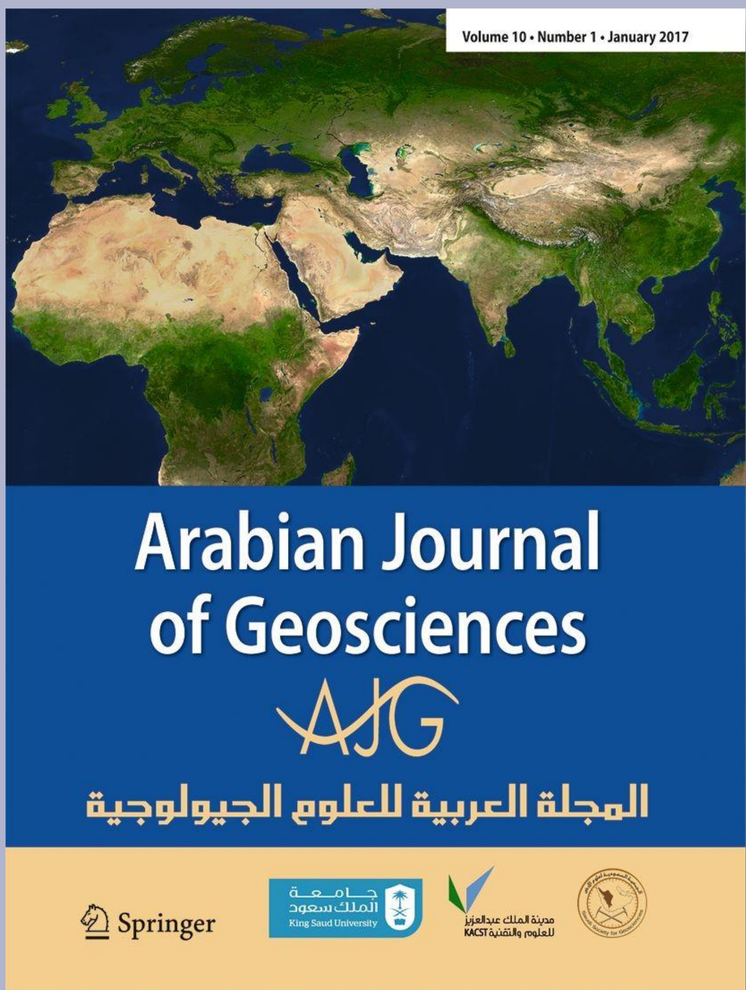
Assessment of the Aeolian sand dynamics in the region of Ain Sefra (Western Algeria), using wind data and satellite imagery

Said Bouarfa, Sid Ahmed Bellal & Mohammed Nadir Belmahi



Arabian Journal of Geosciences

ISSN 1866-7511
Volume 11
Number 3

Arab J Geosci (2018) 11:1-16
DOI 10.1007/s12517-017-3346-9
DOI 10.1007/s12517-018-3606-3

Arabian Journal of Geosciences (2018) 11:240
https://doi.org/10.1007/s12517-018-3606-3

CORRECTION

Correction to: Assessment of the Aeolian sand dynamics in the region of Ain-Sefra (Western Algeria), using wind data and satellite imagery

Said Bouarfa[1] · Sid Ahmed Bellal[1] · Mohammed Nadir Belmahi[1]

Correction to: Arabian Journal of Geosciences (2018) 11: 56.
https://doi.org/10.1007/s12517-017-3346-9

The article which was recently published contained error. The corresponding author missed to add "Mohammed Nadir Belmahi" in the list of authors. Given in this article is the complete list of authors.

The online version of the original article can be found at https://doi.org/10.1007/s12517-017-3346-9

✉ Said Bouarfa
Said_bouarfa_07@hotmail.com

Sid Ahmed Bellal
bellalsid@yahoo.fr

Mohammed Nadir Belmahi
arcgis@outlook.fr

[1] University of Oran 2 Mohamed ben Ahmed, Station for Experimentation and Monitoring in the Middle Steppic Taouiala, B.P 1015 El M'naouer, 31000 Oran, Algeria

Published online: 22 May 2018

Arabian Journal of Geosciences (2018) 11: 56
https://doi.org/10.1007/s12517-017-3346-9

ORIGINAL PAPER

Assessment of the Aeolian sand dynamics in the region of Ain Sefra (Western Algeria), using wind data and satellite imagery

Said Bouarfa[1] · Sid Ahmed Bellal[1]

Received: 19 May 2017 / Accepted: 11 December 2017 / Published online: 29 January 2018

Abstract
The region of Ain Sefra is an arid region suffering from sand encroachment. In this study, we are calculating the shifted sand quantity and efficient wind directions during a period of 30 years (1985 to 2015) in order to classify the danger. The study shows that efficient winds in the region are characterized by their potential drift estimated at 220 till 329. This classifies the region as medium. Besides, the resultant drift potential is 76 to 99 with a migration coefficient of 0.3 which gives a medium classification to the zone and proves the Aeolian erosion complex system and its interrelation with other factors. Efficient winds generally blow from South-west to North-east with an angle of 234°. Furthermore, there are other directions causing sand drifting. Sand movement quantity is estimated between 23.03 and 15,224 m^3/m/year according to effective wind threshold speed, which is 5 to 6 m/s. Autumn is the period when sand mobility is higher, but it decreases in winter. On the other hand, sand potential movement was well shown through satellite imagery between 1985 and 2015. Indeed, it closely corresponded to the previous study. It showed sand movement direction from South-west to North-east, and sand surface increase reached 16.44% of the global zone surface. Whereas, it decreased − 2.5% between 1985 and 2015. There is an important concentration of sand accumulation under the western mountain foothills along which sand moves. This shows that the ground particularities play a crucial role in this phenomenon.

Keywords Arid region · Drift potential · Dune form · Effective winds · Sand · Sand encroachment

Introduction

The area of the arid zones in Algeria according to the Houerou (1995) is 216,000 km^2 and 386,000 km^2 of superior arid zones (< 100 mm) which occupies 89.5% of the total area of Algeria.

Arid areas in Algeria are characterized by their ecosystem fragility. They are the first zones subject to sand encroachment and degradation phenomenon. Sand encroachment, which is very complex and intrinsically linked to extra zone factors, is both at the climatic level and at the level of sand Aeolian transport regional processes between the source zone and deposit one. The understanding of the phenomenon was possible due to the combined effect of edaphic climatic actions, geological and geomorphologic factors. Wind stayed the principal element responsible for shaping the relief forms (Mainguet 2012), rapid and intensive degradation of the vegetal covering make it easy for wind to carry the sandy material. Next, this carried material is accumulated in other areas, giving rise to the formation of different sand-hill accumulations and starting processes of sand encroachment (Ouessar et al. 2006) where wind rate, frequency, magnitude, and direction are determining factors for form, dynamism, and sand dune migration and accumulation (Cooke and Warren 1973; Lancaster 1988; Pye and Tsoar 2008); accumulations can put in danger urban sites and socio economical infrastructures (Khalaf and Al-Ajmi 1993; Nouar et al. 2014).

We focused on the region of Ain Sefra since it is located in arid zones and present a typical example where sand encroachment is one of the major preoccupations of local collectivities. In this study, our interest is put on wind effects on sandy movements and the region dune modals: we should distinguish between "wind rates" and "potential sand movement." Anemometric data was collected in Ain Sefra

✉ Said Bouarfa
Said_bouarfa_07@hotmail.com

Sid Ahmed Bellal
bellalsid@yahoo.fr

[1] University of Oran 2 Mohamed ben Ahmed, Station for Experimentation and Monitoring in the Middle Steppic Taouiala, B.P 1015 El M'naouer, 31000 Oran, Algeria

station according to 16 directions and 8 daily observation readings during 30 consecutive years, from 1985 to 2015. The data was treated to estimate the removed sand quantity and evaluate sand encroachment phenomenon.

The second method, which is based on the treatment and interpretation of satellite images aimed to locate the sandy accumulation areas, follow sand movement, and to detect the changes of different dates (1985–2005–2015). Many studies used remote sensing to follow Aeolian dynamism and sand encroachment. Taïbi et al. (2005) used Landsat images MSS of 1977 and TM of 1989. Besides, they used SAR-ERS of 92 and 93 images to realize a diachronic study of three principal themes: thick and steppe vegetation and the sandy formations in five sites of the southern Saharian Atlas piedmont. Bensaid (2006) used satellite images to study sand encroachment in the wilayah of Naama (Algeria) in arid zone. To separate sand-covered areas (accumulation and transfer zones), Benalla et al. (2003) proved dunes advance in many South-east Moroccan areas through the use of high space resolution military and civil images to understand the progression of dune edifices along a 4-year period.

Consequently, transported sand is a real threat for built areas and socio-economic infrastructure. The objective of this work is to evaluate the migration of sand and to try to understand the mechanics of wind erosion in the region, in order to find solutions to encroachment on the sand.

Data and methods

Study area

The region of Ain sefra is situated in the Ksour mounts, which are part of the South-west Oranese high plains, forming the occidental part of the Algerian Atlasic chain. It forms the extension towards the east of the high Moroccan atlas. It is limited by the Oranese high plains in the north, the lower plateau, and the occidental Erg in the south, djebel (djebel = mountain) Amour in the east, and the high atlas in the west.

The Ksour mounts is a rather high mountainous region formed by extended chain mounts towards the South-west and North-east. The altitude of some summits reaches 2000 m such as Aissa, Mzi, Mir El djebel, and Mekter djebel. The passage through the Saharian platform is brutal, and the uneven mount can reach 1200 m. These chain mounts are generally separated by extended shallows that make movement easy between the north and south, and the east and west (Fig. 1).

This long mountainous barrier that extends in more than 150 km is land-marked all along of its North-west declivity by the huge accidental North Atlassic. Parallel to this mountainous barrier, several chain mounts are arranged in parallel series in a South-west to a North-east direction, constituting the Ksour mounts (djebel Saiga, Mir el djebel Mekter, and Aissa djebel…).

Fig. 1 **a** Location map of the study area. **b** The study area reliefs. **c** The study area draped the DTM by a picture in trichrome (742). **d** The study area in 3D by image high resolution ▶

The watershed basin of Ain Sefra is constituted by two oueds (dry rivers) Tirkount a Breij which are situated in the South-west of the Algerian territory, in the west of Ain Sefra town.

The two oueds cross through the town of Ain sefra and meet in the center of the urban area to form Ain Sefra oued; downward, we find the Reghouiba oued forming the upstream of the huge Saharian watershed, which is Namous that empty its water in the Great Occidental Erg.

The region offers an area of mountains of oasis character, but whose mountains are bare, eroded, and often rocky, and a pre-Saharan zone, which constitutes towards the Western Erg the prolongation of the Ksour Mountains, whose climate is at the limit of the arid. A continental sub-arid to semi-arid climate characterized by insufficient rainfall of less than 200 mm and strong seasonal and annual variations, further marked by climate change in recent decades; in the region of the high plains, the soils are shallow and less fertile with a material content organic matter that does not pass the 3% (Aidoud and Touffet 1996). All it takes is a simple rainfall for the soil to freeze, and a film of a few millimeters thick develops quickly. This butane film leads to a decrease in water reserves in the soil and to an increase in runoff.

A geological structure with fragile and erosion-sensitive surface formations, which, combined with climatic effects and insufficient perennial cover, resulted in soil of poor quality for agriculture, and steppe vegetation subject to the perverse effects of climate and overgrazing, which is increasingly shrinking to give way to erosion and sand encroachment (Fig. 1).

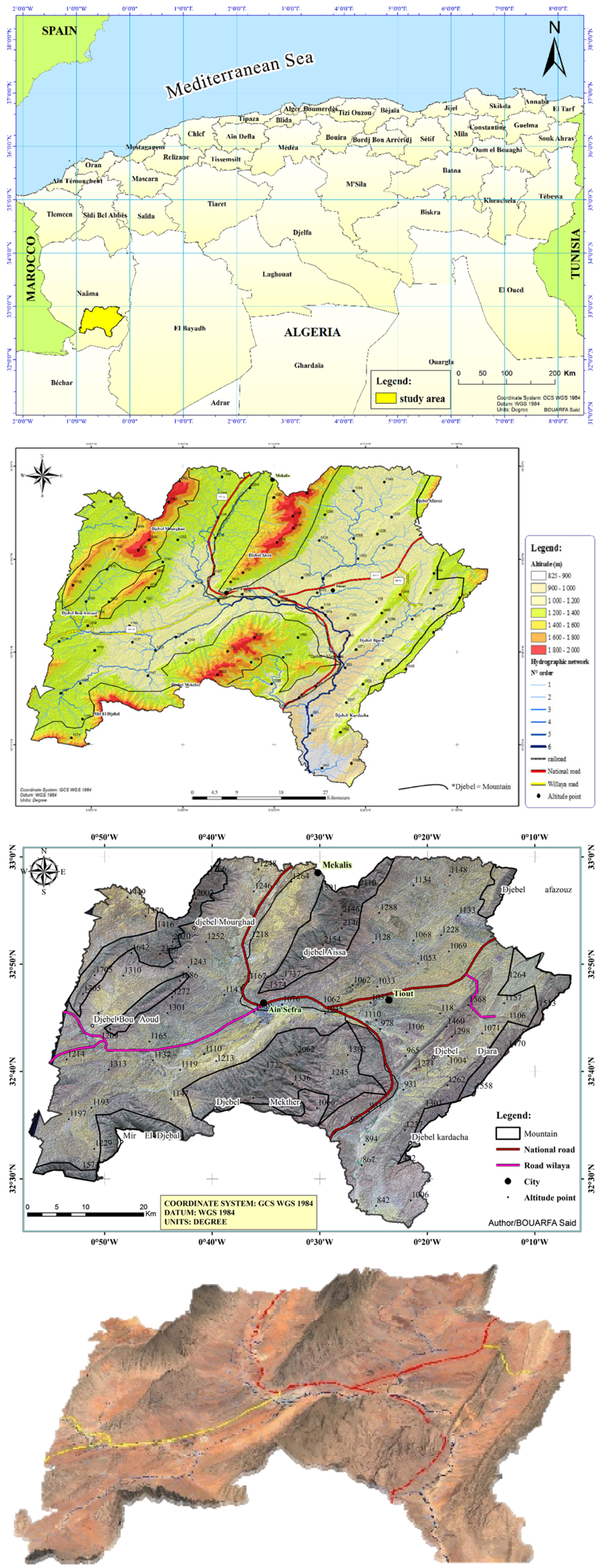
Wind data

Sand migration is one of the major processes of arid regions external geodynamic. Wind carries only the available material. In other words, it can carry material with movable characteristics (Venard 2012). The dunes form, and orientation in the desert depends mainly on the force and orientation of the wind (Dubief 1953).

The study of the wind efficiency rate, i.e., the wind aptitude to detach and carry a sand article, with a speed higher than 4 m/s that was chosen by Y. Callot (1987).

To study the wind rate, we needed the control of wind speed in 16 directions during a period with eight records per day (0, 3, 6, 9, 12, 15, 18, 21 h).

In Ain Sefra, there are nearly 876,007 distributed observations in 30 years × 365 days from 1985 to 2015. The observations are gathered together in speed classes as follows: the speed class under 4 m/s represents low light wind, the one between 4 and 6 m/s represents the effective winds, and the speed class more than 6 m/s represents the efficient moderate and strong


SPAIN
Mediterranean Sea
N
MAROCCO
TUNISIA
ALGERIA
Alger
Boumerdès
Tizi Ouzou
Béjaia
Jijel
Skikda
Annaba
El Tarf
Tipaza
Blida
Chlef
Ain Defla
Médéa
Bouira
Bordj Bou Arréridj
Sétif
Mila
Constantine
Guelma
Souk Ahras
Oum el Bouaghi
Mostaganem
Relizane
Tissemsilt
Oran
Ain Témouchent
Mascara
M'Sila
Batna
Khenchela
Tébessa
Tlemcen
Sidi Bel Abbès
Saïda
Tiaret
Biskra
Djelfa
Laghouat
El Oued
Naâma
El Bayadh
Ghardaïa
Ouargla
Béchar
Adrar
Legend:
study area
0 50 100 200 Km
Legend:
Altitude (m)
825 - 900
900 - 1 000
1 000 - 1 200
1 200 - 1 400
1 400 - 1 600
1 600 - 1 800
1 800 - 2 000
Hydrographic network
N° order
1
2
3
4
5
6
railroad
National road
Willaya road
Altitude point
*Djebel = Mountain
0°50'W
0°40'W
0°30'W
0°20'W
0°10'W
33°0'N
32°50'N
32°40'N
32°30'N
Mekalis
Djebel
afazouz
djebel Mourghad
djebel Aissa
Tiout
Ain Sefra
Djebel Bou Aoud
Djebel
Djara
Djebel
Mekther
Mir El Djebal
Djebel kardacha
Legend:
Mountain
National road
Road wilaya
City
Altitude point
0 5 10 20 Km
COORDINATE SYSTEM: GCS WGS 1984
DATUM: WGS 1984
UNITS: DEGREE
Author/BOUARFA Said

wind. The wind data given by the National Office of Meteorology (N.O.M) has been corrected.

Wind data processing

The relation between the wind force and sand movement is shown; however, there is not necessarily a direct relation between great frequencies and great wind forces.

The wind-recorded observations of Ain Sefra meteorological station cover long periods (1985–2015). Using a software program called sand of B. Shopy (1985), they are represented in a simple diagram with vectors representing sand movement. The laboratory readings of wind movement speed have shown a wind speed between 4 and 6.5 m/s depending on the considered milieu characteristics (Oulehri 1992). According to the authors who have already studied Aeolian sand potential movement, the extraction speed (VI) varies between 4 and 6.25 m/s (wind speed at 10 m height). Therefore, we can quote: R. A. Bagnold (1953), *V*t = 4.4 m/s; R. A. Bagnold (1954), VI = 6.25 m/s; Fryberger and Dean (1979), *V*t = 6.17 m/s; and N. Lancaster (1982), *V*t = 4 m/s.

To know the average diameter of sand particles, we did the granulometric analysis of 11 samples, considering the average sand diameter in the region of Ain Sefra is between 0.20 and 0.25 mm, according to R. A. Bagnold graph (1941) that gives a theoretical upper speed of 20 cm/s at the soil level which is 5 m/s to 10 m height for 0.20 mm and 6 m/s for 0.25 mm.

Without giving more explanation to the threshold velocity value, we consider 5 and 6 m/s as a *V*t value. Also, the sand drift potential (SDP) is calculated with those two threshold velocities, before selecting the one appropriate for reality.

The software program « Sable » was used to calculate the sand movement coefficients and to treat the wind data. The extraction minimal speed or threshold velocity considered were (5 and 6 m/s) Y. Mainguet (1978).

The software program of B. Chopy (1987) which is programmed according to the Lettau formula (1967) and made easier by Fryberger and Dean (1979) permits us to define the following: transport capacity or drift potential (*DP*) and the resultant drift direction (*RDD*), and the unidirectional index (RDP/DP) is the ratio of the resultant drift potential (RDP) to the drift potential; this index value ranges from 0 to 1. In addition, it reflects the effective wind directional variability, so that lower *RDP/DP* values indicate significant directional variability of the effective winds, while higher values indicate that the wind blows from the same direction.

The software relies on the Lettau equation (1969) and made easier by Fryberger and Dean (1979) that proposes a simplified formula taking into account the natural milieu complexity and which does not evaluate the transported sand quantity but sand potential extraction. He considered the extraction speed as

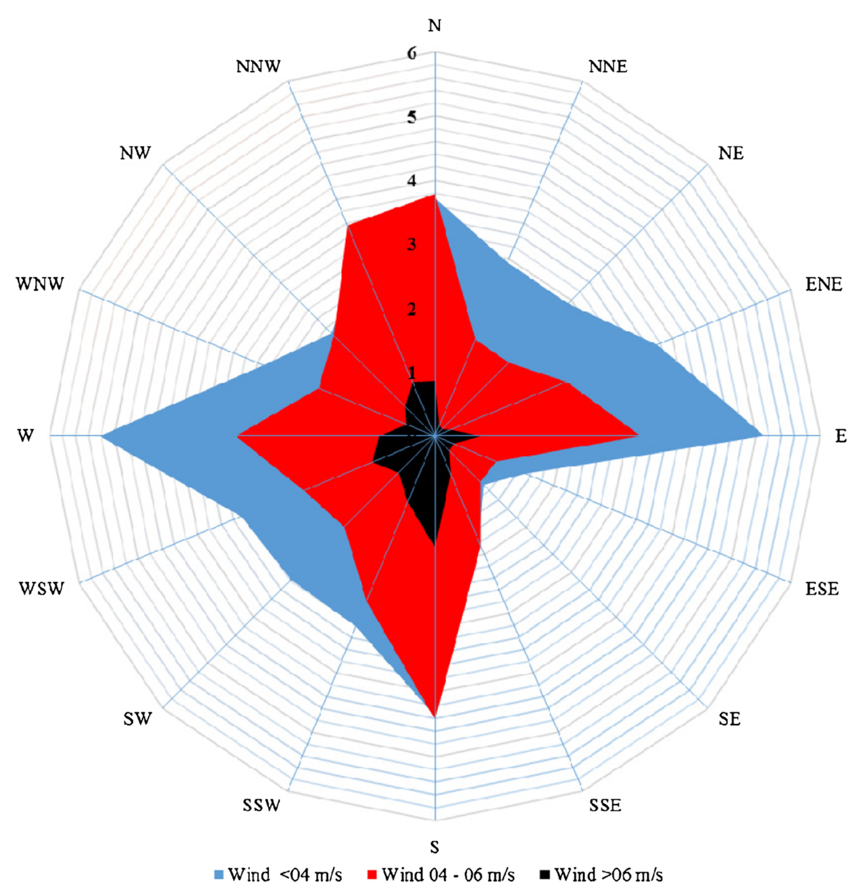


Fig. 2 Wind rose diagram showing the directional and frequency variability of all wind speed categories' percentage, from the station Ain sefra airport. Similar to the whole period 1985–2015

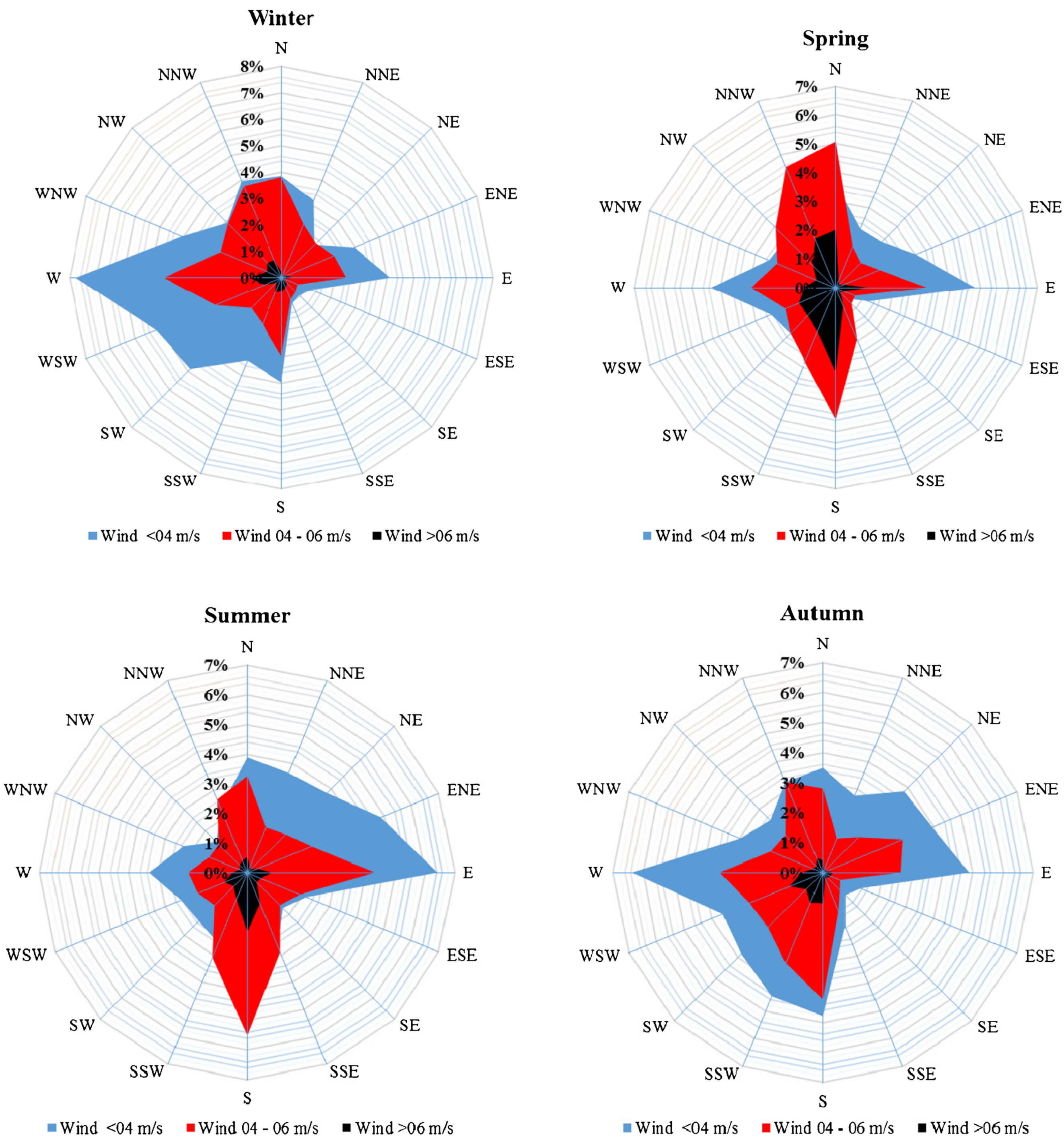


Fig. 3 Winds' rose diagram distribution of the seasonal directional and frequency variability of all wind speed categories' percentage, from the station Ain sefra airport for the period 1985–2015

being proportional to wind speed at a given height. So, it is possible to generalize a formula that evaluates sand potential extraction as follows:

$$q = V^{*2}\left(V^{*}-Vt\right)C'' \times S/g \qquad (1)$$

with q, transported sand quantity; V^*, wind speed; Vt, threshold velocity (sand minimal speed extraction); S, air density; g, gravity constancy—empirical constancy based on particle form, and/or $C'' = C'\ (£\ /\ £\ *)^n$ where C', sand universal constancy (= 6′7); £, transported sand particles diameter; £*, 0.25 mm (standard diameter); and N, empirical constancy. Fryberger simplified this equation to

$$q = V^2(V-Vt) \qquad (2)$$

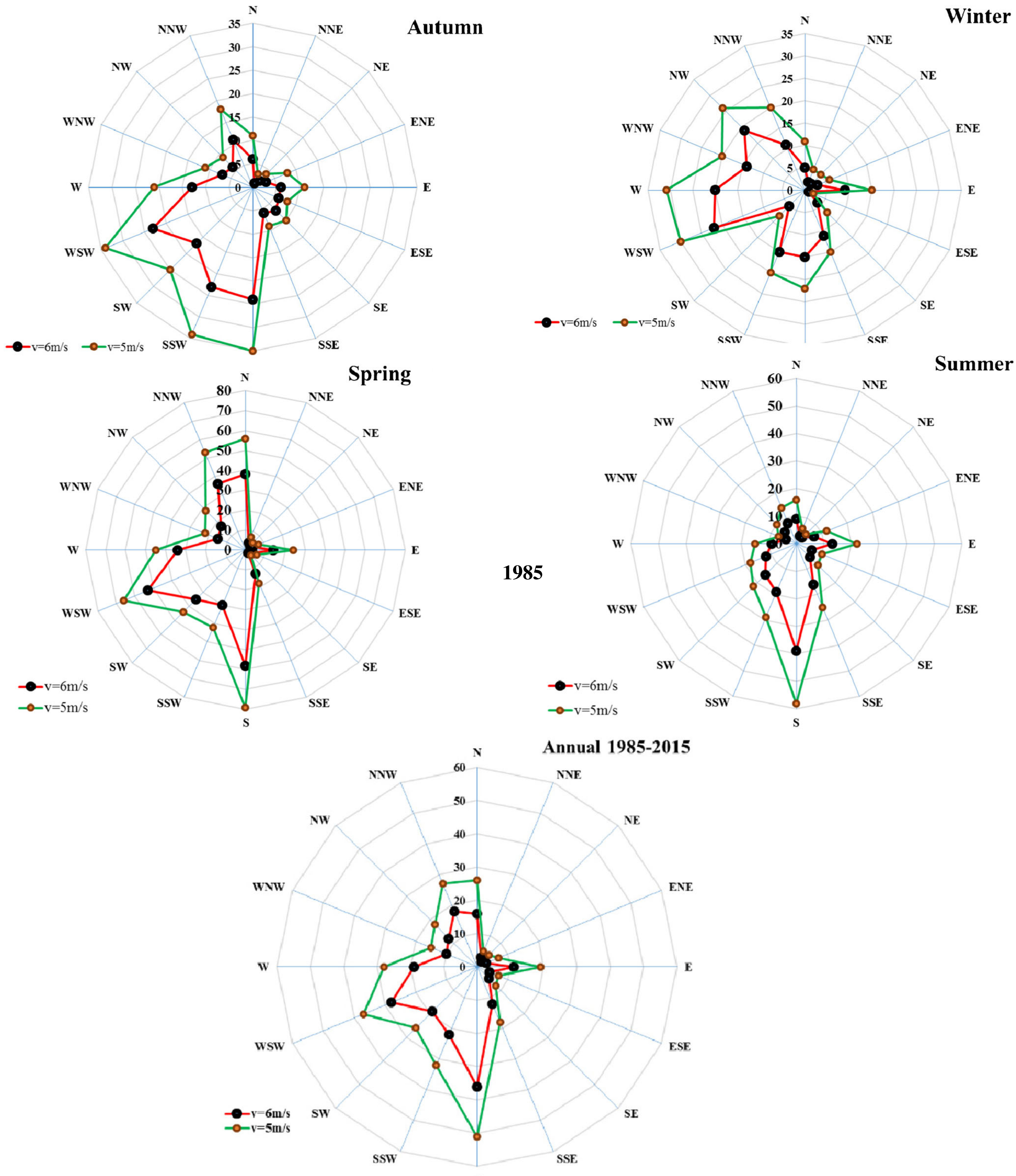


Fig. 4 Seasonal and annual sand roses of drift potential in the region of Ain Sefra during the period 1985–2015

with *V*, 10 m height wind speed (in Knot) and *V*t, 10 m height threshold velocity.

The estimation of sand drift potential in vectorial unity, Fryberger and Dean (1979) made the estimation of sand drift potential possible in m^3/m/an or more in kg/m/an, due to the use of equations that permit the correlation of the transport capacity or drift potential and the moved sand volume. A shift from a theoretical operation to a volume or mass estimation of

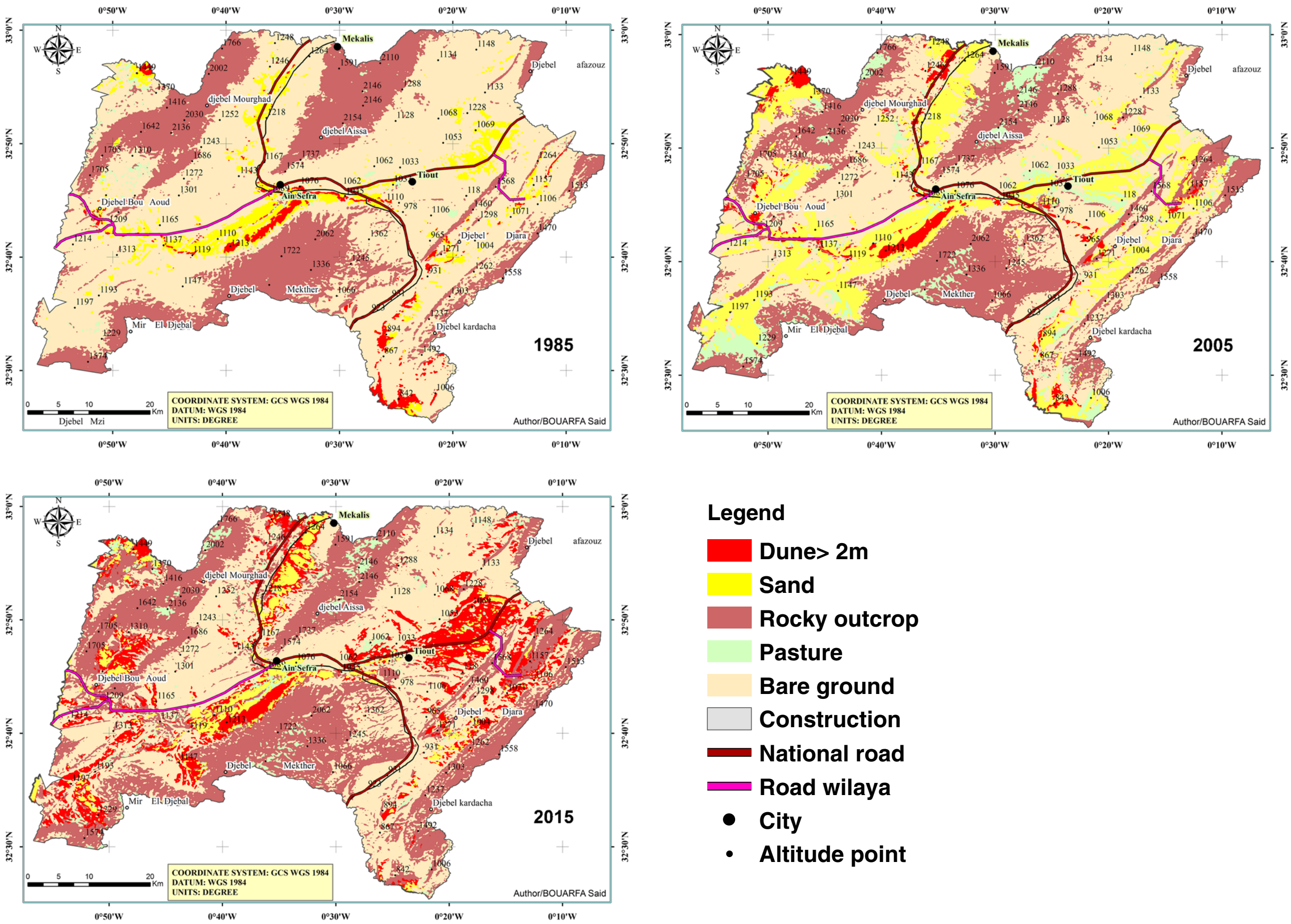


Fig. 5 Classification map on 1985–2005–2015 (in six classes: Dune > 2 m, sand, rocky outcrop, bare ground, pasture, and construction) and wind rose of drift potential 1985–2015

a transported material through a given section and during a given period is necessary.

The equivalent in m^3/m/year of a (DP) in « vectorial unity » varies according to the quantification equation and the used parameter values (rugosity coefficient, etc.…), but this equivalent is always proportional (DP).

A sand mass occupies a volume in a dig and with a test tube; sand is over wetted with water and added a volume (V), adding more water till it covers the sediment surface.

Therefore, sand drift potential in volume (q) can be converted into mass (Q) in (kg/m). A straight correlation in accordance with the previous equation of Lettau (1969) converts the CT to UV to a Q estimation of sand drift potential in m^3/m/an (sand volume through a section of 1 m and per year) (Callot and Oulehri 1996).

A—sand transport capacities or the drift potential amount According to the strong winds' importance in the region, this coefficient permits to distinguish the high-energy milieu where the coefficient is superior to 400, in a medium energy between 400 and 200 and in a weak energy where it is inferior than 200.

B—the resultant drift potential This coefficient is the vector of the potential migration force of the 16 directions, so the resultant of the transport capacity in a vectorial amount forms.

C—the resultant drift direction The medium orientation angle indicates sand migration direction; it represents the resultant vector of sand migration compass card.

The resultant direction and its resultant migration potential are of great importance since it provides information about the direction that wind should take to migrate which can be compared to soil or air photography or to a satellite image.

D—directional variability index It is the conformity between the two coefficients (RDP/DP); this conformity indicates the oriented character of sand movement. This coefficient is considered as the following:

high when superior to 0.8 and produced in long distances of a sand transport. Medium when it is between 0.8 and 0.3 and always producing sand transport in long distances. Weak when inferior to 0.3. In this case, winds have a tendency to blow in all directions and stir sand without really moving it (sand mobility without important movement).

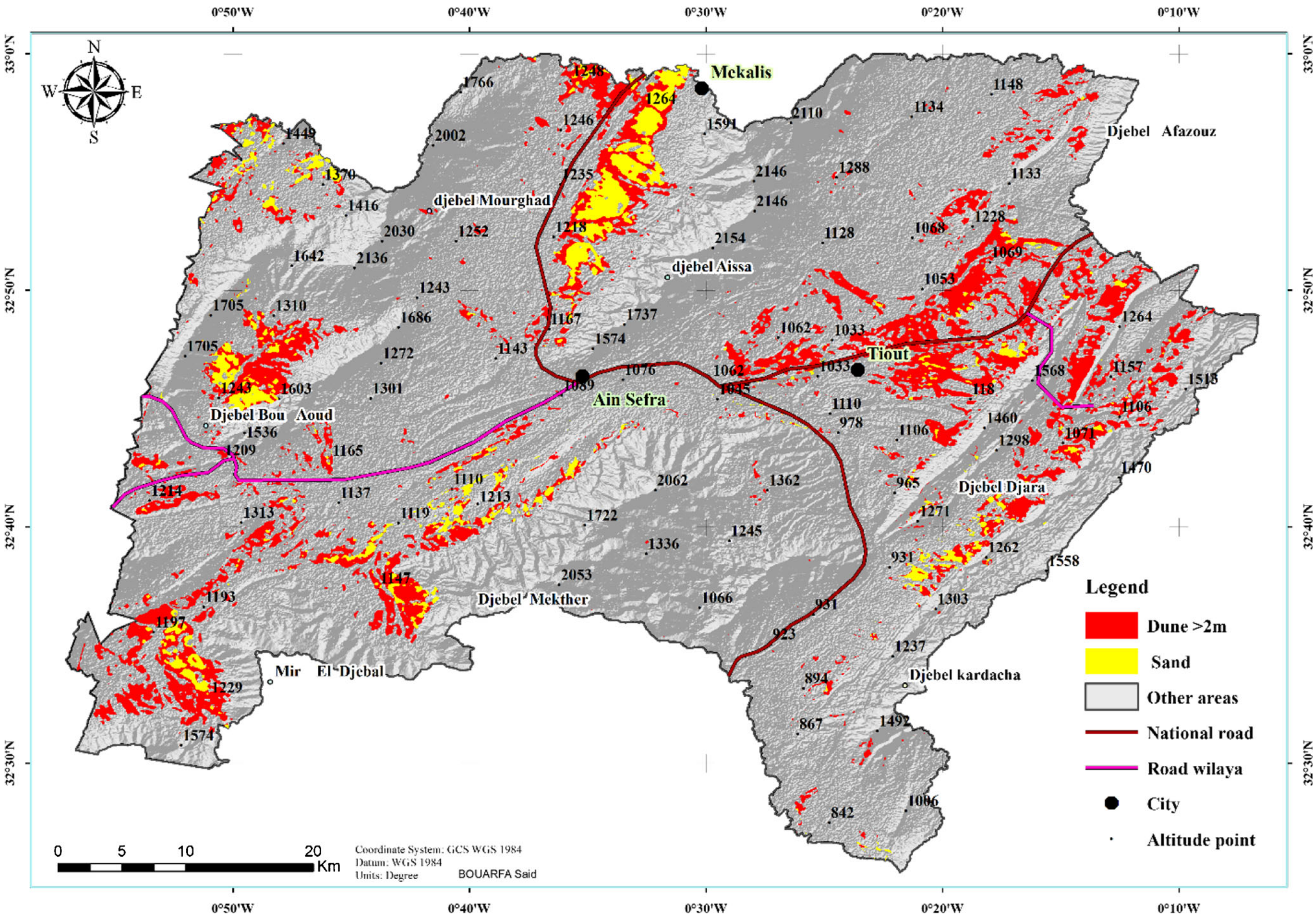


Fig. 6 Change between the years 1985–2015 in the sand and dune classes' areas

These coefficients enabled us to draw sand potential movement compass cards, which we analyzed and compared later.

E—sand migration rose It concerns sand potential movement graphic representation and particularly coefficients mentioned above. It is also the graphic importance of compasses of sand movement or migration and the possibility to compare between them or other regions or even neighboring regions.

According to an increasing dispersion, order (Fryberger and Dean 1979) there are five types of sand migration compasses: a uniform narrow modal with more than 90% of potential transport located in two adjacent directions inside a circular arc of 45°. Large uniform modals with one transport direction top, but with large distribution of sharp bimodals with two modes of distribution and direction, which tops form a sharp angle (90°). Obtuse bimodals which distribution is similar to the previous, but the two tops form an obtuse angle. More than two modes of complex modals, which are difficult to be established in only 16 directions. There is generally no well-defined mode.

Sand cover monitoring

Satellite (Landsat) images were downloaded from the database GLCF (Global Land Cover Facility) of Maryland University and combined in a falsified color combination. They permit to make a diachronic study in the study zone and detect the change using remote sensing, which is the process that permits to identify the different states of an object or a phenomenon when observed in several dates.

Five images of different dates were chosen (1985, 2000, 2005, 2010, and 2015) to do this comparative study. These images were taken in March, during the same period of the year.

The change detection analysis of the multi-date satellite images using the post classification approach was used.

Satellite images treatment Geometrical corrections were already realized from the database by GLCF who orthoadjusted images to the TM and ETM + 30-m resolution. We controlled the superposition with GPS germane points with the pixels of different places in the zone, and a good precision of geometrical correction ± 30 m was obtained.

A—radiometric correction In this case, it becomes necessary to correct these images radiometrically in order to put on in each pixel a radiometrical value, the nearest possible to that taken in the soil.

B—atmospherical correction Atmospheric correction is necessary to do image multi-temporal comparisons, the reflected radiance in the captor is the result of the target and atmosphere reflected radiance. The luminous signal read by the satellites' captor crosses the earth's atmosphere two times.

C—supervised classification, post classification, and change detection Different methods were applied to detect the intervening modifications among optical satellite images in different dates and different captors. They were normalized and calibrated. The images have the same spatial resolution, i.e., 30 m (Landsat TM de 1985) ETM + de 2000, 2005, and 2010 and 2015.

A supervised classification was operated in colored composition combining the canals 7.4.2. This three-canal choice was guided by the spectral profile analysis of arid areas, Landsat ETM images.

Several treatments will be applied on satellite images to detect environmental changes, which affected the studied study area and the morphological and morph dynamics of dune systems. Detection methods of environmental changes and morphogenetic aspects linked to them are being carried out. Realized classification on images in different dates and with different captors will be confronted and compared. The morphological features of dune formation taken from multi-date image excerpt by filtering to bring to light the morphogenetic dynamic are confronted, too.

We will be based on samples of pixels in the images (1985–2000–2005–2015) that are representative of specific classes and then direct the image processing software to use these training sites as references for the classification of all other pixels of the image. Training sites (also known as test sets or input classes) are selected according to our knowledge. We also define the boundaries of the similarity of the other pixels to group them together. These limits are often defined according to the spectral characteristics of the formation zone, more or less a certain increment (often based on "brightness" or reflection force in specific spectral bands). We also denote the number of classes in which the image is classified. Many analysts use a combination of supervised and unsupervised classification processes to develop final result analysis and ranked maps.

The detection of sand-covered areas, with a high Aeolian accumulation presence, was evident for the year 2015. Checking on the ground and the capture of many GPS readings where sand encroachment zones are located made it easy to realize a recent sand encroachment map. However, this was not possible for the other periods; it was a bit difficult to realize precise and compatible maps with the ground realities. The importance of realizing a supervised classification is to extract sandy zones (with high Aeolian accumulation presence) and other classes since we are essentially interested in sand encroachment study and its spatiotemporal dynamic, and five classes has been chosen. The first is more than 2 m sand dunes, the second is sandy accumulation or sand-bank zones named "sand" and include all other landscape components in the area (dune > 2 m, sand, rocky outcrop, pasture, bare ground, and other areas).

Results and discussion

Wind class distribution

In Ain Sefra station, the data that extends from 1985 to 2015 presents relative wind frequencies equivalent to 26,498 readings, which is an average stillness sum of 50.30%.

According to Table 1, we noticed that stillness rate is different from 1 month to the other. It overpasses 50% in only 7 months: January, February, August, September, October, November, and December (the maximum is 57%). The other months present less than 50% rate (a minimum of 39.23% in April). The effective winds are predominant in spring period (vernal) and aestival.

The analysis of directional variability of surface wind data reveals that all speed classes, even effective winds (> 4 m/s).

Effective wind frequencies represent 26,176 observations which is 49.69% (38.6% are between 4 and 6 m/s, and 11.1 are more than 6 m/s) distributed into two speed classes which are the following:

- The speed class between 4 and 6 m/s which is the more frequent with 20,341 observations 77.70%
- The speed class more than 6/s with 5835 observations which is 22.29%

The yearly rates of wind in Ain Sefra station demonstrate: is under the influence of two opposite sectors and S with a dominance of S, SW and N (Table 2 and Fig. 2).

Seasonal distribution of the effective winds

The climatic years in Ain Sefra is divided into two great seasons. A cold and relatively wet season that covers the period of September till April, and a hot and dry one that extends from May to October. In Ain Sefra, readings that cover 30 years (1985–2015) permitted to divide the year into four periods that are not exactly similar to usual seasons—September, October, and November for autumn; December, January, and February for winter; March, April, and May for spring; and June, July, and august for summer (Callot and Oulehri 1996). This subdivision is in correlation with wind rates (Fig. 3).

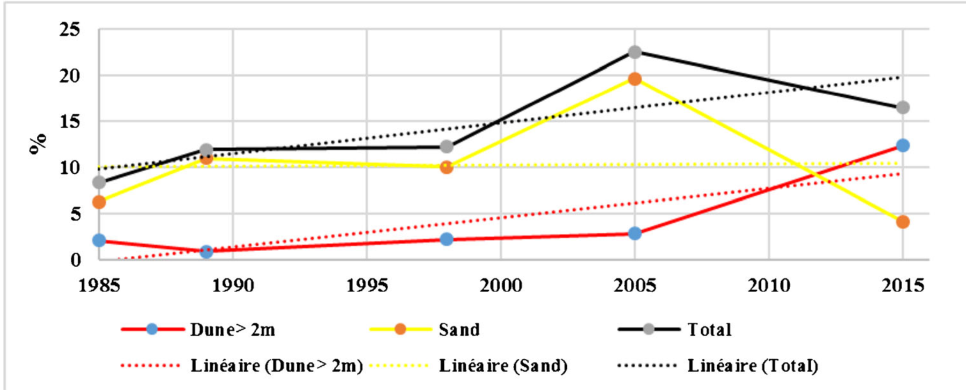


Fig. 7 The percentage of sand and dunes and total sand and dune area from 1985 to 2015 in the study area

Spring (March, April, and May) is the period during which efficient winds are more frequent. The recorded observations are 15,001, which is 30% that are distributed to certain directions: the South, the North, and the NNW.

Summer (June, July, and august)—during this season, we notice that efficient winds represent 14,671 which is 27.6% and are more frequent in the southern sector, then in the SSW, the SSE, and in the East.

Autumn—effective wind repetition is less in this period, it is represented by 11,998 observations which is 22.7%. We notice that wind follows many directions: that of the South, SSW, and the NNW.

Winter is the season where efficient winds are less frequent during the year, with only 11,004 observations which represent 20.89%. They are distributed in many directions mainly the North and the NNW.

The link between these yearly, monthly, and seasonal resultants shows that efficient winds are more frequent during spring and summer, but with different directions, and sometimes they are inverted (North and South). In autumn and

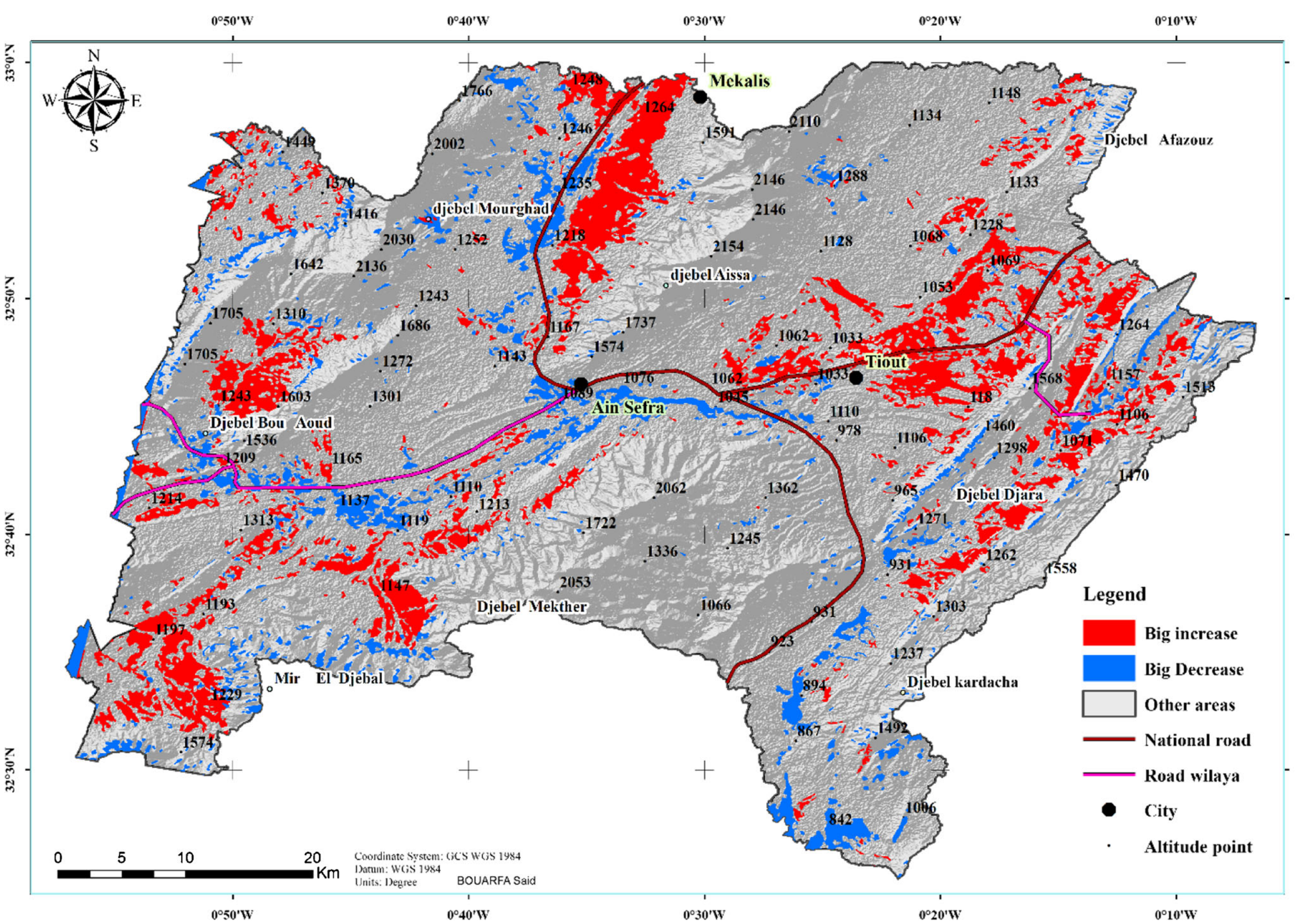


Fig. 8 Increase (red) and decrease (blue) in the area of sand and dunes between 1985 and 2015

Table 1 Monthly frequency occurrence (in percent) of wind classes, and monthly average wind speed at the station Ain sefra airport for 1985–2015

% 1985–2015	January	February	March	April	May	June	July	August	September	October	November	December	Total
< 4 m/s	54.19	54.17	48.1	39.23	41.58	46.54	49.97	55.24	52.91	56.83	55.96	57.1	50.35
4–6 m/s	37.7	37.34	37.52	41.1	40.58	41.86	40.11	35.46	38.6	34.76	37.64	37.36	36.61
> 6 m/s	8.09	8.47	14.37	18.76	18.03	11.6	9.9	9.24	8.48	8.4	6.4	5.54	11.07

winter, efficient wind frequency is less and almost in the same direction (West and South).

The directions of efficient winds have a major role in sand migration, which we especially notice in sand potential movement.

Sand drift potential

After efficient winds, different rates have been determined, the next step of our study is the quantification of sand potential movement through different study areas: an approach based in the use of the software « Sable » of B. Choppy (1985).

The obtained results according to Choppy « Sable » numeration of Ain Sefra wind readings from 1985 to 2015: for 30 years of observation and for the whole study area, the potential energy coefficients of the Ain Sefra region were quantified. The potential movement and drift of sand quantity that wind is able to transport are done towards the North-east direction for the period between 1985 and 2015; we obtained the following results:

In Ain Sefra, the Drift potential is great and is classified in the category medium energy milieu according to the Fryberger classification of 1979. Sand migration coefficient is weak, and it is characterized by a sand mutability without a really noticeable movement, according to the Fryberger classification (1979). When this coefficient reaches a value less than 0.3, winds have a tendency to blow in all directions and they stir sand without really transporting sand.

In fact, there are gaps in the two methods concerning turbulence phenomena of wind that is not measured by any of the meteorological stations (Bensaid 2006).

The drift potential, the transport capacity for the whole series from 1985 to 2015, with an extraction speed of 6 m/s, is 220 UV, a value brought to 100, and 329 of 5 m/s. This lets us say that the region of Ain Sefra is a medium Aeolian energy one. The use of Fryberger and Dean (1979) equations for correlation between transport capacity and the extracted sand volume indicate that the sand mass potentially mobilized from 1985 to 2015 is $Q = 15{,}224$ m^3/m/year which is 25,424 T/m/year corresponding to the speed $Vt = 6$ m/s and if $Vt = 5$ m/s $Q = 23.03$ m^3/m/year which is 38, 46 T/m/year. That means that the global transported volume from 1985 to 2015 according to the formula and $Vt = 6$ m/s is $Qt = Q*30 = 25.424*30 = 762.72$ T/m/30 years. We notice an important transport in spring that reaches 24.84 m^3/m/year (if $Vt = 6$ m/s) which is $Q = 35.35$ m^3/m/year (if $Vt = 5$ m/s). The resultant drift potential (RDP), the vector of the migration potential force of the sixteen directions, is 76 UV for $v = 6$ m/s and 99 UV for $v = 5$ m/s for the whole series.

The migration coefficient (RDP/DP)—concerning the migration coefficient for the 12-year series, we can consider it as weak with only 0.3 and 0.35. So, there is a sand mobility without real movement. However, ranges from 0.43 (autumn) to 0.37 (winter) reflect important directional variability and confirm that prevailing winds blow from different directions (Boulghobra and Dridi 2016).

The resultant direction—the average angle orientation of the series is 234°N that is a resultant direction of WSW towards ENE (Table 3).

The wind compass looks like a large type bimodal, i.e., the opposition between the winds of sector South to North and NNW, West-South-West to NNE (preponderant) (Fryberger and Dean 1979).

Quantification of the DP and its derived parameters of the seasonal for the station Ain sefra (1985–2015)

The best distribution shows better the sand yearly distribution in two periods (Table 4, Fig. 4).

A spring and a summer during which the winds of sector South, North, and West are preponderant and frequent, giving

Table 2 Directional variability of the frequency distribution (in percent) of the wind speed classes at the station Ain sefra airport for the period 1985–2015

%	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total %	8	5	5	6	9	3	2	4	11	7	6	7	9	5	5	8	100
0–4 m/s	4	3	3	4	5	2	1	2	4	3	3	3	5	3	2	3	50
4–6 m/s	4	2	2	2	3	1	1	2	4	3	2	2	3	2	2	4	39
Plus 6 m/s	1	0	0	0	1	0	0	1	2	1	1	1	1	0	1	1	11

Table 3 Summary of the yearly drift potential DP, resultant drift potential RDP, resultant drift direction, RDD, and wind variability index RDP/DP in the station Ain sefra airport for the period 1985–2015

Threshold speed		6 m/s	5 m/s
Drift potential	*Values in UV*	115,618	173,009
	Values reduced to 100	220	329
The resultant drift potential (RDP)	*Values in UV*	40,120	51,854
	Values reduced to 100	76	99
RDP/DP		0.34	0.30
The resultant drift direction (RDD)		234°	234°

an average migration coefficient of (0.37–0.38) producing long distances sand transport, with a movement orientation WSW–W-S-N.

Wind compass is nearly large and unimodal, i.e., the opposition of south winds to north (preponderant) in summer large bimodal with an opposition of winds of sector, WSW, S, and North in spring. A less windy autumn and winter, without preponderant directions and with important coefficients in autumn that reach 0.43.

Detection of sand change by Landsat images: the supervised classification method

The classification evaluation was based on the confusion matrix. In fact, this matrix shows for every accomplished class, the trust level and the principal confusions done during an image classification (certain class pixels can be confused by others), and the classification quality was evaluated by the Kappa coefficient. When Kappa coefficient overpasses 0.8 (80%), the classification is conventional and is considered as pertinent; in our case, and in the four realized classifications, Kappa coefficient exceeded 0.8 (1985, 97.7%; 2000, 86%; 2005, 82%; 2015, 89%). This permitted us to validate our results.

The obtained results are two kinds: occupation soil maps and changes, and the statistics dealing with cartography unity surfaces.

Sandy dynamism during the five chosen dates in this study (1985, 1989, 2000, 2005, and 2015) has known many phases that vary from regression to progression. This change is due

Table 4 Directional distribution of the seasonal drift potential, (*Q** Quantity de sable transporter) and summary of resultant drift potential, resultant drift direction, and directional variability index for the station Ain Sefra (1985–2015)

	Annual		Autumn		Winter		Spring		Summer	
Vt	*6 m/s*	*5 m/s*	*6 m/s*	*5 m/s*	*6 m/s*	*5 m/s*	*6 m/s*	*5 m/s*	*6 m/s*	*5 m/s*
N	16	26	6	11	5	11	38	56	9	16
NNE	3	5	1	3	2	5	4	7	3	6
NE	2	5	2	4	2	5	3	5	3	5
ENE	3	7	3	8	3	6	4	7	7	12
E	11	19	6	11	9	15	14	24	13	22
ESE	4	7	6	8	1	2	4	6	6	10
SE	5	8	7	10	4	7	2	4	7	11
SSE	12	18	6	9	11	15	13	18	16	25
S	36	51	24	35	15	22	58	79	39	58
SSW	22	32	23	34	15	20	30	42	19	29
SW	19	26	17	25	5	8	35	44	16	22
WSW	28	37	23	34	22	30	53	66	12	18
W	19	28	13	21	20	31	34	45	9	15
WNW	10	15	7	11	14	20	15	22	4	7
NW	12	18	6	9	19	26	17	28	6	10
NNW	18	27	11	18	11	20	36	53	8	14
Total DP	220	329	161	251	159	243	359	505	178	281
RDP	76	99	70	96	59	79	135	167	65	91
RDP/DP	0.35	0.30	0.43	0.38	0.37	0.33	0.38	0.33	0.37	0.32
RDD	234°	234°	222°	223°	254°	262°	249°	254°	189°	187°
Direction	WSW	WSW	SW	SW	WSW	w	WSW	WSW	S	S
Q m^3/m/an	15.22	23.03	11.14	17.57	11.00	17.01	24.84	35.35	12.32	19.67

Table 5 the percentage of sand and dune area from 1985 to 2015 in the study area

Class %	1985	1989	1998	2005	2015
Dune > 2 m	2.03	0.89	2.18	2.84	12.33
Sand	6.26	10.97	10.02	19.67	4.11
Total	8.30	11.86	12.19	22.51	16.44

mainly to many factors that are climatic (drought, wind speed….), anthropoids (extensive labors, overgrazing…..), and physical (vegetal cover, kind of soil…).

The period between 1985 and 2015 is considered as a transgression phase (Table 5, Fig. 5), and a top phase was registered during the year 2005; however, the period between 2005 and 2015 is considered as a regression one. Sand encroachment generally increased. This increase has continued till the present time; sand accumulations have taken a reduced form from 2005 to 2015, but sand encroachment is always present in the study area and presents a real threat.

Concerning sand and dune progression, it was registered a big increase of 30,968,6120 ha for dunes which represent 506%; doubled fivefold from 1985 to 2015, and big decrease of − 6462.9883 ha which is – 34.32% for sand (Fig. 6). After our different map examination, we noticed that sandy accumulations in the area have known an evolution and an unsteadiness through time. Sand encroachment from 1985 to 2015 was 49,454,6833 ha which is 16.44% of the entire zone surface which is equivalent to 300,735,2422 ha. The increase in dunes more than sand can be interpreted by a change of sand into dunes all along these years.

The estimated recorded regression, during the 30 years, is – 6462.98 ha of sand, which is − 2.5% of all the zone surface, and − 34.32% for the area of sand. In fact, there is no sand encroachment decrease, but sand shifted to other places in or outside the region. In general, the total area of sand and dunes between 1985 and 2015 was estimated at 24,505.62 ha, which means an increase of 98.22% for the total area of sand and dunes higher than 2 m for 1985 (Table 6, Fig. 7).

-Theoretically the transported sand quantity, during the 30 years, and the total mobilized sand surface during the same period is 24,505,6237/30 = 816,8541 ha per year (Fig. 8).

Therefore, we cannot compare the transported sand quantity calculated by Chopy software program that gives the following result: $Q = 15{,}224$ m^3/m/year which is 25,424 T/m/year corresponding to the speed $Vt = 6$ m/s. And if $Vt = 5$ m/

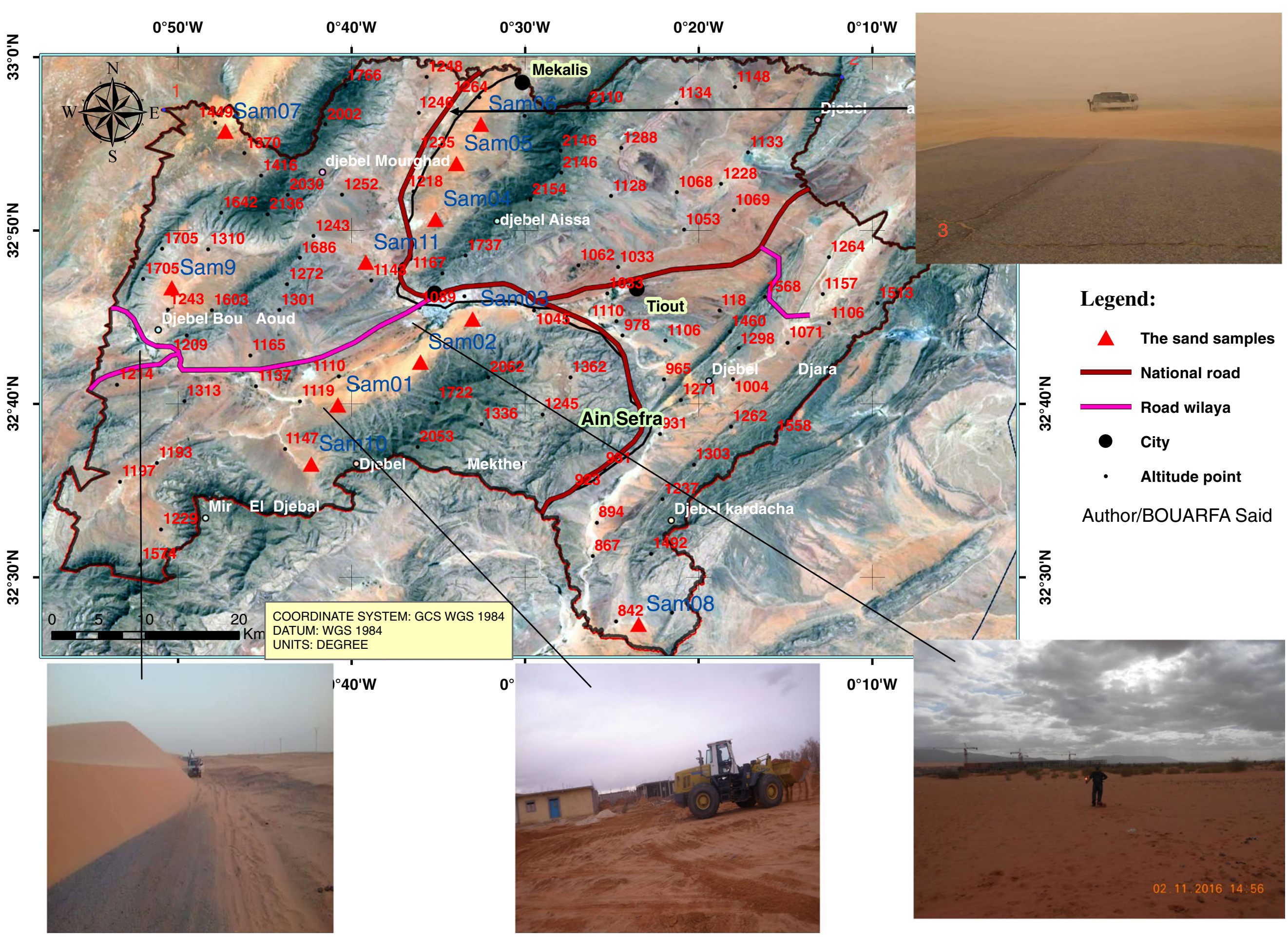


Fig. 9 The risk of sand encroachment in the Ain sefra and the sand samples localized

Table 6 Change in the percentage of sand and dune area from 1985 to 2015 in the study

Class change %	1985–1989	1989–1998	1998–2005	2005–2015	1985–2015
Dune > 2 m	− 56	144	30	334.4	506
Sand	75	− 8	96	− 79	− 34
Change total	43	2.7	84	− 27	98

Table 7 Comparison of results sand assessment between wind treatment and remote sensing 1985–2015

Results	D.P.	Détection le changement
Moyenne	$V = 6$ m/s, $Q = 15.2$ m^3/m $V = 5$ m/s, $Q = 23.03$ m^3/m	816 ha
30 years	$V = 6$ m/s, $Q = 456.72$ m^3/m/30 year $V = 5$ m/s, $Q = 690.9$ m^3/m/30 year	24,505 ha

s $Q = 23.03$ m^3/m/year which is 38.46 T/m/year. In other words, the global transported volume is de 1985–2015 according to formulas and $Vt = 6$ m/s is $Qt = Q*30 = 25.424*30 = 762.72$ T/m/30 years; and change detection result of sand by Landsat images due to the difference among the calculating unities. To have a useful comparison taking into account the two methods, a topographic lift of the sandy surface is needed in order to calculate the volume of the mobilized sand covering, nowadays (Table 7).

The sand encroachment, in this period, was space located under the wet watershed of mountains (ubac), i.e., the WSW and SW. This confirms the previous wind study (Figs. 9), this repartition is generally in flash forms and dispersed sand accumulation.

Other sandy accumulations extend in interriver zones; in fact, these zones occupy great surfaces as a witness for an ancient icy field. This icy area is covered by calcareous and gypsum crust on which thin sandy horizons take place.

Sand encroachment is a real danger to humans and infrastructure. It impeded transportation, displaces the population, and eliminates agriculture and vegetation when thousands of hectares of land are burned annually (Fig. 10).

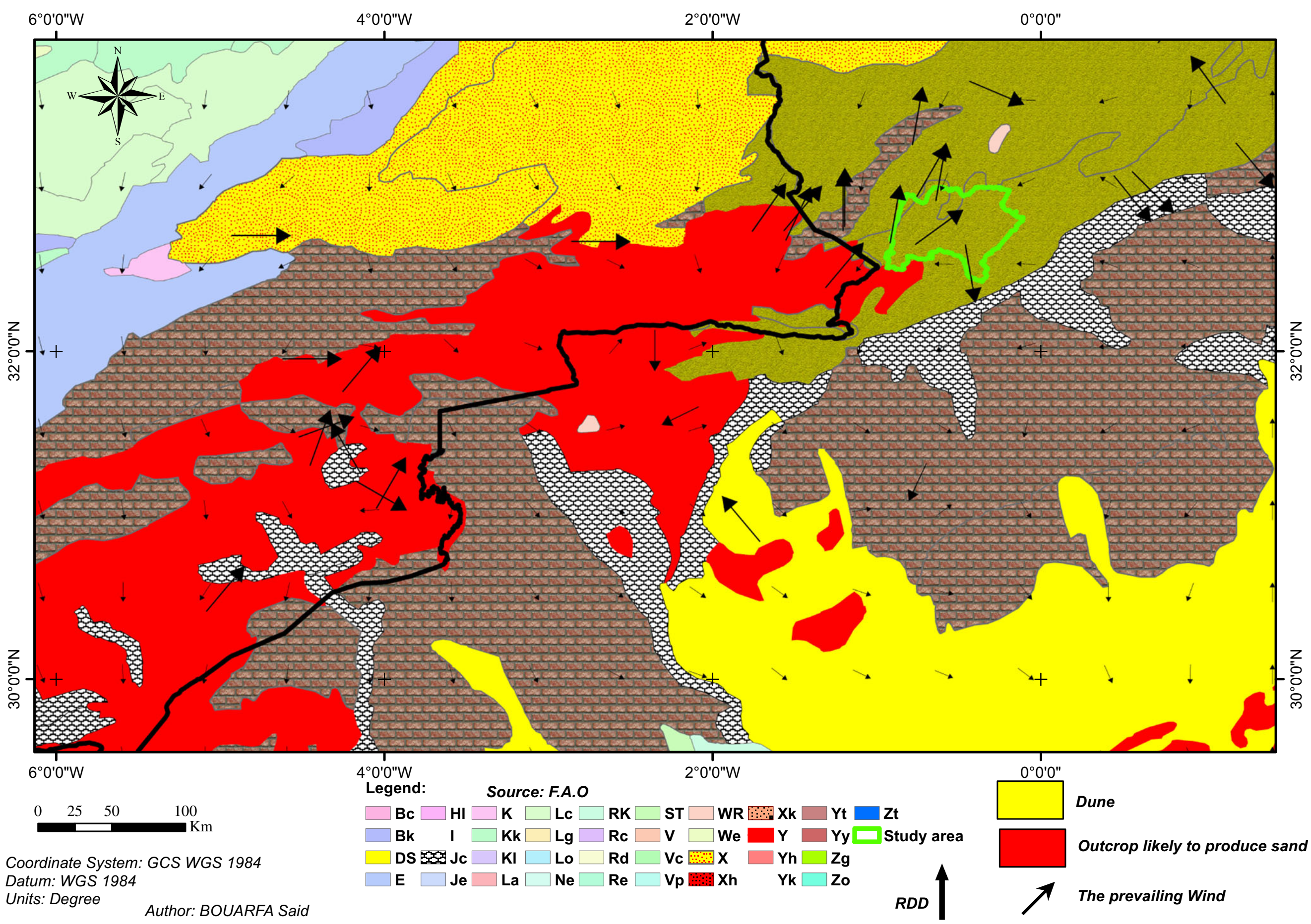


Fig. 10 The zones of departure, transport, and accumulation of sand

Conclusion

The Ain Sefra region, which is part of the Ksour mounts, is suffering from a serious sand encroachment problem in many of its localities. These problems that are due to hard climatic conditions, geologic leveling friability, and the non-rational use of natural resources constitute the most spectacular phenomenon of sand encroachment (Fig. 7).

The quantification attempt has the interest of being the only approach to the difficult problem, which are Aeolian movements. It has some drawbacks since it cannot cover certain parameters. Wind turbulence, which is not measured by any meteorological station, and has an important role in sand movement and in the sand movement resultant, can be different from that of sand roses. The study of anemometric data either by wind rate or by sand potential movement permitted to determine efficient wind directions and the yearly resultant direction of sand potential movements and seasonal, too. Moreover, it permitted to estimate the probable mobilized sand mass. Dominant winds mainly come from South and North sectors and secondarily from the East and West sectors, of sand transport rate, which is of one direction. In fact, only the winds of the south sector and WSW are efficient and capable of generating a sand movement. The period representation on which the sand drift potential (SDP) calculations are based becomes clear that sand transport is a cyclic phenomenon, in intensity and direction, in daily and seasonal schedules.

This cycle includes two phases: a spring and a summer—the drift potential (DP) are very high and sand generally moves from WSW towards NNE and from S towards during this period, there is an average migration coefficient (0.37–0.38) regularly producing a long distance sand transport. An autumn and a winter—the DP is very weak and sands, too. In this period, winds blow the least and without preponderant directions.

Other techniques to study sand mobilization and treat satellite images between 1985 and 2015 were realized through stages that are obligatory, to obtain a more authentic image since we integrated the soil data that are called "supervised classification" and the two classified images crossing to detect the change in sand encroachment extension. In general, the total area of sand and dunes between 1985 and 2015 was estimated at 245,056,237 ha, which means an increase of 98.22% for the total area of sand and dunes higher than 2 m for 1985.

According to satellite imagery study, Aeolian formations in the area have known, during the 30 years, different phases that vary between regression and progression of the sand cover. The sand encroachment study needs wind data and teledetection to be completed.

Whereas, to know the impact of sand encroachment phenomenon on the morphology and evolution of sand deposits, we need to link this technique with very précised topographic readings that permit the calculation of sand volumes deposited or eroded by wind.

Acknowledgements The authors thank Boulghobra N and the Center of Scientific and Technical Research on Arid Regions (CRSTRA), Biskra, Algeria.

References

Aidoud A, Touffet J (1996) La régression de l'alfa (Stipa tenacissima L.), graminée pérenne, un indicateur de désertification des steppes algériennes. Science et changements planétaires/Sécheresse 7:187–193

Bagnold R (1953) Forme des dunes de sable et regime des vents Actions Eoliennes:23–32

Bagnold R (1954) Physical aspects of dry deserts. in: jc cloudsley-Thompson Edit, Biology of deserts:7–12

Benalla M, Alem EM, Rognon P, Desjardins R, Hilali A, Khardi A (2003) Les dunes du Tafilalet (Maroc): dynamique éolienne et ensablement des palmeraies. Science et changements planétaires/Sécheresse 14:73–83

Bensaid A (2006) SIG ET TÉLÉDÉTECTION POUR L'ÉTUDE DE L'ENSABLEMENT DANS UNE ZONE ARIDE: LE CAS DE LA WILAYA DE NAÂMA (ALGÉRIE). Université Joseph-Fourier-Grenoble I

Boulghobra N, Dridi H (2016) Fine resolution imagery and GIS for investigating the morphological characteristics, and migration rate of barchan dunes in the Erg Sidi Moussa dunefield near In-Salah (Algeria) Geographia Technica 11

Callot Y (1987) Géomorphologie et paléoenvironnements de l'Atlas saharien au Grand Erg Occidental These de doctorat, Université de Paris 6

Callot Y, Oulehri T (1996) Aeolian sand geodynamics in the north-western Sahara: relations between aerology and geomorphology. Geodin Acta 9(1):1–12. https://doi.org/10.1080/09853111.1996.11417259

Cooke RU, Warren A (1973) Geomorphology in deserts. Univ of California Press,

Dubief J (1953) Essai sur l'hydrologie superficielle au Sahara. vol 1. Gouvernement général de l'Algérie, Direction du service de la colonisation et de l'hydraulique, Service des études scientifiques,

Fryberger SG, Dean G (1979) Dune forms and wind regime: a study of global sand seas 1052:137–169

Khalaf F, Al-Ajmi D (1993) Aeolian processes and sand encroachment problems in Kuwait. Geomorphology 6(2):111–134. https://doi.org/10.1016/0169-555X(93)90042-Z

Lancaster N (1982) Dunes on the Skeleton Coast, Namibia (South West Africa): geomorphology and grain size relationships Earth surface processes and landforms 7:575–587

Lancaster N (1988) Controls of eolian dune size and spacing. Geology 16(11):972–975. https://doi.org/10.1130/0091-7613(1988)016<0972:COEDSA>2.3.CO;2

Le Houérou H-N (1995) Bioclimatologie et biogéographie des steppes arides du Nord de l'Afrique. Centre international de hautes études agronomiques méditerranéennes, Institut agronomique méditerranéen de Montpellier

Mainguet M (2012) Desertification: natural background and human mismanagement. Springer Science & Business Media

Mainguet M, Callot Y (1978) L'erg de Fachi-Bilma, Tchad-Niger: contribution à la connaissance de la dynamique des ergs et des dunes des zones arides chaudes vol 18. Éditions du Centre national de la recherche scientique

Nouar B, Toufik H, Mamar B (2014) Using Landsat imagery for monitoring the spatiotemporal evolution of sanding in dryland, the case of In-Salah in the Tidikelt (southern Algerian Sahara) Geographia Technica 9

Ouessar M, Yahyaoui H, Ouled Belgacem A, Boufalgha M (2006) Aménagements et techniques de lutte contre la désertifcation: inventaire et bilan Entre la désertification et le développement: la Jeffara tunisienne, edited by: Genin, D, Guillaume, H, Ouessar, M, Ouled Belgacem, A, Romagny, B, Sghaier, M, and Taamallah H, CERES Editions, Tunis:147–161

Oulehri T (1992) Etude géodynamique des migrations de sables éoliens dans la Province de Laayoune (Nord du Sahara marocain). these, universty paris 6

Pye K, Tsoar H (2008) Aeolian sand and sand dunes. Springer Science & Business Media,

Taïbi AN, Gassani J, Elghadi AV, Ballouche A, Moguedet G, Baba MLO, Jidou MO (2005) Diagnostic de la dynamique des ressources hydriques de surface et des processus de «désertification» du lac d'Aleg et son bassin versant (Brakna, Mauritanie) par télédétection multidate Télédétection 5:35-45

Venard C (2012) La morphodynamique éolienne en régions sèches: des échelles spatiales et temporelles aux outils. Lyon 2