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Remote sensing, land cover changes, and vector-borne diseases: Use of high spatial resolution satellite imagery to map the risk of occurrence of cutaneous leishmaniasis in Ghardaïa, Algeria

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ABSTRACT

Ghardaïa, central Algeria, experienced a major outbreak of cutaneous leishmaniasis (CL) in 2005. Two *Leishmania* species occur in this region: *Leishmania major* (MON-25) and *Leishmania killicki* (MON-301). The two species are transmitted respectively by the sandflies *Phlebotomus papatasi* and *Phlebotomus sergenti* and probably involve rodent reservoirs with different ecologies, suggesting distinct epidemiological patterns and distribution areas.

The aims of this study were to establish risk maps for each *Leishmania* species in Ghardaïa, taking into account the specificities of their vectors and reservoirs biotopes, using land cover and topographical characteristics derived from remote sensing imagery. Using expert and bibliographic knowledge, habitats of vectors and reservoirs were mapped. Hazard maps, defined as areas of presence of both vectors and reservoirs, were then combined with vulnerability maps, defined as areas with human presence, to map the risk of CL occurrence due to each species. The vector habitat maps and risk maps were validated using available entomological data and epidemiological data.

The results showed that remote sensing analysis can be used to map and differentiate risk areas for the two species causing CL and identify palm groves and areas bordering the river crossing the city as areas at risk of CL due to *L. major*, whereas more limited rocky hills on the outskirts of the city are identified as areas at risk of CL due to *L. killicki.*

In the current context of urban development in Ghardaïa, this study provides useful information for the local authorities on the respective risk areas for CL caused by both parasites, in order to take prevention and control measures to prevent future CL outbreaks.

1. Introduction

Leishmaniasis is a parasitic vector-borne disease caused by Protozoa of the genus *Leishmania*, transmitted by the bite of female sandflies belonging to the genus *Phlebotomus* in the Old World and *Lutzomyia* in the New World. It occurs in 98 countries and comprises two diseases, visceral leishmaniasis (VL) and cutaneous leishmaniasis (CL) which are estimated to affect between 0.2–0.4 and 0.7–1.2 million cases worldwide respectively (Alvar et al., 2012). CL is more widely distributed than VL. In North Africa CL has been increasing since the 1980s, both in terms of incidence and distribution (Aoun and Bouratbine, 2014). Algeria belongs to

Abbreviations: BI, brightness index; CL, cutaneous leishmaniasis; DEM, digital elevation model; GPS, Global Positioning System; MSAVI, Modified Soil Adjusted Vegetation Index; NDVI, Normalized Difference Vegetation Index; SPOT, Satellite Pour l'Observation de la Terre; SRTM, Shuttle Radar Topography Mission.

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the ten countries with the highest number of CL cases, with these ten countries accounting for 70–75% of CL incidence in the world (Alvar et al., 2012).

Transmission cycles of leishmaniasis are complex, implicating large numbers of parasites, vectors and reservoirs. Several *Leishmania* taxa can cause CL, each of which is involved in specific epidemiological cycles, *i.e.* associated with specific vectors and, for some, with specific reservoir hosts. Chaara et al. (2014) reviewed the epidemiological features of leishmaniasis in the Maghreb region (Chaara et al., 2014). In Algeria until recently, two forms of CL had been described: the sporadic form caused by *Leishmania infantum* in the North, and the classic form caused by *Leishmania major* in central and southern parts of the country. Between 2004 and 2006, one other taxon, *Leishmania killicki*, was detected in Ghardaïa (central Algeria) (Harrat et al., 2009) and in Constantine City (North-eastern Algeria) (Mihoubi et al., 2008). The present study focused on the epidemiological cycles occurring in Ghardaïa.

In 2005, a major outbreak of CL occurred in the province of Ghardaïa: 2040 human cases were recorded, many of them from urban areas. Besides the first detection of *L. killicki* in Algeria, this outbreak also led to the description of a new enzyme variant *L. killicki* (MON-301), which was shown to coexist sympatrically with *L. major* MON-25 (Harrat et al., 2009). The two species causing CL were associated with their typical vectors, *Phlebotomus papatasi* for *L. major* and *Phlebotomus sergenti* for *L. killicki* as the latter is a variant of *L. tropica* (Ben Ismail et al., 1987; Boubidi et al., 2011; Harrat et al., 2009; Jaouadi et al., 2012; Tabbabi et al., 2011). CL due to *L. major* is of the zoonotic type, involving wild rodents of the genera *Psammomys* and *Meriones*, in particular with *Psammomys. obesus* and *Meriones. shawi* as reservoirs (Belazzoug, 1983; Izri et al., 1992). CL due to *L. killicki* also seems to be zoonotic, as *Ctenodactylus gundi* was found naturally infected by *L. killicki* in Tunisia (Bousslimi et al., 2012; Jaouadi et al., 2011), and different studies in Tunisia suggest that *L. killicki* infections differ from *L. tropica,* with strictly zoonotic transmission (Haouas et al., 2012; Maubon et al., 2009). Furthermore, in Ghardaïa, *P. sergenti* was found naturally infected in the neighbourhood of *Massoutiera mzabi* ('Mzab Gundi') burrows (Boubidi et al., 2011), suggesting that this rodent, which is particularly abundant in this area, could also act as a reservoir. The zoonotic transmission of *L. killicki* in Ghardaïa is also supported by the studies on the CL cases in this region, showing that no secondary cases were reported in the household or in the vicinity of confirmed CL cases (Epidemiology and Prevention Department of the Ministry of Health of the district of Ghardaïa, unpublished).

Control of CL remains difficult as no vaccine exists and tools for interrupting transmission (vector and reservoir control) are limited. It is therefore essential to better understand the epidemiological cycles and develop methods to anticipate the occurrence of outbreaks or the establishments of new foci (Chaves and Pascual, 2006). This paper set out to map risk areas for the occurrence of both species causing CL (*L. major* and *L. killicki*) in several urban areas of Ghardaïa province, using eco-epidemiological knowledge on their respective vectors and hosts, and remotely sensed data. The approach developed here consisted in using satellite imagery and a digital elevation model to map the land cover of the study area. Expert and bibliographic knowledge on CL vectors and suspected reservoirs was then used to map CL hazard (Vector × Reservoir) and risks (Hazard × Vulnerability, vulnerability being defined as residential areas). These maps were validated using ground truth data for the land cover map, and entomological data for the vector habitat maps. As the cases of CL in Ghardaïa could not be associated with each of the two *Leishmania* species (*L. major* and *L. killicki*), the available epidemiological data were only used to assess the global consistency of the CL risk map.

2. Material and methods

2.1. Study area

Ghardaïa wilaya (province) is located in the central part of the Northern Sahara, 500 km south of the capital Algiers (Fig. 1a), on a limestone plateau with valleys and ravines. It is a desertic region covering an area of 86,650 km^2, located between 1° and 5° East (about 200 km) and 31°30′ and 33° North (about 450 km). The climate is dry and arid, rainfall is low and erratic, and the vegetation is sparse. The average monthly temperature is maximal in July (36 °C) and minimal in January (12 °C). Ghardaïa wilaya comprises 400,000 inhabitants located in 13 municipalities, of which four (Ghardaïa and three neighbouring municipalities, namely Bounoura, Dhayet Bendhahoua, and El Atteuf) were included in the study area (Fig. 1b).

2.2. Review of expert knowledge on CL vectors and reservoirs in Algeria

In Central Algeria, CL caused by *L. major* involves the sand fly species *P. papatasi* as the vector (Izri et al., 1992) and wild rodents (gerbils *P. obesus* and *M. shawi*) as reservoirs (Belazzoug, 1983; Izri et al., 1992). On the other hand, CL caused by *L. killicki* involves the sand fly species *P. sergenti* (Boubidi et al., 2011); the rodent species *M. mzabi* is suspected of being a reservoir of *L. killicki* (Boubidi et al., 2011; Harrat et al., 2009).

The respective species acting as vectors and reservoirs of CL are associated with different environmental conditions. *P. papatasi* requires the presence of vegetation cover and humid soils, whereas *P. sergenti* can also be found in drier areas such as rocky soils (Adam et al., 1960; Gouat and Gouat, 1984; Gouat, 1988; Gouat et al., 1984; Izri et al., 1992; Schlein and Jacobson, 1999). The sand rodents *P. obesus* and *M. shawi* are present in plains, vegetation covers and sandy soils, whereas *M. mzabi* can live in much drier conditions (rocky soils), in hillside burrows (Adam et al., 1960; Gouat and Gouat, 1984; Gouat, 1988; Gouat et al., 1984; Izri et al., 1992; Schlein and Jacobson, 1999). Thus, the distribution of CL caused by *L. major* may be associated with the presence of large vegetation areas, such as palm groves, close to human settlements (see Fig. 1b and c), whereas CL caused by *L. killicki* may more likely occur in dry areas (see Fig. 1b and e). The risk of CL occurrence may be lower in dense urban areas (Fig. 1d), because of the absence of wild rodent reservoirs in those areas.

Table 1 summarizes the environmental conditions of the distribution of vectors and reservoirs of both species causing cutaneous leishmaniasis in central Algeria (Adam et al., 1960; Fichet-Calvet et al., 2000; Gouat and Gouat, 1984; Gouat, 1988; Gouat et al., 1984; Izri et al., 1992; Kravchenko et al., 2004; Muller et al., 2011; Schlein and Jacobson, 1999; Wasserberg et al., 2003).

2.3. Mapping the environmental conditions suitable for vectors and reservoirs of CL

A map of environmental elements that modulate the habitats of vectors and reservoirs of CL (i.e. vegetation, soil type (sand or rock), soil moisture, see Table 1) was produced using satellite imagery and a digital elevation model (DEM). Spectral and textural indices were extracted from Satellite Pour l'Observation de la Terre (SPOT) images and combined with elevation data in a decision-tree classification. The classification was evaluated by comparing classification results with reference points.

2.3.1. Elevation data

A DEM is a representation of the topography of an area of land. DEM data files contain the elevation of a given area – usually at an