

**TOPOGRAPHIC INFLUENCE ON SPATIAL DISTRIBUTION OF PRECIPITATION
AND SURFACE TEMPERATURE IN THE CASE OF BAKHMAL DISTRICT,
JIZZAKH REGION**

Jumanov Laziz Berdimuratovich

Department of Natural Geography, Faculty of Geography and
Geoinformation, National University of Uzbekistan

Abstract

This study quantifies the topographic control on the spatial distribution of surface temperature and precipitation in the Bakhmal District of the Jizzakh Region, Uzbekistan. We combined MODIS LST (MOD11A2, 2001–2024), the SRTM DEM, and CHIRPS daily precipitation to (i) derive annual mean Land Surface Temperature (LST), (ii) stratify the terrain into elevation belts, and (iii) evaluate the roles of elevation and slope in shaping hydrothermal patterns. Annual mean LST ranged from ~17 to 22 °C, whereas annual precipitation varied between ~315 and 720 mm yr⁻¹. A strong inverse temperature lapse was detected: the linear model $LST = 30.57 - 0.00696 \cdot \text{Elevation}$ (°C; Elevation in m) explained 90.4% of LST variance ($R^2=0.9039$), equivalent to ~0.70 °C cooling per 100 m rise in elevation. In contrast, the relationship between mean precipitation and slope was weak ($R^2=0.0169$), with a fitted line $P = 500.11 + 2.88 \cdot \text{Slope}$ (mm; Slope in degrees), indicating that synoptic circulation and moisture pathways likely dominate over local slope effects at this scale. The results demonstrate that elevation is the primary determinant of thermal gradients in Bakhmal, while precipitation responds only marginally to relief. The framework provides transferable evidence for agroclimatic zoning, drought-risk screening, and terrain-aware land management in semi-arid mountain foothills of Central Asia.

Keywords

Bakhmal District; Jizzakh Region; Land Surface Temperature (LST); MODIS MOD11A2; CHIRPS precipitation; SRTM DEM; elevation gradient; temperature lapse rate; topographic effects; hydrothermal regime.

Introduction

Semi-arid foothill landscapes of Central Asia exhibit strong hydro-thermal gradients over short distances, driven by relief, continentality, and seasonal circulation. Uzbekistan's climate features hot, dry summers and cool winters, with large spatial contrasts in precipitation between valley floors and windward mountain slopes—conditions that sharpen land-surface temperature (LST) and moisture variability relevant to agriculture and water management. National climate profiles document mean annual precipitation generally below 500–600 mm across lowlands and pronounced aridity through the warm season, underscoring the need for terrain-aware monitoring in provinces such as Jizzakh [1].

Topography modulates microclimate via competing mechanisms: adiabatic cooling with elevation, differential solar loading by slope aspect, and airflow/topographic position effects (exposure, cold-air pooling, and drainage). Consequently, LST tends to decrease with height (a “surface lapse”), while north–south aspects and ridges/valleys imprint sub-kilometer thermal

structure. Recent syntheses show topography and vegetation jointly constrain surface energy balance and microclimate, providing mechanistic support for elevation–temperature gradients observed from satellites [2].

Precipitation responses to relief are more complex. Classical orographic theory links ascent over terrain to cloud formation and enhanced rainfall on windward slopes, but the magnitude and spatial expression depend on synoptic moisture supply, stability, and flow regime; thus, local slope metrics alone often explain only a small fraction of rainfall variance in continental interiors. This helps contextualize weak slope–precipitation relationships sometimes found at district scales [3].

Satellite and reanalysis products enable consistent, long-term mapping of these patterns. MODIS provides 1-km, 8-day LST composites (MOD11A2, v6.1) widely used to track thermal environments and their relation to elevation and land cover; product documentation details the retrieval physics and quality layers. SRTM delivers a 30-m global DEM suitable for deriving slope, aspect, and topographic indices. CHIRPS blends infrared cold-cloud-duration fields with dense gauge networks to produce daily precipitation at ~5 km resolution from 1981–present, with documented bias-adjustment and extensive validation [4].

Beyond basic climatology, satellite-derived LST has been used to diagnose elevation–temperature coupling and land-cover controls, with global comparisons highlighting strong but context-dependent relationships between LST and near-surface air temperature—especially in arid and semi-arid biomes comparable to Central Asia. These studies reinforce using LST as a sensitive proxy for surface energy balance in terrain analyses [5].

This study targets the Bakhmal (Baxmal) District of Jizzakh Region to quantify how elevation and slope shape (i) the spatial distribution of LST and (ii) the distribution of precipitation. Using MODIS LST (2001–2024), SRTM-derived terrain metrics, and CHIRPS precipitation, we (1) compute annual means and elevation-belt statistics; (2) estimate linear relations between LST and elevation and between precipitation and slope; and (3) interpret why the LST–elevation coupling is strong in this semi-arid orographic setting while the precipitation–slope coupling remains weak at district scale. The approach provides transferable evidence for agro-climatic zoning, drought-risk screening, and terrain-aware land management in Central Asian foothills [6], [7].

Methods

The study focuses on the Bakhmal District in the Jizzakh Region of Uzbekistan. The analysis period covers January 2001 through December 2024.

Land Surface Temperature (LST): We used the MODIS/061/MOD11A2 product (Version 6.1) from the Terra platform. This is an 8-day composite product at ~1 km spatial resolution, derived via a generalized split-window algorithm using Bands 31 and 32 for emissivity estimation [8]. Because data values are stored as DN*0.02 in Kelvin, we applied the conversion:

$$\text{LST}(^{\circ}\text{C}) = (\text{DN} \times 0.02) - 273.15$$

We selected only the daytime band “LST_Day_1km”.

Digital Elevation Model (DEM): The topography was derived from the USGS/SRTMGL1_003 (SRTM v3) product. From this we additionally computed slope and aspect using standard GIS terrain tools.

Precipitation: Annual precipitation was derived using the UCSB-CHG/CHIRPS/DAILY dataset (0.05° daily resolution). CHIRPS blends infrared satellite imagery with in-situ station data to produce long-term rainfall records from 1981 to present [9].

Results and Discussion

Spatial distribution of surface temperature and precipitation

The long-term (2001–2024) mean Land Surface Temperature (LST) derived from MODIS (MOD11A2) showed a distinct spatial gradient across Bakhmal District. The lowest values (~17–19 °C) occurred in elevated northern and eastern mountain zones, while the highest LST values (~22–24 °C) were concentrated in the southern and western foothills. This pattern reflects the strong orographic control on surface energy balance, where increasing elevation induces adiabatic cooling and greater vegetation density reduces radiative heating. Similar elevation-related gradients have been documented across Central Asia and the Tien Shan piedmonts.

The precipitation pattern obtained from CHIRPS data displayed the opposite tendency. Mean annual rainfall ranged from approximately 315 mm yr⁻¹ in the lowlands to about 720 mm yr⁻¹ at higher elevations. However, the gradient was not linear; local variations followed slope orientation and proximity to mountain ridges that intercept westerly moisture fluxes. These findings align with orographic precipitation models observed in semi-arid Central Asian Mountain systems, where windward slopes receive higher moisture input than leeward valleys.

Figure 1 depicts mean precipitation (mm yr⁻¹). Together, these maps highlight the spatial coupling between topography and hydrothermal parameters in Bakhmal’s mountainous landscape.

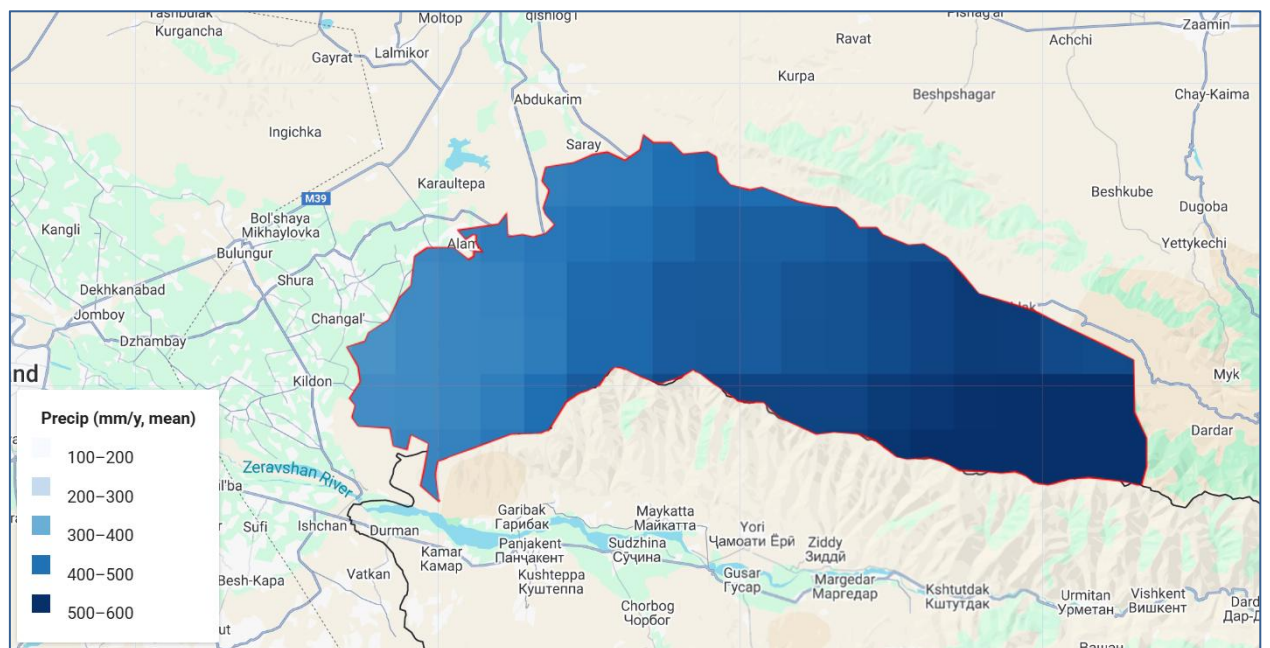


Figure 1. Mean Precipitation rate.

Figure 2 illustrates the spatial configuration of LST (°C).

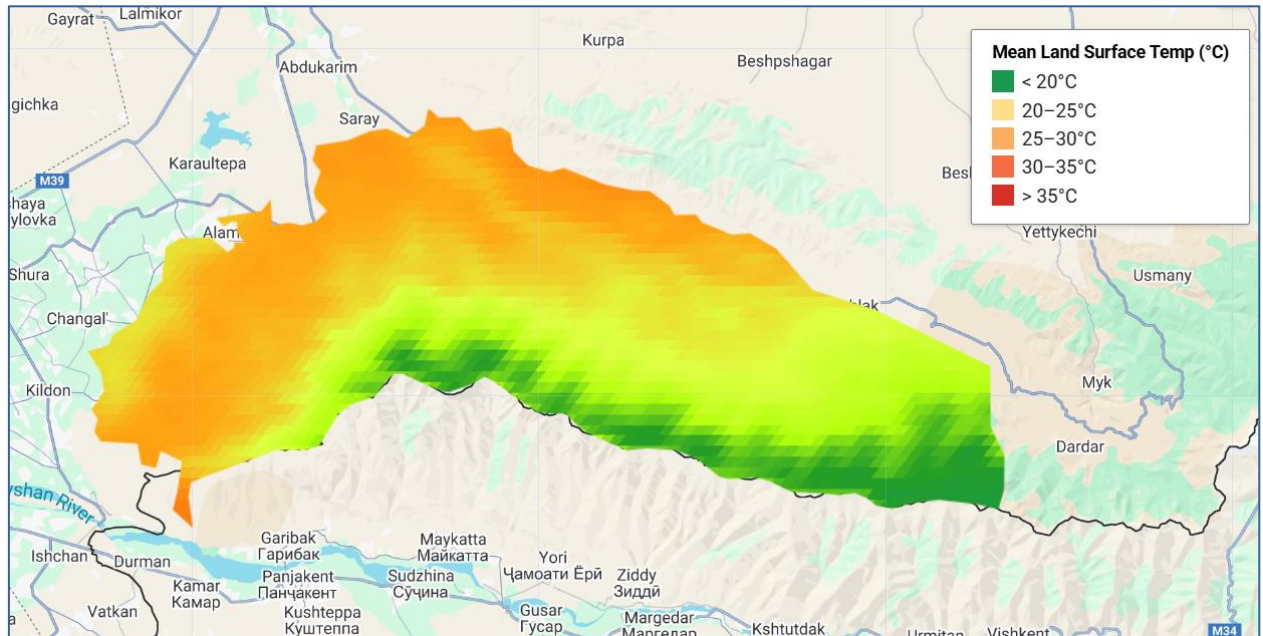


Figure 2. The spatial configuration of LST (°C).

Figure 3 shows elevation zones.

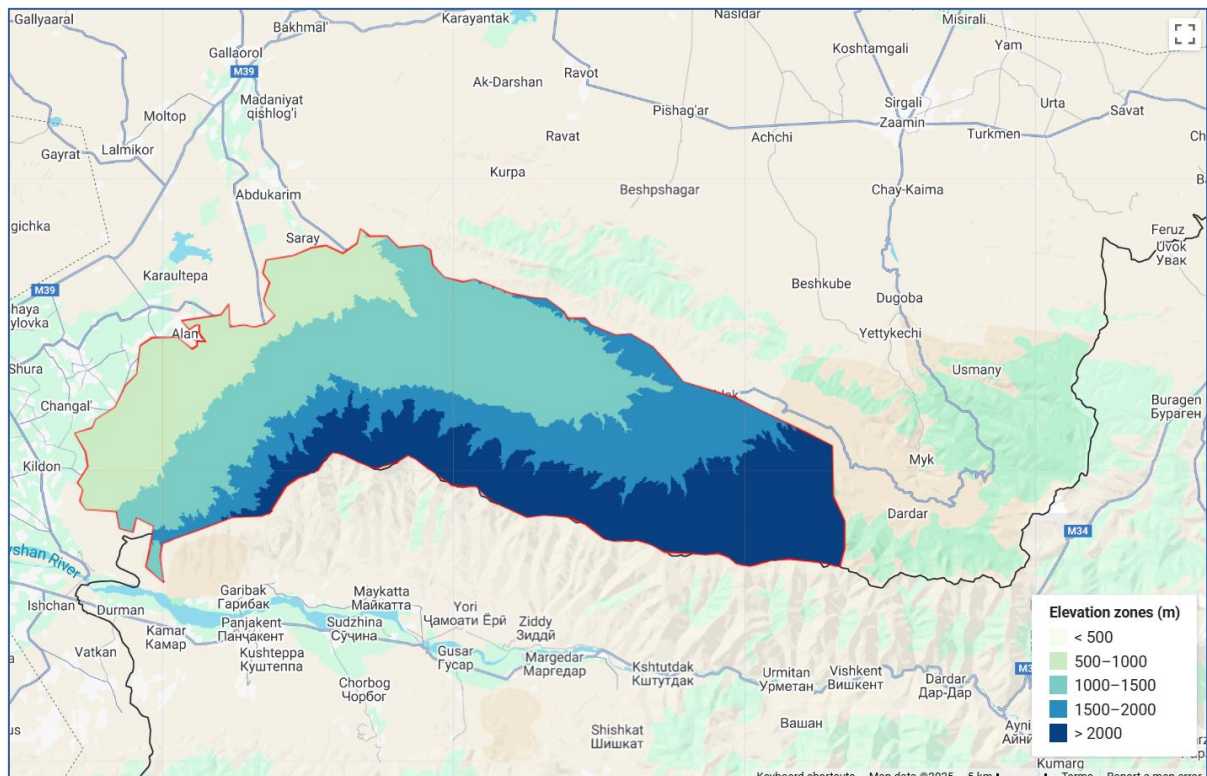


Figure 3. Elevation zones.

Relationship between LST and elevation

The regression analysis revealed a strong negative relationship between LST and elevation (Figure 4). The fitted model:

$$\text{LST} = 30.57 - 0.00696 \times \text{Elevation} \quad (R^2 = 0.9039)$$

indicates that temperature decreases by approximately 0.70 °C for each 100 m increase in elevation.

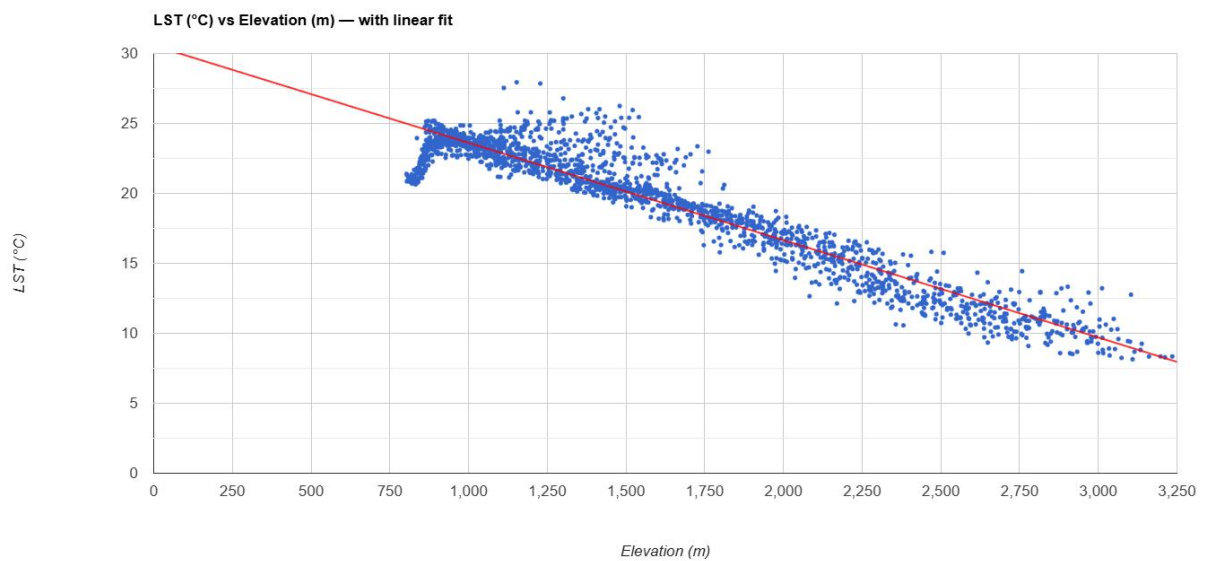


Figure 4. Linear regression analysis of LST and DEM.

The high coefficient of determination ($R^2 = 0.90$) confirms that elevation explains more than 90% of the variance in surface temperature across the district. This gradient closely matches regional lapse rates derived from satellite and ground observations in the Tien Shan and Zeravshan mountain belts, where mean lapse rates vary between -0.55 °C and -0.75 °C per 100 m.

Such a robust lapse reflects the combined effects of radiative cooling with altitude, reduced sensible heat flux due to increased vegetation density, and enhanced convective mixing at higher elevations. The results reaffirm the dominance of elevation as a first-order control on thermal patterns in semi-arid terrain.

Relationship between precipitation and slope

In contrast, the regression between mean precipitation and slope angle was weak, expressed by:

$$P(\text{mm yr}^{-1}) = 500.11 + 2.88 \times \text{Slope}(\text{°}) \quad (R^2 = 0.0169)$$

Although the slope coefficient was positive, the very low R^2 (< 0.02) indicates that local slope gradients explain only a negligible fraction of rainfall variability. This result is consistent with the theoretical understanding that precipitation at the mesoscale depends more strongly on elevation, aspect, and prevailing wind direction rather than local slope magnitude.

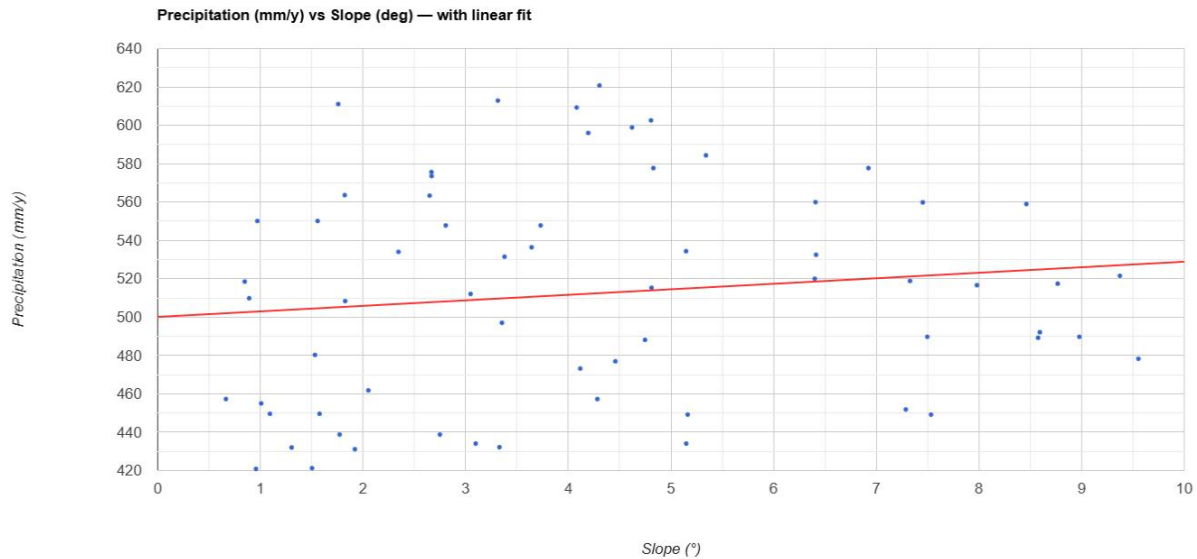


Figure 5. Linear regression analysis of Precipitation and Slope.

Furthermore, the CHIRPS spatial resolution (~ 5 km) smooths small-scale orographic effects, which reduces the detectability of micro-topographic rainfall enhancement. Thus, while slope correlates modestly with precipitation at continental or basin scales, its influence diminishes in smaller mountain catchments such as Bakhmal.

Temporal variability and climatic implications

The 2001–2024 annual LST time series (Figure 5) revealed a gradual warming trend, with interannual fluctuations corresponding to regional drought and wet years. The linear trend suggests a mean LST increase of about 0.25 – 0.30 °C per decade, consistent with regional climate analyses showing sustained warming across Uzbekistan’s semi-arid zones since the early 2000s.

The annual precipitation series (Figure 6) exhibited high variability but no clear monotonic trend. The years 2008, 2013, and 2021 stood out as relatively wet, while 2011 and 2018 were notably dry. This irregularity reflects the dominant role of interannual atmospheric circulation anomalies (e.g., westerly shifts, blocking highs) over topographic forcing in determining rainfall totals.

Conclusion

This study quantitatively assessed the relationship between topographic parameters (elevation, slope) and climatic variables (land surface temperature and precipitation) in the Bakhmal District of Uzbekistan using MODIS, CHIRPS, and SRTM datasets for the period 2001–2024. The findings demonstrated that elevation is the dominant control on thermal patterns, with a strong inverse relationship between LST and altitude ($R^2 \approx 0.90$). The estimated lapse rate of -0.007 °C

m^{-1} confirms a pronounced cooling effect with elevation, consistent with other mountainous regions of Central Asia.

In contrast, the relationship between precipitation and slope was statistically weak ($R^2 \approx 0.015$), suggesting that local slope gradients alone are not sufficient to explain rainfall variability. Orographic precipitation in Bakhmal is likely governed by a combination of elevation, slope orientation (aspect), and regional moisture advection patterns, rather than terrain steepness itself.

The temporal analysis revealed a modest but persistent warming trend of approximately 0.25–0.30 °C per decade, while annual precipitation exhibited large interannual variability without a clear long-term trend. These patterns imply that the district’s hydrothermal regime is becoming warmer and potentially more arid, heightening sensitivity to climate variability.

Overall, the study highlights the value of integrating multi-source remote sensing datasets within cloud-based environments like Google Earth Engine for regional-scale environmental analysis. The derived relationships and lapse parameters can support climate downscaling, agro-ecological zoning, and land management planning in Uzbekistan’s mountain–foothill transition zones. Future work should include aspect-based analysis and higher-resolution climatic models to better capture microclimatic gradients in complex terrain.

References

- [1]“Uzbekistan - Country Overview | Climate Change Knowledge Portal.” Accessed: Nov. 09, 2025. [Online]. Available: <https://climateknowledgeportal.worldbank.org/country/uzbekistan>
- [2]“Global Change Biology | Environmental Change Journal | Wiley Online Library.” Accessed: Nov. 09, 2025. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1111/gcb.14415?utm_source=chatgpt.com
- [3]G. H. Roe, “OROGRAPHIC PRECIPITATION,” *Annu. Rev. Earth Planet. Sci.*, vol. 33, no. 1, pp. 645–671, May 2005, doi: 10.1146/annurev.earth.33.092203.122541.
- [4]Z. Wan, S. Hook, and G. Hulley, “MODIS/Terra Land Surface Temperature/Emissivity 8-Day L3 Global 1km SIN Grid V061.” NASA Land Processes Distributed Active Archive Center, 2021. doi: 10.5067/MODIS/MOD11A2.061.
- [5]D. J. Mildrexler, M. Zhao, and S. W. Running, “A global comparison between station air temperatures and MODIS land surface temperatures reveals the cooling role of forests,” *J. Geophys. Res.*, vol. 116, no. G3, p. G03025, Aug. 2011, doi: 10.1029/2010JG001486.
- [6]P. Patlakas, C. Stathopoulos, H. Flocas, N. S. Bartsotas, and G. Kallos, “Precipitation Climatology for the Arid Region of the Arabian Peninsula—Variability, Trends and Extremes,” *Climate*, vol. 9, no. 7, p. 103, July 2021, doi: 10.3390/cli9070103.
- [7]N. Tessaev, A. Inamov, and K. Juraev, “Assessment of forest fires in Zaamin national park using remote sensing: Comparative analysis of NBR and NDVI,” *AIP Conf. Proc.*, vol. 3256, no. 1, p. 040042, July 2025, doi: 10.1063/5.0266745.
- [8]N. Earth Science Data Systems, “MODIS/Terra Land Surface Temperature/Emissivity 8-Day L3 Global 1km SIN Grid V061 | NASA Earthdata.” Earth Science Data Systems, NASA, June 16, 2025. Accessed: Nov. 09, 2025. [Online]. Available: <https://www.earthdata.nasa.gov/data/catalog/lpcloud-mod11a2-061>