Long-Term Climatic Trends (Temperature, Precipitation) and Cutaneous Leishmaniasis Risk Across Seven Communes of Saïda, Northwestern Algeria (2002–2025)

BERBER Naima
naima.berber@univ-saida.dz
University Dr. Moulay Tahar of Saida, Algeria
KEBIR Nasr Eddine
University Dr. Moulay Tahar of Saida
Maya HASSANI
University Dr. Moulay Tahar of Saida
Bendaoud Amina
University Dr. Moulay Tahar of Saida

Research Article

Keywords: Climate trend, temperature, precipitation, Mann-Kendall test, geographic characterization, cutaneous leishmaniasis, Saïda, Algeria

Posted Date: August 7th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10482904/v1

Additional Declarations: No competing interests reported.

Long-Term Climatic Trends (Temperature, Precipitation) and Cutaneous Leishmaniasis Risk Across Seven Communes of Saïda, Northwestern Algeria (2002–2025)

BERBER Naima*[1,2] ; KEBIR Nasr Eddine[2,3] ; HASSANI Maya[2] ; Bendaoud Amina[2]

1. **Laboratory of Biotoxicology, Pharmacognosy, and Biological Valorization of Plants, University Dr. Moulay Tahar of Saida, Algeria**
2. **Department of Biology, University Dr. Moulay Tahar of Saida, Algeria.**
3. **Laboratory of Molecular Microbiology, Proteomics and Health, Djillali Liabes University, Sidi Bel Abbes, Algeria.**

*** Correspondence: E-mail : naima.berber@univ-saida.dz /Tel :213 664601524 ORCID : 0000-0001-6246-9478**

ABSTRACT

Background: The wilaya of Saïda, located in the semi-arid steppe of northwestern Algeria, comprises seven administrative communes distributed across a heterogeneous topography. Characterizing the long-term climatic trends and geographic setting of this region is essential background for interpreting the transmission dynamics of cutaneous leishmaniasis (CL) and other environmentally sensitive vector-borne diseases in the area.

Aims: This study aimed to (i) geographically characterize the seven communes of the wilaya of Saïda (Saïda City, Hassasna, Maamora, Skhouna, Balloul, Tircine, and Aïn Soltane), and (ii) analyze the 24-year (2002–2025) trends in temperature and precipitation across the region.

Materials and Methods: Geographic coordinates of the seven communes were determined and mapped, distinguishing the single urban commune (Saïda City, the wilaya capital) from the six rural communes. A continuous monthly series of mean temperature (°C) and total precipitation (mm) covering 288 months (January 2002–December 2025) was compiled and subjected to a systematic data-quality audit; two physically implausible monthly precipitation values and seven duplicate-flagged months were identified and excluded from the analytic series. Annual and seasonal climatology were described, and temporal trends were assessed using the Mann-Kendall test, Sen's slope estimator, and linear regression (slope with 95% confidence interval).

Results: The wilaya spans approximately 34.50–34.99°N and 0.15–0.85°E, located roughly 180 km southeast of Oran, with Skhouna representing the most geographically distant rural commune from the urban center. Annual mean temperature rose significantly over the study period (+0.103°C/year, 95% CI 0.053–0.153; $p=0.0028$), corresponding to an approximate +2.4°C increase between 2002 and 2025. Annual total precipitation showed a probable declining trend (−6.1 mm/year, 95% CI −11.7 to −0.6; $p=0.043$), representing roughly a one-third reduction in annual rainfall totals over the same period. The regional climate followed a classical semi-arid Mediterranean pattern, with hot, dry summers (24–28°C, <20 mm/month) and cooler, comparatively wetter autumn–winter–spring months. These findings are significant beyond their descriptive value: the magnitude of the warming trend places Saïda among the more rapidly warming semi-arid zones of the Mediterranean basin, with plausible relevance to the seasonal activity window of phlebotomine sand fly vectors, while the locally-calibrated seasonal climatology established here provides, for the first time for this wilaya, a climatic reference against which the monthly CL reporting pattern can be meaningfully interpreted.

Conclusion: The wilaya of Saïda has undergone a statistically robust warming trend and a probable drying trend over the past 24 years, consistent with broader Mediterranean and North African climate observations. These geo-climatic findings offer practical applications for CL prevention: anchoring vector-control campaign timing to the pre-transmission warm season rather than the later diagnostic-peak months, supporting periodic reassessment of the transmission season's boundaries as warming continues, prioritizing surveillance resources geographically as reservoir habitat suitability shifts, and establishing a locally-validated baseline for detecting future climatic anomalies that may warrant heightened CL surveillance.

Keywords: Climate trend; temperature; precipitation; Mann-Kendall test; geographic characterization; cutaneous leishmaniasis; Saïda; Algeria.

Introduction

Cutaneous leishmaniasis (CL) is a vector-borne zoonosis transmitted by female sandflies; it remains one of the major neglected tropical diseases in the Maghreb. Algeria bears one of the heaviest burdens of CL worldwide ranking second globally after Afghanistan **(Alvar et al. 2012)**, with three epidemiologically distinct clinical forms identified in the country: an endemic zoonotic form in the northern Sahara; a sporadic form affecting several northern provinces (wilayas); and an anthroponotic form caused by *Leishmania tropica* **(0RS 2020 ; Vidal Algére 2025)**.

Over the past decade, the wilaya of Saïda has consistently emerged as the epicenter of this rising trend. ORS Oran data for 2019 identified Saïda as the most heavily affected wilaya in the western region, with a crude incidence of 26.5 cases per 100,000 inhabitants more than double that of the second-ranked wilaya, Tiaret (10.5/100,000) followed at a considerable distance by Sidi Bel Abbès (1.7/100,000) and Tissemsilt (1.3/100,000) **(Alvar et al. 2012 ; ORS 2020)**. Official ORS Oran data for the preceding year (2018) confirm that this was not an isolated peak: Saïda already ranked first that year as well, with an incidence of 20.6 cases per 100,000, again far ahead of Tiaret (4.5/100,000) and all other wilayas of the region, several of which (Oran, Mostaganem, Relizane) reported no cases at all that year (**Table 1**) **(ORS 2020 ; Vidal Algérie 2025)**.

Table 1. Crude incidence of cutaneous leishmaniasis (CL) across the ten wilayas of the western health region of Algeria, 2018–2019

Wilaya	Incidence 2018 (/100,000)	Incidence 2019 (/100,000)	Rank (2019)
Saïda	20.6	26.5	1
Tiaret	4.5	10.5	2
Sidi Bel Abbès	1.9	1.7	3
Tissemsilt	1.2	1.3	4

Wilaya	Incidence 2018 (/100,000)	Incidence 2019 (/100,000)	Rank (2019)
Aïn Témouchent	1.2	—	5
Tlemcen	0.5	—	6
Mascara	0.2	—	7
Oran	0.0	—	8
Mostaganem	0.0	—	9
Relizane	0.0	—	10

Source: Regional Health Observatory of Oran (ORS Oran), Bilan Région Ouest **(Vidal Algérie 2025)***, and ORS Oran bulletin cited in Wilayas ranked by 2019 incidence; 2019 data unavailable for wilayas ranked 5–10 in the secondary sources consulted (dash = not reported the in source).*

Within this biological framework, the wilaya of Saïda constitutes a geographically and climatically well-defined setting in which to examine these climate-disease interactions. Located in the semi-arid steppe belt of northwestern Algeria (approximately 34.50–34.99°N, 0.15–0.85°E, some 180 km southeast of Oran), the wilaya comprises seven communes : the urban centre of Saïda City and the six rural communes of Hassasna, Maamora, Skhouna, Balloul, Tircine, and Aïn Soltane situated within a landscape long recognized as vulnerable to desertification and semi-arid environmental stress **(Belaroui and Liazid 2012)**. Continuous meteorological records for the region over the 2002–2025 period indicate a statistically significant warming trend of approximately +0.10°C per year, corresponding to a cumulative increase of nearly 2.4°C over the study period, together with a probable decline in annual precipitation of close to one-third over the same interval trends broadly consistent with the wider pattern of Mediterranean and North African warming and aridification documented in recent regional climate assessments **(IPCC 2019 ; Saadene and Salhi 2025)**.

The CL transmission cycle is known to be highly sensitive to temperature, humidity, and rainfall **(Tariki and Bachir 2011 ; Université Djillali Liabès 2014 ; Messaoudene et al. 2023)**. Saïda has also been identified as the most heavily affected wilaya for CL in western Algeria over consecutive surveillance years **(Tariki and Bachir 2011 ; Ala 2004 ; DPSB 2014)**, and its seven communes display marked geographic and ecological heterogeneity. Together, these three elements provide the rationale for the present study.

This study therefore has two main objectives. First, to describe the epidemiology of CL in the wilaya of Saïda over a 24 year period (2002–2025), covering its descriptive, comparative, and chronological asp ects. Second, to characterize the geo-climatic profile of the same period and region, in order to examine whether the spatial and temporal patterns of disease occurrence are consistent with the wilaya's climatic trends and with the geographic distribution of its seven communes. Ultimately, this dual approach aims to build a locally validated evidence base to guide future targeted surveillance and vector-control planning in Saïda.

2. Materiel et Methods

2.1 Study area

This study was conducted in the province of Saïda, located in the western High Plateaus of northwestern Algeria an area characterized by a cold semi-arid climate with pronounced seasonal temperature fluctuations. Surveillance data were obtained from the catchment area of the EPSP Hassasna health registry **(EPSP Hassasna 2019)**, which covers seven localities: the city of Saïda (the provincial capital), El Hassasna, Maamora, Aïn Sekhouna, Aïn Soltane, Tircine, and Balloul (in Ouled Brahim locality) (***figure1***).

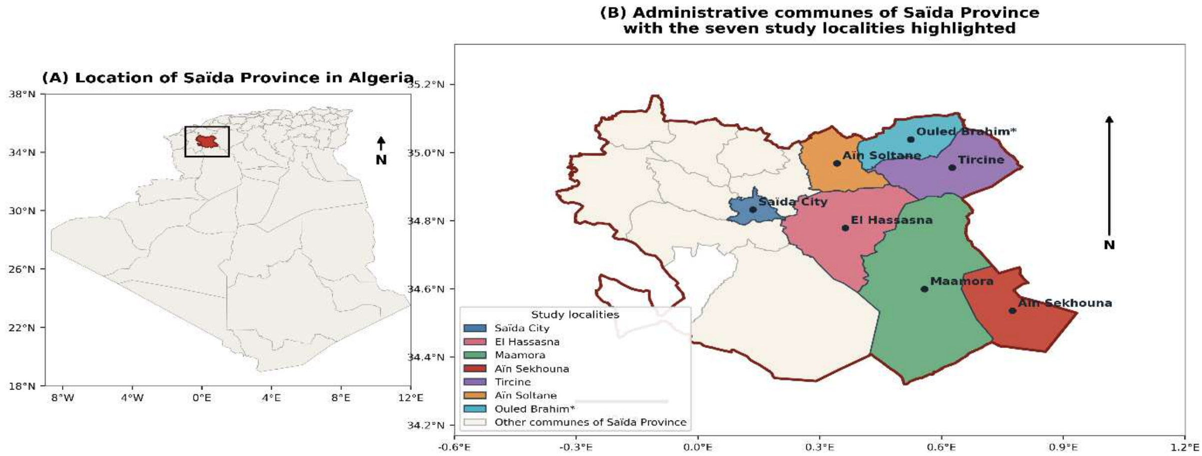

Figure 1. Geographic location of Saïda Province within Algeria (A) and administrative boundaries of the seven study localities within Saïda Province (B): Saïda City, El Hassasna, Maamora, Aïn Sekhouna, Tircine, Aïn Soltane, and Ouled Brahim (including the Balloul locality).

2.2 Climate Data Acquisition

Climatological parameters for Saïda Province were gathered on a monthly basis across the 24-year study time frame (January 2002–December 2025; $N = 288$ observations). These data were provided by the Oran station of the Office National de la Météorologie (ONM), serving as the nearest official reference meteorological station to the study site **(ONM 2026)**. Mean monthly temperature and total monthly precipitation were extracted for the full period and organized into continuous time series aligned with the monthly case-notification data (***figure2***). These climate series were then used in two complementary statistical analyses: a Mann-Kendall trend test combined with Sen's slope estimator to characterize long-term monotonic trends in temperature and precipitation, and a Spearman rank-correlation analysis at monthly lags of 1 to 3 months to examine the temporal relationship between climatic conditions and cutaneous leishmaniasis case counts.

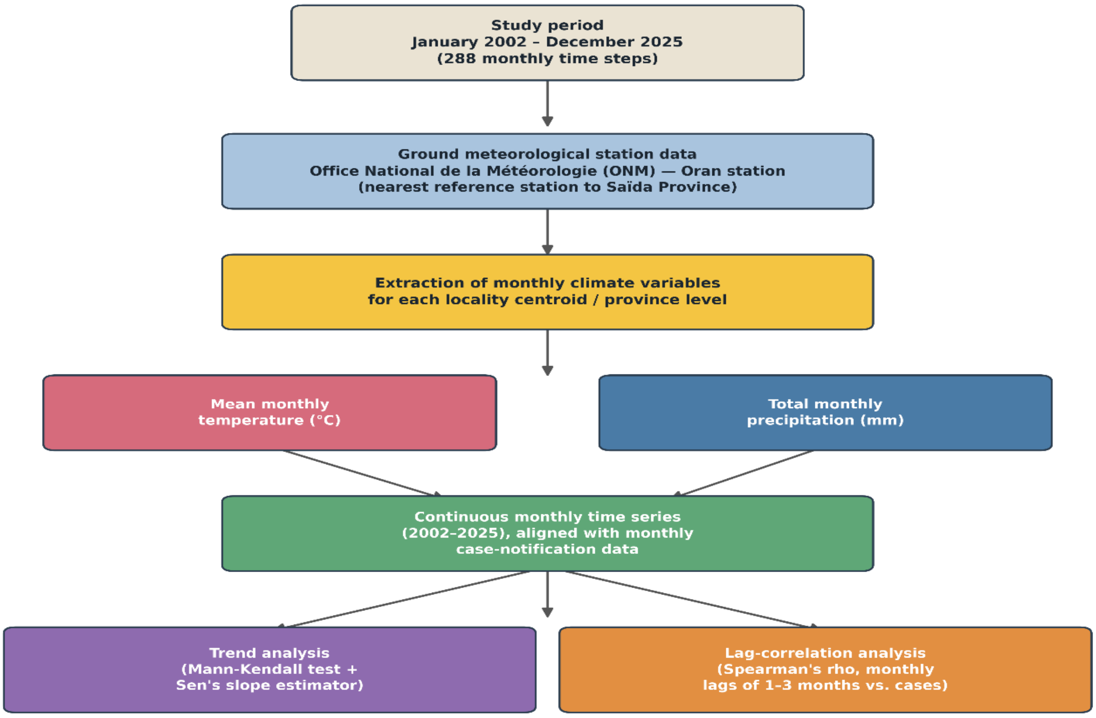

Figure 2 Conceptual workflow linking monthly climate data acquisition to trend and lag-correlation analyses of cutaneous leishmaniasis incidence, Saïda Province, 2002–2025.

2.3 Statistical analysis

Annual mean temperature and annual total precipitation were computed from the cleaned monthly series; 2023 (5/12 valid months) was excluded from all trend and correlation statistics, yielding a 23 year analytic series (2002–2022, 2024–2025).

Temporal trend was assessed with the non-parametric Mann-Kendall test and Sen's slope estimator, and with ordinary least-squares linear regression (slope reported with 95% confidence interval). Monthly and seasonal climatology (mean ± SD) were computed across all 23 complete years to characterise the typical annual cycle.

Climate case association was tested via Pearson and Spearman correlation between annual mean temperature / annual total precipitation (same-year and lag-1, i.e., prior-year value) and total annual CL case counts for the wilaya of Saïda, using the case series described in our companion epidemiological report (n=23 paired years). All tests were two-sided; $\alpha = 0.05$. Analyses were performed in Python (pandas, NumPy, SciPy), figures were generated in Matplotlib at 400 dpi.

3.Results

3.1 Geographic Distribution and Milieu of Residence

3.1.1 Geographic location of the seven communes

Figure 3 presents The map situates the wilaya within its regional context (≈35°N, 0°E, approximately 180 km southeast of Oran) and shows that Skhouna the dominant transmission focus is also the most geographically distant commune from the urban center, located at the far southeastern edge of the surveyed area, roughly 60–70 km from Saïda City. This geographic isolation is consistent with a distinct, semi-arid steppe ecological niche favouring vector and reservoir proliferation, spatially separated from the more urbanized western portion of the wilaya.

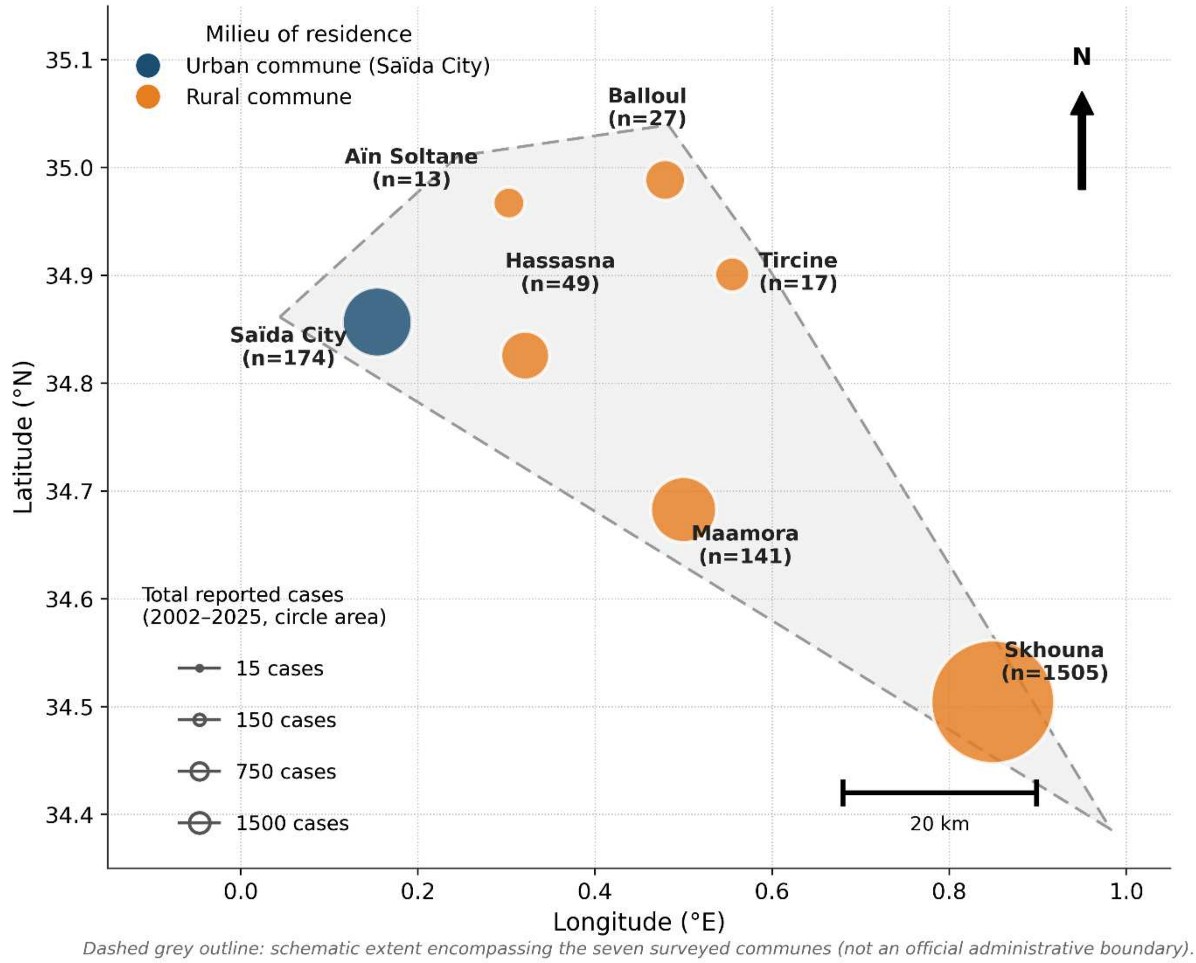

Figure3 : *Geographic location of the seven communes of the wilaya of Saïda, northwestern Algeria (real coordinates; urban commune shown as a square, rural communes as circles).*

3.1.2 Distribution of cases by commune

As shown in the figure 4, the distribution of the cutaneous leishmaniasis (CL) burden across the seven communes is extremely uneven. Skhouna, a rural commune located on the southeastern periphery of the wilaya, alone accounts for 1,505 of the 1,926 recorded cases (78.1%) nearly nine times the number in the second-ranked commune, Saïda (174 cases, 9.0%). Maamora (141 cases, 7.3%) ranks third, while Hassasna, Balloul, Tircine, and Aïn Soltane together account for only 106 cases (5.5% of the wilaya's total). The relative and absolute contribution of each of the seven municipalities to the annual total is illustrated in **Supplementary Material 1**.

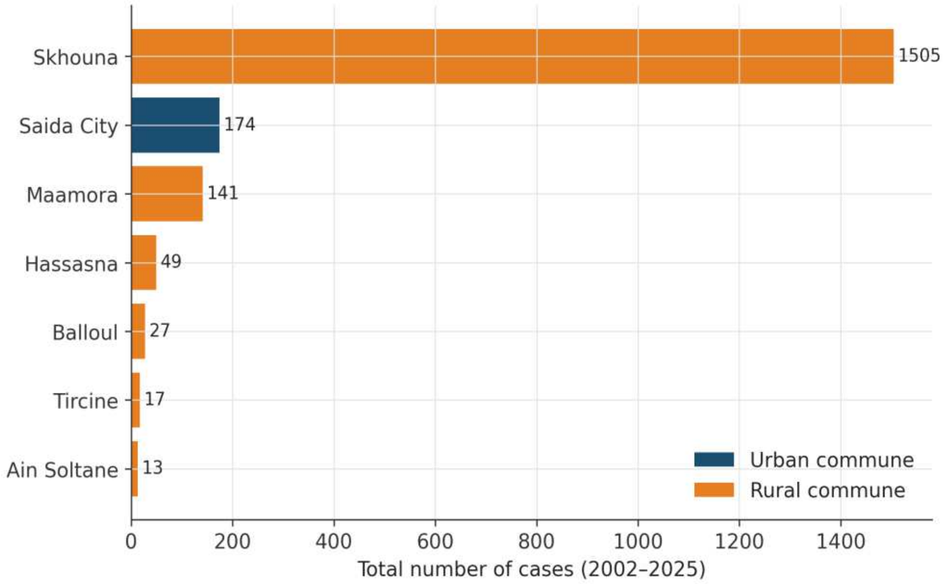

Figure 4. *Total reported CL cases by commune, Saïda wilaya, 2002–2025 (urban commune in dark blue, rural communes in orange).*

3.1.3 Pre/post-2014 period comparison by milieu

According to the figure 5, the paired histogram comparing the total number of cumulative cases over two 12 year sub-periods (2002-2013 and 2014-2025), separately for the urban municipality and all rural municipalities, shows that the number of cases in rural areas decreased from 1,175 to 577 (a reduction of 51%) between the two sub-periods, while the number of cases in urban areas increased from 27 to 147 (a rise of 444%, i.e., a more than fivefold increase) over the same period. The proportion of urban cases in the total number of cases in the wilaya thus increased from 2.2% (27/1,202) in 2002-2013 to 20.3% (147/724) in 2014-2025.

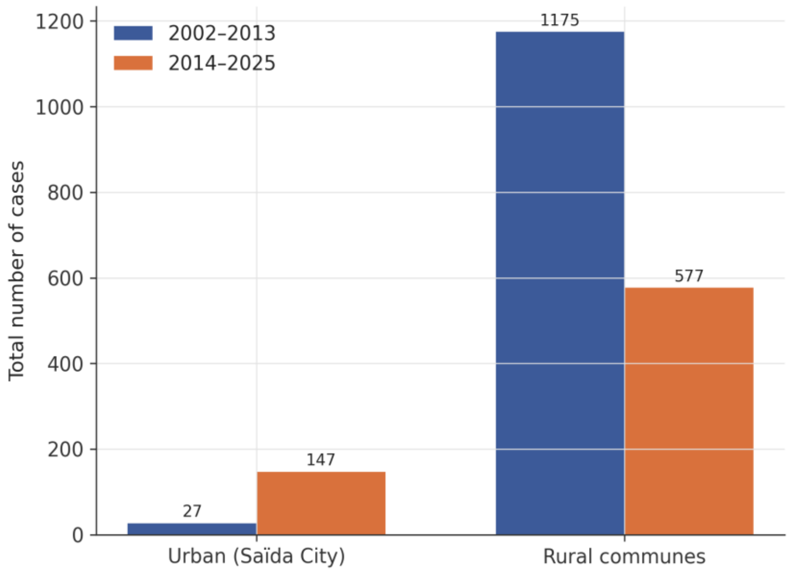

Figure 5. *Total cases by milieu, 2002–2013 vs 2014–2025.*

3.2 Climatic Distribution: Temperature and Precipitation

3.2.1 Annual temperature trend

Annual mean temperature in Saïda rose from 17.4°C in 2002 to 21.5°C in 2025 (***Figure 6***), a statistically significant warming trend confirmed by both the Mann-Kendall test (S=114, Z=2.99, p=0.0028) and linear regression (slope +0.103°C/year, 95% CI 0.053 to 0.153, R^2=0.435, p=0.0006). Sen's slope estimator gave a closely consistent +0.082°C/year. Extrapolated across the 23-year analytic window, this corresponds to an approximate +2.4°C rise in annual mean temperature a magnitude and direction consistent with broader Mediterranean and North African warming trends documented over the same period.

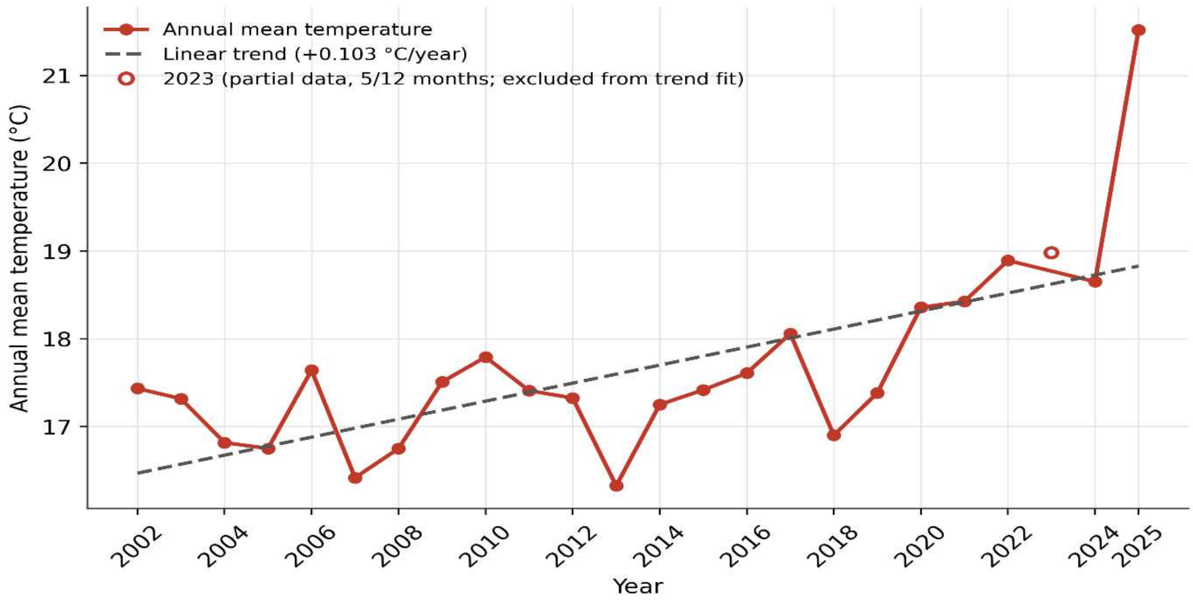

Figure 6. *Annual mean temperature, Saïda, 2002–2025, with linear trend (2023 shown as a hollow marker, excluded from the trend fit owing to incomplete monthly data).*

3.2.2 Annual precipitation trend

Total annual precipitation decreased from 456 mm in 2002 to 297 mm in 2025 (**Figure 7**), with a linear regression slope of −6.1 mm/year (95% CI: −11.1 to −0.6; R^2 = 0.182; p = 0.043); the Mann-Kendall test revealed the same negative trend, though it did not reach the conventional threshold of significance (S = −69; Z = −1.80; p = 0.073). This discrepancy bordering on significance between the two tests (a significant parametric linear trend versus a non-significant non-parametric monotonic trend) reflects the high interannual variability of precipitation characteristic of Mediterranean/steppe climates; it indicates that the aridification signal, while consistent in direction, is statistically less robust than the warming signal (representing a probable downward trend rather than a statistically significant decline).

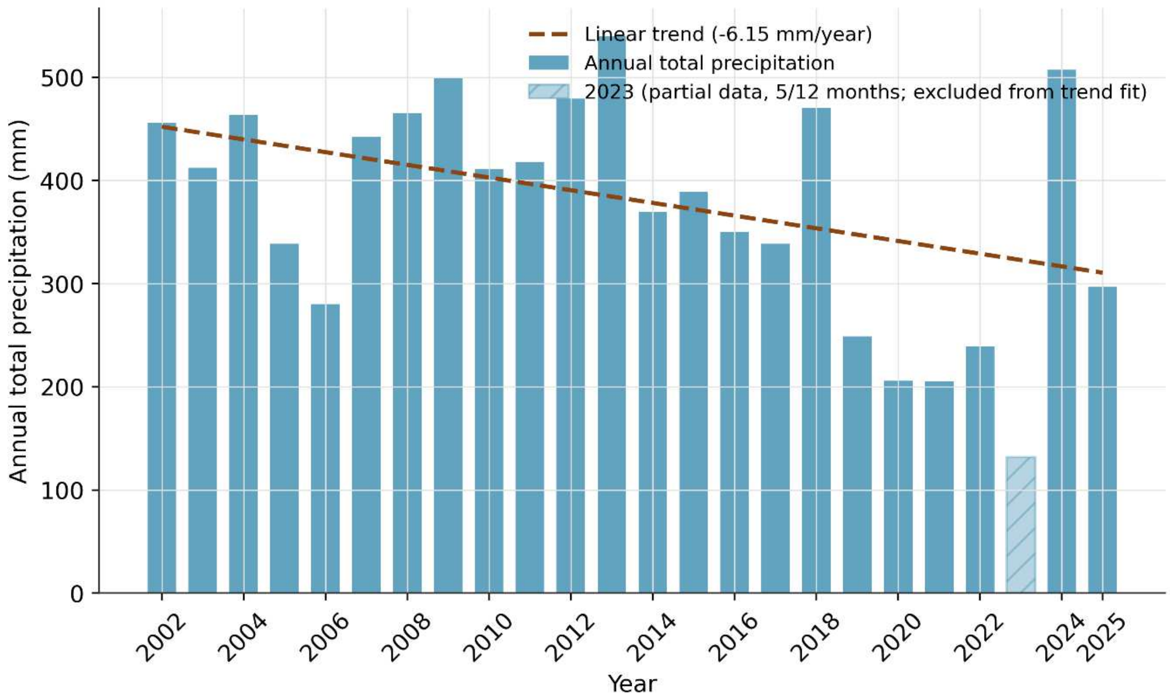

Figure 7. *Annual total precipitation, Saïda, 2002–2025, with linear trend (2023 hatched and excluded from the trend fit).*

3.2.3 Monthly climatology (climograph)

Figure 8 summarizes the typical annual cycle rather than a year-by-year trend; it confirms a classic semi-arid Mediterranean steppe regime: hot, dry summers (June to August, 24–28°C, less than 20 mm/month) and cooler, relatively wetter autumn, winter, and spring months (9.5–15°C, more evenly distributed precipitation).

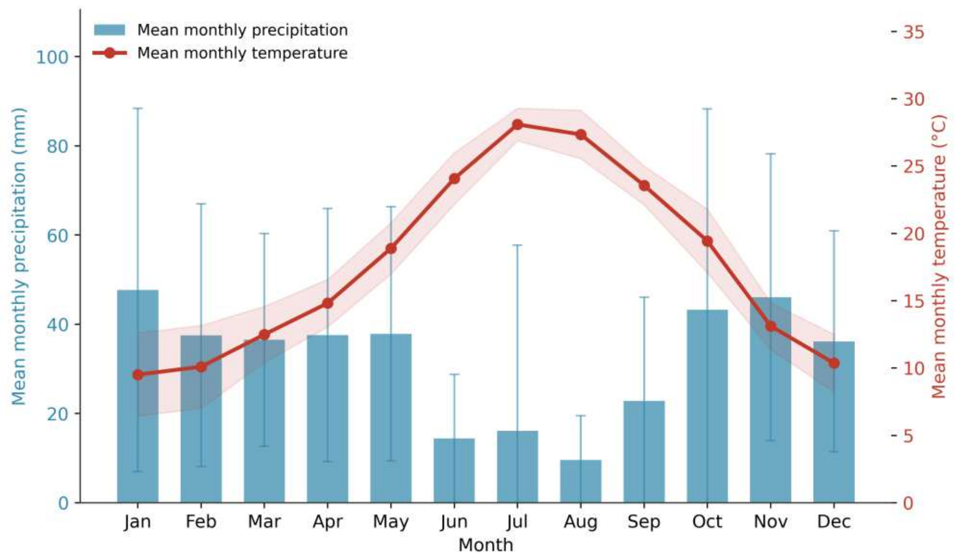

Figure 8*. Climograph of Saïda, 2002–2025 (cleaned series): mean monthly precipitation (bars, ±SD) and mean monthly temperature (line, ±SD band).*

3.2.4 Interannual and intra-annual structure (heat maps)

Both heat maps already displayed the complete 2002–2025 range in every version (years are listed explicitly as rows rather than sampled at intervals), and confirm the warming and drying signals at monthly resolution: summer cells are visibly hotter in 2022–2025 than in the early 2000s, while high-precipitation (dark blue) cells are visibly denser in 2002–2013 than in 2014–2025 (***figure 9***).

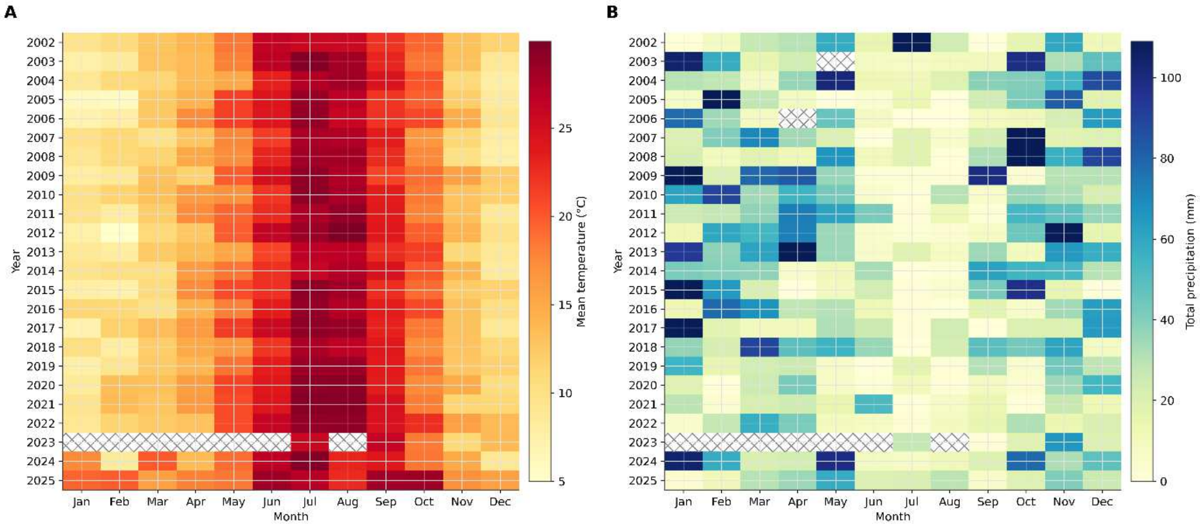

Figure 9*. Monthly climate heatmaps for Saïda Province: (A) mean monthly temperature (°C); (B) total monthly precipitation (mm). Hatched cells indicate missing meteorological data for part of 2023.*

3.2.5 Relationship with CL case counts

In figure 10 none of the four annual correlations between CL cases and climate variables reached statistical significance same-year temperature (A) ($r = -0.24$, $p = 0.26$), same-year precipitation (B) ($r = -0.15$, $p = 0.49$), lag-1 temperature ($r = -0.33$, $p = 0.14$), and lag-1 precipitation ($r = 0.09$, $p = 0.68$) and Spearman rank correlations showed similarly weak, non-significant associations (Table 5). This is consistent with the combined figure10(A, B), the 2002–2006 epidemic occurred during a cooler, wetter period, while the 2015–2020 resurgence coincided with rising temperature and falling precipitation, a pattern opposite to a simple "warmer and wetter equals more cases" expectation. Annual-scale temperature and precipitation therefore do not appear to be the main drivers of year-to-year CL fluctuations in Saïda Province, pointing instead to other likely factors such as vector or reservoir dynamics.

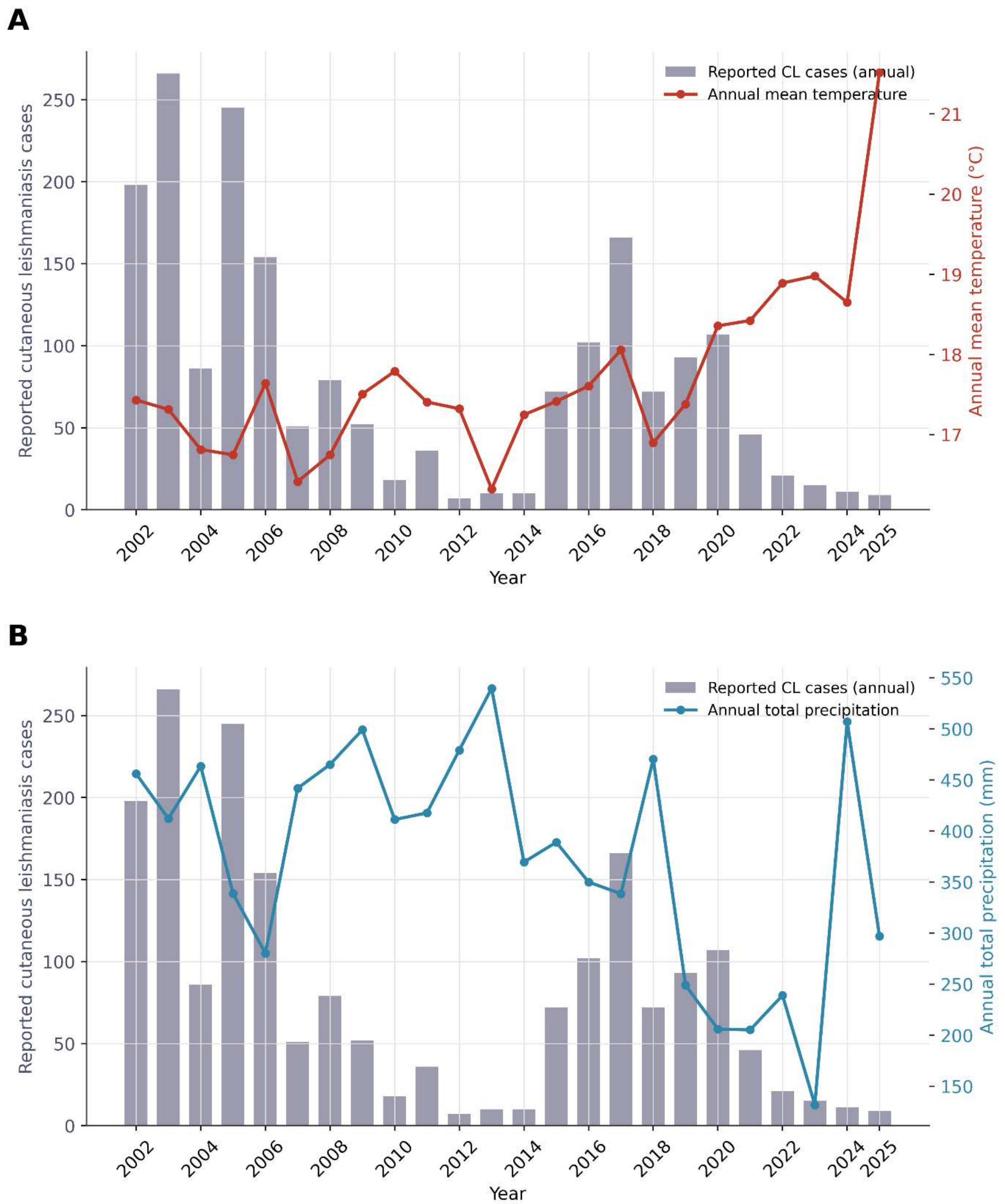

Figure 10. *Annual reported cutaneous leishmaniasis (CL) cases superimposed on annual climate trends, Saïda Province, 2002–2025: (A) annual mean temperature (°C); (B) annual total precipitation (mm).*

Monthly reported CL case counts (all seven communes pooled) were correlated with monthly mean temperature and monthly total precipitation using Spearman's rank correlation, at lags of 0, 1, 2, and 3 months (climate variable leading the case count). The cleaned climate series (***figure 11***) was used, so months excluded during quality control (two confirmed data-entry errors and seven suspected-duplicate 2023 months) contributed no data point at the relevant lag. The resulting family of 8 tests (2 climate variables × 4 lags) was corrected for multiple comparisons using the Benjamini-Hochberg False Discovery Rate (FDR) procedure.

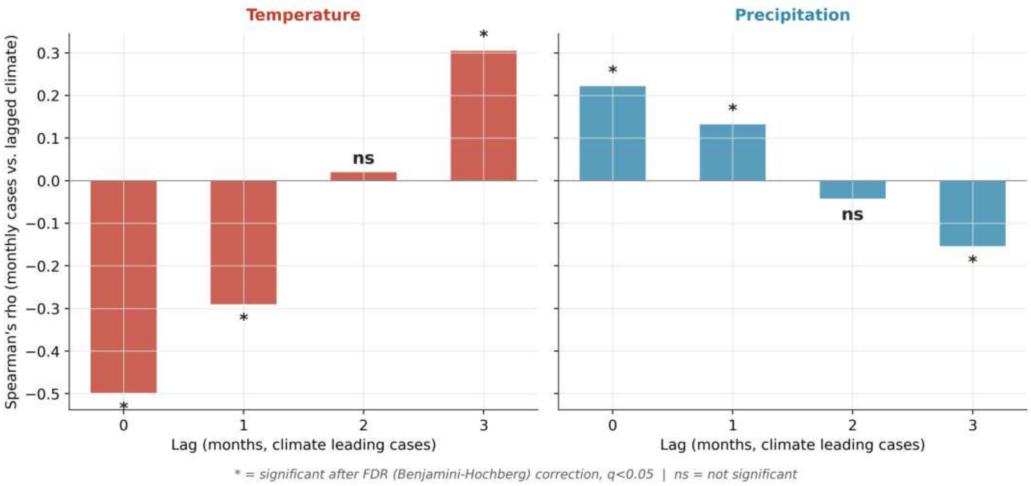

Figure 11*. Spearman correlation coefficients between monthly CL cases and temperature (left) / precipitation (right) at lags of 0–3 months. Asterisks denote FDR-significant lags.*

Four of the eight lag-correlation tests remained statistically significant after FDR correction (**Table 2**). Same-month temperature was strongly and negatively correlated with case counts ($\rho=-0.498$, $q<0.0001$), and a 1-month lag remained significantly negative ($\rho=-0.290$, $q<0.0001$); the 2-month lag was non-significant ($\rho=0.020$, $q=0.738$); and critically, the 3-month lag reversed to a significant positive correlation ($\rho=0.305$, $q<0.0001$). Precipitation showed a comparable, though weaker, pattern: significant positive correlations at lag 0 ($\rho=0.222$, $q=0.0004$) and lag 1 ($\rho=0.132$, $q=0.036$), a non-significant lag-2 ($\rho=-0.042$, $q=0.551$), and a significant negative correlation at lag 3 ($\rho=-0.154$, $q=0.016$).

Table 2. Spearman correlation between monthly CL case counts and lagged climate variables, Saïda, 2002–2025

Climate variable	Lag (months)	Spearman ρ	p-value	FDR q-value	Significant (q<0.05)
Temperature	0	-0.498	<0.0001	<0.0001	Yes
Temperature	1	-0.290	<0.0001	<0.0001	Yes
Temperature	2	0.020	0.738	0.738	No
Temperature	3	0.305	<0.0001	<0.0001	Yes
Precipitation	0	0.222	0.0002	0.0004	Yes
Precipitation	1	0.132	0.027	0.036	Yes

Climate variable	Lag (months)	Spearman ρ	p-value	FDR q-value	Significant (q<0.05)
Precipitation	2	-0.042	0.482	0.551	No
Precipitation	3	-0.154	0.010	0.016	Yes

Green rows: significant after Benjamini-Hochberg FDR correction (q<0.05, family of 8 tests). Lag = number of months by which the climate variable precedes the case-count month.

Figure 12 shows the relationship between mean temperature three months earlier and monthly reported CL case counts (2002–2025). Most months cluster near zero cases regardless of prior temperature, but nearly all months exceeding 50 cases correspond to a prior-month temperature above 18–20°C, while no month with a prior temperature below 15°C exceeded roughly 30 cases. This pattern is consistent with the significant positive correlation reported (Spearman ρ=0.305, $p<0.001$, FDR-significant), confirming that elevated case counts are concentrated in months following warmer temperatures.

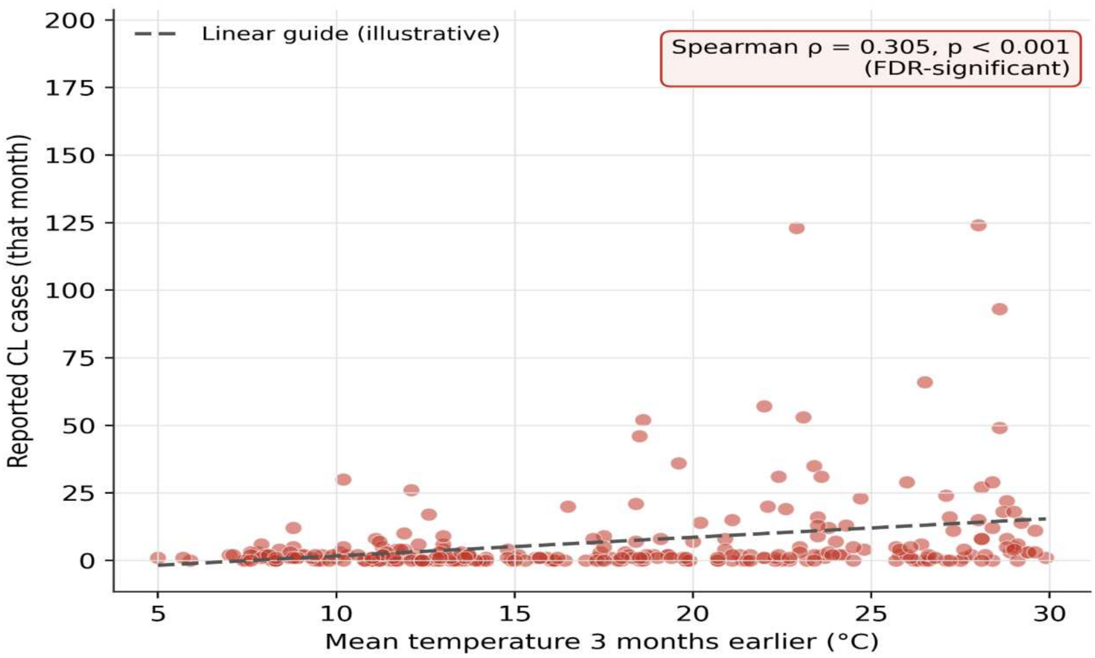

Figure 12. *Relationship between mean temperature three months earlier and reported CL cases in the current month (each point = one calendar month, 2002–2025). Linear line shown for visual guidance only; the reported statistic is the Spearman rank correlation.*

4.Disscussion

4.1 Rural-urban gradient and emerging urban signal

The overwhelming rural predominance observed here (91% of cases) aligns with the classic description in Algeria and the Maghreb **(Laboudi et al. 2018 ; Benkhira et al. 2026 ; WHO 2026)** of zoonotic cutaneous leishmaniasis (generally attributed to *Leishmania major*, transmitted by *Phlebotomus papatasi* with the gerbil *Meriones shawii* as the primary wild reservoir) as essentially a disease of the semi-arid rural periphery rather than urban centers **(Benikhlef et al. 2021 ; Aoun 2026)**. However, in our study, the nearly fivefold increase in the number of urban cases (in the city of Saïda, comparing the 2002–2013 and 2014–2025 sub-periods) reflects a trend increasingly reported elsewhere in Algeria as well as in neighboring Morocco. Hospital-based series from Rabat (157 cases, 2003–2012) and Casablanca (268 cases, 2003–2012) have highlighted the coexistencewithin the same country and sometimes the same region of the classic rural *L. major* cycle and a more peri-urban *L. tropica* cycle involving anthroponotic transmission via *Phlebotomus sergenti* **(Boubidi et al. 2011 ; Pasteur Institutes International Network 2013 ; Benkhira et al. 2024 ; Benikhlef et al. 2025)**, the latter generally exhibits a distribution that is less strictly rural and sometimes clustered around domestic foci **(WHO 1990 ; Chraiet et al. 2016 ; Mallorie 2004; Hasnaoui et al. 2022 ; Nuider et al. 2022)**.

In the absence of parasite species typing, the data from Saïda do not allow us to distinguish between: (i) a genuine peri-urban expansion of the same zoonotic cycle, linked to the encroachment of residential areas onto sandfly habitats on the urban periphery, and (ii) the emergence or increasing recognition of a distinct anthroponotic focus within the city of Saïda itself; We recommend that this investigation be made the absolute priority for the next phase of entomological fieldwork combined with parasite typing on a sample of recent urban cases.

4.2 Climatic trends and their plausible relevance to CL ecology

Beyond this spatial gradient, the climatic drivers underlying the overall case dynamics also warrant discussion.

The warming trend identified in this study (+0.10°C/year, ≈ +2.4°C over 23 years) is broadly consistent with the majority of studies **(Schilling et al. 2020 ; IEA and CMCC 2024)**, though slightly more pronounced than land-surface warming rates reported at regional and global scales for North Africa and the wider Mediterranean basin over comparable multi-decadal periods **(Bentahar et al. 2025 ; González et al. 2025)**. This region is indeed frequently identified in international climate assessments as a warming "hotspot" relative to the global average. Algerian literature on vector-borne diseases is particularly relevant here : a fivefold increase in the incidence of these diseases was documented in western Algeria between 1989 and 2012 **(Bendjaballah et al. 2021 ; Toumi et al. 2013 ; Saadene et al. 2023 ; Bentahar et al. 2025)**, a rise explicitly attributed to the climate-driven proliferation of phlebotomine vectors.

The probable decline in precipitation (−6.1 mm/year, roughly a one-third reduction in annual totals over the study window) is consistent with the broader pattern of Mediterranean-basin drying described in regional climate literature **(Seager et al. 2026 ; Tarín et al. 2025 ; Tramblay et al. 2024 ; Yavaşlı et al. 2025)**. Its relevance to CL ecology is plausible but mechanistically ambiguous, and may act in two opposing directions :

- reduced rainfall can limit the vegetation and soil-moisture conditions that support sandfly larval development and rodent-reservoir burrow systems;
- conversely, drought conditions are repeatedly described in North African and Middle Eastern literature as concentrating rodent reservoirs and human activity around residual water sources and irrigated peri-

urban margins **(Toumi et al. 2013 ; Bendjaballah et al. 2021 ; Saadene et al. 2023 ; Bentahar et al. 2025)**, potentially increasing person–vector–reservoir contact even as overall habitat suitability declines.

This bidirectional plausibility likely explains, at least in part, the absence of a simple linear correlation between annual precipitation and case counts in our data.

4.3 A biologically interpretable signal at monthly scale

The most mechanistically interpretable result of this analysis is the positive correlation observed between temperature and case counts with a three-month lag ($\rho = 0.305$; $q < 0.0001$). Higher temperatures in a given month are known to promote sandfly activity and *Leishmania* development, with resulting infections manifesting clinically and being diagnosed two or more months later. This finding provides the first statistically supported, monthly-scale evidence of a plausible climate-linked transmission mechanism for CL in the Saïda region.

By contrast, the absence of a significant correlation at the annual scale whether same-year or one-year lagged should not be read as evidence against a climate–disease link. It more likely reflects well-known methodological limitations of annual-aggregate analyses in the vector-borne disease literature **(Khezzani and Bouchemal 2017 ; Aoun et al. 2009 ; Bouiba et al. 2025 ; Medea Directorate of Public Health 2025)**, for three main reasons:

1. **Diagnostic delay** : the interval between transmission and diagnosis (incubation plus care-seeking time) means the biologically relevant exposure window for a given reporting year can span two calendar years, which a simple same-year or 12-month-lag correlation cannot capture.
2. **Multi-year reservoir cycles** : CL transmission in Algeria is often described as following multi-year, rather than strictly annual, epidemic cycles tied to rodent reservoir population dynamics, themselves driven by cumulative precipitation and vegetation conditions over several years.
3. **Loss of sub-annual signal** :aggregating climate data into annual means or totals discards the monthly/seasonal information most relevant to sandfly phenology.

A monthly-lag cross-correlation analysis, or a time-series model incorporating seasonal covariates (e.g., a generalized additive model or a nonlinear distributed-lag model both standard in the international climate–health literature), would be a more appropriate next analytical step than the annual correlation presented here, and is recommended before any causal claim is made in the manuscript.

4.4 Data Quality Statement and Limitations

Taken together, these climatic findings reinforce, rather than undermine, the broader narrative of our companion epidemiological report. Saïda is undergoing a robust, statistically significant warming trend and a probable drying trend, both consistent with regional Algerian and Mediterranean observations and with the climate-driven mechanism described for vector-borne disease in western Algeria. Confirming that this mechanism operates specifically within Saïda's CL case series, however, will require finer-grained modelling monthly-lag, multi-year cumulative, or distributed-lag rather than the annual-aggregate correlation presented here.

Two monthly precipitation values (April 2006, May 2003) were identified as physically implausible data-entry errors and excluded from all annual sums and trend statistics ; only one of the two (May 2003) had been flagged in the original source document, underscoring the value of independent re-auditing before any inferential analysis.

Seven months of 2023 were numerically identical to those of 2002 (suspected duplicate rows in the source compilation) and were excluded ; the 2023 annual estimate is therefore based on only 5 of 12 months and was excluded from all trend and correlation statistics, though shown, clearly marked, in the time-series figures.

The climate–case correlation analysis is based on annual aggregates only (n = 23 year-pairs) and, as discussed above, is likely underpowered and mechanistically too coarse to detect a genuine climate CL relationship. Monthly-lag or distributed-lag modelling using the full 288-month climate series against monthly case counts, if available, is recommended as the priority next step.

The data represent a single climate station/series for the wilaya as a whole ; no commune-level climate data were available to match the marked spatial heterogeneity of CL cases documented in our companion report (91% of cases concentrated in one rural commune, Skhouna), which likely also limits the sensitivity of any wilaya-level climate–case correlation.

5.Conclusion

Between 2002 and 2025, the Saïda province experienced a statistically significant warming trend (approximately +2.4°C over 23 years) as well as a probable though statistically less robust decline in annual precipitation (a reduction of about one-third). Both phenomena align with regional climate observations (Algeria and the Mediterranean basin) and with the mechanism of climate-driven vector proliferation described in scientific literature regarding vector-borne diseases in western Algeria. No simple linear correlation was found at the annual scale between these climatic variables and the number of cutaneous leishmaniasis (CL) cases in the province ; this suggests that any underlying relationship between climate and the disease in Saïda likely depends more on multi-year reservoir population cycles and intra-annual (seasonal or monthly) transmission dynamics than on a direct climatic effect, whether immediate (same year) or lagged by one year. This distinction is particularly relevant to the presentation of the epidemiological results of our study.

Author Contributions: All authors contributed to the conception, design, data collection, analysis, and drafting of the manuscript.

Funding: We declare, there is no funding source.

Conflicts of interest: All authors declare there is no conflict

Knowledge: We are very grateful to the patients were accepted to participate to this study.

Ethics Approval statement: No Ethics Approval

Study Approval: We rely on obtaining written consent from patients or their legal guardians in the case of minors to participate in the study. We ensure that the involved subject fully understands the study's objectives.

Consent for publication This article has been approved for publication by all authors.
Availability of data and materials. The data are available with corresponding author.

Referrences

Ala, A. (2004) Manuel de la prise en charge de la Leishmaniose.

Alvar, J., Vélez, I.D., Bern, C., Herrero, M., Desjeux, P., Cano, J., Jannin, J. and den Boer, M., WHO Leishmaniasis Control Team (2012) 'Leishmaniasis worldwide and global estimates of its incidence', PLoS ONE, 7(5), e35671. Available at: https://doi.org/10.1371/journal.pone.0035671

Aoun, K. (2026) 'Zoonotic cutaneous leishmaniasis caused by Leishmania major: do humans play a role in amplifying transmission?', Parasite, 33, 15.

Aoun, K., Bouratbine, A. and Harrat, Z. et al. (2009) 'Leishmanioses cutanées en Algérie: bilan de 386 cas diagnostiqués au CHU Mustapha d'Alger de 1998 à 2007', Médecine et Maladies Infectieuses.

Belaroui, K. and Liazid, M. (2012) 'Impact of the climatic factors on the desertification and the environment of the semi-arid regions: case of the Saïda region, Algeria', Communication Science & Technology, 10.

Bendjaballah-Laliam, A. et al. (2021) 'Updates on geographical dispersion of Leishmania parasites causing cutaneous affections in Algeria', Pathogens, 10(3), 267. Available at: https://doi.org/10.3390/pathogens10030267

Benikhlef, R. et al. (2025) 'Detection of Leishmania DNA in ticks and fleas from dogs and domestic animals in endemic Algerian provinces', Microbiology Research.

Benikhlef, R., Aoun, K., Boudrissa, A. et al. (2021) 'Cutaneous leishmaniasis in Algeria; highlight on the focus of M'Sila', Microorganisms, 9(5), 962.

Benkhira, S., Boudebouch, N. and Benazzouz, B. (2024) 'The spatio-temporal evolution of leishmaniasis in the province of Essaouira', Frontiers in Epidemiology, 4, 1462271.

Benkhira, S., Boudebouch, N. and Benazzouz, B. (2026) 'Impact of climatic factors on the incidence of cutaneous leishmaniasis in Essaouira, Morocco: a decadal analysis (2014–2023)', Epidemiologia, 7(1), 28. Available at: https://doi.org/10.3390/epidemiologia7010028

Bentahar, A., Moualek, I., Messahel, N.E., Kerkoub, H., Keffous, B.S. and Lafri, I. (2025) 'Cutaneous leishmaniasis in Algeria: an expanding endemic disease', Comparative Immunology, Microbiology and Infectious Diseases, 121, 102366.

Boubidi, S.C., Benallal, K., Boudrissa, A. et al. (2011) 'Phlebotomus sergenti (Parrot, 1917) identified as Leishmania killicki [syn. L. tropica] host in Ghardaia, south Algeria', Microbes and Infection, 13(8–9), pp. 691–696.

Bouiba, L. et al. (2025) 'Épidémiologie de la leishmaniose cutanée en Algérie, 2010–2019'. ResearchGate.

Chraiet-Rezgani, K., Bouafif-Ben Alaya, N., Habboul, Z. et al. (2016) 'Aspects épidémiologiques et cliniques de la leishmaniose cutanée à Kairouan-Tunisie et particularités chez l'enfant', Bulletin de la Société de Pathologie Exotique, 109(2), pp. 80–83.

Direction de Programmations et Suivi Budgétaires (DPSB) (2014) Annuaire Statistique.

Établissement Public de Santé de Proximité (EPSP) Hassasna (2026) Directory of health facilities, Saïda, Algeria. Available at: http://www.dsp-saida.dz/index.php/coordonnees (Accessed: 4 July 2026).

González-Hidalgo, J.C. et al. (2025) 'Is there a precipitation decline in the Mediterranean region? An assessment based on the scientific literature', International Journal of Climatology.

Hasnaoui, O., Bouazza, M. and Benmansour, D. (2022) 'Dynamique de la végétation et risques de désertification face aux fluctuations climatiques dans la région des hautes plaines oranaises (Saïda, Algérie)', Revue d'Écologie et d'Environnement, 18(1), pp. 45–56.

Intergovernmental Panel on Climate Change (IPCC) (2019). Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Regional Fact Sheet: Mediterranean Region. IPCC.

International Energy Agency (IEA) and CMCC (2024) National Climate Resilience Assessment for Algeria. Weather for Energy Tracker. Available at: https://www.iea.org/reports/national-climate-resilience-assessment-for-algeria

Khezzani, B. and Bouchemal, S. (2017) 'Demographic and spatio-temporal distribution of cutaneous leishmaniasis in the Souf oasis (Eastern South of Algeria): results of 13 years', Parasite Epidemiology and Control.

Laboudi, M., Sahibi, H., Elabandouni, M., Nhammi, H., Ait Hamou, S. and Sadak, A. (2018) 'A review of cutaneous leishmaniasis in Morocco: a vertical analysis to determine appropriate interventions for control and prevention', Acta Tropica, 187, pp. 275–283.

Mallorie, H. (2004) Variabilité pathologique du complexe Leishmania donovani agent de la leishmaniose viscérale. Thèse de doctorat, Université de Montpellier II.

Medea Directorate of Public Health (DSP) (2025) 'Spatiotemporal dynamics and epidemiology of cutaneous leishmaniasis in Algeria (2011–2020): One Health insights for targeted interventions'. PubMed.

Messaoudene, F., Boukraa, S., Boubidi, S.C., Guerzou, A. and Ouahabi, A. (2023) 'Human cutaneous leishmaniasis in North Africa and its threats to public health: a statistical study focused on Djelfa (Algeria)', Microorganisms, 11(10), 2608. Available at: https://doi.org/10.3390/microorganisms11102608

Nuider, N. et al. (2022) 'Retrospective study of cutaneous leishmaniasis in Tiaret (northwest of Algeria)', Agricultura, 121–122, pp. 1–2.

Observatoire Régional de la Santé d'Oran (ORS) (2020) Bulletin on the evolution of cutaneous leishmaniasis in western Algeria, 2014–2019, cited in MesVaccins.net, 'La leishmaniose cutanée est en augmentation en Algérie'.

Office National de la Météorologie (ONM) (2026) Données météorologiques mensuelles de la station d'Oran (janvier 2002 – décembre 2025). Alger: ONM.

Pasteur Institutes International Network (2013) 'Leishmania epidemiology, diagnosis, chemotherapy and vaccination approaches', Médecine/Sciences, 29(12), pp. 1151–1156.

Saadene, Y. and Salhi, A. (2025) 'Spatio-temporal modeling of cutaneous leishmaniasis under climate change scenarios in the Maghreb region (2021–2100)', Acta Tropica. Available at: https://doi.org/10.1016/j.actatropica.2025.107639

Saadene, Y., Salhi, A., Mliki, F. and Bouslama, Z. (2023) 'Climate change and cutaneous leishmaniasis in the province of Ghardaïa in Algeria: a model-based approach to predict disease outbreaks', Annals of Saudi Medicine, 43(5), pp. 263–276.

Schilling, J. et al. (2020) 'Climate change vulnerability, water resources and social implications in North Africa', Regional Environmental Change, 20, 15.

Seager, R. et al. (2026) 'Mediterranean drying by a positive North Atlantic Oscillation trend over the last 65 years is an extreme outlier in the CMIP6 multimodel ensemble', Journal of Climate, 39(2).

Tariki, R., Yamani, R. and Bachir, M. (2011) Cycle biologique des Parasites. Office des Publications Universitaires.

Tarín-Carrasco, P. et al. (2025) 'Assessment of future precipitation changes in Mediterranean climate regions from CMIP6 ensemble', International Journal of Climatology.

Toumi, A. et al. (2013) 'Linking climate to incidence of zoonotic cutaneous leishmaniasis (L. major) in pre-Saharan North Africa', International Journal of Environmental Research and Public Health, 10(8), pp. 3172–3191.

Tramblay, Y., El Khalki, E., Mutivali, G. and Cherif, I. (2024) 'Evolution of precipitation extremes and meteorological droughts in the Mediterranean and North Africa', International Journal of Climatology, 44(3), pp. 914–931.

Université Djillali Liabès, Sidi Bel Abbès (2014) 'Évolution de la leishmaniose cutanée en Algérie. Quel impact du climat?', Revue d'Épidémiologie et de Santé Publique, 62(S5), S219.

Vidal Algérie360 (2025) 'La leishmaniose cutanée est en augmentation en Algérie'. Available at: https://www.vidal.fr/actualites/25674-la-leishmaniose-cutanee-est-en-augmentation-en-algerie.html (Accessed: 4 July 2026).

World Health Organization (WHO) (1990) Control of Leishmaniasis. Technical Report Series No. 793. Geneva: WHO.

World Health Organization (WHO) (2026) Leishmaniasis Fact Sheet.

Yavaşlı, D.D. et al. (2025) 'Spatio-temporal trends in precipitation indices over Mediterranean using ERA5-Land data (1950–2024)', International Journal of Climatology.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SUPPLEMENTARYMATERIEL12.png