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Climate Variability, Environmental Change, and Livestock Health in Al-Bayda, Libya: An Evidence-Informed Narrative Review and Secondary Climatological Analysis

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Abstract

Livestock systems in Al-Bayda and the wider Al-Jabal Al-Akhdar region are exposed to seasonal water limitation, high summer thermal load, rangeland change, and climate-sensitive disease hazards. This study synthesizes the available evidence on pathways through which environmental and climatic conditions may affect livestock health, welfare, and production in the region. An evidence-informed narrative review was combined with a reproducible descriptive analysis of NASA POWER monthly MERRA-2 data for a point near Al-Bayda (32.76°N, 21.76°E) for 2001–2025. Annual mean 2-m air temperature increased by 0.29 °C decade^{-1} (ordinary least squares [OLS] $p = 0.006$; Kendall τ $p = 0.009$). Annual precipitation was highly variable (108–638 mm); its positive OLS slope was not statistically significant at the 0.05 level (64.5 mm decade^{-1}; $p = 0.056$), illustrating why a simple "declining rainfall" claim cannot be made from this series. The 2001–2020 climatology shows a pronounced summer dry period, a critical exposure window for water, forage, and heat management. The literature supports biologically plausible links between heat load, drought-related feed deficits, vector ecology, and compromised animal performance. However, publicly traceable, contemporaneous district-level data on herd inventories, births, deaths, production, and laboratory-confirmed disease incidence were not

identified; consequently, local effect sizes and population dynamics are not estimated here. The paper proposes a sentinel-monitoring and One Health adaptation framework that links climate, rangeland, veterinary, and farm-management indicators. Reliable local surveillance is essential before causal attribution, precise loss estimates, or district-wide livestock-population claims can be made.

Keywords: Al-Bayda; Al-Jabal Al-Akhdar; climate variability; livestock health; heat stress; rangelands; tick-borne disease; One Health; MERRA-2

*** Key Messages**

1-The examined gridded climate series shows a statistically supported warming signal (+0.29 °C decade^{-1}), not a farm-level temperature measurement.

2-Rainfall is highly variable; this analysis does not validate a simple claim of declining rainfall in Al-Bayda.

3-Publicly traceable district livestock-population, loss, and carrying-capacity data were not identified; exact local estimates are therefore not reported.

4-A sentinel One Health surveillance system is the priority research investment needed to quantify local climate–livestock relationships.

1. Introduction

Livestock is central to food provision, household income, and the use of rangeland resources across Libya (Food and Agriculture Organization of the United Nations [FAO], 2018). In the northeastern uplands, Al-Bayda lies within the environmentally distinctive Al-Jabal Al-Akhdar landscape, where orographic rainfall supports a sharper north–south moisture gradient than in much of the country (Hunt et al., 2025). This relative climatic advantage should not be interpreted as immunity from climate risk. Climate-related risks to food systems and vulnerable production systems are expected to intensify with further warming (Intergovernmental Panel on Climate Change [IPCC], 2022). Livestock enterprises remain sensitive to hot and dry summer conditions, irregular rainfall, changes in vegetation and water availability, and the interaction of these conditions with infectious and parasitic hazards.

Climate affects animals through direct and indirect pathways. Direct exposure to heat can alter thermoregulation, feed intake, immune function, reproductive performance, and welfare. Indirect effects occur when temperature and rainfall alter forage quantity and quality, drinking-water reliability, vector habitat, animal movement, housing microclimate, and the cost of maintaining production (Nardone et al., 2010; Rojas-Downing et al., 2017; Lacetera, 2019). These pathways have particular relevance in mixed grazing systems, where a seasonal feed deficit can coincide with elevated water demand and higher risk of overstocking on remaining vegetation.

The climate–livestock relationship must nevertheless be framed carefully. A warm year, a disease outbreak, or a decline in a herd size is not by itself evidence of climate causation. Livestock outcomes are also shaped by feed markets, movement restrictions, veterinary access, genotype, vaccination, farm management, conflict and infrastructure, and the quality of routine records. Precise district-level population, loss, productivity, and carrying-capacity values require a traceable, date-stamped local dataset. Because FAOSTAT is generally national rather than district-level, national figures must not be presented as verified Al-Bayda results without an identified administrative or survey source.

This study therefore has two aims: (i) to synthesize credible local, regional, and global evidence concerning climate-sensitive livestock-health pathways relevant to Al-Bayda; and (ii) to provide a transparent, reproducible descriptive climate analysis that informs—not substitutes for—local animal-health surveillance. The review addresses four questions: What environmental exposures are most relevant to livestock health in Al-Bayda? What is the strength and geographic relevance of the current evidence? What can and cannot be inferred from existing data? Which surveillance and adaptation actions would make a future district-level study publishable?

2. Materials and Methods

2.1 Study setting. Al-Bayda is located in the Al-Jabal Al-Akhdar uplands of northeastern Libya. The region has strong local topographic and coastal controls on precipitation and vegetation. A recent regional study compiling local meteorological data reported 518 mm annual rainfall for Al-Bayda, while illustrating substantial rainfall gradients across the wider uplands (Hunt et al., 2025). These local-scale contrasts are important when interpreting coarse gridded climate products.

2.2 Review design and evidence appraisal. The work was structured as an evidence-

informed narrative review, not as a systematic review or a primary epidemiological study. Sources were prioritized in the following order: (1) direct evidence from Al-Bayda, Al-Jabal Al-Akhdar, or Libya; (2) studies from climatically comparable North African or Mediterranean systems; and (3) high-quality global reviews and consensus reports. Each source was assessed for geographic relevance, outcome definition, data provenance, and whether its design supported causal or descriptive inference. The review does not pool effects because the available evidence is heterogeneous in species, endpoints, exposure definitions, and observation periods. A future scoping or systematic review should be registered and reported using the PRISMA-ScR or PRISMA 2020 framework, including a full search log, deduplication record, screening flow diagram, and risk-of-bias assessment (Tricco et al., 2018).

2.3 Reproducible climate analysis. Monthly 2-m air temperature (T2M) and corrected precipitation (PRECTOTCORR) were obtained from the NASA Prediction Of Worldwide Energy Resources (POWER) API for 32.76°N, 21.76°E, using the MERRA-2 source and the period January 2001–December 2025. Annual mean temperature was calculated as the mean of 12 monthly values. Annual precipitation was calculated by multiplying each monthly mean daily precipitation by the number of days in the respective month and summing the 12 monthly totals. Ordinary least-squares (OLS) slopes and two-sided p values were used as descriptive trend summaries; Kendall's τ was calculated as a non-parametric corroboration. The full source data, formulas, and figure notes are supplied in the accompanying workbook.

2.4 Interpretation boundaries. The NASA POWER series is a gridded reanalysis estimate and is not a farm weather station record. It can describe broad exposure patterns but cannot establish animal-level heat load, pasture biomass, or farm-level rainfall. No primary animal sampling, clinical examinations, or laboratory testing were undertaken. District population, mortality, production, and disease-frequency values should be used for effect estimation only when a data custodian, geographical unit, reporting period, definitions, and raw or auditable aggregate records are documented.

2.5 Ethics. The work used public climate data and published literature only. No animals, people, biological specimens, or identifiable records were involved; therefore, formal animal ethics approval was not required.

3. Results

3.1 Climatic exposure profile. The gridded annual mean T2M series rose from a minimum of 19.51 °C (2005) to a maximum of 21.37 °C (2024). The OLS trend was +0.029 °C $year^{-1}$ (+0.29 °C $decade^{-1}$; $p = 0.006$), and the Kendall result supported a monotonic increase ($\tau = 0.37$; $p = 0.009$). In contrast, annual precipitation was highly variable, ranging from 108 mm (2004) to 638 mm (2023). Its apparent OLS increase did not achieve the conventional 0.05 significance threshold ($p = 0.056$), while Kendall's τ was non-significant ($p = 0.156$). The appropriate interpretation is variability and uncertainty in this gridded series, not a verified local long-term decrease in rainfall.

3.2 Seasonal exposure window. The 2001–2020 MERRA-2 climatology shows very low precipitation in June–August and highest monthly temperatures in July–August. This summer coincidence is operationally important: drinking-water demand rises while rain-fed forage regeneration is limited. Farm-level heat risk will depend on shade, ventilation, stocking density, transport, breed, physiological status, and humidity, none of which is observed in the climate dataset. Heat-load assessment should therefore combine local weather monitoring with animal indicators such as respiratory rate, panting score, water intake, milk yield, body condition, and reproductive performance.

3.3 Evidence for climate-sensitive livestock-health pathways. Table 2 summarizes the pathways most relevant to the region. The strongest general evidence concerns heat stress and feed/water limitation. Heat exposure can reduce voluntary intake and alter endocrine, metabolic, and immune responses; cattle and poultry are often especially sensitive where cooling, shade, or ventilation are insufficient (Bernabucci et al., 2010; Polsky & von Keyserlingk, 2017). Drought and irregular rainfall may reduce forage availability, increase reliance on purchased feed, and intensify grazing pressure. Land-cover change in Al-Jabal Al-Akhdar has been documented using satellite time series, indicating that landscape management must be considered alongside meteorology (Alawamy et al., 2020).

Vector-borne disease risk is climate-sensitive but not climate-determined. Temperature, moisture, vegetation, host density, animal movement, and vector-control practice jointly influence tick survival and pathogen transmission (Caminade et al., 2019; Dantas-Torres, 2015). Hard ticks have been documented on the northeastern coast of Libya (Elmhalli & Garboui, 2024), and bovine piroplasmosis and anaplasmosis have been reported elsewhere in Libya (El Maghrbi et al., 2008). These observations justify targeted surveillance in Al-Bayda; they do not, however, quantify local prevalence or prove that observed infections are increasing because of climate change.

3.4 Absence of validated district population-dynamics data. The evidence review did not identify a documented, longitudinal Al-Bayda dataset that provides annual herd inventories together with births, purchases, sales, deaths, movements, production, and clinical/laboratory outcomes. Consequently, it is not scientifically defensible to report exact local population composition, season-specific herd reductions, loss percentages, grazing densities, or carrying-capacity thresholds as established findings. This is a central result of the data-integrity assessment, rather than a weakness to be hidden. A robust future population-dynamics analysis requires the minimum data structure listed in Table 3.

Indicator	Period / method	Estimate	Interpretation
Annual mean 2-m air temperature	2001–2025; OLS on annual means	+0.29 °C decade⁻¹; p = 0.006	Warming signal in the selected gridded series.
Temperature monotonic trend	2001–2025; Kendall's τ	τ = 0.37; p = 0.009	Supports a positive monotonic tendency.
Annual precipitation	2001–2025; annualized PRECTOTCORR	108–638 mm	Large interannual variability in gridded estimates.
Precipitation linear trend	2001–2025; OLS on annual totals	+64.5 mm decade⁻¹; p = 0.056	Not significant at α = 0.05; do not infer a simple rainfall trend.
Seasonality	2001–2020 monthly mean	Very low June–August precipitation; July–August warmest	Potential seasonal exposure window for water, forage, and heat management.

Table 1. Descriptive climate indicators for the selected Al-Bayda gridded point. Source: NASA POWER MERRA-2 data, calculated by the authors. Trend tests are descriptive and do not establish attribution.

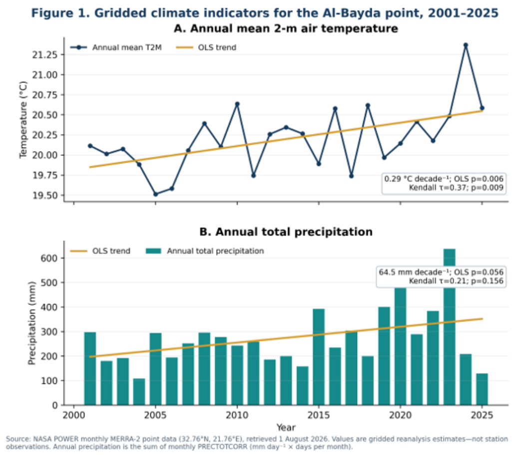

Figure 1. Gridded climate indicators for the Al-Bayda point, 2001–2025. See figure note and accompanying workbook for provenance and calculations.

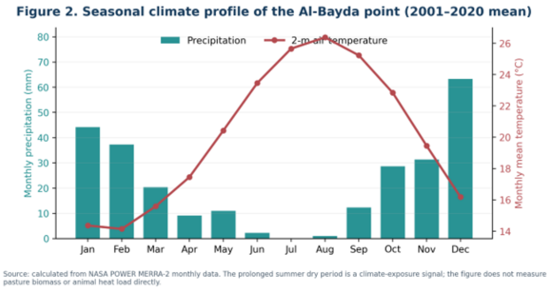

Figure 2. Seasonal climate profile of the Al-Bayda point (2001–2020 mean).

Exposure pathway	Mechanism and likely outcome	Evidence relevant to Al-Bayda	Confidence / boundary
Heat load	Reduced feed intake; altered thermoregulation, immunity, fertility, and performance.	Strong biological and livestock evidence; local quantified heat-load and production data are absent.	High for general mechanism; low for local effect size.
Rainfall variability / drought	Reduced forage and water availability; increased feed cost and grazing pressure.	Al-Jabal Al-Akhdar has marked rainfall and vegetation gradients; local pasture and herd data are insufficient.	Moderate–high for mechanism; low–moderate locally.
Land-cover and rangeland change	Changes in vegetation cover and grazing resources; possible nutritional stress.	Satellite evidence documents land-use/land-cover change in Al-Jabal Al-Akhdar.	Moderate; local causal livestock estimates absent.
Ticks and tick-borne pathogens	Climate and habitat influence vector survival; host movement and control practices also matter.	Hard ticks reported on Libya's northeastern coast; livestock haemoparasites reported elsewhere in Libya.	Moderate for surveillance priority; low for Al-Bayda prevalence/trend.
Water quality and sanitation	Enteric disease and dehydration risk where water is scarce or contaminated.	Biologically plausible; no district laboratory surveillance dataset identified.	Plausible but unquantified locally.

Table 2. Climate-sensitive livestock-health pathways relevant to Al-Bayda. Confidence refers to the strength of the stated interpretation, not to the certainty that a local outcome has occurred.

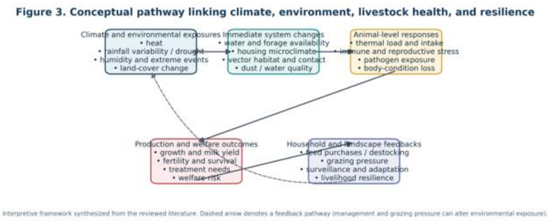

Figure 3. Conceptual pathway linking climate, environment, livestock health, and resilience.

Data element	Minimum specification	Why it is essential
Herd inventory	Farm/herd ID; species; age/sex class; breed; monthly or quarterly counts; reporting unit.	Provides denominators and distinguishes demographic change from reporting variation.
Demographic events	Births, purchases, sales, gifts, slaughter, deaths, movements; date and stated cause.	Allows true population dynamics and mortality rates to be calculated.
Health outcomes	Syndrome, case definition, examination date, diagnostic method, laboratory result, treatment, outcome.	Prevents disease counts from being mistaken for prevalence or incidence.
Production and welfare	Milk yield where relevant; body condition; fertility; growth; feed and water access; housing/shade.	Links exposure to meaningful animal and farm outcomes.
Environmental covariates	On-farm weather; water source; pasture biomass/cover; stocking rate; tick sampling; remote-sensing indices.	Enables exposure assessment at a scale relevant to animals.
Analysis plan	Pre-registered hypotheses; missing-data rules; mixed-effects or time-series model; confounders.	Reduces selective reporting and inappropriate causal claims.

Table 3. Minimum data structure required for a publishable Al-Bayda livestock-population and climate–health study.

4. Discussion

The analysis indicates a warming exposure signal at the selected gridded point and a seasonally dry summer window that are relevant to livestock management in Al-Bayda. The result is consistent with the broader literature showing that climate change can increase the probability of thermal stress and resource constraints in livestock systems (Thornton et al., 2009; Nardone et al., 2010; Anuta et al., 2025). Yet the findings should be read as exposure evidence, not as a measurement of disease burden, productivity loss, or herd decline. The distinction is essential for scientific credibility and is particularly important in a region with strong spatial variation in elevation, rainfall, vegetation, and production systems.

The rainfall result is instructive. A visually plausible narrative of "decreasing rainfall" can be attractive, but the examined MERRA-2 point series does not support a statistically significant decreasing trend. The series instead shows marked interannual variability and the potential influence of extreme years. Moreover, the gridded estimate has an annual climatology that differs from the local station compilation reported by Hunt et al. (2025), a reminder that mountain–coast gradients and data resolution matter. A publication focused on observed local climate change should use quality-controlled station data, explicitly quantify missingness and homogeneity, and report trend uncertainty. Where possible, it should compare station records with at least one reanalysis product rather than treating either as ground truth.

A pragmatic adaptation strategy should be tiered. At farm level, priority actions include reliable access to clean water, shade and ventilation, strategic adjustment of handling and transport during hot hours, heat-tolerant and locally adapted genetics, body-condition monitoring, forage conservation, mineral supplementation where deficiencies are demonstrated, and veterinary-led biosecurity. At landscape level, rotational or deferred grazing, protection of regeneration areas, water-point management, and restoration of degraded rangeland can reduce pressure during dry periods. At veterinary-service level, syndrome-based reporting, tick identification, laboratory confirmation of priority pathogens, vaccination records, and denominator-based disease rates are more informative than unstructured counts of cases.

An integrated One Health system is recommended because environmental conditions, animal health, and household decisions are connected. Figure 4 sets out a minimal sentinel architecture. It should sample representative production systems and grazing zones, with fixed farms or herds followed at regular intervals. Each observation period should record the number of animals at risk; species, age, sex, breed, and physiological class; body condition; clinical signs;

treatments and vaccination; movement; deaths and culling; production indicators; and locally measured environmental conditions. The system should include a priori alert thresholds and a feedback mechanism so that information triggers timely provision of water, feed, shade, vector control, diagnostic testing, or grazing adjustments.

The study has limitations. The review was not a registered systematic search, the climate analysis uses one reanalysis grid point, and the animal-health literature from Al-Bayda is limited. The available evidence therefore cannot support causal attribution or precise local economic estimates. These limitations are explicitly reported to prevent false precision. They also define an actionable research agenda: establish an auditable district dataset, conduct seasonal cross-sectional and longitudinal animal-health surveys, integrate remote sensing of vegetation with field biomass measurements, and use multilevel models that account for farm management and animal-level confounding.

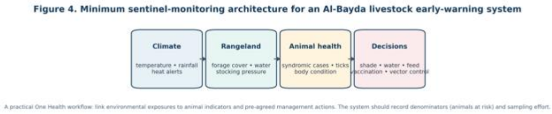

Figure 4. Minimum sentinel-monitoring architecture for an Al-Bayda livestock early-warning system.

5. Conclusions

Al-Bayda's livestock systems are plausibly vulnerable to the combined effects of rising thermal exposure, pronounced summer dryness, rangeland change, and climate-sensitive disease hazards. The 2001–2025 MERRA-2 point series shows statistically supported warming, whereas rainfall is highly variable and does not support a simple local claim of declining precipitation. Existing literature provides a strong biological rationale for preventive adaptation, but current evidence does not validate exact Al-Bayda population dynamics, loss percentages, or disease prevalence. The most defensible next step is to build a sentinel, denominator-based surveillance system that links climate, rangeland, veterinary, and production data. This would allow future studies to estimate local risks with the transparency and methodological strength expected in international peer-reviewed journals.

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