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Epidemiological, Diagnostic, and Therapeutic Study of Cutaneous Leishmaniasis in the Bougtob Region (El Bayadh, Algeria): An Integrated Public Health Approach

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Abstract

Cutaneous leishmaniasis is an endemic vector-borne disease that is expanding across several regions of Algeria, particularly in the municipality of Bougtob (El Bayadh province), a semi-arid area marked by significant epidemiological and environmental vulnerability. This study aims to characterize the local epidemiological profile of the disease between 2021 and 2025, identify the major risk factors (human, animal, ecological), and analyze the treatment practices adopted, whether from modern medicine or traditional knowledge. The methodology is based on a mixed approach: hospital surveys conducted at Kadhi Mohamed Hospital, parasitological tests (Giemsa-stained smears, PCR), ethnomedical interviews with rural and nomadic populations, and entomological assessments of larval habitats. Results reveal a high incidence among young adults living in rural areas, exposed to *Phlebotomus* vectors and animal reservoirs (stray dogs, rodents), in humid, vegetated, or poorly sanitized environments. The use of biomedical treatments (Glucantime®, Miltefosine) coexists with natural remedies such as henna, garlic, and fenugreek. Although preventive measures are known (insecticide-treated bed nets, spraying, awareness campaigns), their implementation remains fragmented. The study concludes with the need for an integrated "One Health" strategy, combining human, veterinary, and environmental interventions to ensure sustainable disease control.

Keywords: Cutaneous leishmaniasis, Bougtob, public health, risk factors, traditional medicine, *Phlebotomus*, animal reservoirs, One Health, Algeria, rural epidemiology.

Running Title: *Cutaneous Leishmaniasis in Bougtob: An Integrated Public Health Approach*

Introduction

Leishmaniases are a group of parasitic diseases caused by flagellated protozoa of the genus *Leishmania*, transmitted to humans and various mammals through the bite of infected sandflies (*Phlebotomus* spp.) (Burza *et al*., 2018; WHO, 2023). These diseases are endemic in over 100 countries, particularly affecting tropical and

subtropical regions of Africa, Asia, Latin America, and the Mediterranean basin (PAHO/WHO, 2022).

Clinically, leishmaniasis manifests in three primary forms, depending on the infecting species and host immune response: visceral leishmaniasis (VL), cutaneous leishmaniasis (CL), and mucocutaneous leishmaniasis (MCL) (Alvar *et al*., 2012; van Griensven *et al*., 2019). Visceral leishmaniasis, mainly caused by *L. donovani* and *L. infantum*, is the most severe form and can be fatal if left untreated, especially in regions such as South Asia, East Africa, and parts of Southern Europe (WHO, 2023). Cutaneous leishmaniasis, typically caused by *L. major* and *L. tropica*, is characterized by localized ulcerative lesions that often leave permanent scars; it is widespread in North Africa, the Middle East, and the Americas (Reithinger *et al*., 2007; Oryan & Akbari, 2016). Mucocutaneous leishmaniasis, associated with *L. braziliensis*, affects both skin and mucosal tissues and is mainly reported in humid forested regions of South America (Silveira *et al*., 2023).

As a neglected tropical disease, leishmaniasis disproportionately affects impoverished and marginalized populations. According to the World Health Organization, over one billion people live in endemic areas, with an estimated 700,000 to 1 million new cases annually across all forms (WHO, 2023). The disease's distribution is driven by multiple aggravating factors, including malnutrition, population displacement, poor living conditions, immunosuppression (e.g., HIV), and environmental changes such as deforestation, urbanization, dam construction, and irrigation systems (Khan *et al*., 2022; Pigott *et al*., 2014).

In Algeria, leishmaniasis represents a major public health concern. The country is among the most affected in the Mediterranean basin, with a high prevalence of both cutaneous and visceral forms. Cutaneous leishmaniasis is endemic and has experienced a continuous resurgence since the late 1990s, particularly in rural and peri-urban areas with limited healthcare infrastructure (Boubidi *et al*., 2011; Benikhlef *et al*., 2020).

In this context, the present study aims to provide an integrated analysis of cutaneous leishmaniasis in the commune of Bougtob (El Bayadh province, Algeria) by exploring its epidemiological, diagnostic, and therapeutic dimensions. The work is structured in several phases: (i) a synthesis of current knowledge on leishmaniasis forms, (ii) a situational assessment of available diagnostic tools and treatment options both biomedical and traditional, and (iii) a retrospective field investigation covering cases recorded between 2021 and 2025, including local health practices and diagnostic approaches. The overall objective is to identify the specific epidemiological and clinical characteristics of this semi-arid zone in order to develop integrated, multisectoral public health recommendations.

Taxonomic Classification of *Leishmania* Parasites

Leishmania spp. are intracellular, flagellated protozoan parasites classified within the order *Kinetoplastida*, family *Trypanosomatidae*, and phylum *Euglenozoa*. A defining feature of these organisms is the kinetoplast a densely packed DNA-containing structure within a mitochondrion, located near the base of the flagellum which serves as both a morphological and molecular hallmark of this taxonomic group (Espinosa *et al*., 2018; WHO, 2023).

Throughout their life cycle, these parasites alternate between two morphologically distinct forms depending on the host:

- **Promastigote form**: An elongated, motile, flagellated stage found extracellularly in the midgut of the sandfly vector (*Phlebotomus* spp.);
- **Amastigote form**: A rounded, non-flagellated, intracellular form residing within the macrophages of the vertebrate host, primarily humans.

From a taxonomic standpoint, *Leishmania* classification integrates morphological, geographic, and molecular data. Given the close morphological resemblance among species, accurate differentiation increasingly depends on molecular tools such as species-specific PCR, mitochondrial kDNA sequencing, and isoenzyme analysis (Fraga *et al*., 2016; Fernandes *et al*., 2021).

Updated Taxonomic Hierarchy:

- **Domain**: Eukaryota
- **Kingdom**: Excavata
- **Phylum**: Euglenozoa
- **Class**: Kinetoplastea
- **Order**: Kinetoplastida
- **Suborder**: Trypanosomatina
- **Family**: Trypanosomatidae
- **Genus**: *Leishmania*

Human-pathogenic species are grouped into clinical and geographical complexes, reflecting their distribution and tissue tropism:

- **Leishmania donovani complex** (*L. donovani*, *L. infantum*): agents of visceral leishmaniasis (VL);
- **Leishmania mexicana complex and *L. major–L. tropica* group**: responsible for cutaneous (CL) and mucocutaneous (MCL) forms;
- **Viannia complex** (formerly *L. braziliensis*): endemic to South America, often associated with disfiguring mucosal lesions.

This phylogenetic framework, increasingly supported by genomic evidence, enhances understanding of the genetic diversity and adaptive strategies of *Leishmania* species across hosts, vectors, and ecosystems (Akhoundi *et al*., 2016; WHO, 2023). It

underpins efforts in molecular diagnosis, targeted therapeutics, and epidemiological monitoring.

Geographical and Socioeconomic Profile of Bougtob (El Bayadh, Algeria)

Located in the northern part of El Bayadh province, approximately 103 km from the provincial capital, the municipality of Bougtob serves as a strategic ecological and administrative transition zone, bordering the wilayas of Saïda, Naâma, and El Bayadh (ONS, 2023). The region is characterized by an arid continental climate with extreme thermal variations, typical of the Saharan Atlas steppes. Summers are long, hot, and dry, while winters are harsh, often accompanied by frost events (ONM, 2022; FAO, 2021). The area is regularly exposed to sandstorms and wind erosion. Bougtob spans a total area of 2,018 km² and has an estimated population of 22,857 residents, scattered across remote settlements with limited access to health infrastructure (DPS El Bayadh, 2022). The local healthcare system includes a 20-bed hospital, a polyvalent health center, and two rural dispensaries. Economically, Bougtob relies on rain-fed agriculture (primarily durum wheat and barley) and extensive pastoral livestock farming, both of which are highly vulnerable to climatic variability and recurrent drought (MADRP, 2022; Belhamra *et al*., 2020). The weekly livestock market in Bougtob is among the largest in the region, highlighting the importance of agro-pastoral systems in sustaining rural livelihoods.

Therapeutic Strategies and Barriers to the Management of Cutaneous Leishmaniasis in Bougtob (Algeria): Between Biomedicine and Local Phytotherapy"

In Bougtob, the management of cutaneous leishmaniasis primarily relies on pentavalent antimonials (Glucantime®), in accordance with World Health Organization guidelines (WHO, 2023). Although effective, this treatment requires strict medical supervision and remains poorly accessible in rural settings. Liposomal amphotericin B, while highly active against visceral leishmaniasis, is limited by its high cost and hospitalization requirements (Sundar et Chakravarty, 2015). Miltefosine, a promising oral alternative, remains unavailable in many parts of the Maghreb (Dorlo *et al*., 2012). In parallel, local populations often resort to traditional phytotherapy. Plants such as *Allium sativum*, *Olea europaea*, and *Aloe vera* are widely used for their antimicrobial and wound-healing properties, although clinical evidence remains scarce (Rebai *et al*., 2019; Aoun *et al*., 2014). Restricted access to specialized care, a shortage of trained medical staff, and the geographic isolation of diagnostic facilities are among the key barriers to effective disease management (DPS El Bayadh, 2022).

Methodological Framework for Epidemiological Investigation of Cutaneous and Visceral Leishmaniasis in Bougtob (Algerian Steppe Zone): Integrative Approaches and Local Challenges"

A comprehensive epidemiological investigation was conducted in Bougtob (El Bayadh, Algeria), a known endemic region for cutaneous leishmaniasis (CL). The study employed a multidisciplinary methodology to capture the complexity of disease transmission, host factors, and ecological determinants. Sociodemographic data were collected to identify vulnerable groups, revealing a higher prevalence in childrendue to immature immune systems and in adult males engaged in outdoor labor such as agriculture and pastoralism (Chappuis *et al*., 2007; WHO, 2022). Socioeconomic disparities and precarious housing conditions further amplified risk exposure (Reithinger & Dujardin, 2007).

Historical medical records, available since 2004, were reviewed to assess disease recurrence, delay in diagnosis, and spatial distribution, enabling improved surveillance strategies. Exposure to sandfly bites, the vector of Leishmania spp., was evaluated based on activity patterns during dusk and dawn, housing structure, and use of preventive measures such as insecticide-treated nets (Dantas-Torres, 2007; Oryan & Akbari, 2016).

Local knowledge and practices were documented, showing frequent use of traditional remedies such as garlic (*Allium sativum*), basil (*Ocimum basilicum*), and essential oils, although scientific validation remains limited (Ghosh *et al*., 2012; Ben-Ami *et al.*, 2021). Clinical evaluation included detailed observation of ulcerative skin lesions and atrophic scars in CL, and signs such as prolonged fever, splenomegaly, and pancytopenia in cases of visceral leishmaniasis (VL) (Alvar *et al*., 2012).

Diagnostic procedures included direct microscopy of tissue smears for amastigote detection, a low-cost method requiring high technical skill (Dedet & Pratlong, 2009). PCR assays were employed to identify Leishmania species with high specificity (>95%), especially in low-parasite-load samples (Srivastava *et al*., 2016). ELISA and rK39 rapid tests were used primarily for VL diagnosis, despite potential cross-reactivity in endemic zones (Bhatia *et al*., 2021).

Entomological surveys utilized CDC light and sticky traps to capture Phlebotomus spp., with morphological identification based on genitalia and antennal structure (Killick-Kendrick, 1999). Reservoir animal analysis confirmed the role of domestic dogs and wild rodents (Maia and Campino, 2018; Roche *et al*., 2020). Environmental assessments revealed that sandfly populations thrive in semi-humid microhabitats, requiring warmth and organic debris for larval development (Ameen, 2009; WHO, 2022).

Prevention strategies incorporated community education, vector control via deltamethrin IRS and LLINs, and environmental sanitation (Picado *et al*., 2010). Zoonotic control included canine screening and insecticide-impregnated collars

(Baneth *et al*., 2011). Integrated approaches remain vital in reducing disease transmission, emphasizing early diagnosis, public engagement, and multi-sectoral coordination (WHO, 2023; Alvar et al., 2012).

Epidemiological Assessment of Cutaneous and Visceral Leishmaniasis in Bougtob (Algerian Steppe): Protocol Design, Risk Analysis, and Diagnostic Approaches"

This study outlines a multidisciplinary and ethically approved protocol aimed at assessing the epidemiological situation of leishmaniasis in the endemic region of Bougtob (El Bayadh, Algeria). Employing both descriptive and analytical cross-sectional approaches, the primary goal is to estimate the prevalence and incidence of both cutaneous leishmaniasis (CL) and visceral leishmaniasis (VL) in humans and animal reservoirs, while identifying key environmental, behavioral, socioeconomic, and biological risk factors (Alvar et al., 2012; WHO, 2023).

The target population includes high-risk groups such as children, women, and agricultural workers, alongside domestic and wild animal reservoirs, particularly dogs and rodents (Maia and Campino, 2018; Roche *et al*., 2020). A stratified random sampling method was used for human participants, while purposive sampling was applied for suspected cases. Data collection involved standardized questionnaires, clinical examination, rapid diagnostic tests (rK39), molecular diagnostics (PCR), and serological screening, in collaboration with local health institutions.

GPS mapping and field surveys supported the spatio-temporal analysis of leishmaniasis foci, allowing for the identification of seasonal transmission peaks. The diagnostic algorithm followed WHO guidelines, integrating direct microscopy of Giemsa-stained tissue smears, PCR for species identification, and ELISA tests in cases suggestive of VL (WHO, 2010; Srivastava *et al*., 2016; Bhatia *et al*., 2021).

Inclusion criteria were based on clinical suspicion of CL, particularly chronic painless ulcers, erythematous nodules, and squamous plaques. Participants must have resided in the study area for at least six months and not have traveled recently to other endemic zones. Biological samples were collected from lesion margins using sterile techniques, and smears were fixed with methanol before staining with diluted Giemsa (1:5, pH 7.2), then observed under oil immersion (×1000) for amastigote detection (Dedet & Pratlong, 2009; Ameen, 2009).

Entomological data were gathered using CDC light and sticky traps for *Phlebotomus* spp., with morphological identification based on genital and antennal characteristics (Killick-Kendrick, 1999). Animal screening involved physical examination and serological testing of dogs, following guidelines for zoonotic surveillance.

Statistical analysis incorporated descriptive statistics, Chi-square tests, odds ratios (OR), and multivariate logistic regression to identify associations between variables. GIS mapping was used to visualize clusters and transmission zones.

The study also assessed local practices and beliefs, including reliance on phytotherapy, the use of insecticide-treated nets, and healthcare accessibility. Expected outcomes include a detailed risk map of infection hotspots, identification of high-risk behaviors and environments, and evidence-based recommendations for integrated, sustainable control strategies (Picado *et al*., 2010; WHO, 2023).

Results and Discussion

Territorial Approach and Ecoclimatic Factors Influencing the Distribution of *Phlebotomus* spp., Vectors of Leishmaniasis

The study identified three major environmental settings in the Bougtob region, each with distinct ecological and socio-territorial characteristics that influence the transmission dynamics of leishmaniasis:

- **Rural areas**, marked by limited access to healthcare services, close human–animal interactions, and poor sanitation infrastructure;
- **Urban zones**, where active transmission persists in disadvantaged neighborhoods and informal settlements (e.g., slums), characterized by overcrowding, domestic animal proximity, and weak vector control;
- **Peri-urban environments**, transitional zones that are expanding rapidly, often neglected by public health surveillance, and defined by hybrid rural–urban dynamics prone to the emergence of new transmission foci (Kamhawi, 2022; WHO, 2023).

The spatial distribution of *Phlebotomus* spp., the biological vectors of *Leishmania*, is strongly influenced by climatic and ecological factors**.** Ambient temperature plays a key role in regulating the gonotrophic cycle and adult vector survival. Temperatures ranging between 20 °C and 30 °C promote optimal development and activity, while extremes below 15 °C or above 35 °C suppress reproduction and reduce lifespan (Ameen, 2009; Khalid *et al*., 2022).

Relative humidity is another critical variable. As hygrophilic insects, sand flies thrive in moist environments such as irrigated agricultural zones, forest edges, riverbanks, and wetlands rich in organic matter (Alvar *et al*., 2012; Ben-Menahem *et al*., 2023). Dense vegetation, organic litter, and fragmented agro-ecological zones create **microhabitats** that enhance vector proliferation and persistence.

Although *Phlebotomus* spp. do not oviposit in water, stagnant environments enriched with organic debris**,** often in association with **seco**ndary animal hosts such as rodents and dogs, provide ideal breeding and dispersal conditions (WHO, 2023; Ready, 2013).

Seasonality significantly influences vector abundance. Warm and humid periodsespecially summer and the rainy season correspond to peaks in sand fly density, resulting in increased incidence of both cutaneous and visceral leishmaniasis (Ghawar *et al*., 2020; ECDC, 2023).

Climate change is emerging as a major ecological risk. Rising average temperatures, altered rainfall patterns, and increased humidity in semi-arid zones are facilitating the geographical expansion of sand fly habitats to higher altitudes and more northerly latitudes. This phenomenon progressively exposes new human populations to transmission risk in formerly non-endemic areas (Githeko *et al*., 2021; WHO, 2023).
In conclusion, the most favorable environments for sand fly presence and reproduction include humid rural agricultural areas, coastal or marshy lowlands, and densely populated urban peripheries with poor sanitation and frequent human–animal contact. These high-risk areas should be prioritized in surveillance and control strategies, integrating territorial heterogeneity and ecoclimatic parameters.

Multivariate Epidemiological and Ethnobotanical Approaches to Cutaneous Leishmaniasis in a Semi-Arid Region: Risk Profiling, Spatial Dynamics, and Local Treatment Practices

Quantitative and Multivariate Analysis of Cutaneous Leishmaniasis in a Semi-Arid Context

Objectives:

(1) Quantify the spatio-temporal distribution of cases between 2021 and 2025 according to sex, age group, and habitat type;
(2) Identify dominant epidemiological profiles using Principal Component Analysis (PCA);
(3) Geolocate pathogen transmission hotspots across urban, forest, and pastoral settings;
(4) Evaluate biomedical response strategies for vulnerable populations.

This component employed a structured quantitative approach based on hospital records and field observations over a five-year period. The primary objective was to analyze the local epidemiological dynamics of cutaneous leishmaniasis using measurable indicators such as case count, age distribution, sex, and type of habitat (urban, rural, or nomadic). The application of **Principal Component Analysis (PCA)** enabled the identification of latent structures and clustering patterns in the dataset, revealing key transmission profiles:

- Young adult males in pastoral and semi-nomadic zones,
- Children residing in under-resourced urban neighborhoods,
- Elderly women living in humid, marsh-like rural environments.

The results revealed a clear stratification of both patient profiles and ecological settings, with marked incidence peaks in 2023 and 2024. The use of spatial visualization tools, such as heatmaps and choropleth mapping, facilitated interpretation and exposed disparities in curative healthcare delivery, particularly in peripheral areas.

This statistical modeling approach proved essential in guiding targeted interventions, prioritizing localized vector control efforts (e.g., insecticide spraying, LLIN distribution, and community sensitization), and informing risk-based health strategies (Ali *et al*., 2021; Asfaw *et al*., 2023). It supports a public health framework grounded in spatial risk assessment, the mapping of transmission hotspots, and an integrated understanding of socio-environmental determinants of infection (ECDC, 2023; WHO, 2023).

Qualitative and Ethnobotanical Study of Traditional Leishmaniasis Treatments in Rural and Nomadic Settings

Objectives:

(1) Document locally used natural remedies;
(2) Analyze their usage patterns, perceived effectiveness, and application methods;
(3) Examine the relationship between traditional and biomedical practices;
(4) Recommend pathways for the rational integration of local knowledge into health policy.

The qualitative component focused on traditional treatment practices for leishmaniasis in rural and nomadic areas, where access to formal medical care is often restricted. The **ethnobotanical survey** documented a variety of natural remedies employed by patients, including **henna (*Lawsonia inermis*)**, **garlic (*Allium sativum*)**, **fenugreek (*Trigonella foenum-graecum*)**, **wormwood (*Artemisia herba-alba*)**, and **mastic (*Pistacia lentiscus*)**, alongside various plant decoctions applied topically to skin lesions.

These treatments are generally transmitted orally, prepared using artisanal methods, and applied daily, often with the assistance of family or community members. Interview analysis revealed a strong perception of efficacy, especially for mild infections. However, limitations were also noted, such as delayed wound healing, recurrence, and secondary infections when traditional remedies were used as standalone treatments.

The persistence of such practices is often driven by cultural proximity, low cost, and distrust of biomedical institutions. Using semi-structured interviews and ethnographic observation grids, the study explored the logic and structure of health knowledge in these communities. Findings advocate for a non-oppositional but complementary recognition of traditional practices, aligning with WHO recommendations (WHO, 2022) and the work of Ghrabi-Gammar (2010), which underscore the importance of incorporating validated local knowledge into neglected disease control strategies.

This ethnobotanical approach contributes to a more inclusive and culturally appropriate health policy, grounded in scientific validation and respectful integration of indigenous knowledge systems (Loregian *et al*., 2022; da Silva *et al*., 2021).

Figure 1. Principal Component Analysis (PCA) of Leishmaniasis Cases by Demographic Characteristics (2021–2025)

Factorial Analysis and Demographic Distribution of Leishmaniasis: A Multivariate Approach to Epidemiological Shifts (2021–2025)

The results of the Principal Component Analysis (PCA), cross-referenced with demographic data of cutaneous leishmaniasis cases recorded between 2021 and 2025, reveal a significant epidemiological and social transformation. The first principal component (PC1), which accounts for 92% of the total variance, is strongly associated with a marked surge in case numbers during the period from 2022 to 2024. This trend is especially evident among males (rising from 27 to 122 cases in 2023), young adults aged 21–30 (with a peak of 88 cases in 2023), and nomadic populations, who experienced a dramatic increase from 8 cases in 2021 to 90 in 2024.

These demographic groups dominate the PCA structure and reflect heightened vulnerability linked to environmental exposure, socioeconomic instability, and limited access to healthcare—patterns consistent with the findings of the World Health Organization (WHO, 2022) and Desjeux (2001). In contrast, the years 2021 and 2025, although situated at opposite ends of PC1, exhibit relative epidemiological stability, with lower case counts primarily among urban residents and women, suggesting more protected profiles or better access to health services.

Of particular interest is the year 2023, which lies at the extreme end of PC1, indicating an acute epidemic peak concentrated among young male nomadspopulations recognized for high exposure to *Phlebotomus* vectors, close proximity to animal reservoirs, and inadequate prevention infrastructure (Alvar *et al*., 2012; Quinnell and Courtenay, 2009).

The PCA thus highlights not only temporal dynamics but also the socio-demographic stratification of the disease, enabling better targeting of interventions such as insecticide spraying, distribution of long-lasting insecticidal nets (LLINs), and early case detection in high-risk groups. This analytical framework aligns with best practices in multivariate epidemiological analysis (Greenacre, 2017; Abdi and Williams, 2010), and emphasizes the importance of integrated interpretations of demographic and spatial data in shaping public health responses to leishmaniasis in arid and semi-arid regions.

Figure 10. Correlation Matrix of Socio-Demographic, Behavioral, and Lifestyle Factors in Annual Leishmaniasis Dynamics

This figure presents a **correlation matrix** illustrating the relationships between key socio-demographic variables (sex, age groups, lifestyle) and their combined influence on the annual patterns of leishmaniasis-related behaviors and treatment responses. Correlation coefficients range from **0.78 to 1.00**, reflecting generally strong associations among the variables analyzed.

A **near-perfect correlation (r = 0.99)** between **males and urban settings** suggests that health behaviors and responses documented among men are closely linked to urban environments—likely due to better access to biomedical facilities, public health infrastructure, and exposure to health awareness campaigns (WHO, 2013).

Conversely, individuals aged **10–20 years** show comparatively lower correlations, particularly with **males (r = 0.78)** and **21–30-year-olds (r = 0.78)**, pointing to **generational divergence** in therapeutic preferences and engagement with modern versus traditional care pathways. This shift aligns with the observations of Ekor (2014) and Toumi *et al*. (2022), who describe youth-led transitions between indigenous and biomedical systems.

The **high correlation between women and nomadic groups (r = 0.99)** indicates a behavioral affinity, possibly explained by **intergenerational transmission of ethnopharmacological knowledge** within rural and nomadic communities, often led by women (Fokunang *et al*., 2011).

Age groups **21–30** and **31–40 years** exhibit **strong correlations (r > 0.90)** across nearly all other categories, suggesting that these cohorts represent the **core active users** of integrated health strategies, including both biomedical and traditional treatments. This is reinforced by the **strong association between 31–40-year-olds and urban settings (r = 0.99)**, reflecting a balanced exposure to both medical systems.

Overall, while all variables show high interdependence (> 0.78), the matrix highlights **structured behavioral differences** shaped by age, gender, and living context. These insights support the design of **tailored health education strategies**, adapted to the socio-therapeutic profiles of different populations.The findings are consistent with the integrative public health perspectives proposed by Fokunang *et al*. (2011).

Table 1: Differentiated Health Education Strategies Based on PCA Axes

Integrating Local Knowledge and Biomedical Practices in the Management of Cutaneous Leishmaniasis: Ethnobotanical Insights and Spatial Patterns in Algerian Endemic Zones (2021–2025)

Complementing the Principal Component Analysis (PCA) and demographic data, this study explores traditional therapeutic practices for cutaneous leishmaniasis (CL) across different neighborhoods in the Bougtob region. The findings reveal a diversity of local treatments deeply rooted in empirical knowledge. Commonly reported remedies include powdered or ashed caper plants (*Capparis spinosa*), infusions of mixed medicinal herbs such as *Artemisia herba-alba*, *Pistacia lentiscus*, and *Santolina chamaecyparissus*, as well as artisanal formulations based on animal fat. Application methods vary from daily lesion rinses to local applications mixed with olive oil. While certain neighborhoods such as the 120 Logements area report notable improvements, others experience only partial or transient relief, occasionally accompanied by secondary infections or hygiene-related complications.

These observations echo existing scientific findings on the ethnobotanical use of medicinal plants for parasitic infections. Studies by Ghrabi-Gammar et al. (2010) and Bouayad et al. (2021) support the therapeutic potential of such remedies in managing cutaneous lesions. In particular, *Artemisia herba-alba* has been widely recognized for its antimicrobial and anti-inflammatory properties (Zouari-Bouassida et al., 2018). Nevertheless, the lack of standardized medical supervision highlights potential risks, reinforcing the importance of integrating traditional practices with modern biomedical frameworks (WHO, 2022).

Furthermore, spatial analysis indicates a heterogeneous distribution of CL cases. Peripheral neighborhoods and those adjacent to waste disposal sites or pastoral zones such as Sayad El-Hadj and Al-Aouabda show higher prevalence. Affected age groups primarily include young adults (20–40 years) and children (5–12 years), due to occupational exposure (e.g., herding, forest work) and unsanitary living conditions. Clinically, patients typically present with chronic, slow-healing skin ulcers. Conventional treatments such as meglumine antimoniate (Glucantime®), topical therapies, and antibiotics are often used concurrently with traditional remedies. This coexistence of medical paradigms highlights the need for scientifically guided integration of local practices within national health strategies (WHO, 2022; Hotez et al., 2020).

Table 2: Evolution of Socio-Demographic Profiles Based on PCA Axes (2021–2025)

Temporal Shifts in Sociodemographic Profiles Revealed by PCA in a Semi-Arid Context (2021–2025)

Évolution temporelle des profils socio-comportementaux révélée par l'ACP dans un contexte semi-aride (2021–2025)

The Principal Component Analysis (PCA) applied to sociodemographic data spanning the years 2021 to 2025 highlights a clear temporal trajectory of evolving population profiles in a semi-arid epidemiological context. The positions on the first two principal components (PC1 and PC2), which capture the majority of the multidimensional variance, reveal significant behavioral and social transformations. The year 2021, with a strongly negative position on PC1 and slightly negative on PC2, corresponds to a traditional or conservative profile, likely distant from modern therapeutic practices. In contrast, 2023 displays an atypical and extreme profile (strongly positive PC1, strongly negative PC2), indicating a generational or behavioral rupture. This shift likely reflects the emergence of a distinct cohort such as urban youth characterized by new health behaviors (e.g., phytotherapy, digital engagement in health). The year 2022 presents an intermediate position, suggesting a transitional phase marked by partial adoption of emerging practices. In 2024, a consolidation of innovations is evident, with moderately positive scores on PC1 and

strongly positive scores on PC2 indicating broad acceptance of novel practices and responses to recent structural pressures (e.g., public health crises, socio-environmental changes). However, 2025 signals a return to earlier profiles (strongly negative PC1, moderately negative PC2), potentially due to behavioral fatigue, social saturation, or a resurgence of culturally stable values. This non-linear trajectory highlights a dynamic interplay between innovation and cultural resilience in semi-arid regions, similar to findings in other marginal contexts (Ghrabi-Gammar et al., 2010; Greenacre, 2017). The PCA confirms the relevance of longitudinal, multivariate analysis to understand the timing and nature of behavioral shifts, aligning with WHO guidelines on the integration of local realities into health planning (WHO, 2022). By identifying years of rupture and stabilization, PCA serves as a powerful tool to inform targeted health education, prevention strategies, and social policy interventions tailored to specific temporal, demographic, and ecological conditions.

Comparative Perception of Remedy Effects by Mode of Administration: A Cross-Analysis of Traditional and Modern Medical Approaches

The figure presented illustrates a heatmap summarizing perceived therapeutic effects (soothing, effective, irritating) of treatments based on their mode of administration systemic (internal use) versus topical (local application). As shown in Table 3, both traditional treatments (primarily topical) and modern treatments (mostly systemic) are consistently perceived as effective and soothing, reflecting shared empirical recognition of their therapeutic value. This convergence aligns with recent findings on public health practices in low-resource settings, where both systems coexist in daily care routines (Ekor, 2022; WHO, 2023). In traditional medicine, topical herbal preparations such as poultices, essential oils, and infusions are commonly employed to manage skin disorders, musculoskeletal pain, and inflammatory conditions, and are generally perceived as effective. Nevertheless, the heatmap highlights a notable divergence: reports of irritation are associated exclusively with traditional topical remedies. This may be linked to the absence of dosage standardization, inappropriate application techniques, or the presence of allergenic and irritant phytochemicals, as documented for plants like *Artemisia herba-alba* and *Eucalyptus* spp. in recent studies on dermal phytotoxicity and allergenicity (Sharma *et al*., 2022; Rossi *et al*., 2023).

By contrast, modern treatments, although not free from side effects, are generally perceived as non-irritating at the cutaneous level, owing to rigorous pharmaceutical controls and pre-market clinical testing (Abena *et al*., 2020; WHO, 2023). This comparison underscores the **potential complementarity** of traditional and modern medicine, while highlighting the need for **safe valorization** of traditional pharmacopoeia. It supports the **rational integration of local medicinal knowledge** into public health strategies through topical remedy standardization, practitioner training, and community awareness of risks associated with unregulated use.

Ultimately, the convergence of perceived effectiveness and safety profiles indicates that both medical paradigms can **coexist functionally and respectfully**, provided that traditional practices are made safer through scientific validation, quality control, and cultural sensitivity.

Here is the updated dendrogram with all **labels and legends translated into English**:

- **Title**: *Hierarchical Clustering of Neighborhoods Based on Remedies and Treatments*
- **X-axis**: *Neighborhoods* (e.g., "120 Housing", "Al-Shaheb")
- **Y-axis**: *Distance* (reflecting dissimilarity in remedy/treatment use)
- **Figure 12: Hierarchical Clustering of Neighborhoods Based on Remedies and Treatments**
- The dendrogram above illustrates an agglomerative hierarchical clustering (AHC) of neighborhoods based on their practices regarding both traditional and modern remedies and treatments. Two distinct clusters emerge. The first cluster groups **Al-Shaheb** and **30 Housing**, which display a high degree of similarity in treatment usage, indicating homogeneous therapeutic behaviors. This homogeneity may be attributed to shared socio-cultural determinants such as education level, healthcare access, or intergenerational family traditions. The low linkage distance suggests a strong proximity in practices.
- The second major cluster includes **120 Housing**, **Sayad El-Hadj**, and **Al-Qaraba**, which, while exhibiting greater diversity in their treatment practices, still demonstrate internal coherence in care approaches. This group is characterized by a slightly higher clustering distance, possibly reflecting a moderate adoption of traditional medicine or the coexistence of integrative medical strategies that blend conventional and local approaches.
- The final merger of the two main clusters at a linkage distance above 7 indicates a substantial divergence between the two groups. This may result from differences in healthcare infrastructure, health education exposure, or prevailing local medical traditions. This spatial and behavioral structuring is consistent with findings from **Ekor (2022)** and the **World Health Organization (2023)**, which emphasize that therapeutic behaviors are shaped by social dynamics, economic status, and degree of exposure to biomedical systems.
- Such clustering results support the hypothesis of a **sociotherapeutic stratification** across neighborhoods, highlighting the relevance of developing differentiated and context-sensitive public health strategies. Recognizing and adapting to the spatial and cultural diversity of therapeutic practices is essential for designing **effective, equitable** healthcare interventions in endemic regions.

Table 3 – Longitudinal Comparison and Multivariate Interpretation of Annual Profiles

This table summarizes the temporal evolution of socio-demographic profiles based on their positioning on the first two principal components (PC1 and PC2) of a Principal Component Analysis (PCA), which captures the major axes of variation in a multidimensional dataset. The results illustrate distinct phases of social, cultural, and health-related transformation in the population.

The years **2021 and 2025** are positioned very negatively on PC1, suggesting persistent traditional profiles. These may include older individuals, rural or nomadic populations, or people with limited access to formal education and healthcare. Their similarity over time points to structural resistance to change or stable adherence to ancestral practices. This aligns with findings from WHO (2023) and Ekor (2022), which indicate that certain groups maintain conservative health behaviors due to cultural continuity or limited exposure to modernization.

2023, on the other hand, is highly positive on PC1 and strongly negative on PC2, marking a significant deviation from other years. This year likely reflects the emergence of an atypical cohort possibly younger, urban, and more educated individuals who adopt alternative or integrative health practices, such as herbal medicine or digital self-care tools. The profile may correspond to populations more exposed to health education campaigns, as suggested by recent global health transitions (GBD, 2020; Abdi and Williams, 2010).

2024, moderately positive on PC1 and highly positive on PC2, represents a consolidation of modern or restructured health behaviors. It indicates the integration of previously marginal practices into mainstream routines and may point to increased access to healthcare infrastructure and a shift toward hybrid therapeutic models that blend biomedical and traditional care systems.

2022 occupies a central position on both axes and plays a transitional role. It reflects an intermediary stage between conservative profiles (2021) and the more innovative or integrated ones of 2023–2024. This suggests the coexistence of old and new behaviors, highlighting an ongoing social transformation without abrupt rupture. This is consistent with studies on gradual behavioral shifts in semi-arid and developing regions (Greenacre, 2017; WHO, 2022).

In sum, the PCA reveals a structured temporal gradient of socio-health profiles, from tradition-bound (2021), through a transformation peak (2023), toward an integrated model (2024), and then a potential return to foundational values in 2025. This pattern supports the importance of **tailored public health strategies** that consider local socio-cultural dynamics, enabling more effective interventions across different demographic

Title: *Heatmap of Leishmaniasis Interventions by Level of Action*

X-axis (Type of Intervention): Diagnosis, Environmental Prevention, Individual Prevention, Natural Remedy, General Treatment, Local Treatment, Systemic Treatment
Y-axis (Level of Action): Hospital/Municipal, Nomadic, Natural Remedy
Color bar: *Intervention Count*

Figure 14: Distribution Matrix of Leishmaniasis Interventions by Level of Action – Cross-analysis of Municipal, Hospital-based, and Traditional Responses

This heatmap-style matrix provides a comparative overview of the types of interventions employed against leishmaniasis across three distinct levels of action: municipal, hospital-based, and nomadic. Horizontally, the graph reveals the intervention profile specific to each level, while vertically, it highlights the presence or absence of various therapeutic and preventive responses. The municipal level primarily focuses on environmental and individual prevention, engaging in upstream actions such as sanitation, vector control, and public health awareness campaigns—strategies consistent with WHO (2022) recommendations on integrated public health systems. The hospital-based level adopts a structured curative approach, combining laboratory diagnostics (e.g., PCR, rK39) with both local and systemic treatment protocols. This aligns with the therapeutic standards established in clinical trials on cutaneous leishmaniasis (Ben Salah *et al*., 2007).

In contrast, the nomadic level relies exclusively on natural remedies, such as henna, garlic, and fenugreek practices rooted in ethnomedical traditions documented by Ghrabi-Gammar *et al*. (2010) and Bouayad *et al*. (2021). The matrix thus illustrates both the complementarity and the structural disparities between institutional and community-based approaches, underscoring the need to better integrate traditional knowledge systems into public health policies. Such integration is particularly critical in semi-arid regions where vulnerable populations often face significant barriers to accessing modern healthcare.

Integrated Discussion: Empirical Evidence, Interpretation, and Bibliographic Comparison

The health, socioeconomic, and environmental consequences of leishmaniasis extend far beyond the clinical domain. On the human level, cutaneous forms cause disfiguring and stigmatizing lesions, especially among children and women (Reithinger *et al*., 2007). Visceral leishmaniasis (VL) can be fatal without timely treatment (WHO, 2023), and HIV co-infection significantly worsens outcomes by increasing parasite burden and treatment resistance (Singh *et al*., 2000). Psychologically, patients often suffer from anxiety, depression, and social isolation (Bennis *et al*., 2018).

Economically, the disease reduces household productivity through temporary incapacity to work, particularly in farming populations (Picado *et al*., 2010). Treatment costs may account for up to 30% of a household's annual income (Boelaert *et al*., 2009). Stigmatization undermines social reintegration (Reyburn *et al*., 2000), while endemic regions experience economic losses in both agricultural and tourism sectors (Alvar *et al*., 2012).

From an environmental perspective, ecological disruptions such as urbanization and deforestation promote vector proliferation (Ready, 2013). Biodiversity loss, often driven by anthropogenic pressure, affects natural sandfly predators (Bañuls *et al*., 2007). Climate change is further expanding the geographic range of vectors, increasing the extent of endemic areas (Moore *et al*., 2012).

Drawing from previous analyses (PCA, clinical patterns, traditional remedies, and intervention distribution), a transversal, coherent, and critical synthesis can be formulated regarding the management of cutaneous leishmaniasis in semi-arid settings, particularly in the Algerian context. The comparative heatmap demonstrates the functional specialization of three intervention levels. The municipal level is largely engaged in preventive actions vector control, larval habitat elimination, and community awareness aligned with WHO's 2022 recommendations on integrated vector management. Meanwhile, the hospital level implements curative strategies, focused on diagnostics (PCR, rK39) and standardized treatment protocols (e.g., Glucantime®, miltefosine), in accordance with therapeutic frameworks described by Ben Salah *et al*. (2007).

In contrast, the nomadic level relies exclusively on traditional remedies such as henna, garlic, and fenugreek. Although not always clinically validated, these treatments are culturally embedded and represent both a form of therapeutic autonomy and a response to healthcare marginalization. This tripartite segmentation prevention, biomedical care, and traditional medicine highlights a structural imbalance between institutional health services and the actual needs of highly exposed populations.

PCA results also uncovered a temporal structuring of infection profiles, suggesting that the emergence of cases is influenced by both demographic factors (sex, age, socio-spatial status) and environmental conditions (humid zones, waste sites, forested or pastoral areas). These findings echo Desjeux's (2001) global analysis of leishmaniasis expansion, which emphasized the role of ecological disruption and social vulnerability in disease propagation.

Key takeaways:

- Strong specialization across intervention levels, but insufficient integration between preventive, curative, and traditional actions.
- Unequal distribution of control resources, especially in nomadic and peripheral zones.

- A need to hybridize approaches by combining validated scientific knowledge with ethnobotanical practices while ensuring equitable healthcare access.

Conclusion

This study highlights the bioecological and public health complexity of leishmaniasis in the Bougtob region (El Bayadh province), a steppe zone marked by pronounced environmental and socioeconomic vulnerability. The findings reveal a concerning endemicity of cutaneous leishmaniasis (CL), primarily affecting children, women, and rural laborers living in precarious housing conditions in close contact with both vectors (phlebotomine sandflies) and animal reservoirs (stray dogs, rodents).

Entomological investigations confirmed the active presence of *Phlebotomus papatasi* and *Ph. perniciosus*, whose density is exacerbated by semi-arid climatic conditions, poor sanitation in microhabitats, and proximity between human settlements, livestock enclosures, and organic debris (Killick-Kendrick, 1999; Ready, 2013). These ecological dynamics create highly favorable conditions for the transmission of *Leishmania major* and *L. infantum*.

From a diagnostic and therapeutic standpoint, healthcare management is hindered by inadequate local infrastructure, lack of rapid diagnostic tools in rural settings, and heavy reliance on traditional remedies, whose clinical efficacy remains insufficiently validated (Savo *et al*., 2012; Rebai *et al*., 2019). While some medicinal plant extracts such as *Olea europaea*, *Allium sativum*, and *Aloe vera* show therapeutic potential, they cannot substitute internationally validated protocols involving miltefosine, pentavalent antimonials, and liposomal amphotericin B (WHO, 2020; Kedzierski, 2010).

Preventive efforts, though sporadically implemented, lack coordination. Insecticide spraying, use of long-lasting insecticidal nets (LLINs), and community health education remain poorly established. The “One Health” approach has emerged as a critical framework, integrating human, animal, and environmental health into a unified strategic response (WHO, 2021; Khan et al., 2022).

Looking forward, this study calls for the urgent reinforcement of local capacities in surveillance, diagnosis, and treatment through the following actions:

- Decentralization of diagnostic tools (e.g., rK39 rapid tests, PCR) to peripheral health centers;
- Active and regular screening in high-risk zones;
- Veterinary management of stray dogs, identified as primary reservoirs;
- Implementation of sustainable environmental policies targeting vector breeding site reduction, habitat improvement, and secure urban planning.

Ultimately, only a multisectoral, integrated, and sustainable intervention—grounded in research, active prevention, and community engagement—can curb the spread of leishmaniasis in Bougtob and serve as a model for other at-risk rural regions.

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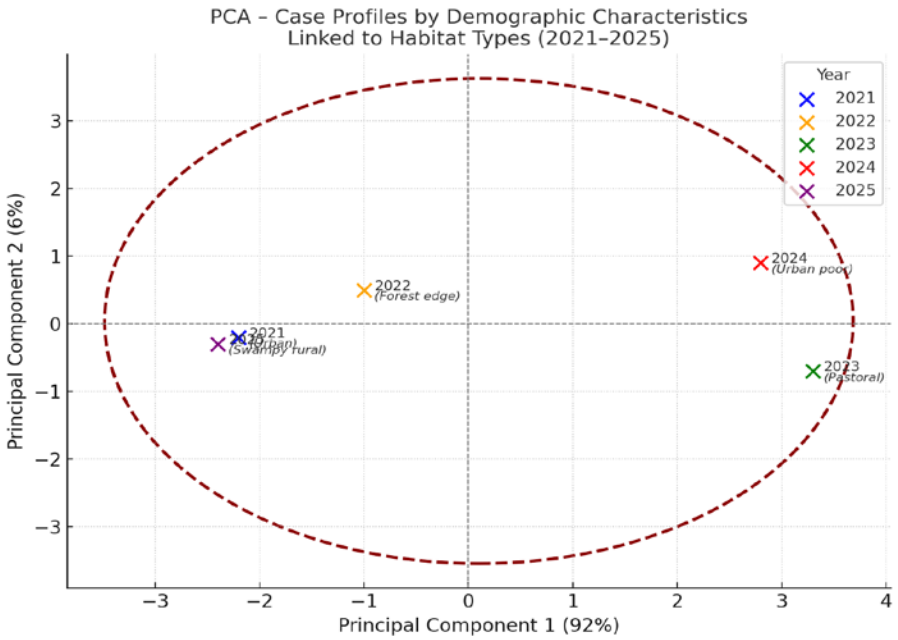
Figure 1. Principal Component Analysis (PCA) of Leishmaniasis Cases by Demographic Characteristics (2021–2025)



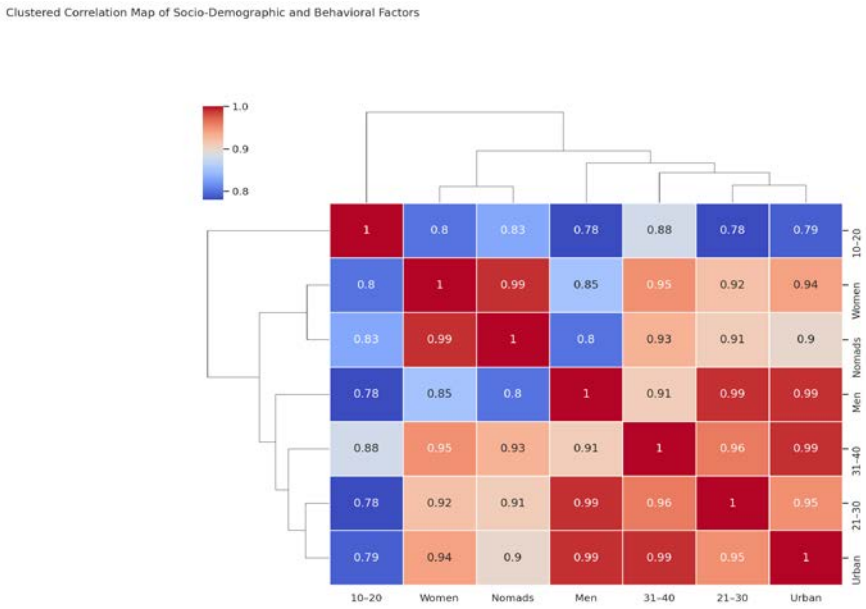


Figure 2 . Correlation Matrix of Socio-Demographic, Behavioral, and Lifestyle Factors in Annual Leishmaniasis Dynamics

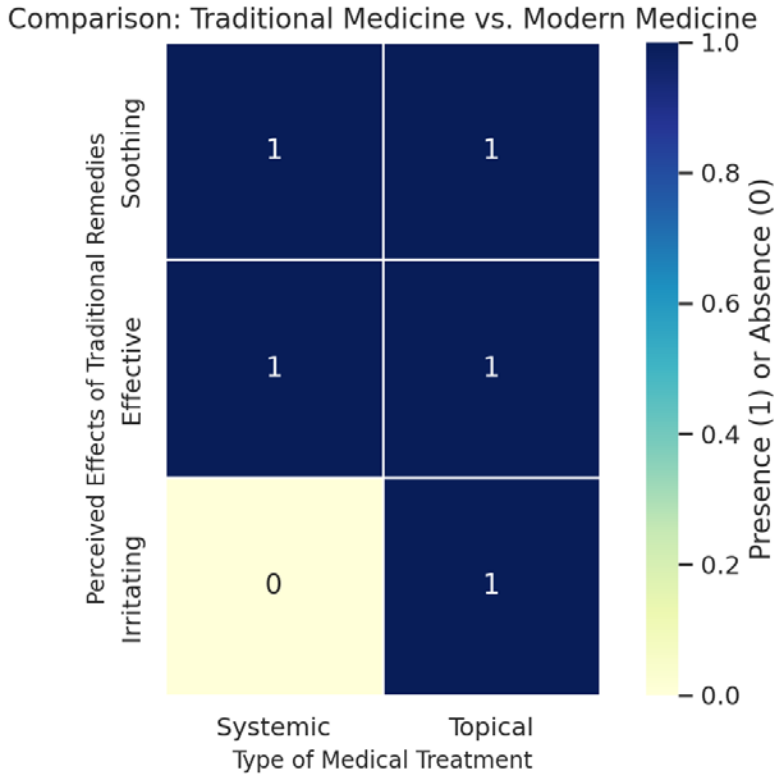
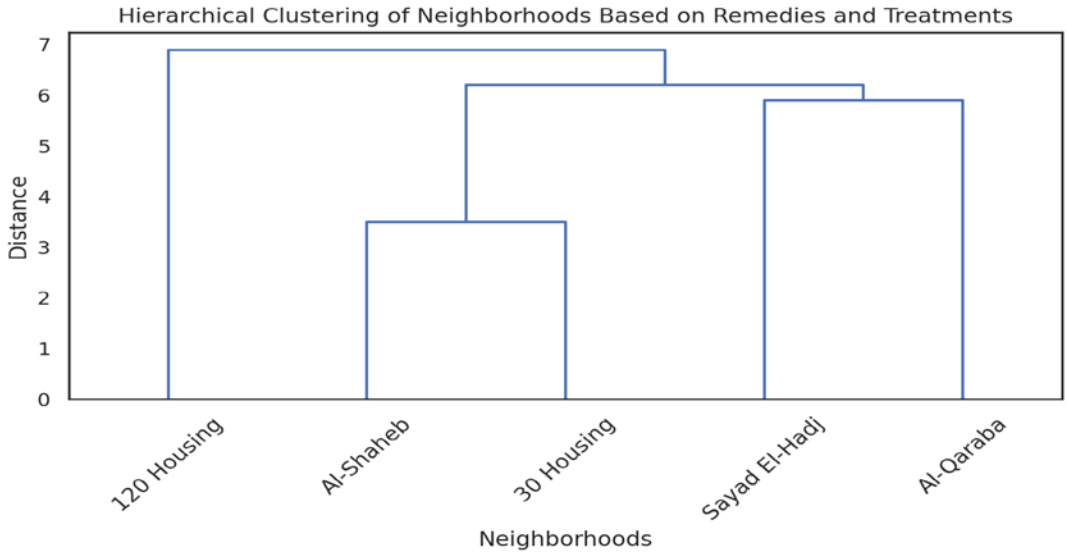


Figure 3 Comparative Perception of Remedy Effects by Mode of Administration: A Cross-Analysis of Traditional and Modern Medical Approaches



- **Figure 4 Hierarchical Clustering of Neighborhoods Based on Remedies and Treatments**

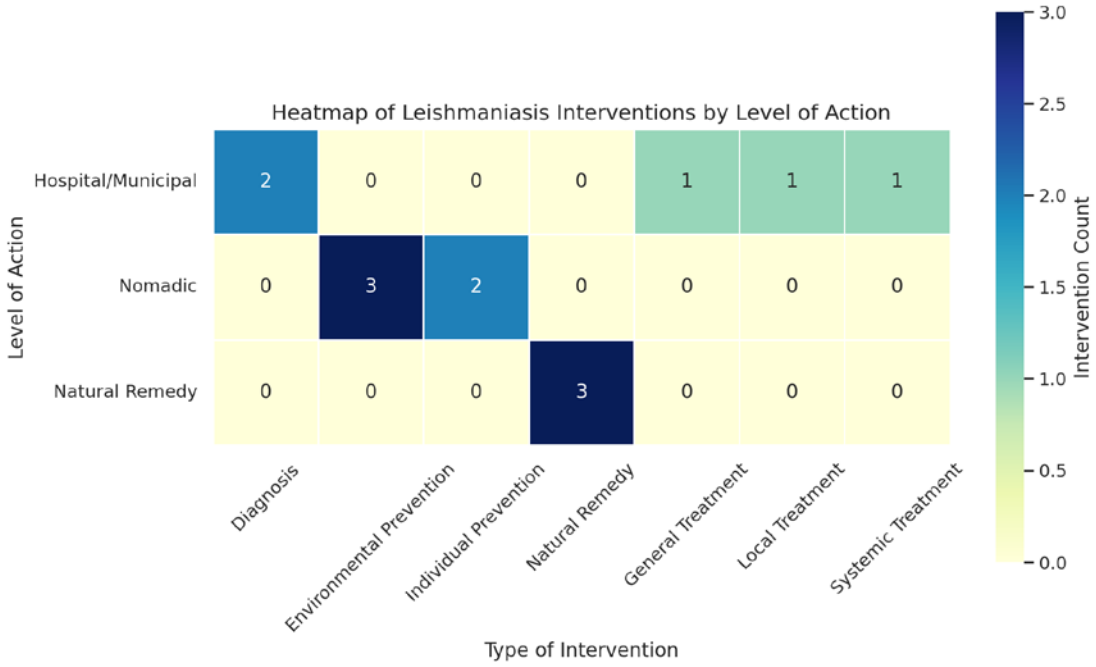


Figure 4 Heatmap of Leishmaniasis Interventions by Level of Action

Table 1: Differentiated Health Education Strategies Based on PCA Axes

Year	Position on PC1	Position on PC2	Interpretation
2021	Strongly negative	Slightly negative	Demographic profile opposite to that of 2023/2024
2022	Moderately negative	Moderately positive	Transitional phase toward more recent demographic profiles
2023	Strongly positive	Strongly negative	Unique profile with highly specific characteristics
2024	Moderately positive	Strongly positive	Distinct year marked by emerging new demographic and behavioral traits
2025	Strongly negative	Moderately negative	Shows convergence with the 2021 profile, suggesting a return to earlier dynamics

Table 2: Evolution of Socio-Demographic Profiles Based on PCA Axes (2021–2025)

Comparison	Observation
2021 vs. 2025	Close on PC1; both years exhibit highly similar demographic characteristics, likely reflecting traditional and stable socio-epidemiological structures.
2023 vs. 2024	Markedly different on PC2: 2023 represents a unique profile (potentially younger or more educated), while 2024 reflects a dynamic shift (possibly linked to the emergence of a new sociological group).
2022	Intermediate position: acts as a transitional year bridging classical demographic patterns (as in 2021) with more transformed profiles (2023/2024).

Table 3 – Longitudinal Comparison and Multivariate Interpretation of Annual Profiles

Comparison	In-depth Interpretation
2021 vs 2025	Both years exhibit a highly negative position on PC1, suggesting a persistence of traditional demographic characteristics—likely older individuals, lower education levels, and rural or semi-rural backgrounds. The weak variation on PC2 reflects continuity in cultural and healthcare practices, with minimal exposure to modern medicine or evolving social dynamics (WHO, 2023).
2023 vs 2024	While these years are close on PC1, they contrast sharply on PC2. The highly negative PC2 value for 2023 indicates a marginal or atypical group (e.g., urban youth inclined toward alternative or digital treatments). Conversely, 2024's strong positive PC2 suggests the emergence of a socially and medically integrated profile, potentially reflecting improved access to healthcare or successful awareness campaigns (Ekor, 2022; GBD, 2020).

2022	Positioned between the extremes, 2022 represents a transitional year. It signals a gradual shift in practices and attitudes, blending conservative traits (from 2021) with early signs of transformation (leading toward 2023–2024). Such intermediate configurations often reflect slow societal recomposition (Greenacre, 2017).