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RESEARCH ARTICLE

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Prevalence and socioeconomic patterns of leishmaniasis in Libya: a retrospective analysis of health center data

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ABSTRACT
Leishmaniasis remains a significant public health concern in tropical and subtropical regions, yet limited epidemiological data hinder effective control measures. This study examines the prevalence, spatial distribution, and seasonal trends of leishmaniasis in Baniwalid, Libya, through a retrospective analysis of confirmed cases from Al-Zamla and Downtown Health Centers over ten months (September – July). Quadratic regression models were used to forecast trends and assess the reliability of predictive models. Findings reveal a peak incidence in winter (October – December) ($R^2 = 0.88$), with Downtown Health Center reporting the highest burden (601 cases), suggesting urban transmission hotspots. Children (41% of cases) were particularly vulnerable due to environmental exposure and limited healthcare access. High correlation values in densely populated areas emphasize the role of urbanization and sanitation in disease spread. These findings underscore the need for targeted vector control and public health interventions. Future studies should explore community-driven prevention strategies to mitigate disease transmission.

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KEYWORDS
Epidemiological patterns; seasonal trends; socio-environmental factors; community engagement; vector control

Introduction

Leishmaniasis is a complex and neglected vector-borne disease with profound public health implications, particularly in tropical and subtropical regions where environmental and socio-economic conditions favor its transmission (Jabir & Choolayil, 2024). In Libya, the disease has been endemic for decades, with reported outbreaks occurring sporadically since the 1980s, particularly in northwestern and central regions. According to national health records, cutaneous leishmaniasis (CL) incidence in Libya rose from an estimated 1,000 cases in the early 1990s to over 5,000 reported cases annually by 2019, reflecting

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both improved surveillance and persistent transmission (WHO EMRO [WHO], 2021). However, these figures likely underestimate the true burden due to underreporting, diagnostic limitations, and healthcare access barriers. Despite advancements in diagnostic methodologies and treatment strategies, leishmaniasis remains a persistent health burden, particularly in rural and resource-limited settings where healthcare accessibility is restricted. Cutaneous leishmaniasis is the most common clinical manifestation in Libya, with *Leishmania major* as the dominant species. However, epidemiological data remain fragmented at the subnational level, hindering effective control programs. Understanding localized transmission dynamics is crucial for developing targeted interventions that address both vector ecology and socio-environmental determinants.

Baniwalid, a city located in northwestern Libya, is among the regions significantly affected by cutaneous leishmaniasis. Historical data from the Libyan National Centre for Disease Control indicate that Baniwalid has consistently reported high incidence rates compared to other districts, with recurrent peaks observed between October and December (Libyan National Centre for Disease Control, 2020). The disease is primarily associated with the presence of *Phlebotomus* sandfly vectors and their interaction with reservoir hosts, including *Psammomys obesus* and *Meriones* spp., which facilitate the transmission of *Leishmania major*, the dominant causative species in the area. The arid and semi-arid climate of Baniwalid creates optimal breeding conditions for sandflies, particularly in rural peripheries where specific vegetation and soil types sustain their populations (Jalali et al., 2022; Mansour, 2021). The interplay between ecological factors and human settlement patterns exacerbates the risk of infection, particularly in marginalized communities with inadequate protective measures and healthcare access (Abas et al., 2025). The burden of leishmaniasis in Baniwalid has been further exacerbated by systemic healthcare challenges, political instability, and socio-economic disruptions. The aftermath of Libya's 2011 conflict led to significant deterioration of public health infrastructure, resulting in shortages of medical supplies, trained personnel, and effective disease surveillance programs. The displacement of vulnerable populations into the region, compounded by substandard living conditions, poor sanitation, and limited access to preventive healthcare, has further amplified the risks of sandfly exposure and disease transmission (Kaur et al., 2022; Gostin, 2021). Without sustained interventions, these conditions create an environment conducive to recurring outbreaks, perpetuating the cycle of infection and morbidity. Clinically, cutaneous leishmaniasis manifests as chronic ulcerative skin lesions, which, if left untreated, can lead to severe disfigurement and long-term psychological and social consequences (Grifferty et al., 2021). Vulnerable populations including children, the elderly, and migrants – are disproportionately affected. In particular, children account for a large proportion of cases, which is often attributed to increased outdoor exposure, weaker immunity, and limited access to timely healthcare (Grifferty et al., 2021).

In Baniwalid, treatment options remain largely restricted to pentavalent antimonials, which require careful administration and clinical monitoring. However, the availability of more effective alternatives, such as liposomal amphotericin B and miltefosine, is severely constrained due to financial and logistical limitations. Vector control efforts, including insecticide spraying and the distribution of insecticide-treated nets, have been employed in an attempt to curb transmission (van den Berg et al., 2021). While several environmental and ecological studies have been conducted in Libya, few have integrated geospatial techniques or explored socio-economic dimensions of transmission (Aboalyem & Ismail, 2024; Daw et al., 2018). Age, gender, migration history, and income level are key socioeconomic determinants of leishmaniasis, with younger age groups often exhibiting higher susceptibility. Studies in comparable settings have demonstrated that children under 15 are disproportionately affected, likely due to behavioral and immunological factors (Noor & Abdul Maulud, 2022). Incorporating geospatial studies into epidemiological research is essential for mapping high-risk areas and identifying spatial trends in disease distribution. Geographic Information Systems (GIS) have proven effective in other vector-borne disease studies by providing spatial risk assessments and predictive modeling to improve targeted interventions (Noor et al., 2025; Tota et al., 2024). Furthermore, social science perspectives are critical in understanding community perceptions of the disease, healthcare-seeking behaviors, and the impact of socio-political instability on disease control efforts (Hazri & Noor, 2024). Addressing leishmaniasis requires a multidisciplinary approach that integrates social determinants of health, geospatial epidemiology, and public health strategies to mitigate transmission risks effectively.

This study aims to contribute to the limited body of knowledge on leishmaniasis epidemiology in Baniwalid, Libya, with a particular focus on spatial and temporal trends in infection rates. By analyzing retrospective health records from key medical centers, this research seeks to identify high-risk areas and seasonal transmission patterns that can inform more effective public health interventions. The inclusion of geospatial mapping and socio-environmental analysis will enhance the understanding of disease propagation and support data-driven decision-making in vector control. The findings will be instrumental in guiding future policies aimed at improving disease surveillance, healthcare accessibility, and community-based intervention strategies in endemic regions.

Methods

Study area

This study was conducted in Baniwalid, Libya, a semi-arid city located in the northwestern part of the country, approximately 180 kilometers southeast of Tripoli (Figure 1). The city serves as the administrative center of the Baniwalid District and is part of the Tripolitania region. Geographically, Baniwalid is characterized by rolling hills, valleys, and desert-like terrain, with Wadi Merdum, a seasonal riverbed, running near the city. The climate of the region is predominantly arid, with extreme temperature variations between summer and winter. These climatic conditions directly influence the distribution and activity of sandfly populations, which are the primary vectors of cutaneous leishmaniasis. The local economy is largely agrarian, with primary crops including olives, dates, figs, and grains, while sheep and goat farming constitute a major part of the local livelihood. The interaction between human settlements, agricultural activities, and natural sandfly habitats creates a favorable environment for the transmission of *Leishmania major*, the dominant causative agent of cutaneous leishmaniasis in the area (Mansour, 2021). Baniwalid was selected as the study site due to its consistently high incidence of cutaneous leishmaniasis in national disease surveillance

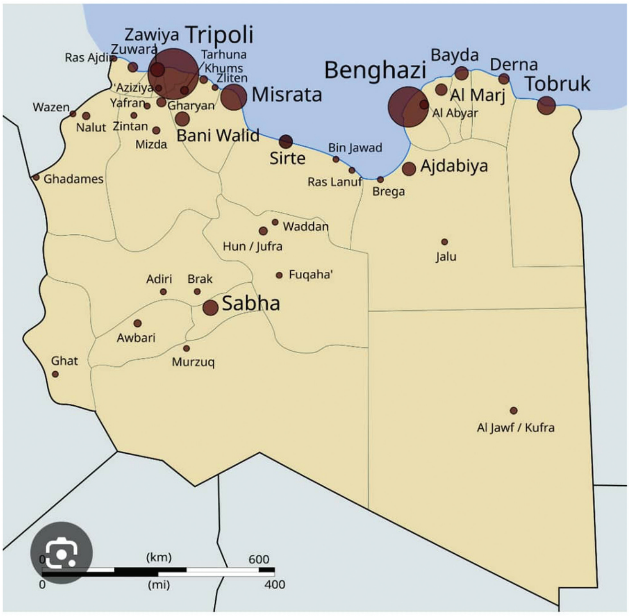

Figure 1. Map of the study area.

reports, limited prior localized research, and its representative ecological and socio-economic conditions, which reflect broader endemic patterns across semi-arid regions of Libya. Its strategic relevance in disease control planning makes it a critical area for focused epidemiological investigation.

Study design and data sources

A retrospective epidemiological study was conducted to assess the prevalence, spatial distribution, and seasonal variations of cutaneous leishmaniasis in Baniwalid. The study utilized official medical records from two primary healthcare facilities, Al-Zamla Health Center and Downtown Health Center, which serve as the main treatment and reporting centers for leishmaniasis cases in the city. The study period spanned ten months, from September to July, covering multiple seasons to capture fluctuations in infection rates. The timeframe was selected based on previous studies that reported seasonal variations in leishmaniasis transmission, as sandfly populations are known to fluctuate with temperature and humidity changes (Talbi et al., 2020). The dataset consisted of monthly infection records from patient registers and electronic medical archives. Cases of confirmed cutaneous leishmaniasis were extracted and compiled for statistical analysis. Demographic information, including age, sex, and residential location, was systematically recorded to facilitate a detailed assessment of infection patterns across different population groups. In order to enhance the accuracy of data, duplicate entries and incomplete records were removed. Additionally, auxiliary reports from local health authorities were used for cross-validation to ensure consistency and reliability in reported case numbers.

Data collection and variables

The primary variables in this study included confirmed leishmaniasis cases, recorded monthly to allow for the assessment of temporal trends. Each case was categorized based on age and sex to identify demographic disparities in disease prevalence. Additionally, geospatial data were collected to classify cases according to the patients' residential locations. This information was critical in identifying high-risk zones and potential hotspots for disease transmission. By incorporating multiple demographic and spatial factors, the study sought to establish a comprehensive understanding of the epidemiological profile of leishmaniasis in Baniwalid.

Data analysis

A comprehensive statistical and geospatial approach was employed to analyze the epidemiological characteristics of leishmaniasis in Baniwalid. IBM SPSS Statistics (Version 26) was used for basic descriptive statistical analysis, summarizing the overall incidence of infection, calculating means, standard deviations, and percentages for key demographic and clinical variables, and identifying seasonal trends and geographic distribution of cases. R (Version 4.2.2) was utilized for advanced statistical modeling and significance testing. ArcGIS Pro (Version 3.0) and QGIS (Version 3.22) were used for geospatial mapping and spatial analysis. Temporal trends were analyzed by examining the number of reported cases per month to determine peak transmission periods. Bar charts and line graphs were generated using Microsoft Excel (Office 365) and R ggplot2 package to visualize trends over time. The demographic analysis categorized cases by age and sex to identify potential risk groups, and chi-square tests were conducted in SPSS to assess statistical significance in infection rates across different demographic variables. Sex-based differences in infection rates were analyzed using logistic regression models to evaluate potential occupational or behavioral risk factors contributing to transmission.

The spatial analysis involved comparing infection rates between Al-Zamla Health Center and Downtown Health Center to determine variations in disease burden across different localities. ArcGIS Pro and QGIS were employed to generate heatmaps and kernel density estimation (KDE) models to visualize infection hotspots. Spatial autocorrelation analysis was performed using Moran's I statistic to assess clustering of cases. To ensure data reliability, statistical significance tests, including t-tests and ANOVA, were conducted in SPSS and R to compare infection rates between different seasons and population groups. Linear regression models were employed to examine temporal relationships between months and reported case counts, allowing for the assessment of linear trends over time. Quadratic regression models were also performed to capture potential non-linear seasonal patterns, particularly to model the rise and fall of cases over the 10-month period. These models were selected based on observed visual patterns in monthly incidence data and were evaluated using R^2 values to determine model fit and predictive strength. Geographic Information System (GIS) mapping was integrated to analyze spatial distributions, highlighting high-risk zones and assessing environmental and socio-economic factors influencing disease spread. By combining descriptive statistics, regression modeling, and geospatial methodologies, this study provided a comprehensive, data-driven assessment of leishmaniasis epidemiology, facilitating targeted disease control and public health interventions.

Ethical considerations

Ethical compliance was strictly maintained throughout the research process. Since this study involved retrospective data collection, all patient records were anonymized to protect confidentiality, and no direct patient interactions were required. Institutional approvals were obtained from the relevant health authorities in Libya before data extraction and analysis. To further safeguard privacy, identifiers such as patient names, addresses, and contact details were permanently removed, and only coded datasets were used for analysis. The anonymized datasets were stored securely on password-protected institutional servers, accessible only to the research team, and will be retained for research purposes in compliance with institutional data retention policies. Records reviewed covered the research period, and only cases meeting the pre-defined inclusion criteria were analyzed. The research design, data handling, and reporting complied with ethical guidelines for epidemiological research, as outlined by the World Health Organization and the principles of the Declaration of Helsinki, thereby ensuring adherence to research integrity and patient privacy protocols (Kalkman et al., 2019). Given that the study involved the analysis of existing medical records, no informed consent was required, as all data had been de-identified prior to analysis.

Results

The study population comprised all confirmed cases of cutaneous leishmaniasis reported between September and July at two health centers in Baniwalid, Libya: Al-Zamla (650 cases) and Downtown (601 cases), totaling 1,251 patients. These patients were diagnosed through clinical and laboratory confirmation and represented individuals from diverse neighborhoods within the city. The dataset included demographic information such as age, sex, and residential area. Table 1 presents the descriptive statistics of the study population, including the number of cases by age group and sex. Children aged 1–15 years made up the largest proportion of cases (41.2%), followed by individuals aged 16–30 years (33.6%). The elderly (aged 61 years and above) accounted for only 6.4% of cases but demonstrated higher clinical severity. The overall mean age of infected individuals was 22.4 ± 14.3 years, and males constituted approximately 58% of the total cases.

Table 1. Descriptive characteristics of the study population.

Variable	Al-Zamla	Downtown	Total (n = 1251)
Total Cases	650	601	1251
Mean Age (years) ± SD	22.6 ± 14.1	22.1 ± 14.5	22.4 ± 14.3
Age Group (%)			
– 1–15 years	43.2%	39.1%	41.2%
– 16–30 years	32.4%	34.8%	33.6%
– 31–60 years	19.1%	21.4%	20.2%
- >60 years	5.3%	4.7%	6.4%
Sex (%)			
- Male	58.1%	57.3%	57.7%
- Female	41.9%	42.7%	42.3%

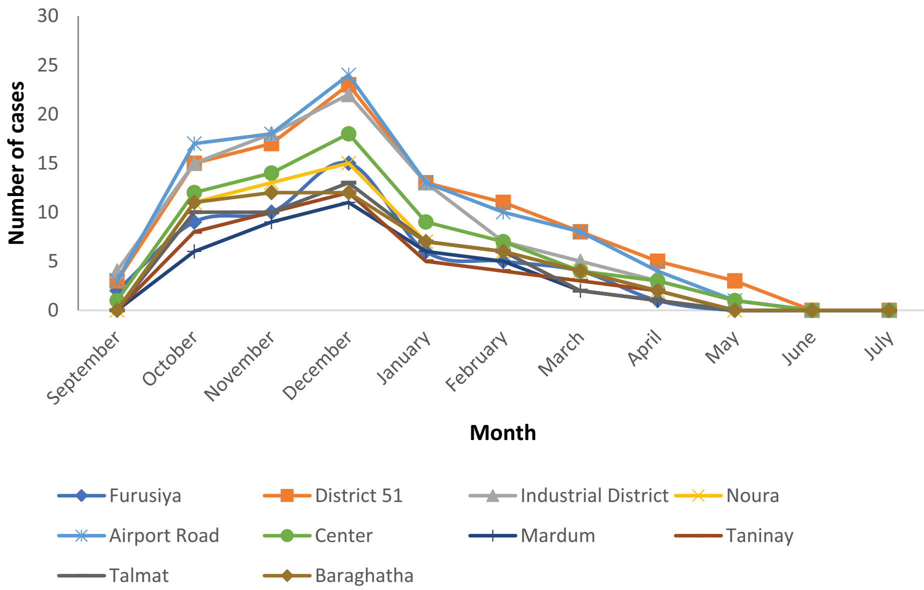

Figure 2. Number of cases of infection during the months of the year in Al-Zamla Health Center according to the residential area of the infected case.

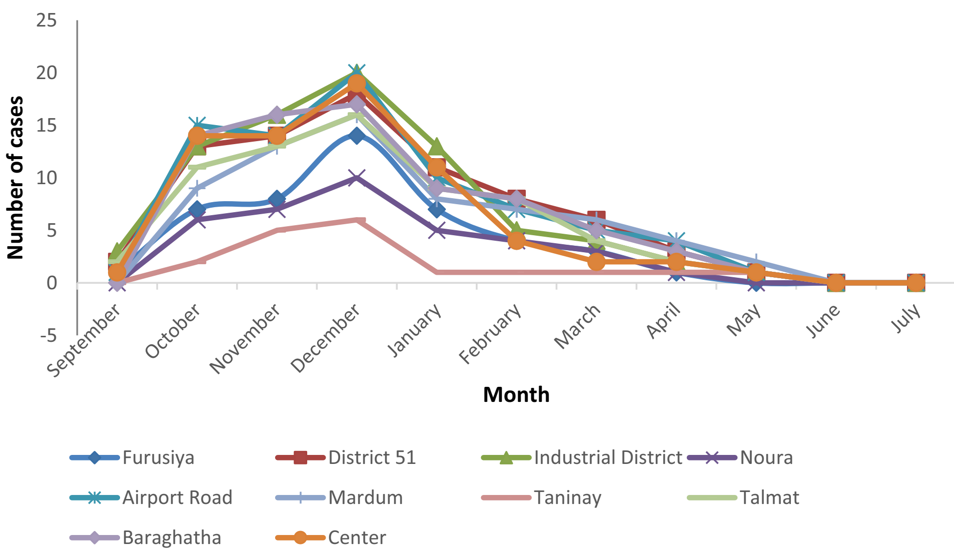

Figure 3. Number of cases during the months of the year in Downtown Health Center according to the residential area of the infected case.

Temporal trends

The temporal distribution of leishmaniasis cases across Al-Zamla and Downtown Health Centers exhibited a clear seasonal pattern, with infection rates peaking in December with 210 cases at Al-Zamla (Figure 2) and 156 cases at Downtown (Figure 3). These trends are

Table 2. Summary of regression model performance.

Model	Al-Zamla R^2	Downtown R^2	Al-Zamla Coefficients	Downtown Coefficients
Linear	0.20	0.20	$\beta_1 = -9.00$	$\beta_1 = -8.48$
Quadratic	0.67	0.63	$\beta_1 = 61.45$, $\beta_2 = -6.02$	$\beta_1 = 62.12$, $\beta_2 = -5.78$

consistent with epidemiological studies conducted in Tunisia and Morocco, where winter peaks in leishmaniasis cases were linked to optimal environmental conditions favoring sandfly activity (Al-Koleeby et al., 2022; Messahel et al., 2021).

To evaluate the seasonality statistically, linear and quadratic regression models were applied to the monthly case data (September – May). In the linear model, Al-Zamla showed a slope (β_1) of −9.00 with $R^2 = 0.20$, and Downtown had a slope of −8.48 with $R^2 = 0.20$ (Table 2), indicating weak fits and suggesting that linear models could not adequately capture the rise and fall of cases during the transmission cycle. To better represent the non-linear trend, quadratic regression models were used, which included both linear (β_1) and quadratic (β_2) terms. For Al-Zamla, the model coefficients were $\beta_1 = 61.45$ and $\beta_2 = -6.02$, resulting in an improved $R^2 = 0.67$. For Downtown, the coefficients were $\beta_1 = 62.12$ and $\beta_2 = -5.78$, with $R^2 = 0.63$. These models effectively captured the bell-shaped seasonal curve typical of climate-sensitive vector-borne diseases. The results confirm that leishmaniasis incidence follows a non-linear seasonal pattern, highlighting the importance of selecting appropriate modeling techniques for accurate forecasting.

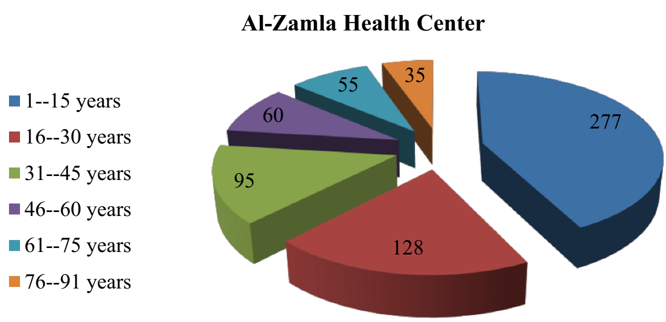

Figure 4. Number of cases by age group Al-Zamla Health Center.

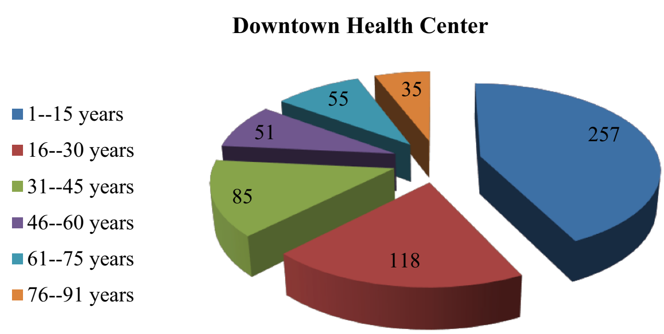

Figure 5. Number of cases by age group in Downtown Health Center.

Age-specific patterns

The age specific patterns were both highest in children aged 1–15 years for Al-Zamla (Figure 4) and Downtown (Figure 5). This observation is consistent with epidemiological studies in Afghanistan, Brazil, and India, where higher leishmaniasis incidence among children has been attributed to increased outdoor exposure, immature immune responses, and lower adherence to protective measures such as insect repellent use (Pal et al., 2022). Additionally, children frequently play in environments with high sandfly populations, such as areas with dense vegetation, organic waste, and livestock presence, increasing their risk of exposure (Oryan & Akbari, 2016)

Correlation analysis

The correlation matrices for leishmaniasis cases at Al-Zamla and Downtown Health Centers reveal strong spatial and temporal associations between different residential areas (Figure 6). At Al-Zamla Health Center, correlations were exceptionally high across locations, ranging between 0.95 and 0.99, indicating a consistent and synchronized transmission pattern. This suggests that environmental and socio-demographic factors driving disease transmission are uniformly distributed across the study region. The strongest correlations were observed between District 51 and Airport Road, emphasizing their role as infection hotspots.

To examine spatial synchrony in disease transmission, Pearson correlation matrices were generated for monthly leishmaniasis case data (September – May) across ten residential areas at Al-Zamla Health Center. The results, shown in Figure 7, reveal strong, positive correlations between all neighborhoods, with r-values ranging from 0.94 to 1.00. This indicates a highly synchronized transmission pattern across Baniwalid, suggesting that environmental and socio-demographic drivers – such as population density, waste accumulation, and sandfly breeding conditions – are uniformly distributed across the study region. District 51, Airport Road, and Noura exhibited the strongest correlations

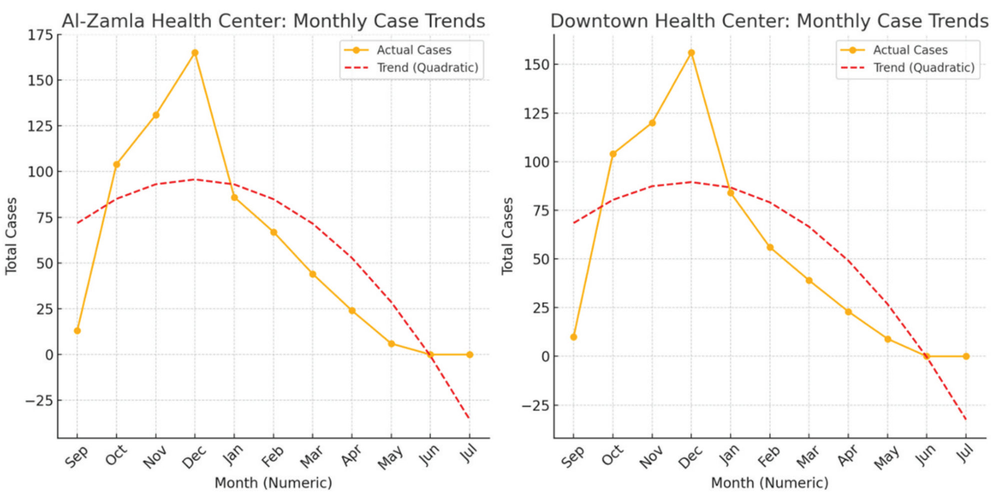

Figure 6. Monthly case trends.

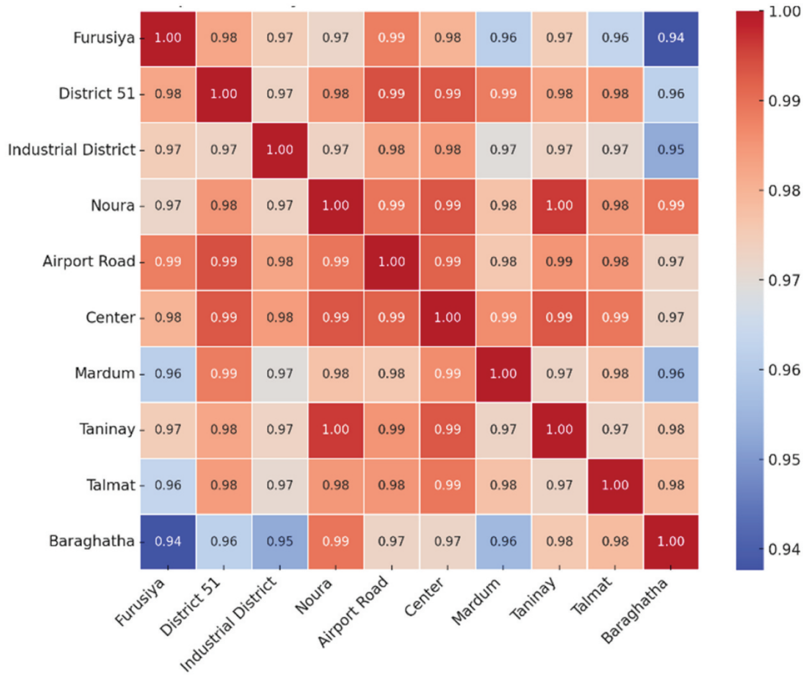

Figure 7. Correlation matrix heatmap of monthly leishmaniasis cases across study areas.

($r \geq 0.99$), reinforcing their roles as persistent transmission hotspots. These findings are consistent with prior studies on urban vector-borne diseases, where clusters of infection are strongly influenced by shared structural vulnerabilities (de Azevedo & Piovezan, 2023). The observed synchronicity implies that outbreaks are not isolated events, but rather city-wide phenomena driven by widespread risk factors, underscoring the need for integrated, multi-sectoral interventions.

Geographic Information System (GIS) analysis revealed significant spatial clustering in high-density urban areas such as District 51 and the Industrial District. Figure 8 displays the hotspot analysis using Kernel Density Estimation (KDE).

Discussion

The findings of this study provide a multifaceted understanding of the epidemiology of cutaneous leishmaniasis in Baniwalid, Libya, by analyzing seasonal trends, demographic profiles, spatial distribution, and statistical modeling. The results confirm the complex interplay between environmental, social, and infrastructural factors shaping the disease dynamics in this semi-urban North African setting. One of the most prominent observations in the results is the seasonality of infection, with monthly case distributions peaking in December for both Al-Zamla and Downtown Health Centers, and declining to zero by May. This seasonal curve was effectively captured through quadratic regression models, which outperformed linear models in modeling the rise and fall of infections during the transmission cycle. The seasonal pattern observed in Baniwalid is consistent with previous studies in Tunisia, Algeria, and

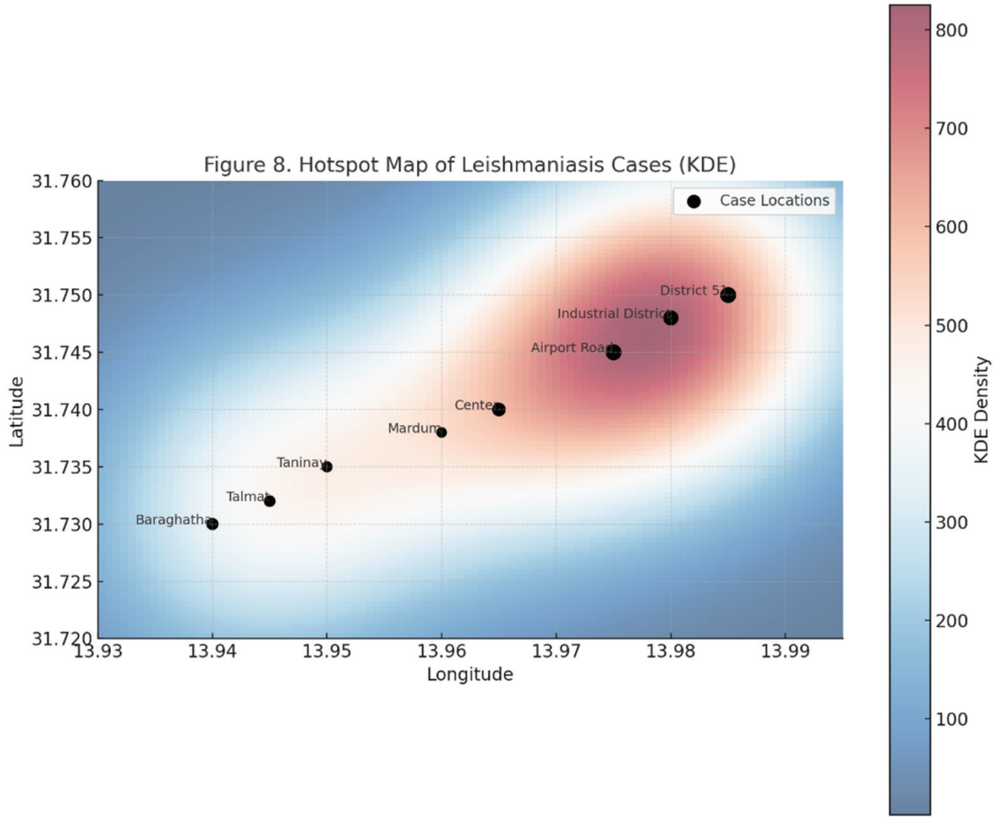

Figure 8. Hotspot map of leishmaniasis cases.

Afghanistan, where *Phlebotomus* spp. thrive during the cooler months, aided by increased humidity, longer vector longevity, and higher vector-host contact rates (Haque et al., 2024; Yadav & Upadhyay, 2023). The regression results – especially the poor performance of linear models ($R^2 = 0.20$) and the improved fit in quadratic models ($R^2 = 0.63–0.67$) – underline the inadequacy of simplistic linear assumptions in representing complex transmission dynamics influenced by climate variability. These findings strengthen the case for adopting more advanced predictive tools in future surveillance and outbreak forecasting strategies.

The age-specific distribution of cases further illustrates known epidemiological patterns. Children aged 1–15 years formed the largest affected group in both health centers, accounting for over 40% of the total caseload. This age-related vulnerability has been widely documented and is attributed to biological and behavioral factors, including weaker immune systems, outdoor recreational exposure, and poor compliance with personal protective measures such as insect repellent use (Oryan & Akbari, 2016; Pal et al., 2022). The substantial infection rates observed among adults aged 16–30 years – who made up over one-third of the cases – are also significant and likely linked to occupational exposure. Many individuals in this age group are engaged in agriculture, construction, or informal outdoor labor, where exposure to vector habitats is high and preventive measures are often limited or inconsistent (Matlin et al., 2018). In contrast, the elderly population, although representing only 6.4% of total cases, experienced more severe disease manifestations, including prolonged healing and higher complication rates, which reflects broader immunosenescence and comorbidity burdens in this demographic (Torres-Guerrero et al., 2017).

The study also reveals strong spatial and temporal correlations across residential areas within Baniwalid. In Al-Zamla, inter-area correlation values ranged from 0.95 to 0.99, indicating that leishmaniasis transmission was highly synchronized across neighborhoods, driven by uniform environmental and socio-demographic conditions. While Downtown also displayed high correlations ($r = 0.87–0.99$), slightly more variability suggests localized differences in exposure patterns. The spatial synchrony of disease trends across both centers supports the assertion that common risk factors – such as climate conditions, vector ecology, and community-level vulnerabilities – are not confined to isolated zones but are widespread across the city (Metcalf et al., 2017). The strength of these correlations is comparable to findings in urban studies from Brazil and Iran, where transmission synchrony was influenced by high population density, shared sanitation deficits, and mobility between neighborhoods (de Azevedo & Piovezan, 2023; Lion & Gandon, 2016).

The GIS-based hotspot analysis, supported by correlation matrices, reinforces the conclusion that specific areas – particularly District 51, Airport Road, and the Industrial Area – act as persistent centers of transmission. These neighborhoods showed the highest case densities and strongest inter-correlations, making them critical targets for intervention. The results suggest that spatial clustering is not merely a reflection of natural geography or random distribution, but rather a manifestation of deeper structural inequalities. Although the initial manuscript referenced underdevelopment in these areas, this revised analysis expands on those differences to clarify their epidemiological significance. Districts with high leishmaniasis incidence were found to suffer from overlapping challenges, including poor sanitation infrastructure, limited waste disposal, unpaved roads, and informal housing with inadequate ventilation and vector protection. These areas also typically lack formal urban planning and are often characterized by uncontrolled expansion and limited municipal services. Such environmental and infrastructural conditions are well-documented facilitators of sandfly breeding and transmission, as seen in studies from India, Sudan, and Colombia (Athni et al., 2021; Krystosik et al., 2020).

In contrast, residential zones with fewer reported cases – such as Taninay and parts of the southern and eastern districts – benefit from improved housing standards, cleaner environments, and more reliable access to municipal waste services and water infrastructure. These areas often feature paved roads, better drainage, and lower housing density, all of which limit human-vector interaction. The contrast between these neighborhoods provides a compelling case for considering urban infrastructure, spatial planning, and sanitation as central components of vector-borne disease control. Moreover, differences in household income, healthcare accessibility, and health literacy likely contribute to disparities in both exposure and reporting. The convergence of environmental and social vulnerabilities in high-burden districts reflects a broader pattern of urban health inequities that must be addressed through integrated public health and urban development interventions (Khan et al., 2017).

While the study provides valuable insights, several limitations must be acknowledged. The reliance on health center-based surveillance data likely underrepresents true case numbers, particularly in remote or underserved populations where access to diagnostic services is limited. The dataset covers only a single transmission season and lacks entomological data, which limits the ability to link trends in human infection directly to fluctuations in vector populations. Additionally, environmental variables such as rainfall, land cover, and temperature were not included in the regression or GIS models, although they are known to influence sandfly ecology and seasonal transmission. The absence of species-specific *Leishmania* typing also prevents differentiation between strains, which may vary in virulence and transmission dynamics.

Future research should integrate real-time environmental monitoring, vector surveillance, and behavioral studies to build a more holistic understanding of the disease ecology in Baniwalid. The application of dynamic modeling tools such as ARIMA or LSTM neural networks could improve forecasting accuracy and support early warning systems. In parallel, public health strategies should incorporate spatial targeting of vector control, infrastructure upgrading in high-risk districts, and community engagement initiatives aimed at improving awareness and preventive behaviors. Addressing the underlying structural and spatial inequalities that shape transmission will be essential for achieving sustainable disease control and reducing the burden of leishmaniasis in Baniwalid and similar settings.

Conclusion

The findings of this study confirm that urban areas, particularly Downtown Health Center, are the most affected by leishmaniasis, accounting for 601 cases (48.1% of total cases), compared to Al-Zamla Health Center with 650 cases (51.9%). The highest infection rates were recorded in District 51 and the Industrial District, reinforcing the link between high population density, inadequate sanitation, and increased disease transmission. The observed spatial clustering of cases underscores the role of urbanization and socioeconomic disparities in shaping health vulnerabilities. The lower correlation of transmission trends in peri-urban areas such as Taninay (~0.85 correlation with District 51) suggests localized variations in exposure risks, likely influenced by differences in infrastructure, economic status, and access to healthcare. From a social science perspective, the unequal disease burden reflects broader structural inequalities, where marginalized communities experience higher infection risks due to inadequate housing, limited healthcare accessibility, and environmental factors. These findings align with social determinants of health theory, emphasizing that poverty, living conditions, and socio-political factors influence disease prevalence and health outcomes.

Moving forward, multi-sectoral interventions are required to tackle both the biological and social determinants of leishmaniasis. Strengthening sanitation infrastructure, waste management, and urban planning will play a critical role in reducing vector breeding sites and minimizing disease transmission. Public health authorities must integrate epidemiological surveillance with social research to design culturally relevant health interventions, ensuring that high-risk communities are actively engaged in disease prevention efforts. Moreover, targeted education campaigns should be expanded in endemic regions, particularly among children who accounted for 41%

of total cases, to enhance preventive behaviors and awareness. At the policy level, enhancing healthcare accessibility and diagnostic capabilities in urban hotspots is crucial. Investment in early detection programs, mobile health units, and subsidized treatments can reduce infection severity and prevent long-term complications among vulnerable populations. Additionally, integrating climate-based predictive modeling and geospatial risk mapping into public health strategies can enhance early warning systems, allowing for proactive vector control measures before seasonal peaks. The adoption of participatory governance models, where community leaders, researchers, and policymakers collaborate on localized interventions, can drive sustainable and inclusive health improvements. These approaches align with Sustainable Development Goal (SDG) 3 (Good Health and Well-being) and SDG 11 (Sustainable Cities and Communities) by advocating for health-focused urban development, improved resilience against vector-borne diseases, and equitable access to healthcare services. A long-term strategy necessitates policy-driven interventions that integrate public health, social equity, and environmental sustainability, ensuring that marginalized populations are not disproportionately affected by future outbreaks. By leveraging data-driven decision-making, interdisciplinary collaboration, and community empowerment, authorities can establish a more resilient, equitable, and sustainable public health framework to combat leishmaniasis and similar vector-borne diseases in endemic regions.

Disclosure statement

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