.027

Wan, Z. (2008). New refinements and validation of the MODIS land-surface temperature/emissivity products. *Remote sensing of Environment*, *112*(1), 59-74. https://doi.org/10.1016/j.rse.2006.06.026

Wan, Z., Wang, P., & Li, X. (2004). Using MODIS land surface temperature and normalized difference vegetation index products for monitoring drought in the southern Great Plains, USA. *International journal of remote sensing*, *25*(1), 61-72. https://doi.org/10.1080/0143116031000115328

Wan, Z., & Dozier, J. (1996). A generalized split-window algorithm for retrieving land-surface temperature from space. *IEEE Transactions on geoscience and remote sensing*, *34*(4), 892-905. https://doi.org/10.1109/36.508406

Wang, S., Li, X., Ge, Y., Jin, R., Ma, M., Liu, Q., ... & Liu, S. (2016). Validation of regional-scale remote sensing products in China: From site to network. *Remote Sensing*, *8*(12), 980. https://doi.org/10.3390/rs8120980

Wan, Z., Zhang, Y., Zhang, Q., & Li, Z. L. (2002). Validation of the land-surface temperature products retrieved from Terra Moderate Resolution Imaging Spectroradiometer data. *Remote sensing of Environment*, *83*(1-2), 163-180.

Zakšek, K., & Oštir, K. (2012). Downscaling land surface temperature for urban heat island diurnal cycle analysis. *Remote Sensing of Environment*, *117*, 114-124. https://doi.org/10.1016/j.rse.2011.05.027