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Geographic distribution of *Meriones shawi,Psammomys obesus,* and *Phlebotomus papatasi the main reservoirs and principal vector* of zoonotic cutaneous leishmaniasis in the Middle East and North Africa

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A R T I C L E I N F O

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A B S T R A C T

Rodents play a significant role in the balance of a terrestrial ecosystem; they are considered prey for many predators like owls and snakes. However, they present a high risk to agriculture (damaging crops) and health. These rodents are the main reservoirs of some vector-borne diseases like leishmaniasis. *Meriones shawi* (MS) and *Psammomys obesus* (PO) are the primary Zoonotic cutaneous leishmaniasis (ZCL) reservoirs in the Middle East and North Africa (MENA). A review on the MS and PO at the MENA scale was explored. A database of about 1500 papers was used. 38 sites were investigated as foci for MS and 36 sites for PO, and 83 sites of Phlebotomus papatasi (Pp) in the studied region. An updated map at the regional scale and the trend of the reservoir distribution was carried out using a performing proper density analysis. In this paper, climatic conditions and habitat characteristics of these two reservoirs were reviewed. The association of rodent density with some climatic variables is another aspect explored in a case study from Tunisia in the period 2009–2015 using Pearson correlation. Lastly, the protection and control measures of the reservoir were analyzed. The high concentration of the MS, PO, and Pp can be used as an indicator to identify the high-risk area of leishmaniasis infection.

1. Introduction

Rodents are mammals with adaptations to terrestrial and arboreal habitats. According to several studies, rodents cause the transmission of cutaneous leishmaniasis diseases. Gerbil is desert rats, including a hundred species adapted to arid conditions (Masoumeh et al., 2014).

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Globally, several studies recorded that *Rhombomys opimus, Tatera indica, Meriones hurrianae, and Meriones libycus gerbils* are the principal hosts of the Zoonotic cutaneous leishmaniasis (ZCL) (Javadian et al., 1998; Rasi et al., 2001; Afshar et al., 2011). Gholamrezaei et al., 2016 reviewed and modelled the distribution of ZCL reservoirs in Iran.

The *Meriones shawi* have been recorded in North Africa since the Middle Pleistocene (Stoetzel et al., 2017). *M. libycus is hosts ZCL* in Riyadh province and Saudi Arabia (Ibrahim et al., 1994), inhabiting the dry and hot deserts (Johnson et al., 2016). Yaghoobi-Ershadi et al. (1996) recorded that *M. libycus* was infected by *Leishmania major* in Badrood city (Central Iran) and the *R. opimus* was the primary host further east. However, *Psammomys obesus* is the primary reservoir host of ZCL in Al-Hassa oasis (Elbihari et al., 1987) and primary reservoir host in western Asia including Nizzana and North Africa (Ashford, 2000).

Many papers were studied the physiology of the reservoir (*M. libycus* deserts of Saudi Arabia) (Johnson et al., 2016), the genetic and reproduction (Boufermes et al., 2014), Systematics, genetic, and evolution of the *M. shawi* (Stoetzel et al., 2017), reproduction of *M. shawi* in southern Morocco (Zaime et al., 1992), the taxonomy, genetic, and biochemical of *P. obesus* (Mostafa et al., 2006) in Tunisia, the systematic and genetic of *R. opimus,* the reservoir of *Leishmania major* in central and south Asia (Oshaghi et al., 2011).

M. shawi is among rodents adapted to arid climates (Petter, 1961). In the Middle East and North African countries, the *P. papatasi* is the principal vector and PO is the host in North Africa (Masoumeh et al., 2014). Like other species such as insect vectors, the leishmaniasis hosts are broadly extending to new sites and the surveillance becomes an urgent action.

In this paper, a review of *M. shawi* (MS) and *P. obesus* (PO) at global scale was explored. The *M. shawi* was found in Tunisia (Ghawar et al., 2011; Ghawar et al., 2014), in Algeria (Aoun and Bouratbine, 2014), in Morocco (Thévenot and Aulagnier, 2006; Ouzaouit, 2000; Ouanaimi et al., 2015; Aoun and Bouratbine, 2014, Postigo, 2010), and in Libya (Kimutai et al., 2009). Regarding *P. obesus*, it was recorded in Algeria (Aoun and Bouratbine, 2014; Tomás-Pérez et al., 2014), in Tunisia (Tomás-Pérez et al., 2014; Ghawar et al., 2011), in Libya (Aoun and Bouratbine, 2014; Postigo, 2010), in Saudi Arabia (Saliba et al., 1994; Postigo, 2010), Jordan (Postigo, 2010), and in Syria (Postigo, 2010).

Rodents like *P. obesus* have a diurnal activity, but depending on surrounding temperature; in winter they appear in the middle of the day and summer in the morning and afternoon, and at night avoiding the heat (Biagi, 2004).

The *P. papaptasi* is the main vector of the ZCL (Parvizi et al., 2005). In the region of PO and MS (MENA countries), the presence of *P. papatasi* was recorded in Morocco by Lahouiti et al., 2013, Zouirech et al. (2013), Boussaa et al., (2016, 2014, 2010, & 2005), Echchakery et al. (2017), Karmaoui (2020), Talbi et al. (2015), in Algeria by Benmahdi-Tabet et al. (2017) and Boudrissa (2005), in Tunisia by Chelbi et al. (2007). However, in Libya it was found by Dokhan (2008), Abdel-Dayem et al. (2012), Ashford et al. (1977), Annajar (1999), Tabit et al. (2005), El-Buni and Refai (2005), in Egypt by Samy et al. (2014) and Ali et al. (2016). The presence of Pp was also signaled in Saudi Arabia by Doha and Samy (2010) in Jordan by Schlein and Jacobson (1999), and in Palestine by Sawalha et al. (2017).

For effective regional surveillance, there is a need to determine the geographical information on these hosts in association with *P. papatasi*. Consequently, a review of some rodent species linked to *cutaneous leishmaniasis* was carried out at a regional scale. A special attention was granted to *M. shawi* (MS) and *P. obesus* (PO).

This paper explores the rodents and vector of the ZCL data collected throughout the review of a large number of papers in countries with the presence of MS and PO from 1931 to 2017. The study was designed to explore the associations between the two reservoirs and the *P. papatasi* main vector of *L. major*. The findings can affirm, update or change our understanding of the repartition of the ZCL disease. Furthermore, this distribution can help to determine the expansion of the disease with time and the area where surveillance and control of both rodents and vectors must be taken.

2. Material and methods

To update the geographic distribution of rodent hosts of *cutaneous leishmaniasis*, various, scientific databases (Science Direct, Plos, Wiley, and Google Scholar) were used for papers from 1931 to 2017. The headings terms used in this review were “Leishmaniasis”, “Rodent”, “Hosts”, “Reservoirs”, “Epidemiology”, and the scientific name of some rodent species was also used, mainly, *M. shawi* (MS) and *P. obesus* (PO).

Geographic and ecological data on MS, PO, and *P. papatasi* were extracted and used from a large number of papers (1500). The studied species were confirmed in several countries. In this endemic region, many forms of leishmaniasis were found and several recent epidemic outbreaks have been hosted (McDowell et al., 2011).

The input of geographic and ecological data was processed using the GIS software (Arc-Gis v.10). Mapping the species distribution density of *M. shawi* (MS), *P. obesus* (PO) and *Phlebotomus papatasi* (PP) was carried out using the point density tool. This method allows estimating the density of point features around each output raster cell (http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-point-density-works.htm). The analysis was done using the following steps as explained in the Quantifying Point Patterns (https://mgimond.github.io/ArcGIS_tutorials/Point_pattern_analysis.htm#_Toc519667228):

- Using a vector layer, the process allow to create of a raster;
- Define the extent in the Environments setting;
- Populate the Point Density tool fields (input point feature, population field, output raster, output cell size, and neighborhood settings;
- Run the geoprocessing.

The used cell size (x, y) is (0.086941467, 0.086941467), with the angular unit: Degree (0.0174532925199433).

The mapping of the risk caused by the presence of one or more species (reservoirs or vector) is ensured by the toolbox (Raster calculator) of Arc-GIS software, which allowed aggregate isolated risks and produced a global map whose degree risk varies between 1 (Very low risk) and 4 (High risk) (Table 1).

The spatial dispersal of *P. obesus, M. shawi*, and *Phlebotomus papatasi* was used to draw the maps of distribution, density, and leishmaniasis risk.

Lastly, the association between the rodents and some climatic variables was another aspect studied in this review. A case study from Tunisia was carried out. The climatic variables (rainfall, maximum, minimum and average temperature, and relative humidity) and rodent density data were referred to the supplements presented in the work of Talmoudi et al. (2017). To our knowledge is the only study in the MENA region that provides numeric data for seasonal rodents associated with maximum and minimum, rainfall, relative humidity, and seasonal cases of ZCL.

A statistical analysis of the data through a Pearson correlation is a descriptive method associating the climatic and biological variables with the ZCL incidence. The method makes it possible to explore the various relationships, the fluctuations, and trends of the ZCL disease and the variables mentioned above in the central region of Tunisia for seven years (2009–2015). This correlation between climatic variables (temperature, rainfall, and humidity) and leishmaniasis cases were also investigated by many researchers, particularly by Chalghaf et al. (2016) and Toumi et al. (2012) using interesting modeling approaches.

3. Results and discussion

The geographic information was gathered and compiled in Tables 2, 3, and 4 and in Fig. 1.

To find associations between the two reservoirs of L. *major*, a review of the distribution of the main vector of this disease was done (Table 4). In addition, the database of papers was also used to extract the distribution of *P. papatasi* in the countries MENA with MS and PO as hosts.

4. Rodents and *Phlebotomus papatasi* geographic distribution

This study revealed the spatial distribution of the main reservoirs and vector of ZCL in MENA countries using spatial statistical analysis. Similar studies have been used to explore the leishmaniasis vectors in Brazil (Menezes et al., 2015) and the leishmaniasis outbreak in Spain (Gomez-Barroso et al., 2015). The collected and gathered information in this review allow the realization of a spatial distribution of two main reservoirs of ZCL, *P. obesus* and *M. shawi* and the associated vector, *P. papatasi*. Therefore, this review can constitute a database on reservoirs and vector of ZCL in arid regions. A map (Fig. 2) on MENA countries showing these reservoirs and the principal vector performing proper density analysis was carried out. In Fig. 2a, the *M. shawi* is concentrated mainly in Morocco (center and southeastern part), in Algeria (North), and Tunisia (Center). For the *P. obesus*, Fig. 2b shows a high density between Palestine and Jordan, north of Algeria and Central Tunisia followed by Morocco, Libya, and Egypt. Aoun and Bouratbine (2014) note the same distributed through the semi-desert. However, the ZCL vector is mainly active in the north of the MENA countries with a high density observed in Morocco, Libya, and Palestine-Jordan (Fig. 2c). Fig. 2d depicts the association between the two reservoirs and the peincipal vector of the ZCL. This map shows a very high risk of leishmaniasis in northern Algeria, Central Tunisia, and a high risk in Morocco (Center and southeastern). The increase of cutaneous leishmaniasis incidence was reported since the 1980s in Morocco, Algeria, Tunisia, and Libya (Anon & Bouratbine, 2013). However, in Egypt, a low risk of leishmaniasis is recorded, which is in accordance with Alvar et al. (2012) reporting a low number of leishmaniasis cases.

This paper presents the first study exploring the spatial analysis of the main reservoirs and the vector of L. *major* in the MENA region. Reviewing the Cutaneous Leishmaniasis (the three types: *L. major, L. tropica,* and L. *major*) in North Africa (Algeria, Libya, Morocco, Tunisia, and Egypt), Anon & Bouratbine (2013) describe the same geographical distribution of cutaneous leishmaniasis cases. This spatial method showed that the North African countries are highly at risk and can be affected by the ZCL. Moreover, the density of the studied reservoirs and the primary vector were spatially associated and correlated with the distribution of ZCL found by Anon & Bouratbine (2013).

These findings are in accordance with previous studies noting that this disease can be associated with the reservoirs and vector. *P. obesus* is the main host of ZCL in Al-Hassa oasis (Elbihari et al., 1987) in western Asia including Nizzana and North Africa (Ashford, 2000). *M. shawi* is the reservoir of L. *major* in Tunisia (Foroutan et al., 2017; Ghawar et al., 2011), and the vector *P. papatasi* is

Table 1
ZCL degree risk according to the reservoirs and vector densities and associations.

Type of association	Risk degree			
	1	2	3	4
Meriones shawi	+			
Psammomys obesus	+			
Phlebotomus papatasi	+			
P. obesus + *M. shawi*		+		
P. obesus + *M. shawi*			+	
Phlebotomus papatasi + *P. obesus*			+	
P. obesus + *M. shawi* + *Phlebotomus papatasi*				+

Table 2
:Geographic information on *Meriones shawi* in 8 countries (38 sites).

Country	Zone	Latitude	Longitude	Altitude	Period	References
Morocco	Ouarzazate	30°55′N	6°55′W	1100	2005	Boussaa et al. (2010)
	Boulmane	33°21′N	4°43′W	1730	–	Settaf et al. (2000)
	Al-Haouz	31°22′N	7°48′W	318–2579	2014–2015	Echchakery et al. (2017)
	Zagora Tamezmoute	30°39′N	6°08′W	855	2015	El Mezouari et al. (2015)
	Marrakech	31°42"N	8°04′W	318–2579	2014–2015	Echchakery et al. (2017)
	Oulad Fredj	32°57′N	8°13′W	125	–	Delanoe (1931)
	Tata center	29°44′N	7°57′W	681	–	Rioux et al. (1982)
	Tata oasis	29°45′N	7°59′W	705		Petter (1988)
	Errachidia	31°56′N	4°26′W	–	2010–2012	Bennis et al. (2015)
	Essaouira	31°30′N	09°46′W	–	2006–2011	Diatta et al. (2012)
	Palm grove Tinejdad	31°30′N	5°01′W	1000	2006	Earl (2006)
	Tagdilt -Boumalne Dadès	31°22′N	5°59′W	1522	2017	Kehoe (2017)
	Marrakech	31°50′N	07°58′W	–	2006–2011	Diatta et al. (2012)
	Chichaoua	31°32′N	8°45′W	395	2014–2015	Echchakery et al. (2017)
	Taroudant	30°24′N	08°55′W	–	2006–2011	Diatta et al. (2012)
	N of Aglou	29°50′N	9°48′W	–	2006–2011	Diatta et al. (2012)
	Guelmim	29°00′N	10°03′W	310	–	Blanc et al. (1947)
	Dakhla	23°54′N	15°48′W	–	2006–2011	Diatta et al. (2012)
Algeria	Aïn Skhouna 1	34°80′N	1°55′E	1000	2010	Benmahdi-Tabet et al. (2017)
	Aïn Skhouna 2	34°15′N	2°30′E	1000	2010	
	Aïn Skhouna 3	34°29′N	1°50′E	1000	2010	
	El M'hir	36°7′N	4°22′E	502	2009	Boudrissa et al. (2012)
	Ksar Chellala	35°13′N	2°19′E	750–900	1986	Belazzoug (1986)
	Aïn Témouchent	35°17′N	0°59′E	254	2009–2012	Malek et al. (2015)
	Laghouat	33°47′N	2°52′E	790	2009–2012	Malek et al. (2015)
	Djelfa	34°39′N	3°15′E	1150	2009–2012	Malek et al. (2015)
	M'Sila	35°13′N	34°11′E	550	2009–2012	Malek et al. (2015)
	Biskra	34°49′N	5°44′E	100	2009–2012	Malek et al. (2015)
	Biskra, Branis	35°03′N	5°6′E	–	2008–09	Bachar (2015)
	Biskra,Tolga	34°42′N	6°93′E	–	2008–09	Bachar, 2015)
	Biskra, Doucen	34°45′N	4°57′-5°17′E	120	2008–09	Bachar (2015)
	Biskra, Sidi okba	34°45′N	5°5′E	120	2008–09	Bachar (2015)
Tunisia	Sidi Bouzid EL KHBINA	35°10′N	9°43′E	221	2008–2010	Ghawar et al. (2011)
	Sidi Bouzid EL MNARA	35°16′N	9°45′E	215	2008–2010	Ghawar et al. (2011)
	Sidi Bouzid ETTOUILA	34°58′N	9°26′E	434	2008–2010	Ghawar et al. (2011)
	Gafsa Douara	34°23′N	8°47′E	400	1987	Ben Ismail et al. (1987)
	Sidi Bouzid AL MNARA	35°12′N	9°49′E	80	2012	Ghawar et al. (2015)
	Bouhedma	34°47′N	9°64′E	–	2007–2014	Khemiri et al. (2017)
	Dghoumes	34°03′N	8°27′E	–	2007–2014	Khemiri et al. (2017)
	Sidi Toui	32°39′N	11°14′E	–	2007–2014	Khemiri et al. (2017)

associated with ZCL (WHO, 2010).

When associating the two reservoirs on one side and a reservoir with the vector on another side, three maps were traced (Fig. 3). The associations between *P. obesus* and *M. shawi* (Fig. 3a) allow observing a high density in southeastern Morocco and the northern parts of Algeria and central Tunisia. In regards to the relationship between *P. papatasi* and *P. obesus*, a high density was recorded in the southeastern of Morocco, the northern side of Algeria, Libya (in the west), Central Tunisia, and Palestine. Finally, for the correlation between the density of *P. papatasi* and *M. shawi*, Morocco presents a very high risk, followed by Algeria and Tunisia. The maps in Figs. 2 and 3 can demonstrate the geographic region with high risk of ZCL and take the output information in formulating an international control program. Such need was expressed in 2005 in the 5th International Symposium on Phlebotomine Sandflies hosted in Tunisia and also in the research and policy conference, entitled LEISHMANIA hosted in Tunisia (in June 2009).

Considering the fact the current study is subject to the limitations of the different periods of the sites and the restricted number of sites to conduct a large-scale spatial distribution study, active regional collaboration is required. Effective scientific cooperation between the MENA countries on the spatial expansion knowledge of the main reservoirs and vectors (annual and monthly data) of the ZCL can give a global vision and open new ways for investigation on leishmaniasis burden. In this context, McDowell et al. (2011) recorded the necessity of global capacity building in science and the participation of the global scientific community. Such collaboration was previously performed by a team of 36 researchers from 8 Mediterranean countries, Portugal, Spain, France, Italy, Greece, Cyprus, Turkey, and Georgia. The study was entitled Seasonal Dynamics of Phlebotomine Sand Fly Species Proven Vectors of Mediterranean Leishmaniasis Caused by Leishmania infantum (Alten et al., 2016). This research project is an excellent example for the MENA region whose ZCL is endemic.

Table 3
Geographic information on *Psammomys obesus* in 8 countries (36 sites).

Country	Zone	Latitude	Longitude	Altitude	Period	References
Morocco	Boumalne Dadès (Tagdilt)	~31°22′N	~5°59′W	–	2006	Earl (2006)
	Near Goulmima	~31°41′N	~4°57′W	–	2017	Kehoe (2017)
Algeria	El M'hir	36°7′N	4°22′E	502	2009	Boudrissa et al. (2012)
	M'sila	34°40′N	4°32′E		1983	Belazzoug (1983)
	Ouarourout (Beni-Abbes)	30°9′N	2°13′W	450	1974	Daly and Daly (1974)
	M'Sila	35°13′N	34°11′E	550	2009–2012	Malek et al. (2015)
	Batna	35°32′N	6°09′E	1050	2009–2012	Malek et al. (2015)
	Biskra, Branis	34°57′N	5°47′E	–	2008–09	Bachar (2015)
	Biskra,Tolga	34°42′N	6°93′E	–	2008–09	Bachar (2015)
	Biskra, Doucen	34°45′N	4°57′-5°17′E	120	2008–09	Bachar (2015)
	Biskra, Sidi okba	34°45′N	5°5′E	120	2008–09	Bachar (2015)
	Saoura Valley Ben-Abbes	34°47′N	0°34′W	880	1997	Khammar and Gernigon-Spychalowicz (1997)
	Aïn Skhouna	34°30′N	0°50′E	1000	2010	Benmahdi-Tabet et al. (2017)
Tunisia	Sidi Bouzid	35°02′N	9°28′E	330	1995–96	Fichet-Calvet et al. (2000)
	Sidi Bouzid R' mila	35°46′N	9°36′E	280	1995–1997	Fichet-Calvet et al. (2003)
	Sidi Bouzid EL KHBINA	35°06′N	9°26′E	198	2008–2010	Ghawar et al. (2011)
	Sidi Bouzid EL MNARA	35°08N	9°26′E	205	2008–2010	Ghawar et al. (2011)
	Sidi Bouzid OULED MHAMED	35°30′N	9°18′E	310	2008–2010	Ghawar et al. (2011)
	Gafsa Douara	34°23′N	8°47′E	400	1987	Ben Ismail et al. (1987)
	Garat an Njila Sidi Bouzid	35°46′N	9°36′E	280	1995–1996	Fichet-Calvet et al. (1999)
Syria	Damascus Dmeir	33°38′N	36°41′E	680	1990–91	Rioux et al. (1992)
	Damascus	~33°20′N	~36°10′E	–	–	WHO, 2010
Libya	Wadi Al-Hai	32°9′N	12°50′E	300	1999	Annajar (1999)
Egypt	Mastroh	31°28′N	30°41′E	10	–	Basuony (2000)
	El-Kom El-Akhdar	31°26′N	30°49′E	10	–	Basuony (2000)
	Al Arish, North Sinai	31°07′N	33°48′E	22	–	Morsy et al. (1996)
Jordan	Qatraneh	31°15′N	36°03′E	770	–	Saliba et al. (1994)
	Hasa	30°53′N	35°40′E	1133	–	Saliba et al. (1994)
	Umm ar-Rasas	31°29′N	35°54′E	750	–	Saliba et al. (1994)
	Mowaqqar	31°48′3N	36°06′E	915	–	Saliba et al. (1994v
	Khaldyah	32°09′N	36°17′E	590	–	Saliba et al. (1994)
	Karameh	31°56′N	35°34′E	−200	–	Saliba et al. (1994)
	Gharandal	30°42′N	35°39′E	1387	–	Saliba et al. (1994)
	North of Jericho	32°00′N	35°30′E	–	1996–97	Schlein and Jacobson (1999)
Saudi Arabia	Eastern province (Dammam)	~26°25′N	~49°59′N	–	–	WHO (2010)
	Al-Hassa (sud-est)	~25°22′N	~49°39′N	–	–	Petter (1988)

5. Rodents and climate, a case study from Tunisia

The impact of climate on the distribution of animal species was studied by Graham in the early 90's (Graham and Grimm, 1990; Graham, 1992; Graham et al., 1996). The climate models allowed predicting the repartition of species based on environmental requirements were used by Hijmans and Graham (2006).

Most vector-borne diseases follow a seasonal change, making these diseases sensitive to climate (Gubler et al., 2001). El-Bakry et al., 1999 reported the roles of the photoperiod or water availability on the reproductive status of *Meriones shawi* in the desert-dwelling. The host density can also be sensitive to climate (Chaves and Pascual, 2006). Fig. 4 (a & b) shows the seasonal rodents density associated with maximum, minimum, and average temperatures from July 2009 to June 2015 in the case study. Generally, the evolution of the rodents shows a peak in March–April (Fig. 4). This evolution depicts an increasing trend of rodents' density in the studied area. One may notice certain elasticity for the average temperature (Fig. 4). Rodent-borne diseases are less directly affected by temperature, while the transmission of the disease depends on environmental conditions and available food (Gubler et al., 2001).

For cutaneous Leishmaniasis, climate affects the transmission dynamics since the vector density depends on climate variability, which gives it the character of seasonality (Chaves and Pascual, 2006). Fig. 5 shows the seasonal rodents associated with the rainfall and relative humidity from July 2009 to June 2015 in the the case study area. As stated above, the rodent density depends on various climatic factors, but, specifically, the association of rodents with rainfall is average because it is not direct. The rodents are sensitive to food favored by the rainfall. For example, *P. obesus* is born between December and April its breeding period depends on food

Table 4
Geographic distribution of *P. papatasi* (83 sites).

Country	Zone	Latitude	Longitude	Period	References
Morocco	Moulay Yacoub Oulad aid	~34°05′N	~4°45′W	2011–2012	Lahouiti et al. (2013)
	Moulay Yacoub Zlilig	33°57°N	5°05W	2011–2012	Lahouiti et al. (2013)
	Azilal province, Ouaouizaght district	32°09′27″N	6°20′57, 58W	2010	Zouirech et al. (2013)
	Azilal	31°58′N	6°34′W	–	Boussaa et al. (2014)
	Ait Majden	31°84′N	6°96′W	2005–2006	Boussaa et al. (2010)
	Damnate	31°73′N	7°00′W	2005–2006	Boussaa et al. (2010)
	Zemrane	31°53′N	8°26′W	2005–2006	Boussaa et al. (2010)
	Marrakech city	31°36′N	8°02′W	2005–2006	Boussaa et al. (2010)
	Ouarzazate	30°55′N	6°55′W	2005–2006	Boussaa et al. (2010)
	Fedragon	30°55′N	6°58′W	2005–2006	Boussaa et al. (2010)
	Tabourihit	30°58′N	7°07′W	2005–2006	Boussaa et al. (2010)
	Amezgan	31°02′N	7°12′W	2005–2006	Boussaa et al. (2010)
	IminTiflet	31°06′N	7°16′W	2005–2006	Boussaa et al. (2010)
	Tagouimat	30°37′N	7°34′W	2005–2006	Boussaa et al. (2010)
	Aguim	31°09′N	7°28′W	2005–2006	Boussaa et al. (2010)
	Douar	30°21′N	7°96′W	2005–2006	Boussaa et al. (2010)
	Touama	31°31′N	7°28′W	2005–2006	Boussaa et al. (2010)
	Tafriat	31°32′N	7°36′W	2005–2006	Boussaa et al. (2010)
	Marrakech city	31°36′N	8°02′W	2005–2006	Boussaa et al. (2010)
	Al-Haouz	31°22′N	7°48′W	2014–2015	Echchakery et al. (2017)
	Al Haouz	31°22′N	7°51′W	–	Boussaa et al. (2014)
	Marrakech	31°42′N	8°04′W	2014–2015	Echchakery et al. (2017)
	Marrakech Urban	31°36N	8°02W	–	Boussaa et al. (2005)
	Sefrou	33°39N	04°38W	–	Talbi et al. (2015)
	Azilal	31°58′N	6°34′W	–	Boussaa et al. (2014)
	Chichaoua	31°20′N	8°30′W	–	Echchakery et al. (2017)
	Chichaoua	31°32′N	8°45′W	–	Boussaa et al. (2014)
	Agadir	30°25′N	9°34′W	2013	Boussaa et al. (2016)
	Essaouira	31°30′N	9°45′W	2013	Boussaa et al. (2016)
	Marrakech	31°39′N	7°59′W	2013	Boussaa et al. (2016)
	Ouarzazate	30°55′N	6°56′W	2013	Boussaa et al. (2016)
	Zagora	30°20′N	5°50′W	2013	Boussaa et al. (2016)
	Errachidia	31°55′N	4°25′W	2013	Boussaa et al. (2016)
Algeria	Aïn Skhouna	34°30′N	0°50′E	–	Benmahdi-Tabet et al. (2017)
	El Hodna	35°18′–35°32′N	4°15′-5°06′E	2004	Boudrissa (2005)
	El khroub Wilaya Constantine (WC)	36°16′N	6°42′E	2013–2014	Sahraoui and Nasri (2015)
	Hamma Bouziane (WC)	36°25′N,	6°36′E	2013–2014	Sahraoui and Nasri, 2015
	Didouche Mourad (WC)	36°27′N	6°38′E	2013–2014	Sahraoui and Nasri (2015)
Tunisia	Sidi Bouzid	~35°02′N	~9°28′E	2005	Chelbi et al. (2007)
Libya	Ajaylat Sabratah Surman	32°45′N	12°22′E	–	Dokhan (2008)
	Fateh Misratah	32°01′N	15°02′E	2010	Abdel-Dayem et al. (2012)
	Al Marg	32°30′N	20°53′E	–	Ashford et al. (1977)
	Sawadek Misratah	32°01′N	15°07′E	2010	Abdel-Dayem et al. (2012)
	Al Twailah An Nuqat Al Khams	32°49′N	12°11′E	2010	Abdel-Dayem et al. (2012)
	Bani Walid Tarhuna	31°59′N	13°58′E	–	Dokhan (2008)
	Benghazi Al Hizam Al Akhdar	32°10′N	20°06′E	–	Ashford et al. (1977)
	Berka Al Hizam Al Akhdar	32°06′N	20°04′E	–	Ashford et al. (1977)
	East Millitah An Nuqat Al Khams	32°51′N	12°12′E	2010	Abdel-Dayem et al. (2012)
	El Bedarna Nalut	31°58′N	11°31′E	1992–94	Annajar (1999)
	Ghazayia Nalut	31°54′N	10°48′E	1992–94	Annajar (1999)
	Guassem Mizdah	31°11′N	13°03′E	–	Dokhan (2008)
	Janzour Tripoli	32°49′N	13°00′E	–	Tabit et al. (2005)
	Kikla Al Jifarah	32°05′N	12°42′E	1975	Ashford et al. (1976)
	North west El Gedida Sabratah Surman	32°48′N	12°15′E	2010	Abdel-Dayem et al. (2012)
	Rabta Yefern-Jadu	32°23′N	12°33′E	2010	Abdel-Dayem et al. (2012)
	Rabta El Gharbiyah Al Jifarah	32°09′N	12°50′E	2010	Abdel-Dayem et al. (2012)
	Sabratah Surman	32°47′N	12°29′E	–	Dokhan (2008)
	Taurgha Medical Center Misratah	32°00′N	15°04′E	2010	Abdel-Dayem et al. (2012)
	Tiji Nalut	32°00′N	11°21′E	1992–94	Annajar (1999)
	Tripoli Tripoli	32°53′N	13°10′E	–	Ashford et al. (1977)
	Uazzen Nalut	31°56′N	10°39′E	1975	Ashford et al. (1976)
	Umm El Gersan Gharyan	32°02′N	12°33′E	2010	Abdel-Dayem et al. (2012)
	Wadi Al Hayy Al Jifarah	32°18′N	12°44′E	1975	Ashford et al. (1976)

(*continued on next page*)

Table 4 (*continued*)

Country	Zone	Latitude	Longitude	Period	References
	Wadi Bir Ayyad Yefern-Jadu	32°09′N	12°25′E	1975	Ashford et al. (1976)
	Wadi Kiaam Al Marqab	32°27′N	14°25′E	–	Dokhan (2008)
	Wadi Latrun Al Qubbah	32°51"N	22°16′E	–	Ashford et al. (1977)
	West El Gedida Sabratah Surman	32°46′N	12°14′E	2010	Abdel-Dayem et al. (2012)
	Zawia Al Zawiyah	32°44′N	12°43′E	–	Dokhan (2008)
	Yafran Gharyan	32°03′N	12°31′E	1975	Ashford et al. (1976)
	Ziliten Al Marqab	32°27′N	14°33′E	–	Dokhan (2008)
	Zwara An Nuqat Al Khams	32°56′N	12°04′E	–	El-Buni and Refai (2005)
	Al Rabta East village	32°9′N	12°50′E	2012–2013	Dokhan et al. (2016)
	Al Rabta West village	32°9′N	12°50′E	2012–2013	Dokhan et al. (2016)
Egypt	North Sinai	30°57′N	34°21′E	2005–2011	Samy et al. (2014)
	North Sinai	31°01′N	34.12′E	2005–2011	Samy et al. (2014)
	Beer Lehfen	30°36′N	33°37′E	2005–2011	Samy et al. (2014)
	Sheikh Zuweid	30°53′N	34°04′E	2005–2011	Samy et al. (2014)
	Rafah	31°17′N	34°14′E	2005–2011	Samy et al. (2014)
	Nekhel	29°54′N	33°44′E	2005–2011	Samy et al. (2014)
	El Hassana	30°27′N	33°47′E	2005–2011	Samy et al. (2014)
	Alexandria (Al-Agamy Province)	31°05′N	29°45′E	2010	Ali et al. (2016)
	Alexandria Al- (Hawareya)	31°14′N	29°58′E	2010	Ali et al. (2016)
	Alexandria (Old King Mariout)	31°09′N	29°54′E	2010	Ali et al. (2016)
Saudi Arabia	Al-Baha	~20°00′N	~41°30′E	1996–1997	Doha and Samy (2010)
Jordan	North of Jericho	32°00′N	35°30′E	–	Schlein and Jacobson (1999)
Palestine	Jenin District	32°20′N	35°8′E	2011	Sawalha et al. (2017)

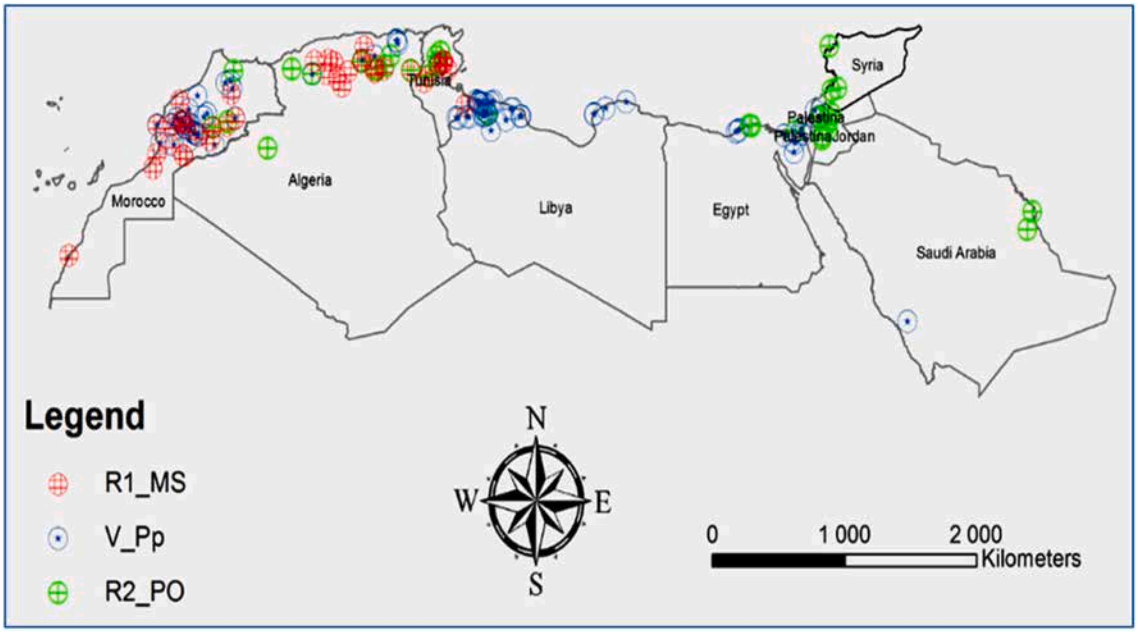

Fig. 1. Distribution of *Meriones shawi* (MS), *Psammomys obesus* (PO), and Phlebotomus papatasi (Pp) in the MENA countries.

availability, consequently, on rainfall and stops completely in drought period (Biagi, 2004).

The number of ZCL cases, the rainfall, and the relative humidity seem to vary seasonally but are hardly correlated (Fig. 6). The Pearson correlation indicates a very low relationship between rodents and relative humidity ($r = 0.186$, a = 0.05) and an average association with rainfall ($r = 0.478$, a = 0.05). Rainfall was also used by Chalghaf et al. (2016) in addition to temperature as major predictors for sand flies and cutaneous Leishmaniasis cases distributions. Their Ecological Niche Modeling predicted that Gafsa, Sidi Bouzid, and Kairouan are at the highest risk of cutaneous leishmaniasis. In the same context using generalized additive model (GAM), Toumi et al. (2012) found that ZCL incidence is rising with high confidence by 1.8% in case of an increase by 1 mm and by 5% when there is a 1% increase in humidity. Chelbi et al. (2009) showed that humidity is a limiting factor for ZCL. ZCL is endemic in arid areas, and therefore, it is absent from Northern Tunisia.

Fig. 7 depicts a high number of rodents in the spring season. The reservoir hosts surviving winter infect the *P. papatasi* during the

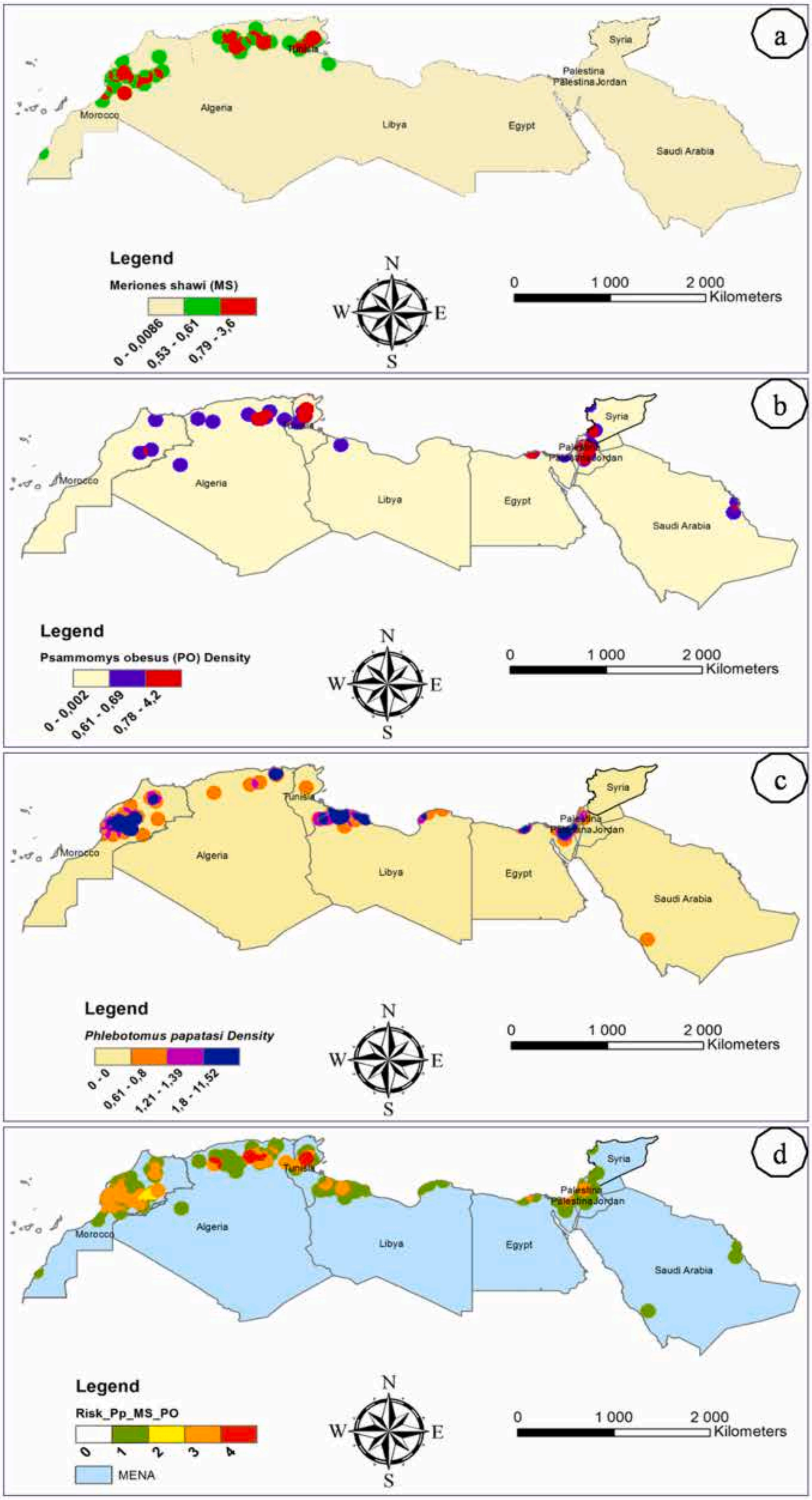

Fig. 2. Distribution of PO, MS, and Phlebotomus papatasi and their associations in the study area.

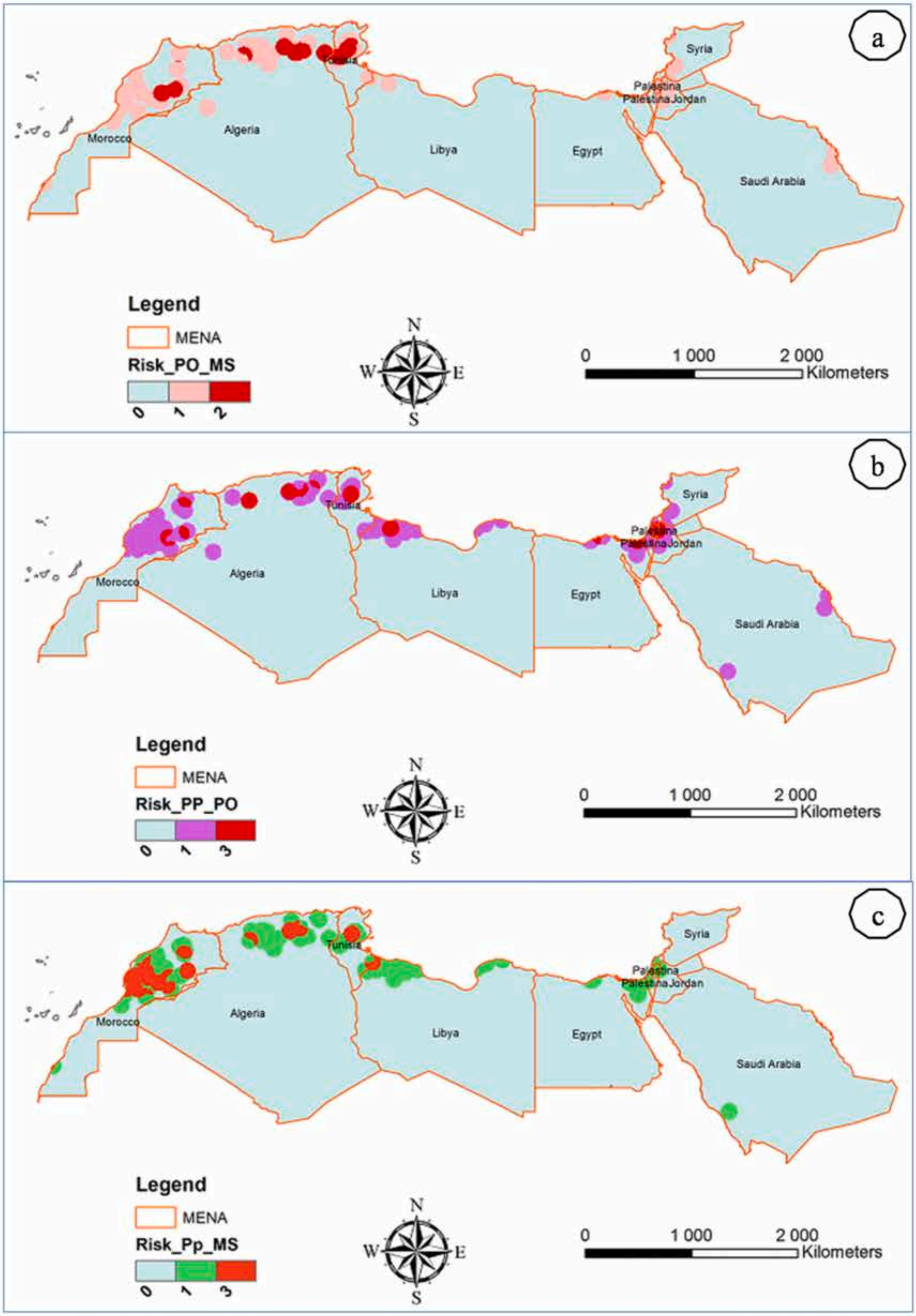

Fig. 3. a, Density map of PO and MS; b, Density map of PP and PO; c, Density map of PP and MS and Phlebotomus papatasi and their associations in the studies areas

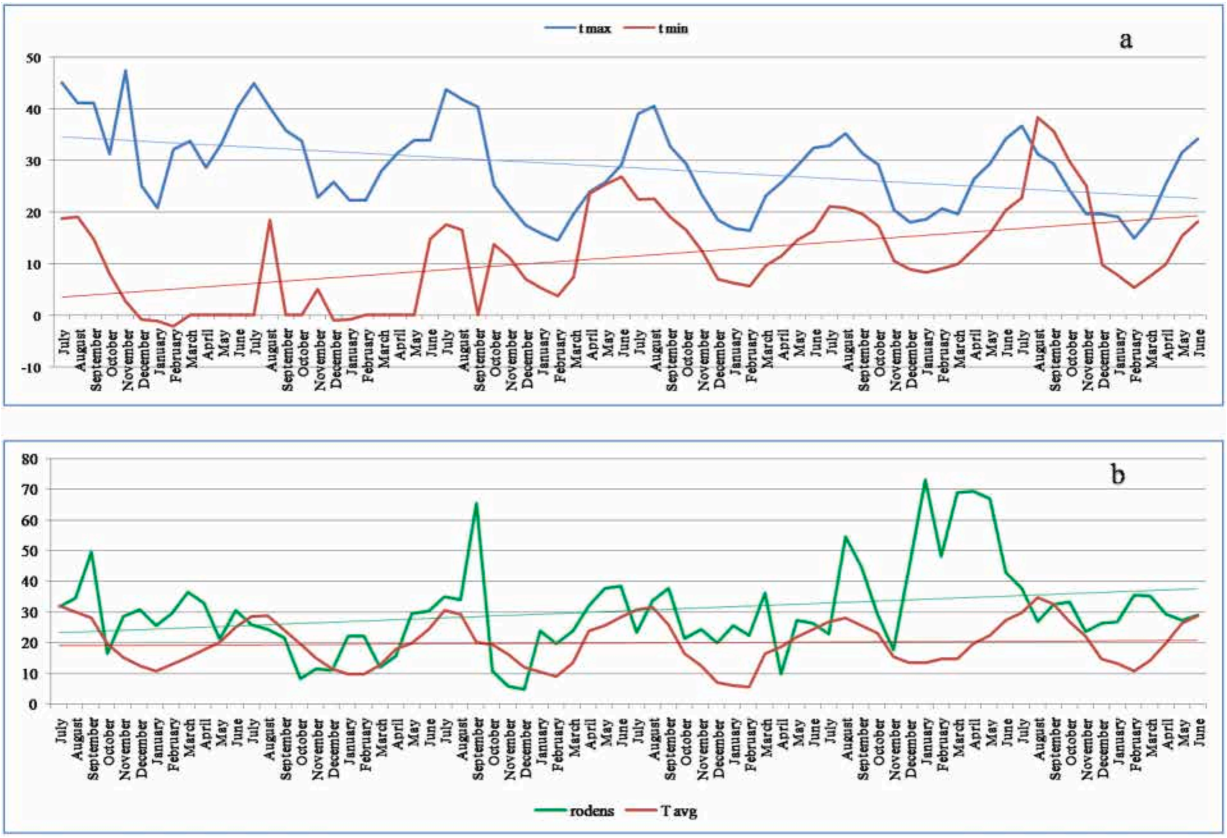

Fig. 4. Seasonal rodents associated with maximum and minimum temperatures from July 2009 to June 2015. Data source: Talmoudi et al. (2017).

following season (spring) and subsequently transmit the *L.major* (Derbali et al., 2012). In this context, Zaime et al. (1992) reported that spermatogonial and steroid are maximal in winter and spring and the sexual activity seems associated with the first rains (*M. shawi* in southern Morocco). Regarding the *P. obesus*, Gernigon et al. (2003) (cited by Bachar (2015) reported that stopping birth in the period from June to September and associated with the slowing down of male and female functions.

The rainfall (60.1 mm), the rodent density (42), and relative humidity (35.7%) are maximal in September month. These values (peaks) preceded the month with maximal recorded ZCL cases. It seems that these conditions of rainfall, relative humidity, and rodent density cause the beginning of an increased incidence of ZCL disease in the case study (Fig. 8). Using the generalized additive model (GAM) and generalized additive mixed models (GAMM), Talmoudi et al. (2017) found the same link between the used climatic variables and the increase in ZCL incidence in this period.

The impacts of climate change and the human intervention on parasites hosted by reservoirs have received little attention. In this paper, a synthesis of bibliographic data on the main reservoirs of ZCL in association with the principal vector, *P. papatasi*, was carried out. What is evident is that the increased rainfall and suitable temperatures may favor the conditions of both rodent and vector populations (Fig. 9). However, the climatic variables cannot explain the presence of rodents, the land use (for example, agriculture and irrigation have also a considerable role in the proliferation of cutaneous leishmaniasis). Irrigation in North Africa favors the emergence of zoonotic visceral leishmaniasis (Barhoumi et al., 2016).

Irrigation, land use, water management have contributed to creating favorable conditions for the proliferation of both vectors and reservoirs of the cutaneous leishmaniasis. For example in Tajikistan, irrigation has favored the conditions for the proliferation of *cutaneous leishmaniasis* reservoirs (Hart, 2013). Traoré et al. (2001) recorded that Dams and irrigation systems are among the factors that may have increased the risk of parasitic diseases such as CL. In addition, the newly established phoeniciculture and arboriculture in Biskra (Algeria) have caused the proliferation of several species of rodents (of a harmful nature) including *Meriones shawi*, a farm rodent causing damage to cereal and fruit crops (Bachar, 2015).

The presence of both, the vector (for example, *P. papatasi*) and the host reservoir (gerbils) favor the cycle of the leishmaniasis disease (ZCL). This was confirmed by Yaghoobi-Ershadi et al. (1996).

Regarding the control strategies, vector control is the most effective method to control the transmission of ZCL (Derbali et al., 2014). However, biological control research can be a very effective second step with caution in introducting predators and their legal protection. This can reduce the number of rodents and thus reduce the risk of transmission of cutaneous leishmaniasis agents. Among the animal species that are considered predators, we quote, the predators of the arid zones focus on this neglected disease, Raptors, Fox, Horned Viper, Fennec, Sand cat, Owl…

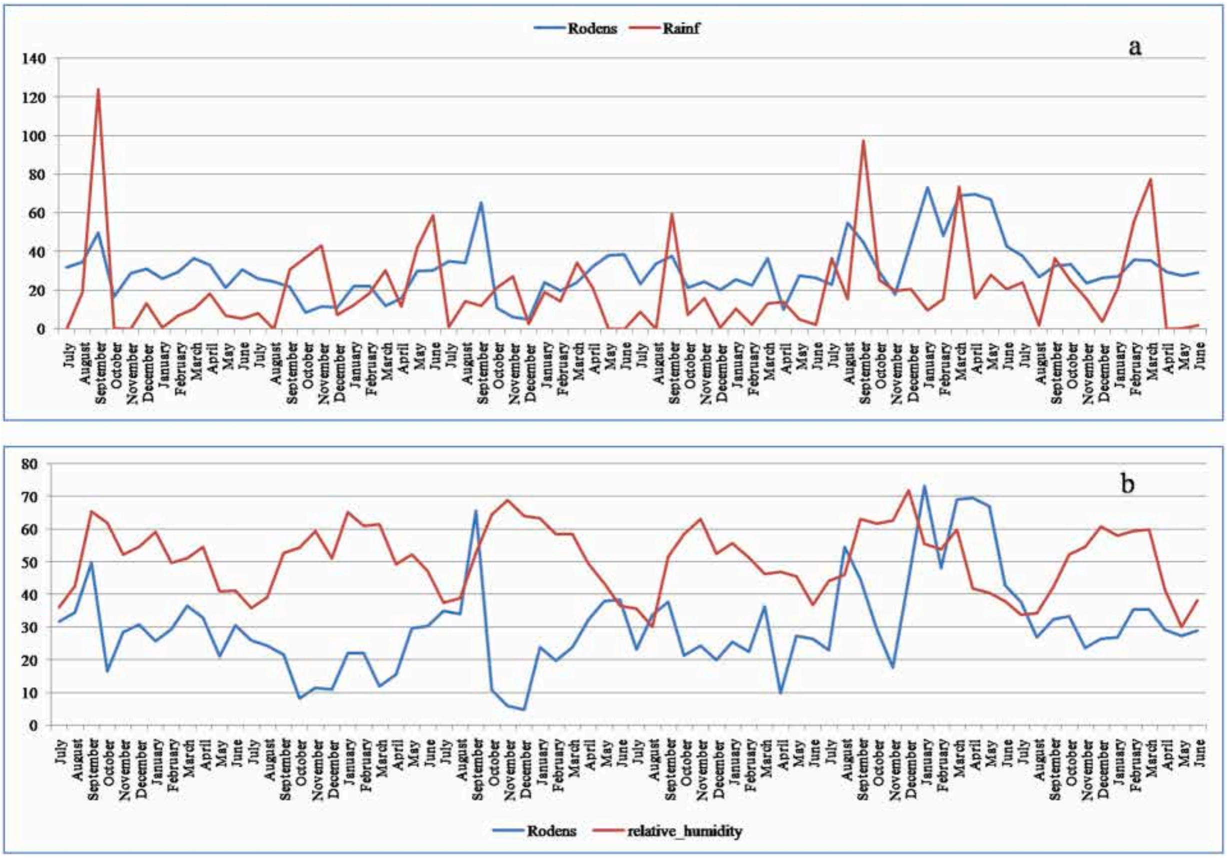

Fig. 5. a, Seasonal rodents associated with the rainfall from July 2009 to June 2015. b, Seasonal rodents related to the relative humidity from July 2009 to June 2015. Data source: Talmoudi et al. (2017).

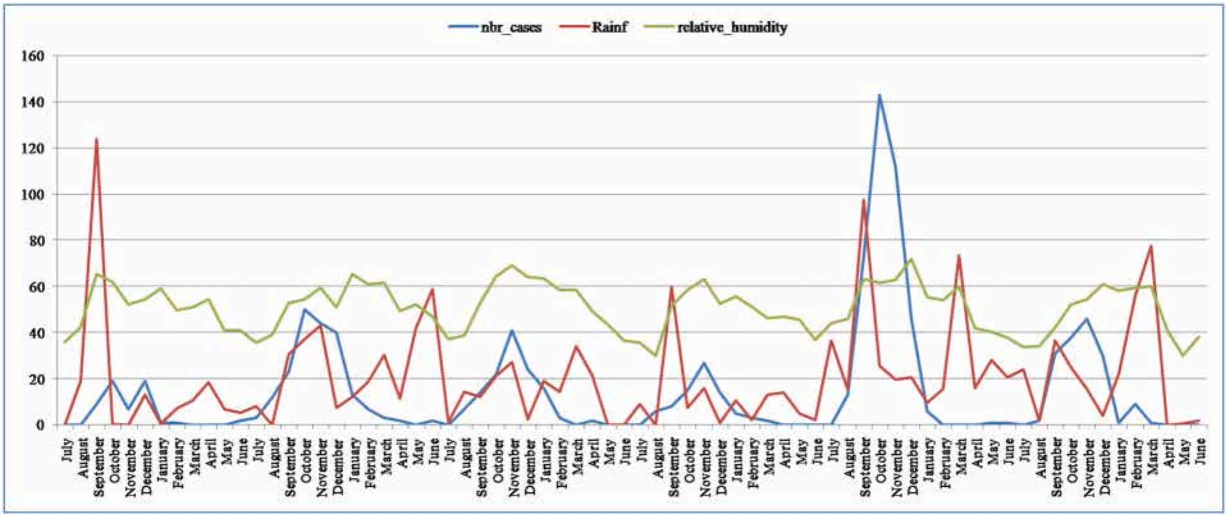

Fig. 6. Seasonal cases of ZCL associated with the relative humidity from July 2009 to June 2015. Data source: Talmoudi et al. (2017).

6. Conclusion

In countries where ZCL is endemic, this disease has become a major public health problem. As mentioned above, in many studies, *P. papatasi* transmits *L.major* from *Meriones shawi* (the main reservoir) in the studied countries which causes the ZCL. In order to update

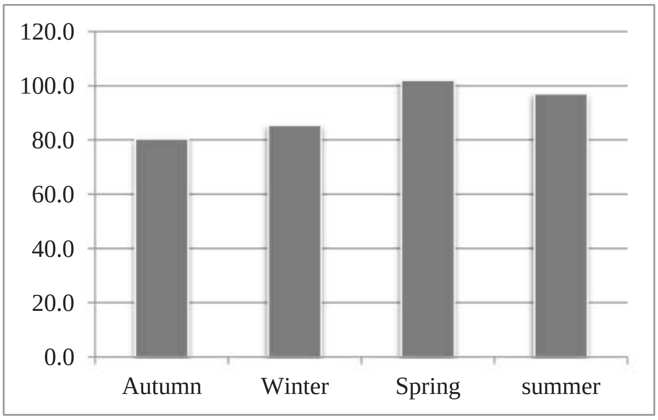

Fig. 7. Seasonal rodents' density from July 2009 to June 2015 in central Tunisia. Data source: Talmoudi et al. (2017).

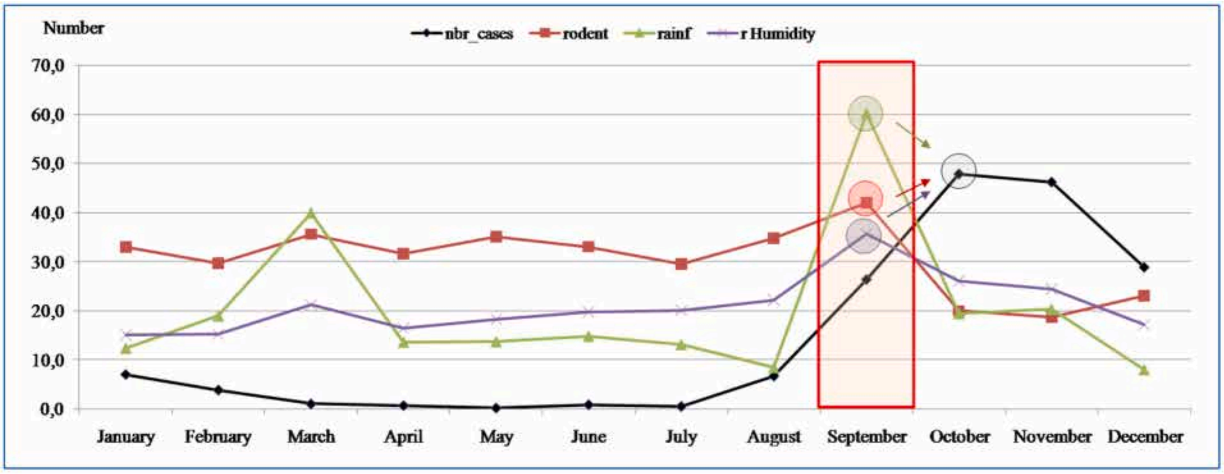

Fig. 8. Seasonal change of the ZCL cases, rodents, rainfall, and relative humidity in the period 2009–2015 in the case study. Data source: Talmoudi et al. (2017).

the ZCL distribution at the MENA region, a map of the distribution of the potential hosts and the main vector P. papatasi was carried out. The findings of this study show for the PO, a high density between Palestine and Jordan, and in the north of Algeria and Central Tunisia followed by Morocco, Libya, and Egypt. However, the ZCL vector is mainly active in the north of the MENA countries with a high density observed in Morocco, Libya, and Palestine-Jordan. The associations between PO and MS allow observing a high density in southeastern Morocco and the northern parts of Algeria and Central Tunisia. In regards to the relationship between *P. papatasi* and PO, a high density was recorded in the southeastern of Morocco, the northern side of Algeria, Libya, Central Tunisia, and Palestine. Finally, for the correlation between the density of *P. papatasi* and MS, Morocco presents a very high risk followed by Algeria and Tunisia. For the associations between rodents and climate in the case study from Tunisia, the evolution of the rodents shows a peak in March–April. It is associated with rainfall and relative humidity. In regards to the number of ZCL cases, the rainfall, and the relative humidity seem to vary seasonally, but are hardly correlated. The results also depict that when rainfall, rodent density, and relative humidity are maximal in September, they may cause the beginning of an increased incidence of ZCL disease in the case study.

This review gives various knowledge of rodents and vectors linked to cutaneous leishmaniasis in all countries where MS and PO are present. These countries showed a high prevalence of ZCL. The international control programs can use the obtained findings to decrease the ZCL prevalence. In additions, decreasing the number of hosts and vectors and increasing the awareness level of the local population can also be used.

Ethics approval

We further confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

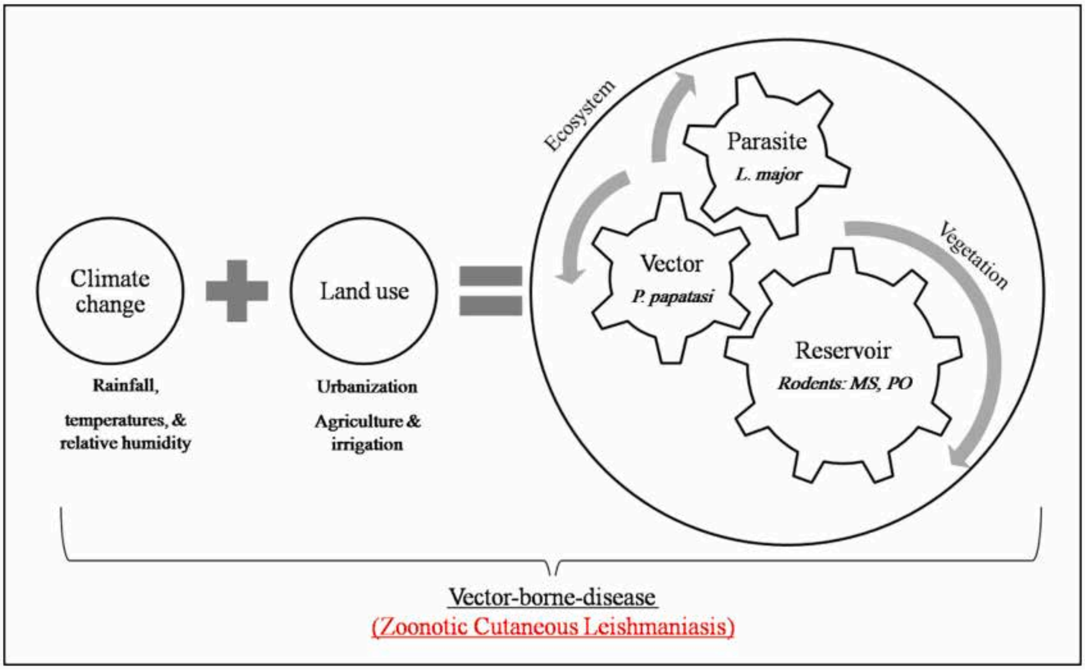

Fig. 9. The impacts of climate change and land use on parasite-vector-reservoir cycle (authors).

Competing interests

I declare no competing interests exist.

Funding source

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