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USING GEOMATICS FOR ASSESSING VULNERABILITY TO CUTANEOUS LEISHMANISAIS. APPLICATION TO THE WILAYA OF BATNA (ALGERIA)

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ABSTRACT: If the typology of epidemics varies considerably, their causes remain substantially related to many physical environment factors. The fact remains that the problem of vector-borne diseases is complex in view of the diversity of these diseases, the large number of vulnerabilities associated with them, and also the objective assessment of the impact of each of these factors. The use of geomatic tools, such as geographical information systems (GIS) and remote sensing techniques as spatial environmental phenomena and through the implementation of a GIS database, has enabled us to highlight the spatial distribution of these diseases and their magnitude, and has allowed us to subsequently relate them to some environmental factors that might explain the emergence of the disease and its importance. The results clearly show that approximately 48.89% of the total area of the province was found to be highly vulnerable, 2.83% at moderate vulnerability, while 48.28% of the province had low vulnerability.

Keywords: Batna, Epidemics, Geomatics, Cutaneous Leishmaniasis, GIS, Vulnerability.

1. INTRODUCTION

Leishmaniasis is a zoonotic protozoan Leishmania [1, 2, 3], from the Trypanosomatidae family [4]. This is an infectious disease due to parasitism mononuclear cells by flagellate protozoa. [5]. these obligatory Di-heteroxenous parasites called heterozygous [6] affect many species of mammals, including [7] humans, which are transmitted by the bite of an infesting blood-sucking Dipteran insect vector of 2 to 4 mm long [8] belonging to the genus Phlebotomus of the old world and Lutzomyia in the new world [9]. Cutaneous leishmaniasis, in fact, often affects infants and is preferentially localized in the face in the form of rich parasite buttons [10].

In the Mediterranean basin, Algeria, by its different climate (humid, sub-humid, semi-arid, arid, and Saharan) remains the country most affected by this disease [10, 11] where 22 Phlebotomine species were recorded by Belazzoug in 1991 [12]. Statistically, between 1991 and 2002 the annual incidence of cutaneous leishmaniasis showed significant changes; there were 15 cases per 100,000 inhabitants in 1991 to 26.62 in 2002. This increase is estimated by [10] to be more than 200 new cases each year, to reach 30,227 cases in 2005 [13].

Geographically, many focus areas are found responsible for this epidemic—in particular, the three historic areas of Barika, Abadla, and the highland of Biskra. In these historic areas, there are newly affected localities in the communities of Sidi Aissa, Laghouat, and Batna.

For the town of Batna, the area for the present study, by its physical and climatic characteristics and especially its geographical proximity and socio-economic exchanges with Biskra, the main source of pathology (a favorable environment for the development of Phlebotomus papatasi) faces this pathology in a scalable and alarming manner. Moreover, according to the Direction of Public Health, in 2003 Batna recorded a peak of 5,400 reported cases of cutaneous leishmaniasis in which Barika, Ain touta, N'gaous, Djezzar, and the capital city were the most affected municipalities. Furthermore, and with a budget of 8 million Algerian dinars mobilized for the acquisition of mosquito pesticides, the town has recorded in recent years a remarkable decrease in the annual incidence of cutaneous leishmaniasis. The number of cases decreased from 2476 cases in 2005 to 333 cases in 2013 to reach 293 cases in 2015. These records, despite the significant decline, still constitute a constraint on the public budget.

Various studies in many cities worldwide have been carried out, and different approaches (fuzzy C means-based neuro-fuzzy inference system, multi-criteria evaluation, boosted regression tree modeling framework, etc.) have been proposed to assess the epidemiology [14, 15, 16]. In fact, many studies concerning cutaneous leishmaniasis in Algeria [13, 17, 18, 19] show that these studies address the issue from a purely analytical view without a prospective vision based on the study of vulnerability factors and their spatiotemporal articulation.

The present work focuses on the relationship and the epidemic-environment ratio, namely the implementation of a spatial relationship with a geomatics approach to physical and environmental factors that might explain the emergence of the disease and its importance. The aim is to obtain an attribute table that contains all entities required for identification and the reclassification of different levels of vulnerability to the epidemiology of cutaneous leishmaniasis in wilaya of Batna.

2. STUDY AREA DESCRIPTION

The wilaya of Batna (Fig. 1) is located in the eastern part of Algeria between 4° and 7° east and 35° and 36° north latitude.

From a total population of 1,425,300 in 2015 and a total area of 12,038.76 km^2, the town is located in an area formed by the junction of Tellian Atlas in the north and the Saharan Atlas in the south. The link with this mountain entity is the main physical feature of the town and thereby determines the climate characteristics and the conditions for human activity. According to the National Meteorology Office (ONM), Batna is characterized by a semi-arid climate with extreme seasonal variations in temperature and precipitation. The average temperature is about 4 °C in January and 35 °C in July. The wilaya of Batna, by its semi-arid climate associated with physical characteristics (altitude, slope, etc.) and socio-economic characteristics (number of people in rural areas, sanitation, road network density, etc.), presents a suitable area for the development and propagation of cutaneous leishmaniasis.

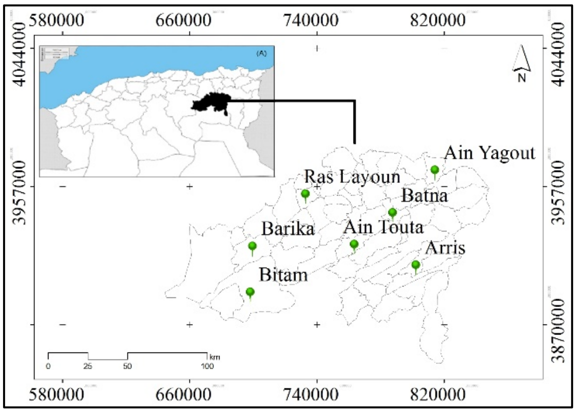

Fig.1 Study area Location Map (A) Batna town, (B) Batna Municipalities.

3. MATERIALS AND METHODS

Studying cutaneous leishmaniasis implies the study of the transmission vector (sand fly) and the physical and environmental factors that are favorable to its proliferation. The difficulty lies primarily in the modeling of vulnerability levels. The efficiency of a model is closely related to the choice and selection of a limited number of measurable parameters and the real impact on the proliferation. In fact, the best models are those that incorporate few parameters, are easy to use, and able to reproduce the reality. On this basis, three key parameters have been selected in order to map the spatial distribution of vulnerability of Batna to the epidemic of cutaneous leishmaniasis. These include the surface, the temperature, the landfills, and the slope classes.

Moreover, the choice of infrared remote sensing as a main source of thermal data is explained by the lack of detailed field data. The study area is covered by a single meteorological station (Batna Station), which provides only one value of temperature for an area of 13,026 km^2, while the study of such epidemic diseases requires quite detailed working scales for understanding the dynamics of the genesis and development of this disease.

In summary, the adopted methodology consists of estimating and interpolating the surface temperatures to determine the different slope levels and identify different types of landfills in the town. These quantified and spatial data are subject to a multi-criteria analysis to identify the vulnerability levels.

3.1 Estimation and interpolation of land surface temperature

In the present study, treatments of thermal infrared data LDCM Landsat 8 were made in three essential steps:

“Eq. (1)”: we transformed the thermal band (band 10 and 11) to land surface temperature (LST). The procedure consists of calculating the spectral radiance factor by multiplying the radiometric rescaling multiplicative factor of infrared thermal bands (IT) with his corresponding band (IT) and adding the additive rescaling factor according to the formula:

$$\boldsymbol{L_\lambda = M_L * Q_{cal} + A_L} \qquad (1)$$

where:

Lλ = top of atmosphere (TOA) spectral radiance (watts/ (m2 * srad * µm));

M_L = band-specific multiplicative rescaling factor; ML = 0.000342;

A_L = band-specific additive rescaling factor AL= 0.1;

Qcal = quantized and calibrated standard product pixel values (digital number).
“Eq. (2):” We converted spectral radiance to brightness temperature.
The thermal infrared sensor (TIRS) band data can be converted from spectral radiance to the brightness temperature using the thermal constants provided in the metadata file:

$$\boldsymbol{TB} = \frac{K_2}{Ln\left[\left(\frac{K_1}{L\lambda}\right)+1\right]} - \mathbf{273.15} \qquad (2)$$

where:
TB: brightness temperature (°C);
K1: band-specific thermal conversion K1= 774.8853 for band 10 and 480.8883 for band 11;
K2: band-specific thermal conversion constant K2 = 1321.0789 for band 10 and 1201.1442 for band 11;
L_λ : TOA spectral radiance.
The land stat emissivity (LSE) from Landsat 8 imagery is estimated using the following equation:

$$\boldsymbol{LSE} = \boldsymbol{\varepsilon_s(1 - Pv) + \varepsilon_v(Pv) + d\varepsilon} \qquad (3)$$

where:
ε_s, ε_v: emissivity of soil and vegetation (Table 1).

Table 1. Emissivity of soil and vegetation for Landsat 8 TIRS band 10 and 11.

	Band 10	Band 11
ε_s	0.971	0.977
ε_v	0.987	0.989

Dε: represents the surface roughness (dε = 0) for homogenous and flat surfaces, but for heterogeneous and rough surfaces dε can reach a value of 2% [20]. This term can be estimated as follows:

$$\boldsymbol{d\varepsilon = (1 - \varepsilon_s)(1 - Pv)F\varepsilon_v} \qquad (4)$$

where:
F: shape factor whose average value is 0.55;
Pv : the vegetation cover fraction; it can be estimated according to [21] by the following equation:

$$\boldsymbol{Pv} = \left[\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}\right]^2 \qquad (5)$$

NDVI : Normalized vegetation index by difference, calculated as the combination of the near infrared and red band:

$$\boldsymbol{NDVI} = \frac{Red - NIR}{Red + NIR} \qquad (6)$$

NIR and RED are the response in the near infrared and red bands, respectively.
NDVIv is NDVI of vegetation equal to 0.585 and NDVIs is NDVI of soil equal to -0.335.
“Eq. (3)” Land surface temperature (LST) is given by:

$$\boldsymbol{LST} = \frac{TB}{1 + w * \left(\frac{TB}{\rho}\right) * Ln(e)} \qquad (7)$$

TB: satellite brightness (blackbody) temperature (°Celsius).
w: wavelength of emitted radiance (11.457 μm).

$$\boldsymbol{\rho} = \frac{h.C}{\sigma} = 1.438 \text{ x } 10^{-2} \text{ m K.}$$

h : Planck’s constant (6.626 x 10^{-34} J sec).
C: velocity of light (2.998 x 10^{8} m/sec).
σ: Stefan-Boltzmann constant
(5.67 x 10^{-8} Wm^{-2} K^{-4}).
e: land surface emissivity.

After obtaining land surface temperatures, we have in a first step interpolated by the temperatures using co-kriging method according to altitudes by selecting 336 samples covering the entire study area. We then checked and validated our choice using the least squares method (Fig. 2). To optimize an interpolation model, it is necessary that the coefficient of correlation between the observed values and those predicted be close to 1 [22].

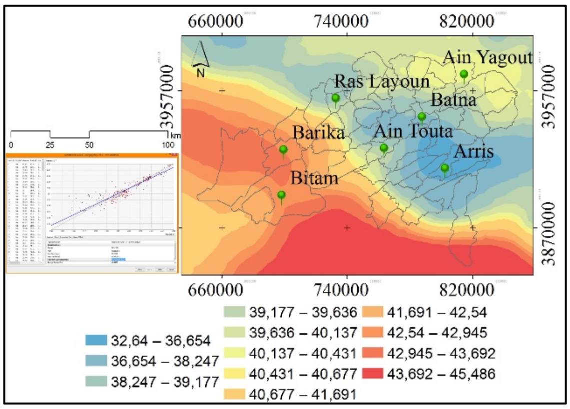

Fig. 2 Land surface temperatures of Batna Town.

It is worth mentioning that interpolation is a value estimation technique for non-indicated locations from existing punctual observations [23].

There are indeed many examples of the spatial interpolation of temperatures, including those known as geostatistical interpolation methods of kriging and co-kriging with many advantages (more efficient in theory, they can model the spatial structure of data, etc.). Based on the work of [24] and [25], the so-called deterministic interpolation methods (polynomial and splines) produce better results on areas with low relief, while kriging appears to be better on monthly and especially daily averages, and better adapted to areas with rough terrain. Given the mountainous nature of the town of Batna (7% of the land exceeds a slope of 8°), co-kriging seems to be more suited for this study (Fig. 2).

3.2 Identification of different types of landfills in Batna

The enormous quantities of solid waste generated daily by the 61 municipalities of Batna generate large numbers of landfills of different kinds, and most of them consist of uncontrolled landfills. Indeed, there are about 52 uncontrolled landfills (or wild) throughout the territory is very anarchic, six controlled landfills and three technical landfill centers (CET), in which the waste treatment process is more efficient and meets hygiene and safety rules. Moreover, through a field survey, we found that the difference between controlled landfills and uncontrolled ones is limited to a metal grid of 2 meters. This difference in typology has no influence on the environmental impact of the development and the proliferation of the disease (Fig. 3).

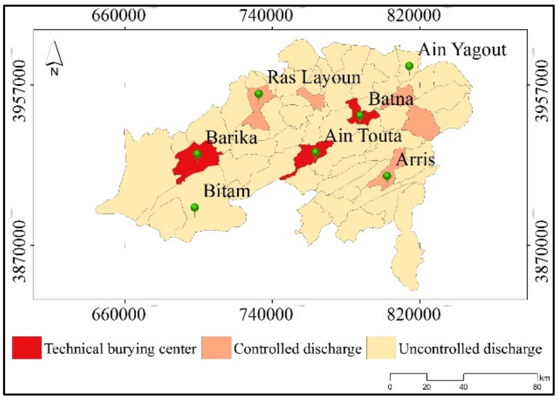

Fig. 3 Types of Landfills in Batna Town.

3.3 Determination of the different slope levels

To determine the different slope levels, we used the spatial analysis tools of Arc Toolbox (ESRI) to extract the slope of a digital elevation model (DEM) covering the town of Batna. A low slope is often associated with stagnation or water retention, making, therefore, a highly suitable environment for the development of sandflies.

According to the slope map (Figure 4), 63% (or 869131.661 ha) of land does not exceed a slope of 3°, and 29% (403809.727 ha) does not exceed 8°. Only 8% (or 113859.511 ha) of the total area of the town exceeds a slope of 8°. Moreover, according to the same map, we can see that low slope levels are mainly concentrated in the southwest and northeast of the town and are characterized by the presence of numerous depressions closed to an endorheic hydrological regime as sebkhas and chotts (Hodna, Gadaine, Tinnsilt, etc.).

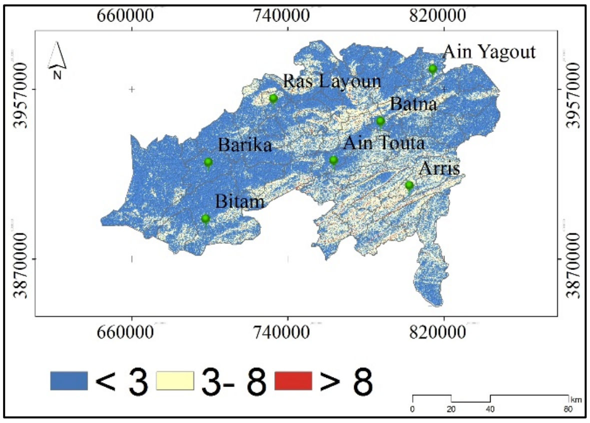

Fig.4 Batna slope levels.

3.4. RESULTS AND DISCUSSION

To assess the vulnerability of the area investigated for this disease, it is necessary to relate all of these parameters to a spatial level (spatial analysis). We must keep in mind that the information has importance and meaning only when it is related to other information. For this final, synthetic approach of vulnerability was established using multiple queries, integrating the three physico-environmental criteria related to the land surface temperature, slope levels, and existing landfills types. The vulnerability map was obtained by a series of requests integrating different combinations of the three criteria that were reclassified into distinct classes.

Indeed, we began with the idea that the presence in the same area of high temperatures associated with lower slope levels in those municipalities where landfills are not controlled, are the most vulnerable areas. Therefore, *ceteris paribus*, low temperatures/high slope levels, low temperatures/high levels of slopes and municipalities with controlled landfills or CET represent low vulnerability areas.

According to the vulnerability map (Fig. 5) and Table 2, it is easy to see that the town of Batna is facing a real risk of cutaneous leishmaniasis. It clearly indicates that 48.89% of the total area of Batna is highly vulnerable. The remaining is divided between 2.83% of middle vulnerability and only 48.28% of low vulnerability. Indeed, these results can be explained through a spatial analysis of selected factors: land surface temperature, landfills, and parameters of the physical environment (slope classes).

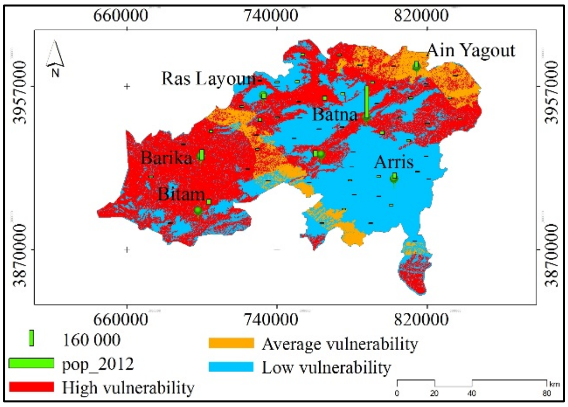

Fig.5 Vulnerability map of cutaneous leishmaniasis in Batna Town.

Table 2. Vulnerability classes to cutaneous leishmaniasis.

Vulnerability class	Area (ha)	Area (%)
Low	6699,14	48,28
Medium	393,64	2,83
High	6785,72	48,89

“Eq. (1)”: A high temperature promotes the proliferation of sand fly larvae because an analysis of the map of the state of the disease indicates that the most affected municipalities are located in the Saharan latitudes (southwest) and at elevations with depression (between 336 m and 975 m) giving a high thermal gradient for the cases of Barika, Djezzar Bitam, Abdelkader Azil, and Amdoukal. It will be noted that the proximity of these municipalities to the town of Biskra (the main cradle of the disease) is another factor favoring this vulnerability.

“Eq. (2)”: Landfills are among the many sources of environmental pollution. They are areas that receive substantial and increasing amounts of detritus in the open air on a daily basis; the risk primarily arises because these landfills are a suitable environment for the life cycle of a sand-fly, and an endless source of food for its development. In the total absence of a system for processing and recycling urban waste in the town, these landfills remain proliferation areas for many diseases. To this end, they completely escape the environmental control of the province.

“Eq. (3)”: The components of the physical environment contribute greatly to aggravate the environmental situation responsible for the appearance and development of this disease. They include slope and altitude parameters. In the present work, a morphological analysis of the region shows that most of the areas are endorheic, characterized by a multitude of closed depressions where water stagnation is omnipresent, in particular in the southwestern and northeastern side of the town (chott Tinnsilt, sebkha ezzemoul, sebkha Djenndli, chott Gadaine, chott Hodna, etc.).

Slopes and their spatial structures can constitute a risk factor, as low slopes (less than 3%) are the source of water stagnation and the appearance of wetlands constitute a favorable environment for the development of many insects. Noted that the risk of cutaneous leishmaniasis is aggravated by the coincidence of high densities of population with the most vulnerable sectors. Indeed, over 68% of the population (i.e. 7651.46 inhabitants) face medium to high vulnerability, as compared to 32% (3553.97 inhabitants), which is concentrated in areas of low vulnerability.

Simultaneous visual comparison between the vulnerability map (Fig.5) with that of the declared cases of cutaneous leishmaniasis shown in Fig.6 reinforces our approach and obtained results. Noted that the most vulnerable sectors localize the most significant numbers of declared cases of leishmaniasis. These sectors include the southwest area represented by the municipalities of Barika (with 392 reported cases), Bitam (61), Abdelkader Azil (37), Djezzar (69), and Ain Touta (61).

This spatial analysis clearly shows that the most significant cutaneous leishmaniasis cases are located in the most populated municipalities. However, an important question arises—whether the number of inhabitants alone determines the importance and the extent of the disease. For this, a correlation analysis (method of least squares) was carried out to confirm this. Indeed, the results of this method (Fig. 7) show that the level of correlation is not significant; $R^2 = 0.1635$ (or a correlation of 40%).

This clearly shows no significant relationship between the population size and declared cases. We can, therefore, conclude that the size of the population is an element of risk that remains poorly defined, and if this factor does not in itself explain the epidemiological situation, the environmental explanation through the three parameters analysis of disease previously chosen is definitely required

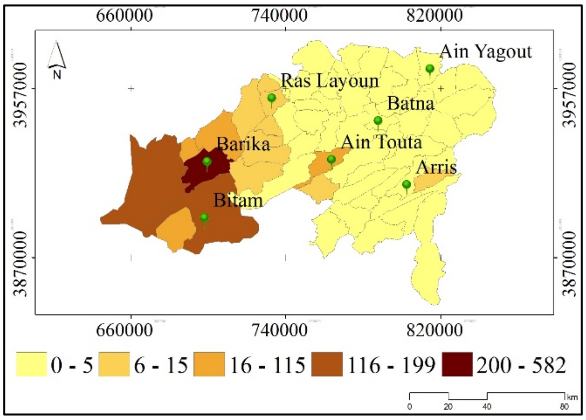

Fig. 6 Spatial distribution of reported cases of cutaneous leishmaniasis.

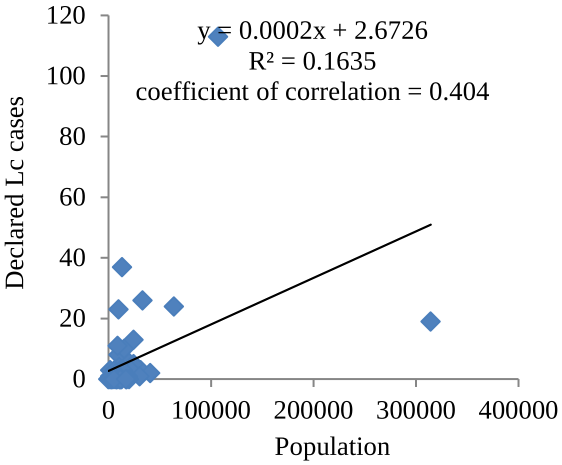

Fig. 7 Scatter plot of the number of population and declared Leishmaniasis cases in municipalities.

3. CONCLUSION

Cutaneous leishmaniasis, because of its pathological nature, magnitude, and growing spatial spread, constitutes a major concern for public health. Batna areas of the present study are strongly affected by this scourge, where the number of recorded cases of leishmaniasis has reached alarming dimensions, which thus requires the support of this problematic in a global and integrated manner.

Our approach is an analytical approach seeking to understand the factors of vulnerability that are potentially responsible for this transmissible disease and its development. Using geomatics tools, namely, remote sensing and geographic information systems (GIS), as spatial techniques has enabled us to identify the environmental factors that might explain the emergence of the disease and its development.

It is evident that there are numerous vulnerability factors with converging effects. However, we have only considered the most important and especially the quantifiable factors, which can be integrated as numerical data into the GIS database. In fact, the components of the topography, landfills, and surface temperature were set in a spatial relationship. Spatial analysis results with SQL queries have shown that many municipalities in the towns (Barika, Ain Touta, Djezzar Bitam, etc.) observe a significant vulnerability rate. It clearly appears that the municipalities of the southwest and northeast of the province have the highest vulnerabilities with a rate of 48.89% of the total area; however, those in the center and southeast are less vulnerable (48.28%).

In summary, the results can be a decision support tool for public health services of the town and can guide their actions in terms of prevention and management of epidemiological situations.

The results of the present study represent only a modest contribution that can open a new path for environment-epidemiology relations and associated geo-analytical databases. However, one cannot lose sight of the influence of other factors of vulnerability on this disease and its proliferation, especially roads and weekly markets—essential vectors that can carry sandflies species that are responsible for cutaneous leishmaniasis which must be apprehended later by Network Analysis.

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