USING LANDSAT IMAGERY FOR MONITORING THE SPATIOTEMPORAL EVOLUTION OF SANDING IN DRYLAND, THE CASE OF IN-SALAH IN THE TIDIKELT (SOUTHERN ALGERIAN SAHARA)

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ABSTRACT
The exposure to sanding risk in the Tidikelt plain is particularly ascribed to its physiographic and climatic conditions, the location of agglomerations, agricultural and socioeconomic activities in a corridor of severe wind action, increases the vulnerability to the risk as a response to the relentless human pressure, which is exerted on an arid environment already subject to climatic extremes. The use of remote sensing tool and the multitemporal Landsat imagery have allowed the regional and static observation of sand accumulation forms, and also monitoring the spatiotemporal dynamics of mobile dunes during 19 years. This gradual mutation still confronted with a noticeably low resilience from the population and the authorities.
Key words: Sanding; Mobile dunes; In-Salah; Algeria; Landsat imagery.

1. INTRODUCTION

The international United Nations convention of desertification combating, defines the term desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UN, 1994). Currently, the subjected areas to desertification occupy 39.2 % of the globe, i.e. nearly 51.6×10^6 km² of degraded land, in which 4.86×10^6 km² in Africa (Thomas, 1995; Arar, 1993).
Algeria includes large arid and semi arid areas subjected to adverse impacts of desertification; 20×10^6 ha area is threatened by wind erosion, 5×10^6 ha area is already in an advanced state of degradation (Bensaid, 2006). These spaces that are part of the Algerian Sahara which covering 200×10^6 ha (80 % of the Algerian territory) have broad aptitudes to the land degradation, i.e. paleoclimate, drought, long duration of insolation and high wind activity. This translates to increased wind erosion and therefore, amplifying the sanding risk which induces not only the decline of ecosystems, but also increased the society vulnerability to climatic risks.
This is the case of the In-Salah region in southern Algerian Sahara, which offers favorable physical and climate context to wind erosion. All human and socio-economic installations in this region are located in a wind corridor of high dynamics, and then present the only stopping obstacles at the actions of moving sands, hence frequent sanding of agricultural lands, palm groves, urban agglomerations and road infrastructures.
This article focuses on the diachronic analysis of the sanding evolution in the In-Salah region using remote sensing tools. The experimental approach involves the study of spatial extension and bi-temporal evolution of mobile dunes, using multitemporal Landsat imagery; the TM scene of 1987 and ETM + of 2005. After determining the physiographic and climatic abilities to sanding in the region, we proceeded to define the various components of the

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landscape (static situation) for each Landsat scene, to finally appreciate the space elements changing during 19 years, in particular, the mobile dunes (dynamic situation).

2. PHYSIOGRAPHIC AND CLIMATIC CONTEXT OF THE STUDY AREA

Between the longitudes 26º, 28º and latitudes 2º, 3º, In-Salah region is linked administratively to the Tamanrasset province, and is part of the Tidikelt plain which is a corridor of northeast-southwest elongation (250×50 km). This topographic depression corresponds to a Mesozoic sedimentary basin located in the southern piedmont of the Tademaït tray (450 m).
The study area extends over 374 km² and takes position in the Tidikelt **(Fig. 1)**; it includes the town of In-Salah and neighboring: Sahela Foukania, Sahela Tahtania, Igostène, Hassi El-Hajar and Foggaret El-Arab. These agglomerations and palm groves sheltering 32,518 inhabitants (NOS, 2008), are parts of a monotonous landscape consisted of vast sand extents, namely Erg Sidi Moussa, the main source of sands, added to endorheic depressions (Sebkhas) occupying the lowlands in the region.

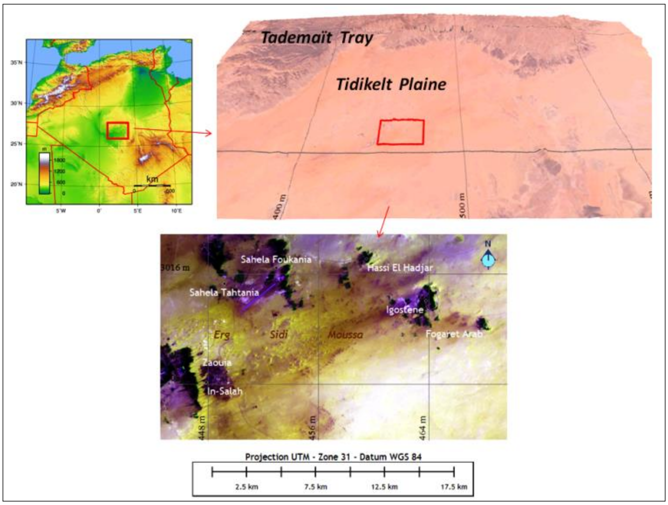

Fig. 1 Geolocation of the study area

In-Salah region is characterized by a Saharan climate of hyper-arid type; 39 years series of climatic data (In-Salah station, 1973-2012), the Demartone aridity index (1925) and the Emberger bioclimatic quotient (1932) are among the lowest values in Algeria; 0.87 and 0.05 respectively. This aridity is mostly due to the continental character of the Algerian Sahara marked by the absence of moist air masses revealing a particularly dry area. Precipitation is scarce and spatiotemporally irregular; the inter-annual normal does not exceed 31.7 mm, with an intra-annual maximum of 8 mm recorded in April **(Fig. 2)**.

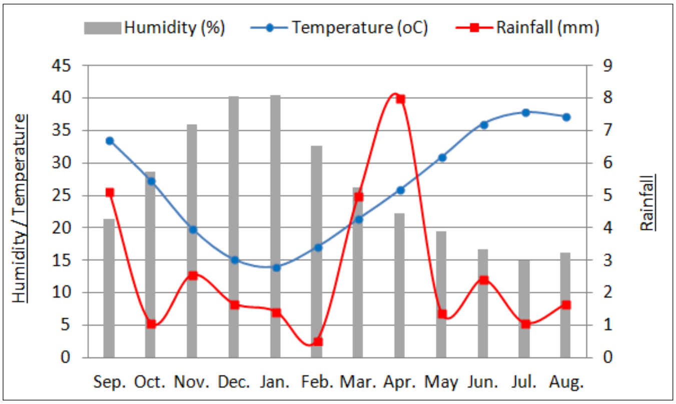

Fig. 2 Intra-annual variations in temperature, rainfall and humidity, In-Salah station, 1973-2012

With an interannuel mean temperature of 26.4 °C, the In-Salah region is among the hottest areas in Algeria. The warm season lasts more than 6 months, with a minimum of 5 ºC in January and a maximum often exceeds 45 °C in July. Duration of solar insolation exceeds 3000 hours/year, while procreating low relative humidity value (26.1 %), reaching 40 % only in January and December.

About the wind dynamics, the central Algerian Sahara (Adrar, In-Salah and Timimoune) is the windiest region in Algeria (Kasbadji Merzouk, 1999). The average wind speed can reach 5 m/s and exceed 8 m/s for the maximum values, the mean winds class (6-11 m/s) is the most frequent with 38.5 %. Also, the frequency of strong winds exceeding 11 m/s is 7 % **(Fig. 3)**. From this threshold, wind becomes efficient and may then perform abrading, transport and accumulation actions. Directions are multiples, but two dominants directions are distinguished **(Fig. 4)**: the east winds (Guebli) and northeast (continental trade wind) with the frequencies 30 % and 22 % respectively (Kerbani, 2013).

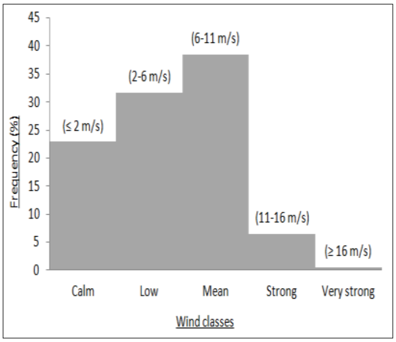

Fig. 3 Frequency distribution of wind classes, In-Salah station, 1998-2008

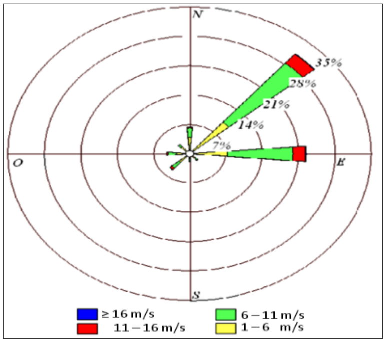

Fig. 4 Compass rose and annual distribution of wind directions, In-Salah station 1998-2008 (Kerbani, 2013)

In general, the study area is very favorable to the wind erosion and sanding, since it offers dry soils, flat and bare lands and favorable climatic context (FAO, 2010). The linear dunes and barchans (20 meters) of Erg Sidi Moussa are the predominant accumulation forms and confirm the importance of the wind dynamics occurred in the region. The direction of frequent and efficient wind is in right coincidence with the Tidikelt elongation direction, so all human and socio-economic installations are located in a high wind dynamics corridor, and subsequently represent the only obstacles to the shifting sands. This is why the frequent and constant sanding of palm groves, habitations and infrastructures **(Fig. 5, 6)**.

Fig. 5 One of silted habitats in Zaouïa, In-Salah (photo crstra, 2013)

Fig. 6 Sanding of palm grove in In-Salah (photo crstra, 2013)

3. DATA AND METHODS

The characterization of physiographic context of In-Salah region required the use of different cartographic supports; topographical map of In-Salah sheet NG 31-2 at a scale of 1/250.000 (U.S. Army, 1953), geological map (Meyendorff and Follot, 1951) at a scale of 1/500.000, Google earth, etc. Also, the climatic study was based on the series of rainfall, temperature, wind and humidity, from the National Office of Meteorology for the periods 1973-2012 and 1998-2008.

The monitoring of the sanding evolution at In-Salah required processing of multitemporal Landsat 5 and 7 images, corresponding to the scene center 194/041. The scenes 205-566 and 220-783 are acquired respectively on March 3. 1987 and April 13. 2005, and are remotely sensed by the TM and ETM + sensors covering a period of 19 years. Their acquisition is freely available via the web portal "Global Land Cover Facility". The choice of the Landsat satellite was due to the medium spatial resolution of images (30 m), allowing analysis on a regional scale. Selection of images depended mainly on their availability, as their quality and spectral resolution (number of bands). These Landsat images were orthorectified, georeferenced, radiometrically corrected and projected in WGS 84, according to the UTM system zone 31, Clarke ellipsoid 1880.

Moreover, detection of the space changing in In-Salah had required the images processing under the ENVI 4.7 software:

- The choice of multispectral bands for both scenes was achieved by using channel 1 (blue), 3 (red) and 4 (near infrared) for a better visualization of the space elements.
- The extraction of the study area had allowed obtaining two scenes of equal size (836×497 pixel) covering an area of 374 km².
- Visualization of the colour compositions than, determination of the space elements.
- Sampling on field assisted by Google earth, location of test plots on the study area and analysis of their separability, by calculating the transformed divergence separability (Richards, 1999) for each Landsat scene, this test gave significant results for scenes TM

(Table 1) and ETM +; the values were around 2.00 in the majority, meaning the good independence of the obtained classes.

- Classification of the images using the supervised mode, and the maximum likelihood method.
- Post classification and developing of static map of the space elements, by determining the occupied area for each landscape unit corresponding to 1987 and 2005.
- Extraction and superposing the "mobile dunes" vector layer for the two scenes, to obtain the dynamic map of the mobile dunes evolution from 1987 to 2005.
- Appreciation of the space elements dynamics by calculating the changing rate (FAO, 1996), expressed as:

$$Ic\ (\%) = \left[1 - \left(\frac{A1}{A2}\right)^{1/n}\right] \times 100$$

Where A1 and A2 correspond to the surface area of a class at the beginning and the end of the period, and n is the number of years of this period.

Table 1. Test of transformed divergence separability for the scene TM, In-Salah 1987

	MD	SE	HBT	ST	BS	MS	PG	AE
MD								
SE	1,78							
HBT	2,00	2,00						
ST	1,95	1,83	2,00					
BS	1,85	1,81	1,99	1,99				
MS	2,00	2,00	1,97	2,00	2,00			
PG	2,00	2,00	2,00	2,00	2,00	2,00		
AE	2,00	1,99	2,00	2,00	2,00	2,00	2,00	

MD: Mobile Dunes ; SE: Sand Erg ; HBT: Habitation
ST: Sand topping ; BS: Bare soil ; MS: Moist soil; PG: Palme grove
AE: Agricultural Enhancement.

4. RESULTS AND DISCUSSION

The visual analysis of the bands trichromy (1-3-4) of each Landsat scenes was particularly significant and represents the field reality. The land investigation has allowed the distinction of the main units of land use in the study area, according to the different degrees of reflectance. We distinguished palm groves, habitations, moist soil, bare soil, and sand forms (erg, mobile dunes and sand toppings) that appear yellow. Maps resulting from the supervised classification by the method of maximum likelihood, allowed the identification of space components in 1987 and 2005 (Table 2).

Table 2. Comparison of the space components at In-Salah on 1987 and 2005

Year / Space component	1987		2005	
	Km²	%	Km²	%
Palm grove	10	3	20	5
Habitations	8	2	14	4
Mobile dunes	23	6	26	7
Sand Erg	89	24	151	40
Sand topping	119	32	29	8
Bare soil	114	31	109	29
Agricultural enhancement	4	1	0	0
Moist soils	8	2	25	7
Total	374	100	374	100

Bare soils and bedrock outcrops are generally located in north, and correspond to the Tademaït tray glacis. The field slopes promote the erosion actions more than accumulation. Urban areas such as palm groves occupy the low parts of the plain, because of the availability of underground water resources (albian aquifer), evermore accompanied by the moist soils resulting from the palms irrigation and waste water.

Sands and mobile dunes from Erg Sidi Moussa occupy large areas in the region, they move in the direction of the efficient winds and deposited on the eastern sides of all palm groves and agglomerations especially In-Salah; wich is the most vulnerable agglomeration The severity of sanding is less important in the other agglomerations, because of their offset position from the low lands of the plain **(Fig. 7a, 7b)**.

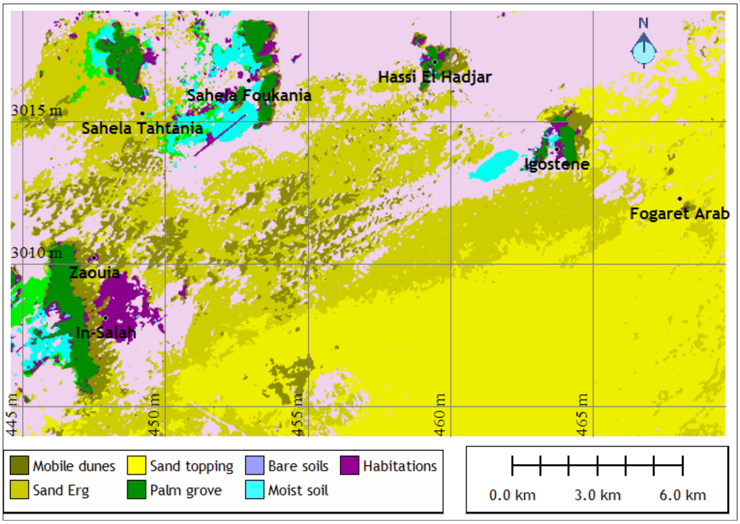

Fig. 7a Classified Landsat image, In-Salah 1987

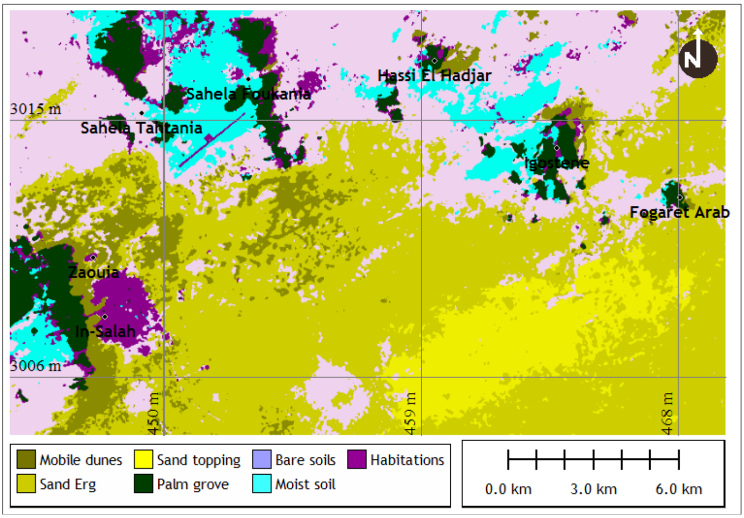

Fig. 7b Classified Landsat image, In-Salah 2005

Also, the diachronic monitoring of the landscape elements shows that the region has undergone significant changes, which results in increasing most of the space units (Table 3).

Table 3. Changing rate of some space components, In-Salah 1987 to 2005

Land use	**area (km²)**		**FAO changing rate (%)**
	1987	**2005**	
Moist soil	7,7	25,3	6,1 (increasing)
Palm grove	9,7	19,5	3,6 (increasing)
Habitations	7,7	13,6	3,0 (increasing)
Mobile dunes	22,9	25,8	0,6 (increasing)

The areas occupied by moist soils are characterized by an exceptional changing rate (6.1 %), this is mainly due to the expansion of date palm areas (3.6 %) being the principal crop for the local population (edaphic, climatic and socio economic raisons). Therefore, this leads to more moist surfaces resulting from drainage. Additionally, because of the demographic pressure, built-up areas have increased from 7.7 km² in 1987 to 13.6 km² in 2005, representing a growth rate of 3 %. The In-Salah agglomeration in particular has expanded in all directions. Therefore, several new buildings were buried in a short time. In the same way, the evolution of sandy areas is clearly visible; the surface of the mobile dunes increases from 22.9 km² in 1987 to 25.8 km² in 2005 **(Fig. 8)**, either a growth rate of 0.6 %.

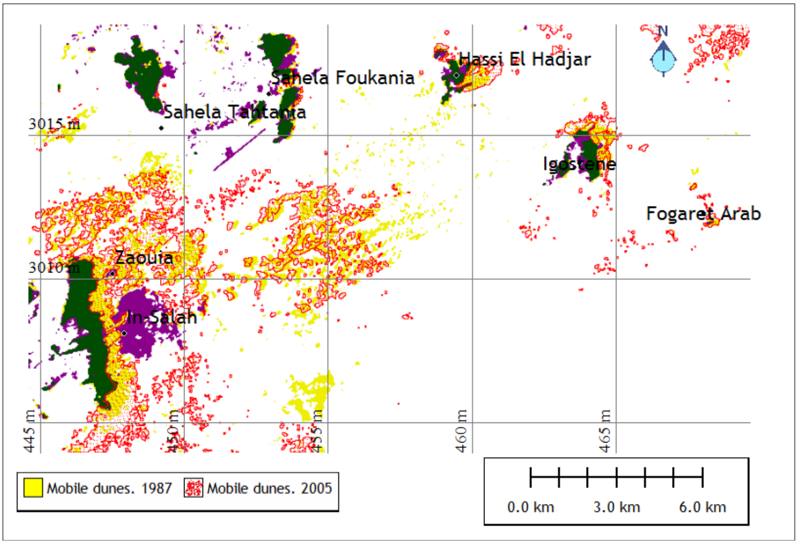

Fig. 8 Spatial evolution of mobile dunes in In-Salah, 1987-2005

This high increase is mainly due to the anterior climatic factors that favored the sand dynamics, the decrease of the relative humidity (26.9 to 25.9 %) and the increase of the temperature (25.9 to 26.5 °C) made the soils more dries and more able to mobilization. Also the increasing of the maximum wind speed (6.4 to 9.4 m/s) has significantly accentuated the sand transport capacity (Table 4).

Table 4. Explanatory elements of the mobile dunes expansion, In-Salah from 1987 to 2005

Multidate comparison parameters	1973 to 1987	1988 to 2005
Mobile dunes area (km²)	22,9 (1987)	25,8 (2005)
Relative humidity (%)	26,9	25,9
Temperatures (oC)	25,9	26,5
Maximum wind speed (m/s)	6,4	9,4

5. CONCLUSION

The risk of sanding in the Tidikelt plain is related to different physical and climatic factors which converge to the acceleration of wind activities. However, the unfortunate installation of urban, agricultural and industrial structures in a high risk area has greatly increased the vulnerability.

The use of satellite imagery highlights a progressive and continuous dynamics of the sand expanses in the Tidikelt, representing subsequently real and perceptible risk that affects all aspects of life in In-Salah region. The substantial and permanent loss of crops, habitats and infrastructures is in constant aggravation and reveals the low resilience of the population in terms of risk. Several actions against land sanding were launched by the different institutions and citizens which led to failure for different reasons; inappropriate choice of control techniques, of land to be developed or even plantation, still the main and real handicaps to an efficient and durable protection.

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