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Assessment of Biotope Suitability of Desert Locust (*Schistocerca gregaria*) in the Region of Hoggar (Southern Algerian Sahara)

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ABSTRACT
Upsurges of desert locusts can cause heavy economic and agricultural losses and threaten the food security of millions of people over dozens of countries. Therefore, monitoring and spatial delimitation of their habitats are necessary for biological control studies and sampling, especially on large surfaces. This study aimed to assess and map suitable biotopes for desert locusts in southern Algeria, through a GIS tool, by integrating multicriteria analysis (Analytical Hierarchy Process) as a decision-making tool for preventive methods, biological control and research. The result is a resolution map, classified into four different zones according to pixel values. The results revealed that 28.51% of the study area is an unsuitable biotope for desert locusts, 35.92% is a survival biotope, 19.5% is a suitable biotope mainly for breeding and eggs lying and 16.05% is highly suitable for desert locust gregarization and concentration. This study offers a simplified mapping procedure to assess locust habitats for decision-making and studies in large areas.

Keywords: desert locust, biotopes, GIS, remote sensing, mapping, Algeria.

INTRODUCTION

Of all orthopteran species, the desert locust has the largest distribution area, it extends from West Africa through the Middle East to South-West Asia [Dutta et al., 2001], *Schistocerca gregaria*, (Forskål, 1775), is a species of caeliferous orthoptera insects of the family *Acrididae* and the subfamily of *Cyrtacanthacridinae* of the tribe Crytacanthacridin; known to be one of the dreaded insects for agricultural production. More than 60 countries, over an area of nearly 50 million hectares are affected to varying degrees during plague development, caused by several consecutive generations of successful breeding, triggered by a favorable sequence of heavy and widespread rainfall [Healey et al., 1996]. Historically, locust invasion had devastating consequences on food security in Africa and Asia, and can affect up to 20% of the Earth surface [Cressman et al., 2003; Magor et al., 2008].

One of the characteristics of this insect is its strong ability to migrate over long distances, crossing many countries, which makes its invasion an international issue [Bensalah, 2009]. According to FAO, desert locust is always present somewhere in the deserts between Mauritania and India. If good rains fall and green vegetation develops, desert locust can rapidly increase in number and within a month or two, start to concentrate and gregarize, which, unless checked, can lead to the formation of small groups or bands of wingless hoppers and small groups or swarms of winged adults; this is called an outbreak and usually occurs with an area of about 5,000 sq. km (100 km by 50 km) in one part of a country, an outbreak can develop into an upsurge then into a plague if the ecological conditions are favorable. The major driver of this phase transformation is population growth and concentration in the vegetated part of desert areas. Sporadic and localized rains cause vegetation growth and allow this population to increase through egg deposition in wet sandy soil and to survive in the developing vegetation; vegetation also provides food for the newly hatched locusts and shelter, as they develop into winged adults [Escorihuela et al., 2018].

Desert locust biotopes can be classified into four classes:

- Hostile environment: where locust cannot survive; generally, these are arid environments with rocky soils (regs and hamada formations), halotrophic soil, where vegetation is not abundant [Duranton et al., 1990].
- Surviving biotopes: where desert locust could subsist pending the appearance of better conditions allowing a resumption of development and growth, particularly the beginning of sexual maturation, they are essentially extensive biotopes where the water supplies are limited to rainfall and where the runoff is more important. Moreover, the vegetation is scarce and offers little interest for the Desert Locust for food or shelter [FAO, 2016].
- Breeding biotopes: where desert locust can not only survive but also finds food and soil texture that allows sexual maturation and laying eggs, essentially around sandy soils as “reg” formation covered with vegetation, and arborous steppes [Babah, 2008].
- Gregarization (outbreak) biotopes: offer better breeding conditions, likely to lead directly or indirectly to densities that can lead to transformation [Klassen and Vreysen et al., 2021], located in relatively well-watered regions; the large and medium wadis that present a powerful fossil hydrographic network inherited from the Quaternary constitute, when the rainfall is sufficient, constitute a highly suitable locust biotopes for gregarization amplification [Keita, 1997].

In recent decades, extensive research has been carried out on the biology and ecology of Schistocerca gregaria (Forskal) and its behavior in field and laboratory [Wilps et al., 1993];

The current strategy to reduce the frequency of plagues and manage desert locust infestations is early warning and preventive control [Cressman, 2013]; as the locust-affected countries with Food and Agriculture Organization (FAO) have adopted many preventive control strategies to manage the desert locust infestations. These strategies rely on early warning and early reaction; that is, to constantly monitor desert locust potential breeding, concentrating and gregarizing habitats by carrying out ground surveys on a regular basis, identifying the desert locust infestations that require treatment, and undertaking control operations before the locusts gregarize and form hopper groups and adult swarms that can lead to an outbreak.

In Algeria, the National Institute of plants protection is in charge of the locust control missions through monitoring and regular assessment of the presence, distribution and evolutionary phase in the Algerian desert, under the supervision of the FAO’s Global Desert Locust Information Service (DLIS), which has the role of closely monitor the global desert locust situation 24/7 and provide forecasts, early warning and alerts on the timing, scale and location of invasions and breeding. The main focus of this control is to search for outbreaks and devise the action tools to control gregarizing populations before they develop into plagues. However, the breeding areas of the desert locust are vast, making effective monitoring of desert locust populations with ground survey teams extremely difficult, as the main concern of desert locust control units is to perform this monitoring in the shortest time by optimizing the prospecting routes of ground crews [Lazar et al., 2015].

Conventional locust monitoring relies on manual field acquisition of locust species, instar and population data by plant protection specialists [Shuhan and Si-jing, 2020]. A better knowledge of the spatial relationship between desert locust populations and potential breeding habitats would improve the survey and control operations. Satellite imagery has been used for almost 30 years to monitor and assess locust habitat mapping [Pedgely et al., 1981; Roffey et al., 1994; Tucker., et al 1985; Bryceson et al., 1993; Voss et al., 1997; Van Huis et al., 1992; Dreiser et al., 1994; Cherlet et al., 1991; Healy et al., 1996; Cressman et al., 2013]. Remote sensing plays an important role in detecting rainfall and green vegetation. Despite recent technological advances in data management and analysis, communications, and remote sensing [Cressman, 2013], most studies utilized the data from optical sensors to derive vegetation distribution and density through the Normalized Difference Vegetation Index (NDVI) and land cover for mapping and monitoring the locust habitats. Furthermore, temperature, precipitation and soil moisture are derived from thermal infrared, passive, and active radar sensors. The use of GIS and remote sensing technology fills the gap of monitoring over large and difficult desert areas, while decision-making support studies (DSS) can largely improve sampling, intervention and management plans.

Algeria, with 12 000 000 km² of desert area, and given its location, has experienced several locust invasion events that were noted since the 19th century. Since 1860, many invasions have occurred: 1860, 1867, 1881, 1888, 1910, 1912, 1919, 1926, 1935, 1940, 1947, 1949, 1962, 1986, 1989, 2003, 2005, which caused heavy losses to farmers over several years [BenHalima, 2006; Kaidi, 2007].

The insect evolution and invasion is generated in the extreme south of the country. The extent of this very wide region, in addition to its desert climatic condition, makes field missions to monitor desert locusts very difficult. This study offers a contribution to the methods of delineating the desert locust habitats, by taking into account different field factors which can determine and limit the presence or the absence of the locust (climate, soil, topography, water and vegetation) and not to be restricted to remote sensing of plant conditions or the state of soil moisture, by integrating a multicriteria analysis in order to bring out a final map that describes and identifies the potential biotopes suitability of the locust.

MATERIAL AND METHODS

Study area

The study area covers an area of 37,933 km²; it is situated in the extreme south of Algeria and includes the regions of: In Guezzam, Tarzouk, Idles, Djanet and Bordj L'haoues. Between 6° 20' 45.6" and 7° 14' 38.4" E and 23° 41' 19.68" and 21° 4' 1.2" N, (Fig. 1), this area is part of the Hoggar

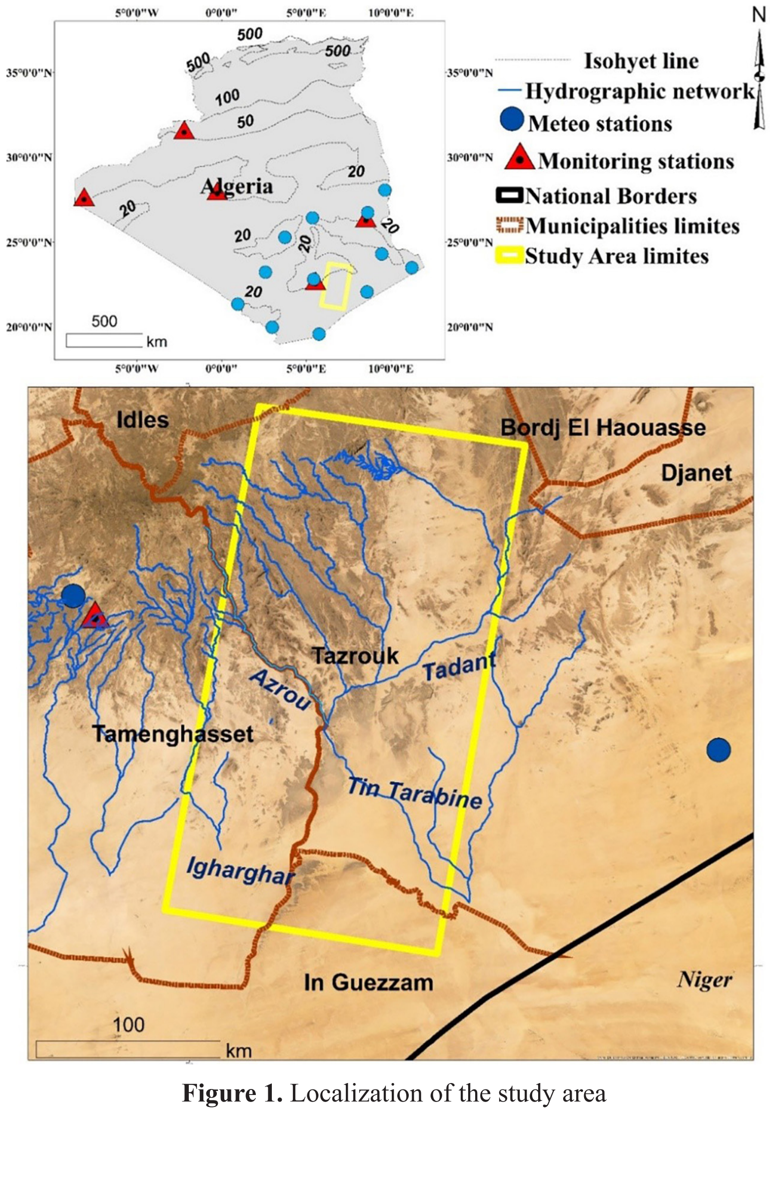

Figure 1. Localization of the study area

region, which includes the Hoggar mountain range, where altitudes can reach over 3000 m a.s.l.

The climate is distinctly continental. Atmospheric precipitation is rare there. The variations of daily temperatures reach 45 °C. Temperatures vary between +54 °C as maximum temperature during the summer period and -6.6 °C as the minimum temperature during the winter period [Elkaiem and Abdelah Bennour, 2016].

Dubief [1959] reported that rainfall is generally low. As for the thermal regime, it is much contrasted, and influenced by altitude and latitude. On average, the month of June is the hottest of the year with 40 °C in Tamanrasset, at an altitude of 1395 m, and 28 °C, at high elevations, and January is the coldest month, with absolute minima approaching very low temperatures (-13.5 °C, in 1993) [Chennoun, 2005].

On soil context, these areas are characterized by generally less evolved soils and dry on the surface due to the lack of humidity, mainly composed of silica sand and limestone or gypsum fragments [Lazar et al., 2015; Ozenda, 1983].

Dense vegetation cover is generally found on the highest peaks and around waterways, flora cover of the region is essentially composed of tall grasses, usually various perennial grasses: *Pennisetum dichotumum*, *Panicum turgidum* in particular and *Asclepiadaceae* (*Calotropis*, *Leptadenia*, *Pergularia*…). Trees mostly of a tropical origin appear in the landscape that characterizes "the desert to thorny steppe". They are represented mainly by the genus *Acacia* (*A. raddiana*, *A. ehrenbergiana*, *A. seyal*, *A. Arabica*, *A. albida* and *A. leata*. *A. raddiana* and *A. ehrenbergiana*), there is also tamarisk (*Tamarix articulata*, *T. gallica*), which form stands in valleys where the water is very shallow.

One can also find isolated desert date palm, *Balanites aegyptiaca*; *Muera crassifolia*; two species of the family *Moraceae* - *Ficus salicifolia* var telouket (endemic to Central Sahara) and *Ficus* ingens. Wild olive trees or lavender can be found on higher elevations [Chennoun, 2005; Quezel,1954, Vassal,1974].

Mapping and reclassifying of factors

In order to monitor and map the different types of biotopes, assessed different ecological factors were assessed: vegetation cover, soil moisture, distance from waterways, topography wind direction and speed through mapping and calculating remote-sensing indices, the images used for this purpose are Landsat images of OLI captor (path 191 row 44 and 45), and digital elevation models DEM (ASTGTM2_N20, 21 and 22, E 5, 6, 7) a mosaicking was necessary in order to cover all the study area.

Vegetation was mapped using the NDVI index (Normalized and differentiated vegetation index); this index measures the total of green biomass in every pixel of the satellite image; it is calculated according to the equation:

$$NDVI = NIR - R/NIR + R \tag{1}$$

where: NIR is the near infrared channel and R is red channel of the satellite image [Rouse et al., 1973].

The elevation was mapped based on the digital elevation model (DEM), after mosaicking the different scenes, high altitudes represent the Ahagar Mountain where the highest elevation in the study area is 2308 m, which then begins to drop gradually to 389 m a.s.l. in the region of Ain Guezzam.

The hydrographic network was obtained after mapping the flow accumulation and direction according to the digital elevation model; then, the distance from the hydrographic was obtained by calculating the Euclidian distance from the waterways.

Soil humidity layer was obtained based on the Soil Moisture for desert locust early Survey (SMELLS) map. Provided by the European space agency (ESA), SMELLS implements an innovative approach to combine the Sentinel-1 SAR data with thermal disaggregated SMOS-derived soil moisture to derive a soil moisture product at both high-spatial and high-temporal resolution to provide a new tool for decision-makers in the desert locust preventive control system.

Wind maps were elaborated based on meteorological stations of the region, followed by spatial interpolation (IDW) to build speed and direction maps.

Once the different factors are mapped, each map was reclassified by reassigning a new attributed value to all its original classes; values from 1 to 4 were assigned to each interval (break); depending on their intervention and role in biotope determination for desert locusts, where, 1 is given for a class of values that present an unsuitable biotope e.g. low NDVI (bare soil), and 4 is given for the a class where the values indicate a suitable biotope e.g high NDVI (a dense vegetation cover) (Table 1).

Table 1. Score attribution and reclassification

Factor	Class value	New score
Vegetation	-0.27 to -0.09	4
	-0.08 to 0.09	3
	0.1 to 0.27	2
	0.28 to 0.45	1
Soil humidity	0.001 to 0.011	4
	0.012 to 0.025	3
	0.025 to 0.030	2
	0.031 to 0.050	1
Elevation	1500 to 2300	4
	1100 to 1400	3
	780 to 1000	2
	390 to 770	1
Distance from waterways	45 to 58	4
	30 to 44	3
	16 to 29	2
	0 to 15	1
Wind speed	2.65 to 2.89	4
	2.9 to 3.12	3
	3.13 to 3.36	2
	3.37 to 3.6	1
Wind direction	NE	4
	E	3
	E to SE	2
	SE	1

Multi-criteria decisions making

Multicriteria analysis was applied in order to obtain a final biotope map based on the importance of each ecological factor in defining a desert locust biotope. A multicriteria decision making is a branch of a general class of operations research model that is suitable for addressing complex problems featuring high uncertainty conflicting objectives, different forms of data and information, multi interests and perspectives and accounting for complex and evolving biophysical and socio-economic systems [Lecoq et al., 2001]. This method is based on mathematics and expert judgment, the use of multi criteria analysis and the geographic information system GIS tool allows developing different assessment methodologies using various factors (criteria) as well as allows decision makers and users to have spatiotemporal information about the extent and the duration of different natural hazards [Wang et al., 2009].

In ecology, the studies of several studies are decision-making situations of the multicriteria analysis offered to researchers and decision-makers several approaches for mapping different phenomena such as vulnerabilities, risks and spatial analysis of the habitat in order to better predict, prevent and manage them [Boultif and Benmessaoud, 2017].

The first step is to build a comparison matrix (Table 2), where the chosen criteria (factors) are compared two by two, using a scale that ranges from 1 to 9, according to the importance or the contribution degree of every criterion, i.e.: one criterion "A" to which we give 9 as a weight which in relation to another criterion "B" will have the weight of 1/9.

The second step is to calculate the eigenvector (*Vp*) which is determined by calculating the geometric mean for each criterion; after that, the weighting coefficient for each criterion is deduced by dividing each eigenvector by their sum, the sum of the weighting coefficients must be equal to 1 (Table 3).

Table 3. Criteria weights

Criteria	Weight
Vegetation	0.191
Elevation	0.037
Soil humidity	0.419
Distance from waterways	0.191
Wind speed	0.079
Wind direction	0.079
Total	1

Table 2. Comparison matrix

Criteria	Vegetation	Elevation	Soil humidity	Distance from water	Wind speed	Wind direction
Vegetation	1	5	0.33	1	3	3
Elevation	0.20	1	0.14	0.20	0.33	0.33
Soil humidity	3	7	1	3	5	5
Distance from water	1	5	0.33	1	3	3
Wind speed	0.33	3	0.20	0.33	1	1
Wind direction	0.33	3	0,2	0.33	1	1
Total	5.53	24	2.00	5.53	13.33	13.33

RESULTS AND DISCUSSION

Factor maps

Vegetation

High values that indicate dense vegetation with significant green biomass range between 0.28 and 0.45 and form almost 6% of the study area (2275,953 km²), while lower values that indicate bare soils and less vegetation form 26% of the area (9862,46 km²) distributed mainly over the rocky outcrops of Hoggar mountains, due to its high altitude, the Hoggar, less warm and less arid than the desert plain, served as refuge and in particular to the relics of Mediterranean or tropical stocks which, in the past, reached these massifs owing to the wetter periods (Fig. 2a).

Soil moisture

High values of soil moisture are localized over the high altitude of Ahaggar Mountains, due to the low temperature and evapotranspiration, these areas form only 2.29% (868.65 km²). The areas with medium humidity rates are located on lower altitudes and form approximately 42% of the study area, whereas dryer soils are located on the rest of the area with 55.46% (21037.39 (Fig. 2b).

Elevation

The terrain of the study area can be classified gradually from the north where the high altitudes reach 2300 m a.s.l. to the south, where the altitudes drop to 389 m a.s.l., elevation is an important factor, as a natural barrier that determines desert locust flight direction; mountains and high altitudes form obstacles to the advance of locust swarms (Fig. 2c).

The areas of high altitudes form nearly 9.76% of the study area, (3702.216 km²), while the areas of lower altitudes where the desert locust swarms could fly easily form 72% of the study area 27311.43 km² (Fig. 2d).

Distance from waterways

The areas less than 15 km away from superficial water form nearly 81% (39973.72 km²), the areas of a distance between 15 and 45 km form 18.30% (6941.65 km²), while the areas more than

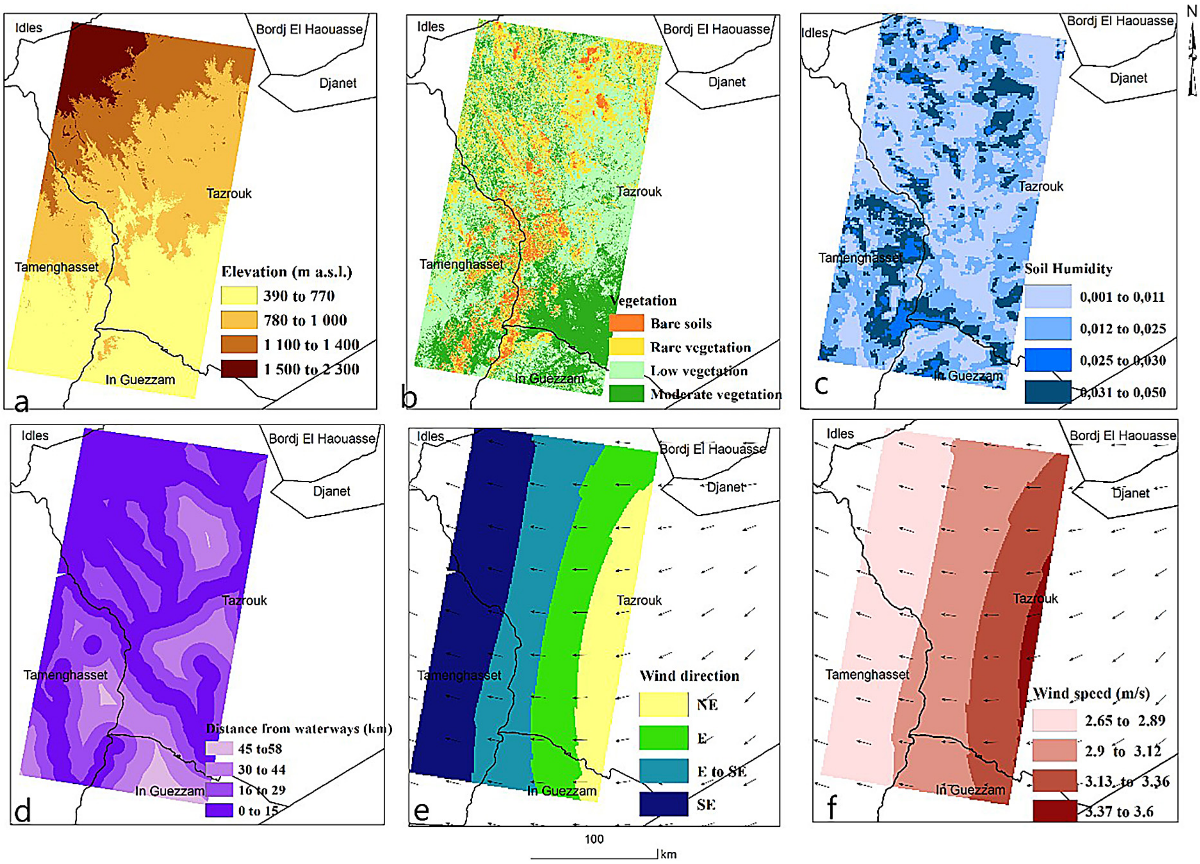

Figure 2. Factors maps: a) elevation map; b) vegetation map; c) soil moisture map; d) distance from waterways; e) wind direction; f) wind speed

45 km (45 to 58 km) away form only 0.358 % of the study area (Fig. 2e).

Wind speed and direction

The Algerian desert presents a winter/spring and a summer breading area for desert locust, driven by southern and eastern winds [FAO, 2016].

Wind direction in the study area is generally north western on more than 90% of the study area down from Ahaggar mountains in the north to lowlands, regions of North to North Eastern direction blow on 8.26 % of the area (4062.224%) (Fig. 2e).

Wind speed is a very important factor for desert locust locomotion, gregerization and outbreaks. Most of the study area is characterized by a wind speed between 2.5 and 3.6 m/s (average of 10.8 km/h), and wind speed ranges between 3.13 and 3.36 m/s almost 45.5% of the study area (Fig. 2f).

Final map

The final mapping lead to spatially delimit four classes that present four different biotopes:

- An unsuitable biotope that does not offer the favorable conditions for desert locust. It covers almost 10814.57 km^2 (28.51%) of the area, located mainly on "El Hoggar" mountains where the elevations ranges between 1700 to 2300 m a.s.l.; with a scarce green vegetation cover and a substratum mainly composed of rocky outcrops; the presence of high mountains proves to be

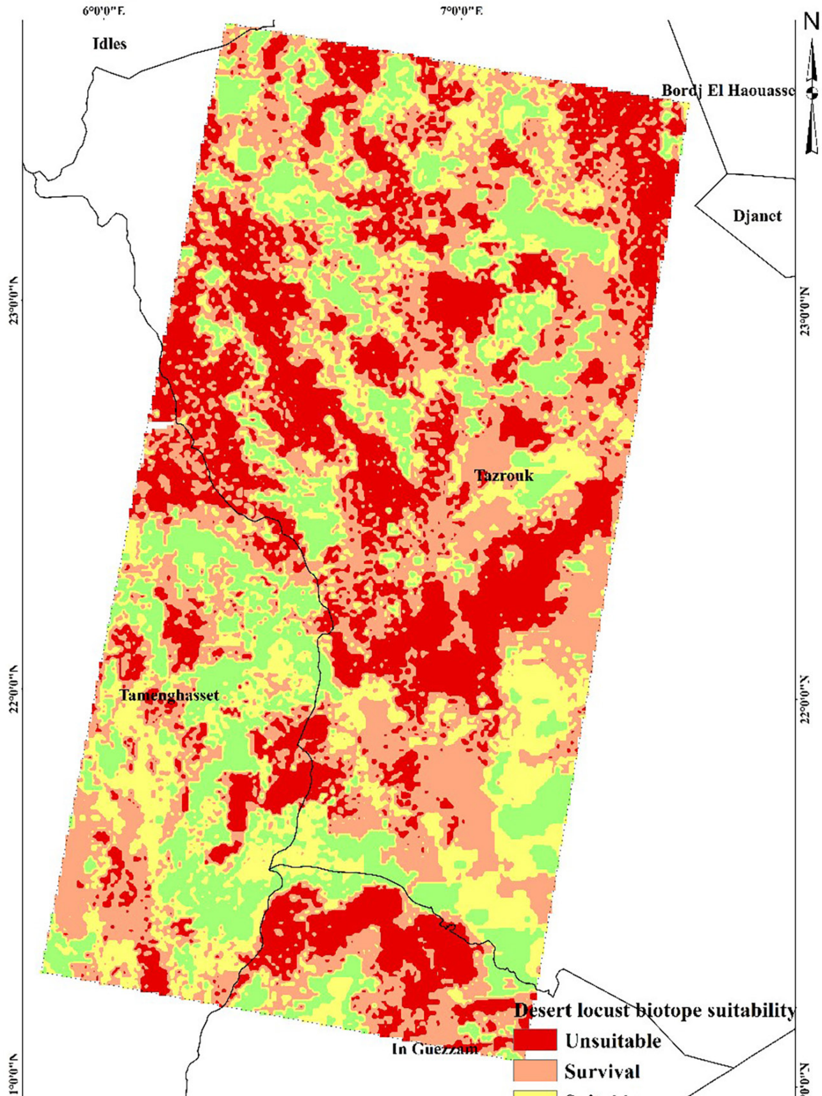

Figure 3. Final biotopes map

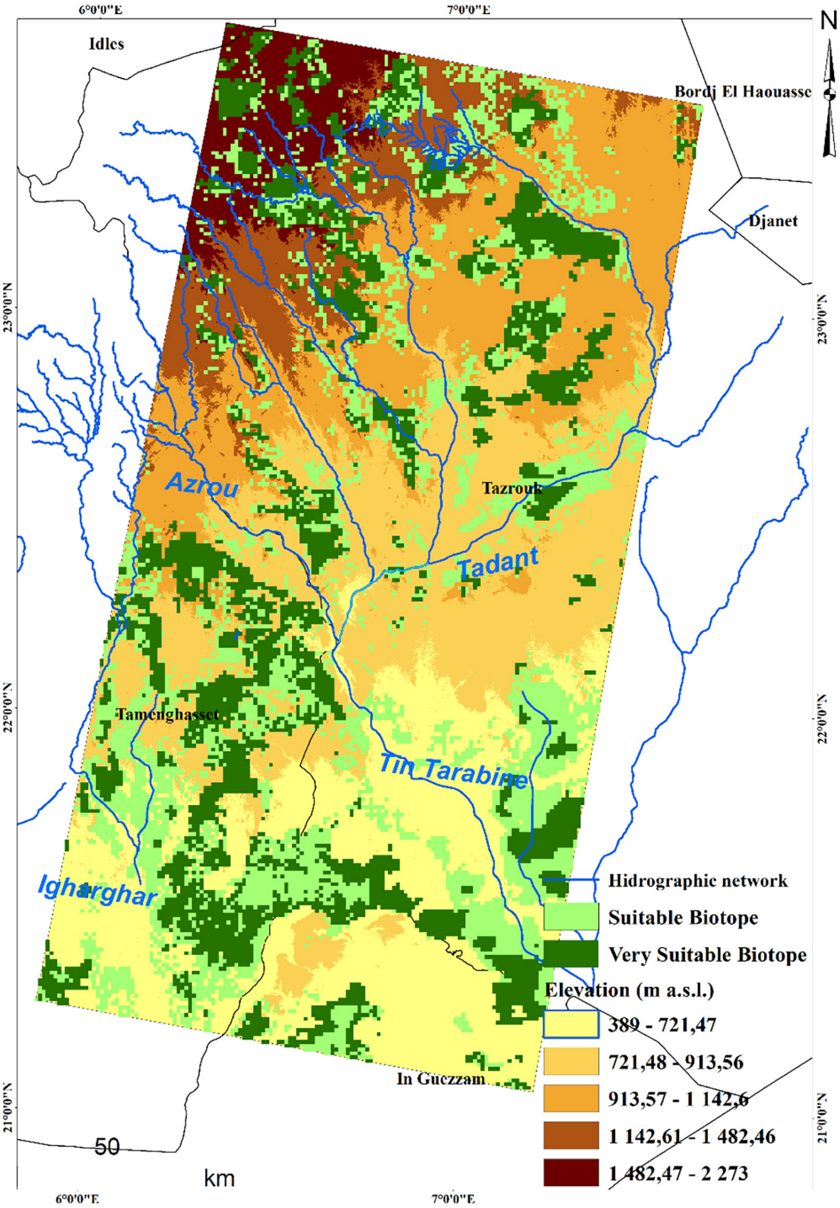

Figure 4. Suitable and unsuitable biotopes distribution according to elevation and waterways

crucial to the locust. Unsuitable habitat appears also in the south of the study area where there is a significant lack of soil humidity.

- A surviving biotope that covers almost 17661.63 km², located on medium elevations of Tarzouk region (1000 to 1700 m a.s.l.); the vegetation in this region is more abundant but water resources remain rare and distant, composed mainly by Acacia (*Acacia Phyllodineae*) and olive trees (*Olea europea*).
- A suitable biotope for reproduction and maturation that covers 9593.18 km² on low altitudes (500 to 1000 m a.s.l.) where green vegetation is a bit denser mainly on the foothills of the mountains, with available water resources as the Oueds (Valleys) coming from the Hoggars e.g "Arzou" and "Tadant" (Fig. 4) form alluvial fans that offer in rainy seasons the best conditions of breeding and eggs laying by increasing soil moisture that helps females to probe the soil and lay the eggs, enabling them to absorb sufficient moisture to complete their development[27].
- A very suitable biotope for gregarization and condensation covers a surface of 6088.17 km² (16.05%) in the regions of Inguezzam, Tamenghaset, to the Algerian-Nigerian borders on low altitude (389 to 500 m a. s. l). The oueds of "Tin tarabine" and "Igharghar" (Fig. 4) that aliment the area present the main water sources, while

the quite dense vegetation cover offers food and shelter to locusts, and ensure a rapid growth of population; also, wind direction from north to north west helps the swarms to gregarine and prepare for a potential invasion.

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