Assessing NASA POWER and TerraClimate datasets for climate analysis and aridity characterization in Saïss basin, Morocco

Saïda Dada[1]*, Fatima-Zahra Tabyaoui[1], Larbi Boudad[1], Hassane Sahbi[1], Rachida Daghmoumi[1], Anass Oihrime[2], Mourad Aqnouy[2]

[1] Geology Department, Water and Environment Geoscience Laboratory (LG2E), Water, Natural Resources, Environment, and Sustainable Development Center (CERNE2D), Faculty of Sciences, Mohammed V University in Rabat, Morocco

[2] Geosciences and Technology Research Team, Department of Geosciences, Moulay Ismail University of Meknes, Faculty of Sciences and Technology, Errachidia, Morocco

* Correspondending author's e-mail: saida_dada@um5.ac.ma

ABSTRACT

Effective management of climate events requires a solid understanding of past and present conditions to mitigate climate change impacts, especially in regions with limited weather station coverage where access to accurate hydro-meteorological data is crucial. This study evaluates the performance of two global climate databases, NASA POWER (PN) and TerraClimate (TC), in the Saïss basin (Morocco), by comparing their estimates with ground observations from Meknes, Chelihate, and Fez. The analysis focuses on precipitation, maximum and minimum temperatures, and extreme climate indices. Results reveal strong correlations between satellite and station data, with performance varying by location. In Meknes, PN provides higher correlation for precipitation (r = 0.9833), while TC shows lower bias (-7.76 mm/month) and a better ratio (0.91). At Chelihate, PN outperforms TC in correlation (r = 0.9773) and bias, whereas TC achieves a more favorable ratio. In Fez, PN shows excellent correlation (r = 0.9935) but higher bias, with TC yielding a better ratio. For temperature, PN achieves higher correlations at all stations, while TC provides lower biases and more balanced ratios. The De Martonne aridity index (1981–2024) indicates a predominance of semi-arid climate, significant interannual variability, and a trend toward increasing aridification over the last two decades. Overall, PN and TC provide valuable climate information in data-scarce regions, but biases, particularly in extreme precipitation, highlight the need for local validation before application in water management, agriculture, and climate impact assessments.

Keywords: NASA POWER, TerraClimate, data scarcity region, satellite-ground discrepancy, Saïss basin, aridity index, Morocco.

INTRODUCTION

Precipitation and temperature are two variables for understanding climate and hydrological dynamics. These variables are essential for analyzing long-term climate trends, predicting extreme weather events, and assessing the impacts of climate change, particularly in regions prone to water scarcity (Xiong and Guo, 1999; Bouizrou et al., 2023; Aqnouy et al., 2024). Accurate estimation of these parameters is crucial for various applications, including water resource management,

environmental risk mitigation, and the design of effective climate change adaptation strategies (Ashu and Lee, 2020; Bouizrou et al., 2022). Precipitation plays a central role in determining the availability of surface and groundwater resources, while temperature influences evaporation rates, soil moisture, and crop growth. These two factors are key drivers of hydrological processes, which include runoff, infiltration, and groundwater recharge (Allaoui, 2019).

Given their importance, reliable and up-to-date data on precipitation and temperature are essential for hydrological modeling, water resource

planning, and assessing the future impacts of climate change. Traditionally, these data have been collected through in situ measurements by meteorological and hydrological agencies. However, these ground-based observations are limited by the sparse spatial distribution of weather stations, particularly in remote or arid regions, making it difficult to obtain continuous and homogeneous coverage over large areas or across diverse climatic zones. This limitation often results in data gaps, hindering the ability to monitor and analyze climate dynamics at regional or global scales. In recent years, satellite remote sensing technologies have revolutionized climate data collection (De Fleury, 2023; Ballah et al., 2025). Satellite platforms, such as those used by PN and TC, provide high-resolution global databases, offering a significant improvement over traditional ground-based measurements (Tan et al., 2023; Et-Takaouy et al., 2024; En-nagre et al., 2025). These technologies enable consistent, near-real-time monitoring of climate variables in regions where direct observations are rare or unavailable. Satellite data have become increasingly reliable and are now widely used for climate analysis and decision-making. Despite their advantages, climate data derived from satellites must be rigorously evaluated to ensure their accuracy and relevance for local applications (Marzouk, 2021).

In particular, it is important to assess the extent to which these databases align with in situ measurements, which are considered the reference for climate data. This study aims to evaluate the performance of the PN and TC climate databases by comparing their precipitation and temperature estimates with in situ data collected from three weather stations in Meknes, Chelihate, and Fez (Tabyaoui, 2005). The objective is to identify the most accurate and reliable satellite data source for climate and hydrological modeling in the Saïss basin, thereby contributing to a better understanding of regional climate variability and improving water resource management strategies in the face of climate change (Belhassan et al., 2010). By rigorously assessing the reliability of satellite data for local-scale applications, this study will provide valuable information on how satellite databases can be used to supplement ground-based observations and inform sustainable water resource management in semi-arid regions such as the Saïss basin (Ragragui et al., 2024).

In addition to this validation, the study incorporates the calculation of the De Martonne aridity index (Bouchaou et al., 2024), a climate indicator combining precipitation and average annual temperature, which allows areas to be classified according to their level of aridity. This index is particularly relevant for characterizing the climate in transition zones, such as the Saïss basin, where anthropogenic pressures and climate change accentuate hydroclimatic variability. Analyzing the evolution of this index over the period 1981–2024 provides a better understanding of regional climate dynamics and identifies trends toward aridification or humidification. By providing a cross-evaluation of satellite data and local observations, this study contributes to a better understanding of climate systems in semi-arid regions. It also offers recommendations for the optimal use of climate data in sustainable water resource management in the face of the growing challenges of climate change.

MATERIALS AND METHODS

Study area

The Saïss Basin (Figure 1) is a fertile agricultural region located in north-central Morocco, covering approximately 2100 km². The basin is defined by two main geomorphological units: the Saïss plain, characterized by its relatively flat topography and rich alluvial soils, and the adjacent Meknes plateau, a gently rolling terrain with elevations ranging from 210 to 966 meters. The region enjoys a semi-arid Mediterranean climate, with hot, dry summers and mild, wet winters (Tabyaoui, 2005). Average annual rainfall ranges from 500 mm to 600 mm, with most precipitation occurring between October and April. Temperatures range from 5 to 8 °C in winter to 30 to 35 °C in summer, with occasional extremes exceeding 40 °C. Agriculture is the dominant economic activity in the Saïss plain, accounting for a significant share of regional employment and income (Kassou et al., 2016). The region is a major producer of cereals, vegetables, fruits, and olives, with irrigated agriculture playing a key role in maintaining agricultural production during the dry season. However, the Saïss basin faces significant challenges related to water scarcity and climate change. Declining rainfall, increased evaporation due to rising temperatures, and growing demand for water from agriculture and urban areas have put considerable pressure on the
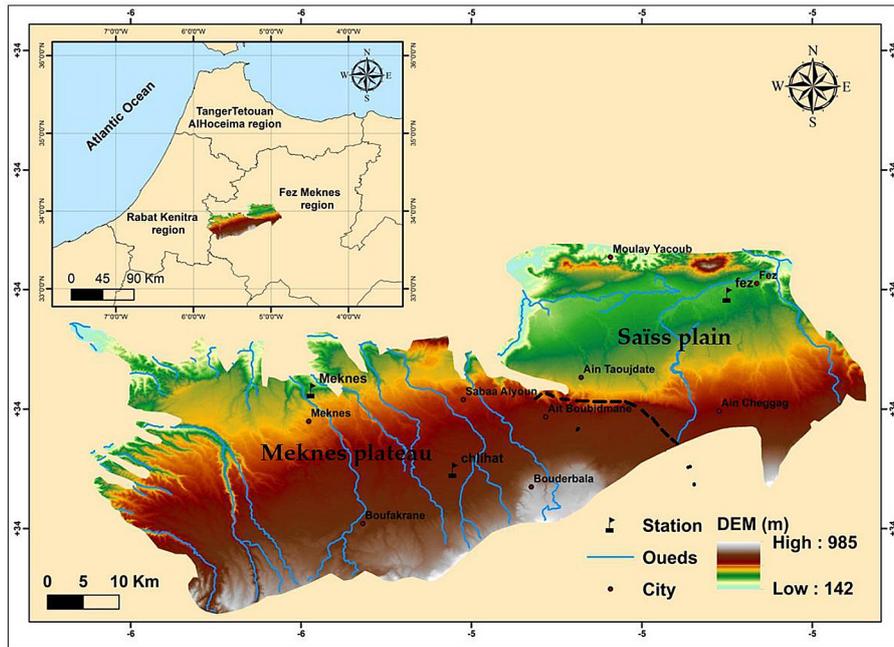
Figure 1. Geographic location map of the Saïss Basin

region's water resources. Unsustainable irrigation practices, overexploitation of groundwater, and land degradation have further exacerbated water scarcity in the region. Effective and adaptive water resource management strategies are therefore essential to ensure food security and environmental sustainability in the Saïss Basin.

Data

In situ meteorological measurements

Daily precipitation and temperature data were obtained from three weather stations located in the Saïss basin: Meknes (33.91N, 5.55°W, elevation 495 m), Chelihat (33.81°N, 5.38°W, elevation 686 m) and Fez (34.03°N, 5.03°W, elevation 393 m). These stations are part of the network operated by Morocco's National Meteorological Directorate (DMN) and provide reliable daily records of temperature, precipitation, relative humidity, wind speed, and solar radiation. The data used in this study covers the period from 1981 to 2018, allowing for a robust analysis of long-term climate trends. The choice of these specific stations was guided by their geographical distribution, data availability, and representativeness of climatic conditions in the Saïss basin. Rigorous quality control measures were applied to the station data to identify and correct any inconsistencies or errors. These measures included visual inspection of time

series plots, detection of outliers using statistical techniques (e.g., z-score analysis), and comparison with neighboring stations to identify any abnormal values. Missing data were completed using a combination of methods, including linear interpolation from neighboring stations (where available) and statistical modeling based on historical data patterns and relationships with other climate variables. Homogeneity tests (e.g., Pettitt test) were also performed to detect any shifts or breaks in the time series due to changes in station location, instrumentation, or observation practices.

NASA POWER

Since 1981, NASA has been developing a project called NASA Prediction of Worldwide Energy Resources (POWER). This project, based on the derivation of satellite model reanalysis, provides long-term climate data with a spatial resolution of 0.5°, covering the entire planet. It provides comprehensive information on precipitation, maximum and minimum temperatures, humidity, solar radiation, and wind speed at all-time scales (hourly, daily, monthly, and annual). NASA POWER was developed to support the renewable energy, agriculture, water, and environmental sectors. The accessibility, free availability, and ease of access to this data encourage scientific, technical, and institutional actors in various climate and environmental fields to use it (Marzouk, 2021).

TerraClimate

TerraClimate is a database developed by the Laboratory of Earth and Environmental Sciences at the University of Idaho, providing global coverage of land surfaces. With a spatial resolution of approximately 4 kilometers and monthly temporal resolution, TerraClimate is based on a sophisticated interpolation method that combines high-resolution climate data from the WorldClim database with monthly time series from lower-resolution satellite and terrestrial sources. It provides information on precipitation, maximum and minimum temperatures, wind speed, vapor pressure, and solar radiation. It also incorporates hydrological water balance models that calculate surface water levels by taking into account several climatic and soil factors, using evapotranspiration, precipitation, temperature, and soil water storage capacity to accurately estimate surface water availability (Hanchane et al. 2023).

The aridity index

The De Martonne aridity index (IDM) is a synthetic tool frequently used to quantify the level of aridity of a climate (Martonne. 1926). It incorporates both total annual precipitation and average temperature to characterize the water balance of a region (Bouchaou et al. 2024). The index is defined by the following formula:

$$IDM = \frac{P}{T + 10} \qquad (1)$$

where: P – average annual precipitation (mm),
$\quad\quad\;\; T$ – average annual temperature (°C).

The index values were calculated for the stations in Meknes, Fez, and Chelihat based on PN and TC data. The index allows the climate (Table 1) to be categorized (arid, semi-arid, sub-humid, etc.), contributing to a better understanding of the regional water balance and its implications for water resources.

The adoption of De Martonne's aridity index is a methodologically robust approach to characterizing climatic conditions in the Saïss Basin, an area particularly sensitive to hydroclimatic fluctuations (Jafarpour et al., 2023). This indicator offers detailed spatio-temporal analysis capabilities, enabling the monitoring of aridification dynamics and the identification of periods of increased water stress. By simultaneously integrating thermal and rainfall components, it is useful for supporting decisions on integrated water resource management

Table 1. De martonne aridity index values

The climate regime	Martonne Index (mm°C⁻¹)
Hyper-arid climate	I ≤ 5
Desert climate	I ≤ I ≤ 7,5
Steppe climate	7,5 ≤ I ≤ 10
Semi-arid climate	10 ≤ I ≤ 20
Temperate climate	20 ≤ I ≤ 30
Humid climate	I ≤ 30

and strategic planning for territories vulnerable to climate change (Morante-Carballo et al., 2022).

Methods

This study was conducted in the Saïss basin, a major hydrological unit in Morocco covering an area of approximately 2100 km². The basin consists of two main geomorphological units: the Saïss plain and the Meknes plateau, with an altitude ranging from 210 to 966 meters. The region has a semi-arid climate, characterized by hot, dry summers, with average annual rainfall of 600 mm in Meknes and 500 mm in Fez (Bouchaou et al., 2024). Given the importance of the basin for agriculture and water resource management, accurate estimation of climate variables is crucial for understanding hydrological dynamics and optimizing groundwater resource management. To achieve this, climate data from multiple sources were used in this study. The observed data were obtained from three weather stations located in the basin, covering the period from 1981 to 2018. In addition, monthly climate data were extracted from the PN and TC databases, which provide gridded climate estimates based on remote sensing and atmospheric reanalysis techniques. The objective was to evaluate the quality and relevance of these satellite and reanalysis databases in relation to in situ observations.

The performance of the gridded databases was evaluated using several statistical indicators. Correlation (r) was used to quantify the degree of linear association between the observed data and the estimates from PN and TC. A bias analysis was performed to identify systematic differences between estimated and observed values, highlighting possible underestimations or overestimations. In addition, a ratio analysis was performed to compare the relative differences between the different databases. These analyses make it possible to determine the ability of PN and TC products to reproduce local

climatic conditions and to assess their applicability to estimating groundwater recharge. Subsequently, an aridity index was calculated for the period from 1981 to 2024 in order to accurately characterize the annual climate regime in the basin.

Figure 2 shows the methodological process adopted for this study. It begins with the collection of in situ and satellite climate data (NASA POWER and TerraClimate), followed by a rigorous pre-processing phase, including quality control and standardization. After selecting the relevant climate databases, temperature and precipitation variables are extracted and compared with ground observations. A statistical evaluation (correlation, bias, ratio) is performed to assess the reliability of the satellite datasets. The results are analyzed and used to calculate the aridity index for the period 1981–2024, ultimately leading to the classification of the climate of the study area Figures 3–8).

RESULTS

Assessment of PN and TC precipitation bases

Graphical analysis of precipitation and temperatures

The evaluation of PN and TC satellite data with in situ measurements was used to analyze the accuracy of their hydrometeorological estimates. Figure 9 illustrates the monthly variation in precipitation (mm/month) and temperature (°C) for the Chlihat, Meknes, and Fez sites, based on three databases: in situ measurements, (PN), and (TC). Precipitation is highly seasonal, with maximums recorded between November and February and minimums between June and August, reflecting a Mediterranean-type rainfall pattern.

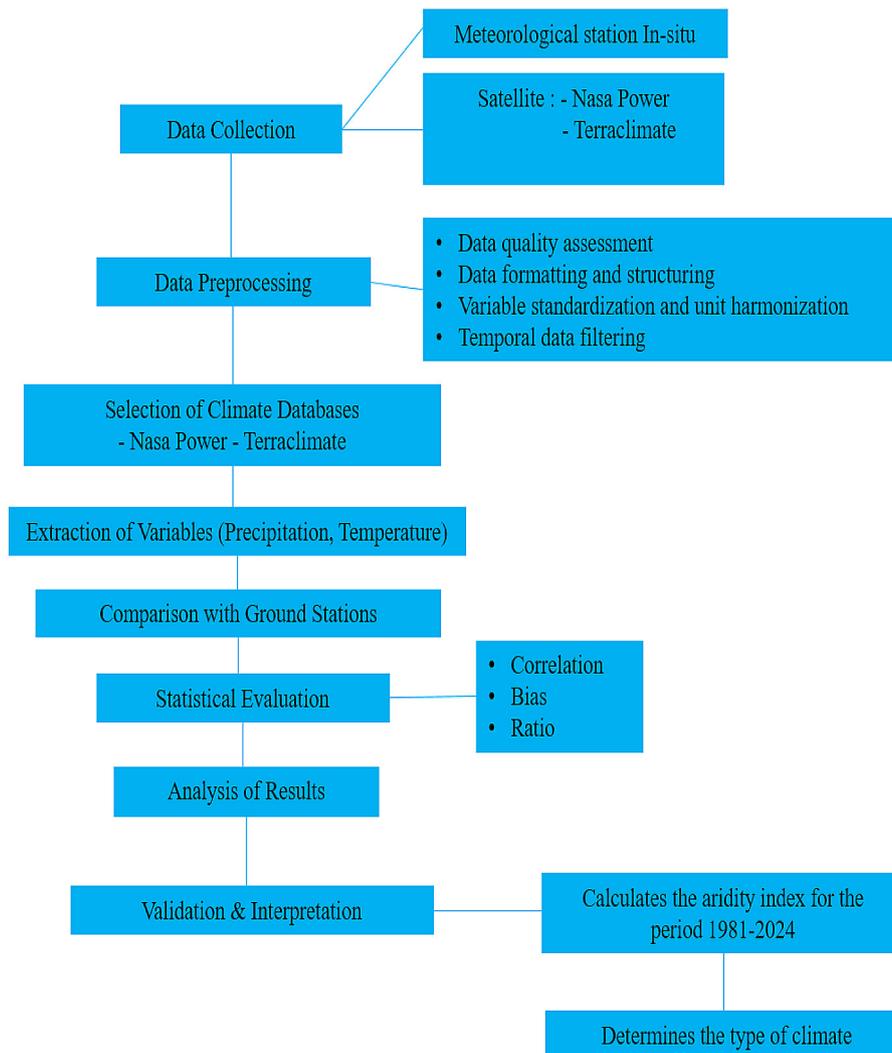There is good agreement between the three databases in Chlihat, although TC tends to

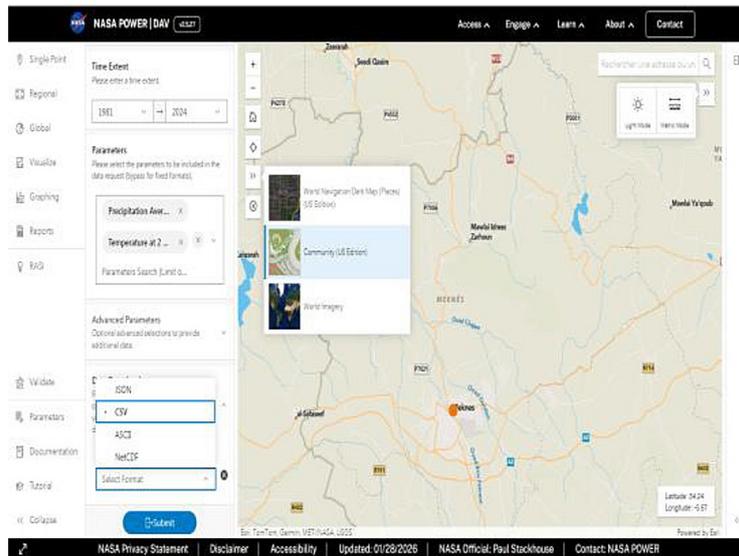**Figure 2.** Workflow of the methodology for climate data validation and aridity index assessment

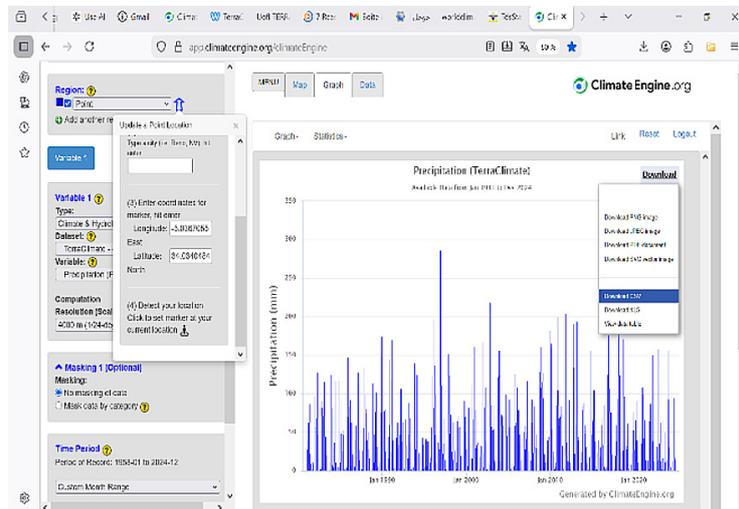**Figure 3.** Downloading monthly precipitation and temperature data from NASA POWER

Figure 4. Downloading monthly precipitation and temperature data from Climate Engine

Figure 5. Data preprocessing – cleaning and preparation in Excel (NASA POWER)
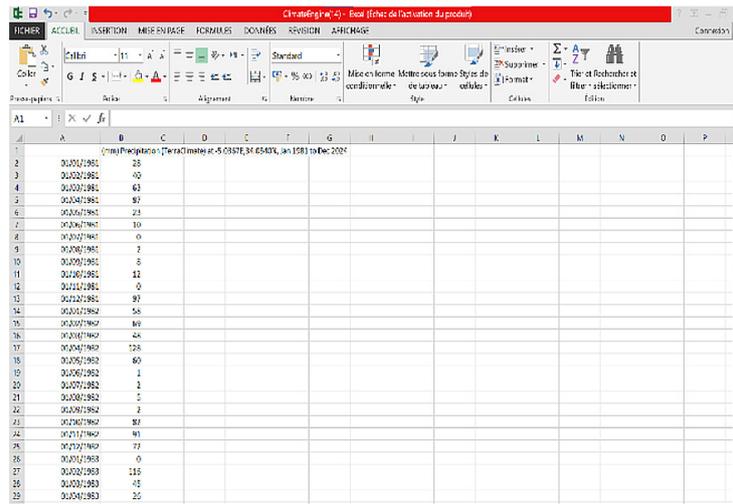
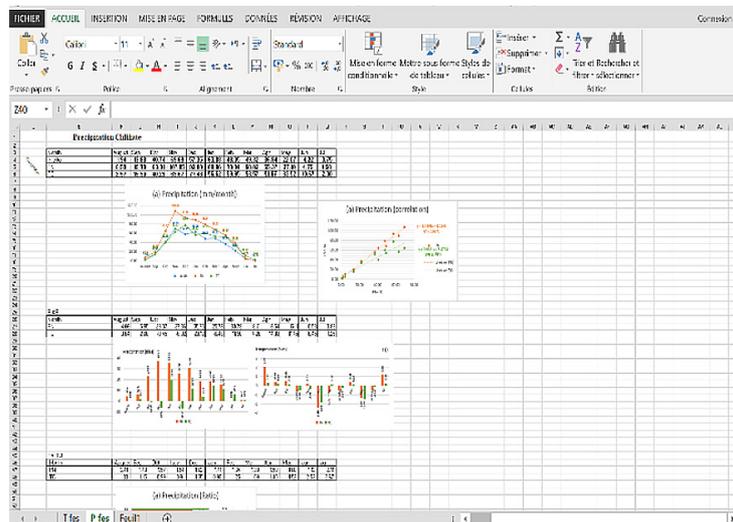**Figure 6.** Data preprocessing – cleaning and preparation in Excel (TerraClimate)

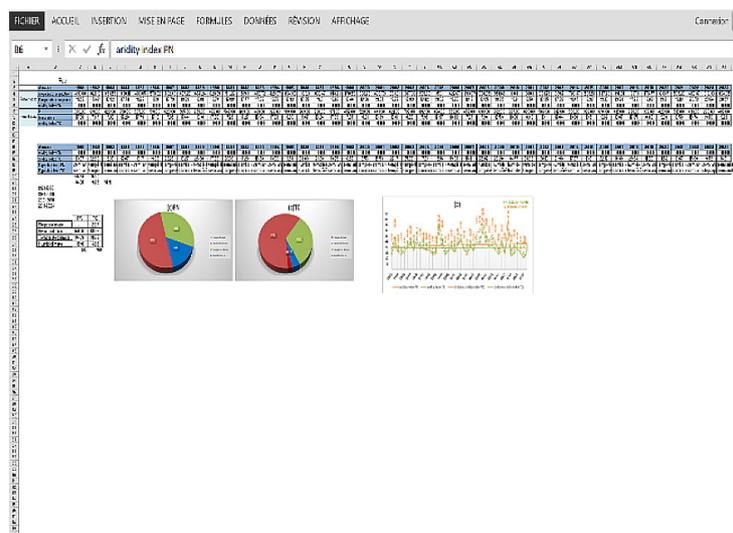**Figure 7.** Comparison with ground station (correlation, bais, ratio)

Figure 8. Calculates the De Martonne aridity index (PN vs TC) and deduces the climate type in the Saiss basin

slightly overestimate winter precipitation. In Meknes, in-situ data show more pronounced peaks, while PN slightly underestimates the values. In Fez, the data show similar trends, but with slightly higher values for PN during the winter. With regard to temperatures, the three sites reveal an inverted U-shaped annual distribution, with minimum temperatures in winter (January-February) and maximum temperatures in summer (June-July). A high degree of agreement is observed between the sources, particularly in Fez, where the curves are almost superimposed. Slight underestimations of winter temperatures by PN are noted in Chlihat (Figure 9).

Analysis of the evaluation parameters for hydrometeorological variables

Table 2 presents the interpretation of the main statistical indicators used to evaluate the performance of climate data (Dang et al., 2023). It allows for the visual identification of overestimation or underestimation trends, as well as the degree of correlation between satellite data and in situ observations.

Table 3 and Figure 9 present a comparative evaluation of the PN and TC climate databases in terms of temperature and precipitation, based on three statistical indicators: correlation coefficient, bias, and ratio. Regarding temperature, the results indicate excellent correlation for both databases, with values exceeding 0.98, reflecting strong consistency with observed data. However, the PN database stands out with slightly higher correlation coefficients, particularly at the Meknes station (0.9984), suggesting better accuracy in representing thermal variations. Nevertheless, PN exhibits a positive bias, indicating a tendency to overestimate temperatures, while TC tends to slightly underestimate, notably at Chlihat. In terms of ratio, both databases display values close to unity, confirming satisfactory overall fidelity.
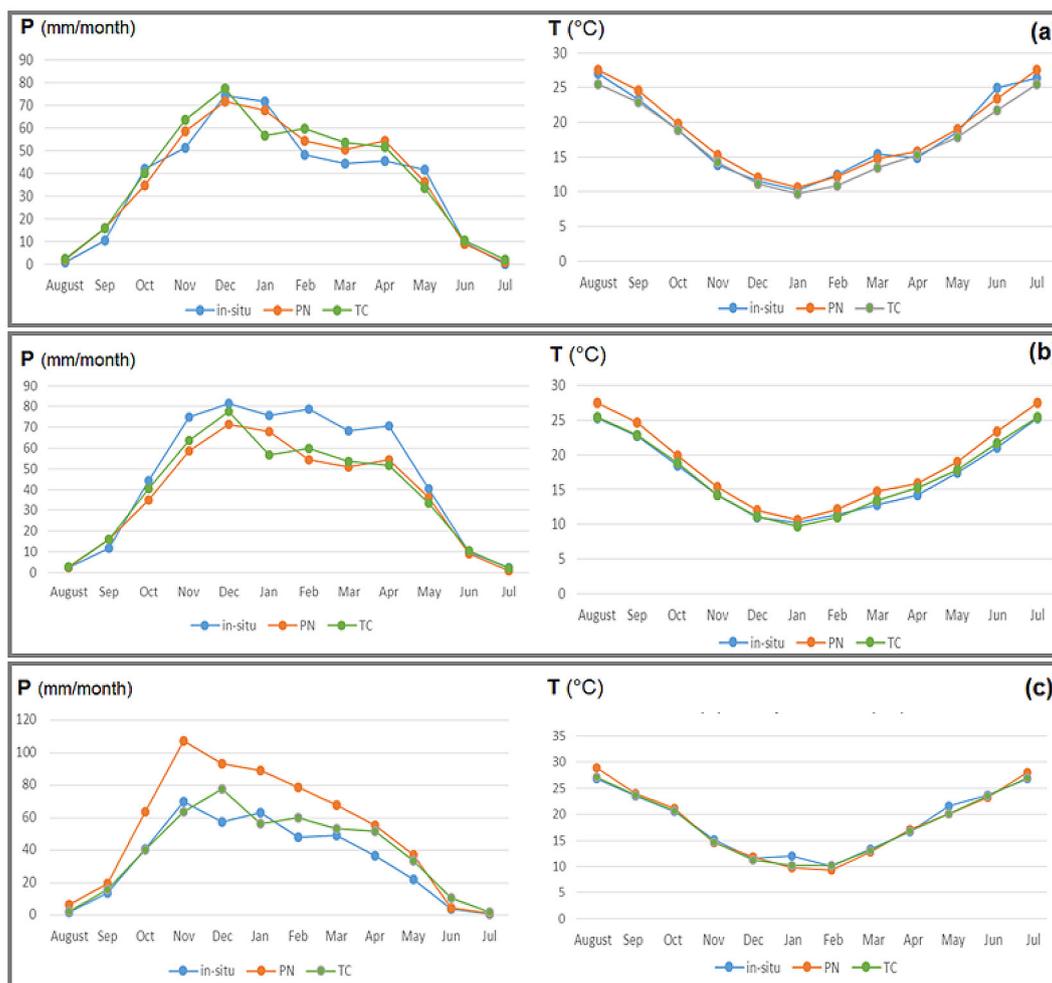
Figure 9. Monthly variation in precipitation and temperature at stations: (a) Chlihat, (b) Meknes, and (c) Fez

Table 2. Statistical indicators and their interpretation for data validation

Indicators	Interpretation
Correlation coefficient	=1 : Perfect positive correlation
	=0 : No linear correlation
	=−1 : Perfect negative correlation
Ratio	>1 : Systematic overestimation
	<1 : Systematic underestimation
	= 1 : Perfect mean agreement
Mean bias	>0: Mean overestimation
	<0: Mean underestimation

Concerning precipitation, the performance of both databases shows greater spatial variability. Although correlations remain strong overall, they are slightly lower than those observed for temperature, with values ranging between 0.9477 and 0.9935. At the Meknes station, TC displays a slightly less pronounced bias and a ratio closer to unity than PN, indicating better representativeness. In Fez, both databases clearly overestimate precipitation, but the discrepancy is greater for PN (bias of 18.0881), while TC presents more moderate overestimation. Conversely, at Chlihate, PN appears more consistent, with lower bias and a more balanced ratio.

Figure 10 shows a strong correlation between satellite-derived products (PN and TC) and ground-based observations for temperature ($R^2 > 0.89$) across all stations, confirming their reliability in capturing spatial and temporal variability of temperature and precipitation. For precipitation, correlations also remain high but exhibit stronger spatial variability depending on the station location. Overall, PN demonstrates the best performance ($R^2 > 0.95$) across the three stations, while TC shows comparable results with R^2 values exceeding 0.89. These findings highlight the potential of integrating satellite-derived climate products into hydrological and climatological studies, especially in regions where ground monitoring networks are sparse.

Figure 11 shows that PN tends to slightly overestimate temperatures, while TC generally underestimates them, with only minor differences overall, indicating that both datasets provide an acceptable representation of thermal conditions. For precipitation, however, the biases are more pronounced and spatially variable: PN aligns more closely with ground measurements at Chlihat, both datasets underestimate rainfall at Meknes, while at Fez, PN markedly overestimates compared to observations, whereas TC provides a more moderate estimation. These results suggest that although both PN and TC are reliable for temperature estimation, their performance for precipitation varies depending on local climatic and topographic conditions. Such spatial discrepancies highlight the importance of conducting localized validation before applying these satellite products for hydrological modeling, flood risk assessment, or water resource management in the region.

Figure 12 reveals good accuracy for both (PN,TC) datasets in estimating temperature, with ratio values close to 1. PN tends to slightly overestimate while TC slightly underestimates, yet both remain within acceptable limits. For precipitation, the results are more variable across stations: at Chlihat and Fez, both datasets show an overall overestimation, more pronounced in PN, whereas at Meknes, systematic underestimations are observed, with TC providing a more balanced performance than PN. These findings confirm the overall reliability of the two satellite products for temperature assessment but also highlight the spatially heterogeneous nature of precipitation estimation. This underlines the need for station-based validation and potential bias correction before their integration into hydrological models or water resource management strategies.

Table 3. Parameters for evaluating hydrometeorological variables in the study area for the period 1981–2018

Parameter	Region	Correlation		Bias		Ratio	
		PN	TC	PN	TC	PN	TC
Temperature (°C)	Chlihate	0.9891	0.9851	0.4210	-0.8938	1.0260	0.9522
	Meknes	0.9984	0.9972	1.5710	0.2562	1.0921	1.0132
	Fez	0.9906	0.9950	0.1069	0.2636	0.9810	0.9801
Precipitation (mm/month)	Chlihate	0.9773	0.9517	1.3258	2.2321	1.3108	1.6118
	Meknes	0.9833	0.9823	-8.6617	-7.7554	0.8425	0.9139
	Fez	0.9935	0.9477	18.0881	5.0050	1.7012	1.4236
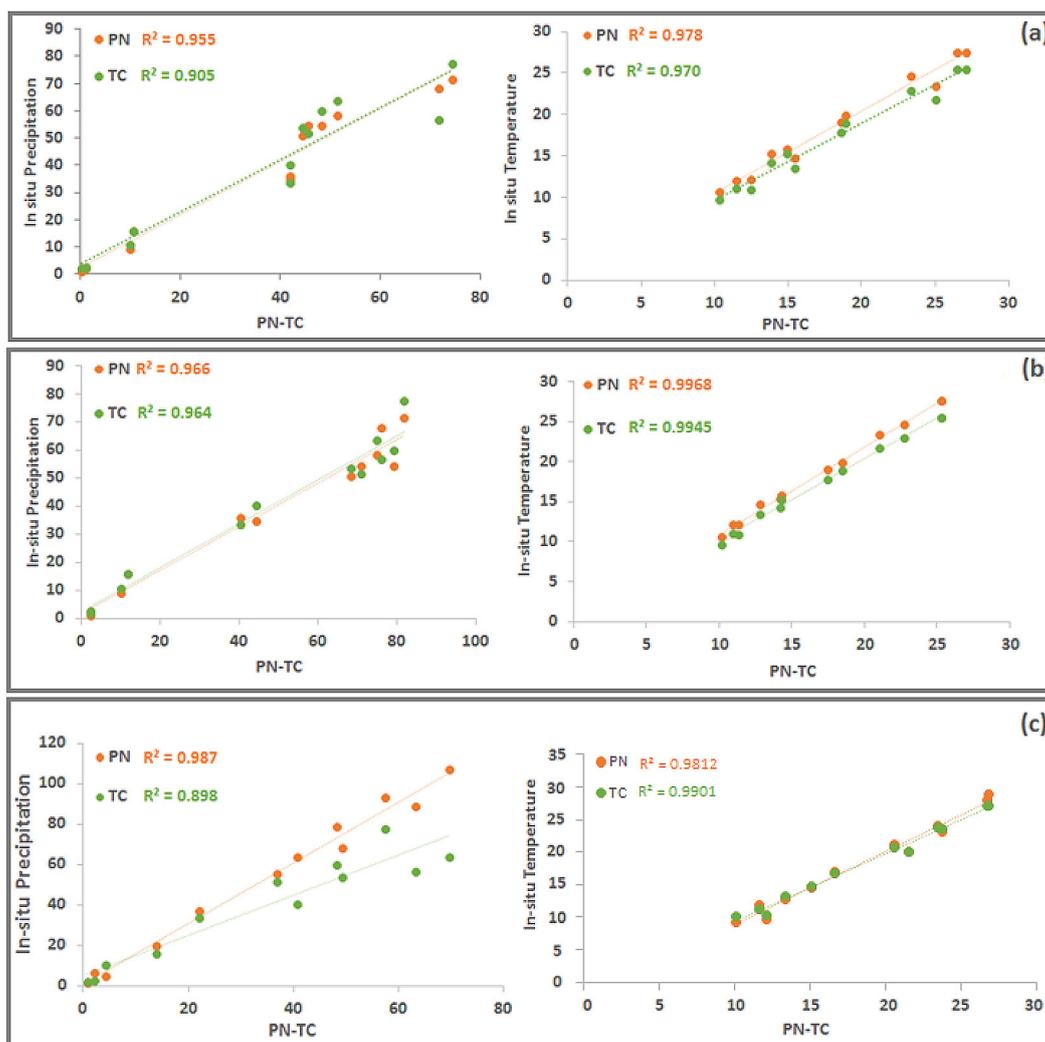
Figure 10. Correlation of monthly precipitation and temperature variations at the stations: (a) Chlihat, (b) Meknes, and (c) Fez

Evolution of the De Martonne aridity index

The aridity index values generally range between 9 and 47, characteristic of an equatorial climate type (Figure 13). For the Chlihat station, based on PN data, the calculated aridity index reached its minimum in 2023 with a value of 8.89 and its maximum of 39.44 in 2018, while for TC data, the aridity index reached its maximum in 1996 with a value of 32.64 and its minimum in 2023 with a value of 9.78. For the Meknes station, based on PN data, the calculated aridity index reached its minimum in 2023 with a value of 8.89 and its maximum of 39.44 in 2018, while for TC data, the aridity index reached its maximum in 1996 with a value of 33.7 and its minimum in 2023 with a value of 9.61. For the Fes station, based on PN data, the calculated aridity index reached its minimum in 2023 with a value of 10.2 and its maximum of 46.89 in 2010, while for TC data, the aridity index reached its maximum in 2010 with a value of 34.8 and its minimum in 2023 with a value of 9.75.

The dominant climate type for the period 1981–2024

The analysis of climate data from the PN and TC databases for the localities of Chlihat, Meknes, and Fes (Figure 14) reveals a clear dominance of semi-arid climate, reaching 61.36% according to PN and 68.18% according to TC in Chlihat and Meknes, and fluctuating between 50.00% PN and 61.36% TC in Fes. The steppe climate remains marginal, capping at 2.27% in all stations and completely absent according to PN in Fes, which confirms the prevalence of dry climatic conditions without extreme aridity. The temperate climate constitutes the second major class, oscillating
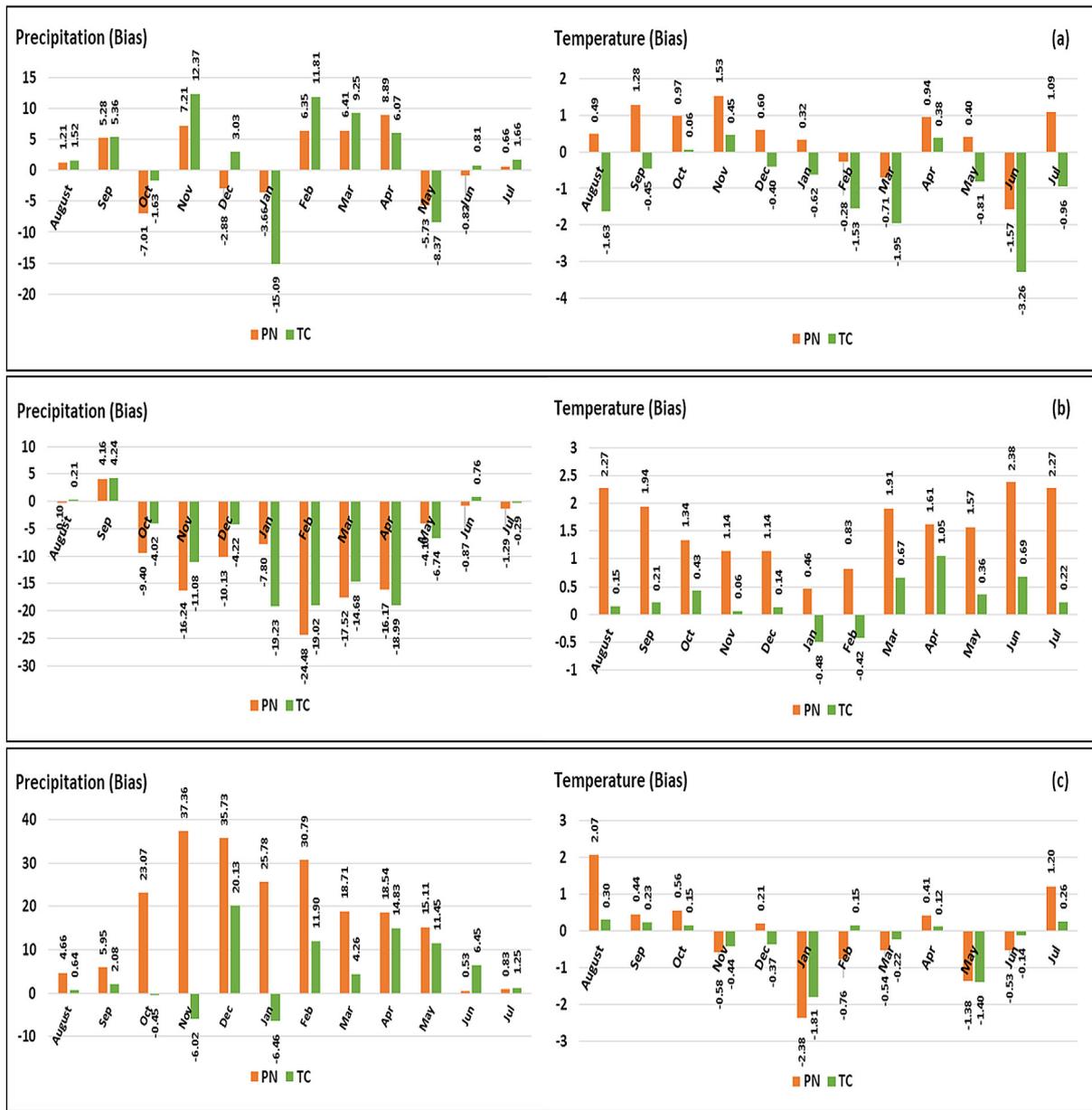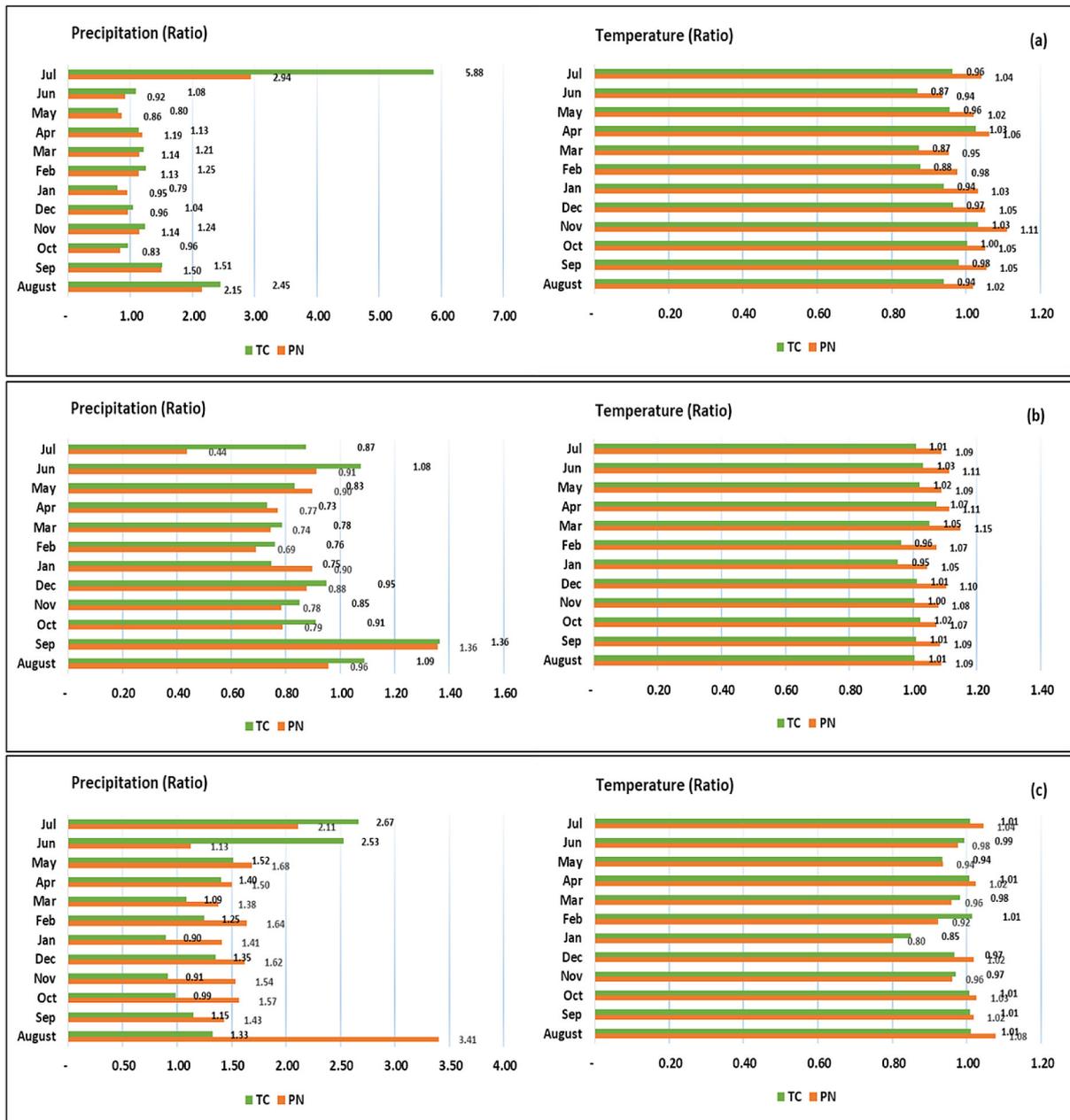
Figure 11. Bias of monthly precipitation and temperature variations at the stations:
(a) Chlihat, (b) Meknes, and (c) Fez

between 25.00% and 34.09%, with higher values in the PN database, notably in Fes (34.09% versus 31.82% in TC), which could reflect greater thermal variability in this zone. The humid climate, generally residual at 4.55% in TC and 6.82% in PN in Chlihat and Meknes, presents a notable exception in Fes where it reaches 15.91% according to PN, reflecting local pluviometric heterogeneity.

DISCUSSION

The analysis of PN and TC data in the Saïss basin highlights the strengths and limitations of these global climate models, particularly in the context of water resource management and climate forecasting in semi-arid regions. While these two databases provide reliable estimates of long-term climate trends, they exhibit significant divergences when estimating extreme climate events. This study demonstrates that atmospheric reanalysis models and global climate models on which these databases rely struggle to capture local variations and highly variable phenomena (Kassou et al., 2016). For instance, during periods of intense precipitation or heat waves, the databases tend to underestimate these events, particularly in specific areas such as Fez, where heavy

Figure 12. Ratio of monthly precipitation and temperature variations at the stations:
(a) Chlihat, (b) Meknes, and (c) Fez

rainfall and storms are frequently observed. This raises concerns about the practical applicability of these databases for sensitive sectors such as groundwater management or agricultural forecasting, which heavily depend on accurate small-scale climate estimates.

One of the main reasons for these limitations lies in the spatial resolution and accuracy of global climate models, which do not always account for crucial local factors such as topographical influence or microclimatic variations that can significantly affect extreme precipitation

and temperatures (Hanchane et al., 2023; Gocić et al., 2025). The underestimation of torrential precipitation in Fez by these databases could lead to errors in groundwater recharge forecasts, directly impacting water management strategies and irrigation planning. These biases are particularly problematic in semi-arid regions where water is a precious resource and extreme climate events can have major impacts on food security and local economies.

Furthermore, although PN and TC databases show high correlations for variables such as
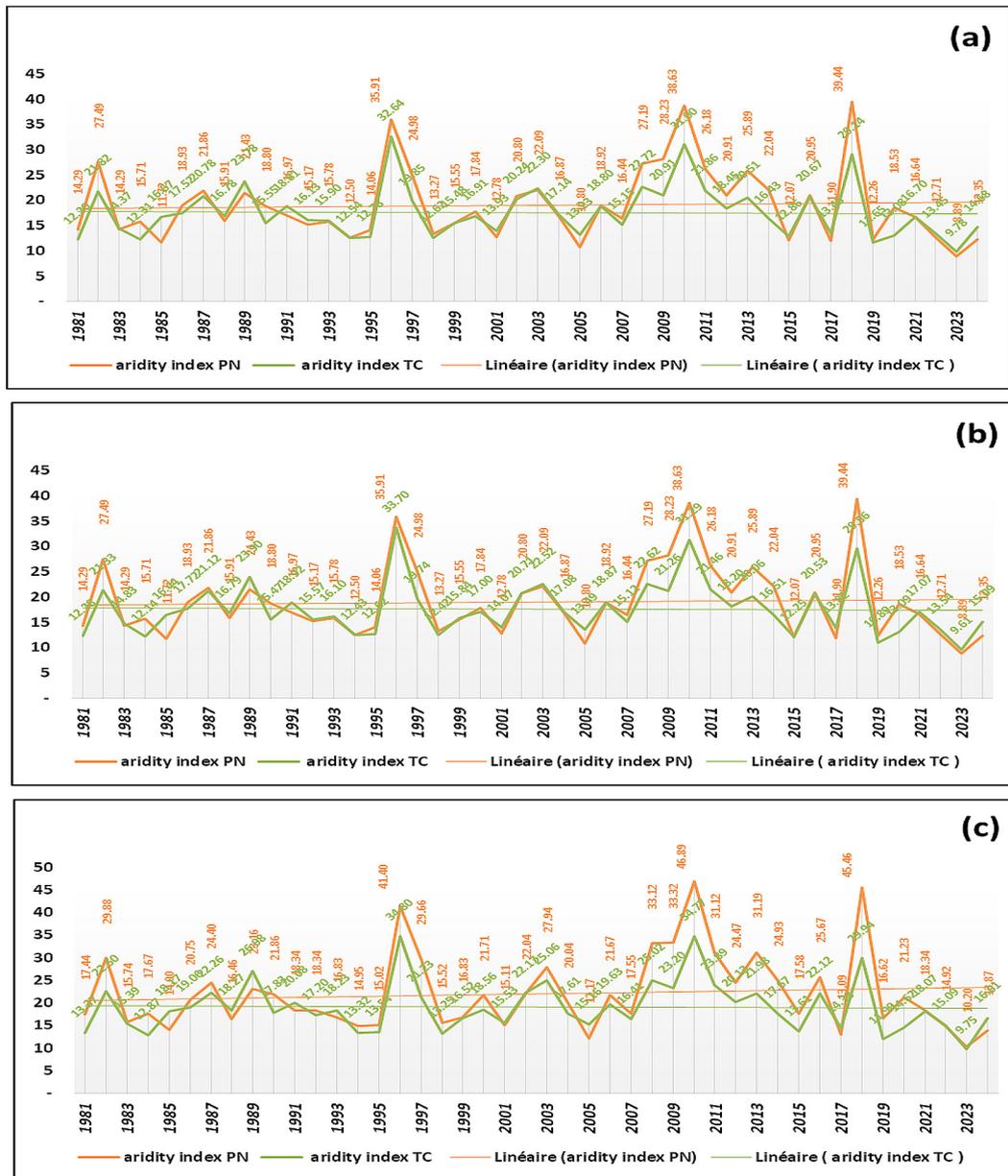
Figure 13. Evolution of the aridity index for the period 1981–2024 for stations: (a) Chlihat, (b) Meknes, and (c) Fez

average temperatures and monthly precipitation, these databases must be supplemented and validated by local measurements to ensure their reliability in specific applications. The combination of satellite data with ground observations is crucial for better understanding local climate dynamics and reducing errors due to systematic biases. Additionally, the integration of local hydrological models could play a key role in optimizing water resource management, enabling more accurate climate forecasts adapted to the characteristics of each sub-region of the watershed.

The results also suggest that future efforts should focus on improving satellite data correction algorithms, particularly for extreme precipitation events, to reduce observed biases and improve estimation accuracy. Techniques such as machine learning models could offer a promising approach to automatically adjust climate data to local conditions and correct discrepancies in precipitation forecasts. Moreover, the development of integrated observation systems, combining weather radars, local stations, and regional climate models, could provide a more robust approach for evaluating and forecasting climate conditions in regions with high climate variability.

The analysis of POWER NASA and Terra-Climate databases in the Saïss basin has enabled

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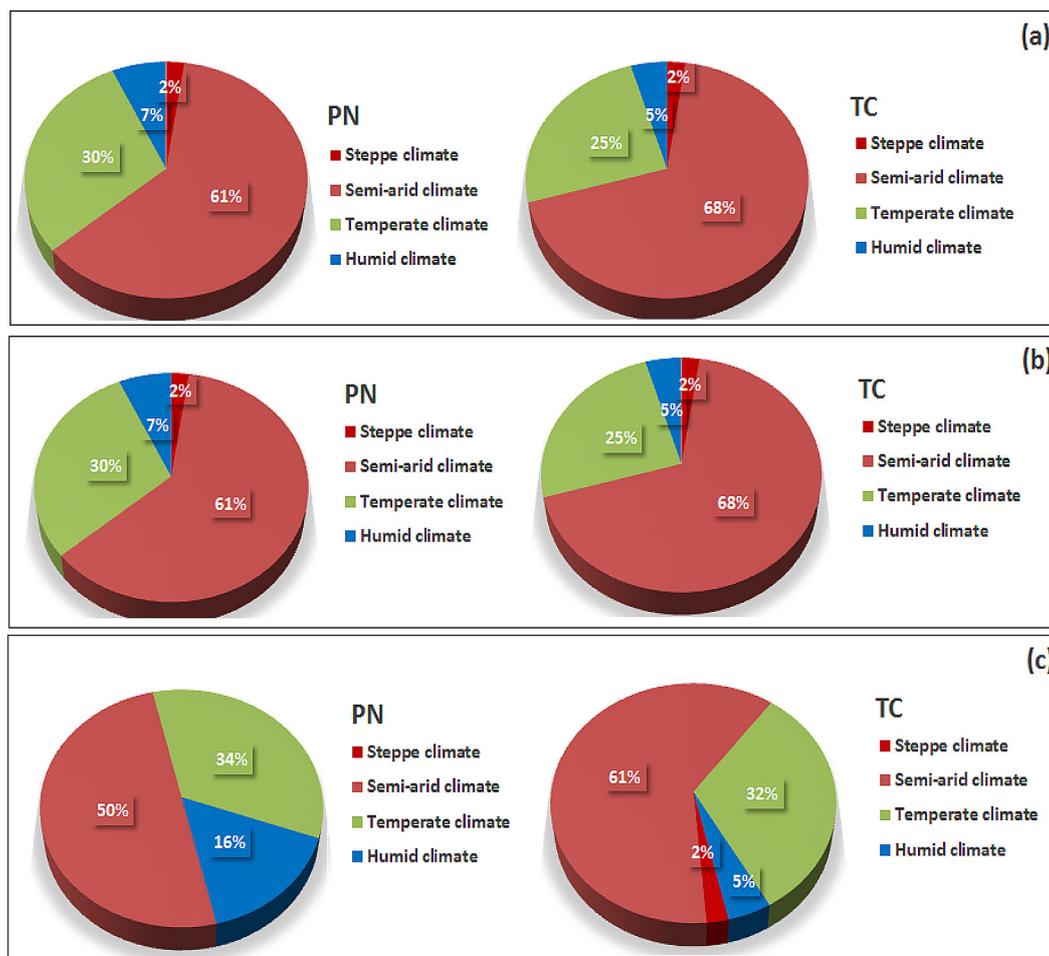
Figure 14. Percentage of dominant climates for the period 1981–2024 for stations: (a) Chlihat, (b) Meknes, and (c) Fez

the evaluation of their performance in representing semi-arid climate conditions. The comparison with in situ data first served to validate these two satellite sources in terms of reliability for key climate variables, namely precipitation and temperatures. The results showed that, despite good representation of general trends, particularly monthly and seasonal averages, these databases present certain limitations, especially in detecting extreme events.

The observed discrepancies, notably the underestimation of heavy precipitation and heat waves, can be attributed to the limited spatial resolution of the databases and their inability to finely integrate local effects such as topography or microclimates. This was particularly visible in the Fez region, often subject to localized convective storms. These biases can affect the accuracy of hydrological analyses, particularly in a context where water resource management relies on reliable climate estimates.

Once the data were validated, the aridity index was calculated to evaluate the evolution of the region's climate regime based on corrected and deemed reliable data. The obtained graphs show a clear alternation between dry and wet periods, consistent with regional climate dynamics. However, certain divergences persist between the two databases: for example, PN tends to produce slightly more arid values than TC, which could be explained by differences in potential evapotranspiration calculations.

The temporal evolution of the aridity index confirms the vulnerability of the Saïss basin to recurrent drought episodes. These results are essential for irrigation planning, water stress assessment, and defining climate change adaptation strategies. They also highlight the importance of rigorously validating climate databases before integrating them into environmental index calculations.

In summary, although PN and TC show satisfactory correlations with ground data, their use in

detailed analyses requires local validation, particularly for climate extremes. The integration of these databases with in situ observations, regional hydrological models, and, in the future, artificial intelligence techniques, could improve the spatial and temporal representativeness of the data. The development of hybrid observation systems (weather stations, radars, regional models) is also recommended to enhance the accuracy of climate estimates in areas with high variability such as the Saïss basin.

CONCLUSIONS

This study examines the use of satellite data for precipitation and temperature estimation, particularly in regions where in situ observations are sparse or unreliable. It demonstrates that PN is more suitable for analyzing large-scale climate variability, while TC offers higher spatial resolution, making it more effective for local hydrological applications (Jahangir and Danehkar, 2022). However, both datasets exhibit limitations in capturing extreme events, necessitating rigorous validation through high-quality ground-based measurements. These findings underscore the need for careful selection of climate data sources based on specific research objectives and emphasize the importance of refining statistical correction techniques and bias adjustment methods to enhance dataset reliability (Qadem et al., 2022). Furthermore, this study contributes to ongoing efforts to improve climate observation and modeling frameworks, which are essential for better understanding hydroclimatic dynamics and developing more robust water resource management strategies in the context of climate change. Future research should prioritize the integration of multi-source datasets, the development of advanced downscaling methodologies, and the incorporation of machine learning approaches to improve forecast accuracy (Sparks, 2019). Additionally, strengthening interdisciplinary collaborations between climatologists, hydrologists, and policymakers will be crucial for translating scientific knowledge into concrete sustainable water resource management strategies.

The results showed that the aridity index calculated over a 43-year period revealed a succession of dry and wet phases, with a clear trend toward increasingly arid conditions in recent years. This trend reflects growing pressure on water resources in the region. These findings are particularly important for guiding sustainable water management strategies, especially with regard to irrigation management, enhancement of groundwater recharge, and adaptation to the challenges posed by climate change. This work thus provides for future research aimed at strengthening the water, agricultural and climate resilience of semi-arid territories in Morocco.

Acknowledgments

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