Aeolian Sand Deposit Assessment in an Arid Area, Case Study: The Region of Ksour Mountains (SW of Algeria)

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Abstract

The phenomenon of aeolian sand deposit constitutes a major problem in the region of Ksour Mountains in Algeria, which causes serious social and economic problems. To assess the textural properties of sands, and to investigate the origin of aeolian sand deposit in the study area, eleven (11) samples were collected from the sands of Ain Sefra. Then the granulometry, calcimetry and morphoscopy of the samples were studied. Granulometric testing of samples from 11 locations showed that sand size was very fine to fine grained, with a mean grain value of 226.5 μm . It sort ranged from 1.22 to 1.90, indicating well sorting the sands and skewness values ranging from -0.4 to 0.66, being mainly negative with an average of -0.06, indicating symmetrical to fine skewed values. The values of kurtosis ranges from 0.79 to 1.5, with an average of 0.93, where 64 percent of samples are Mesokurtotic and 36 percent of samples are Platikurtotic. Calcimetric results show a very low percentage of carbonate, which ranges from 1.85 % to 7.4 % and illustrate a very low content of fine fraction and organic matter. The preliminary examinations of the sands in our study area by morphoscopy showed that 73 percent of sand are in RM category, 19 percent in the rounded and shiny (EL) category. In comparison, 08 percent are represented by the fresh and angular (NU) category. The outcome of various experimentation led to the conclusion that the aeolian sand deposit in the study area, are linked to the wind transport from the Moroccan territory such as Chott Tigri, Oued Maader, the corridor between Figuig, Bouarfa and Massa Daraa, which are the dominant sources of sands in the region of the study area. Therefore, the study better understands the origin of sands and their characteristics in this part of the Ksour Mountains.

1. Introduction

With an increasing danger of aeolian sand migrations from different sources, it is essential to bear in mind how the present sands environment is emerging under human and natural pressures. Aeolian sands have been studied in various fields in the earth and sciences. Early scientific works on the geological origin of aeolian sands have been reported, referring to their physical, chemical, mineralogical, and morphological features.

Blake (1855) was one of the first to notice the extensive development of wind erosion forms in the Sahara, and von Richthofen (1882) identified the fundamental aeolian origin of the huge loess deposits that cover much of northern side of China. Then, there was a surge in interest in aeolian processes in the late nineteenth century and the twentieth century, and some very descriptive references were produced (Beadnell, 1909; McKee, 1979; Pease et al., 1999; Zhu, 1985). Recently, a diversity of research on aeolian sands characterization, the same as approaches to reduce its movement, has been published worldwide (Baratoux et al., 2011; Barrena-González et al., 2020; Bertran et al., 2021; Chojnacki et al., 2020; Fotoohi et al., 2022; Han et al., 2012; Hereher, 2018; S. Liu et al., 2021; X.-J. Liu et al., 2019; Tian et al., 2019; Veit et al., 2015; Wolfe & Lian, 2021). Otherwise, it should be noted that an important lack of scientific studies covering the paper's topic in arid areas, such as Algeria, was identified.

In Algeria, sand dunes serve as one of the country's most prominent geomorphological features in the Sahara, where roughly 20 million hectares are threatened by wind erosion. Algeria's arid regions are known for their fragile ecosystems. They are the main areas affected by Aeolian sand deposits (Nedjraoui & Bédrani, 2008). The arid and steppe areas, constantly affected by the winds, are located in the southwestern part of Algeria and the Saharian Atlas. In this region, there are sandy currents formed by long bands of dunes that are oriented from the southwest (SW) to the northeast (NE) (Nedjraoui & Bédrani, 2008). Aeolian sand migrations do not proceed from a continuous and single movement to the final deposition zone in arid environments. These sandy migrations act by continuously recycling the sand passing through the wadis, spread by the latter at the outlet of a plain, picked up by the wind before accumulating again (Benazzouz, 2003). The wind is the focal component responsible for the transport and deposition of sand sediments and landform modeling (Abuzaid et al., 2021; Mainguet, 2012). Speed, direction, magnitude and frequency are the main elements of wind that define its efficiency. However, only strong winds that reach the threshold speed can have erosive

activity. Three sands types are distinguished, autochthonous and allochthonous, which provide information about past environmental change in the surrounding watershed. Depending on their importance, these types are either transitional or form dunes. A few studies have been reported recently to assess aeolian sands deposit in Algeria. Benazzouz (2003) studied the aeolian sands mineralogy in the Zibans range in the south of Algeria. Boureboune and Benazzouz (2009) carefully designed to combat the desertification in Zibans and Hodna basin in Algeria. Boulghobra (2016) used satellite imagery and climatic data to assess the aeolian sand deposit in the region of In-Salah in the south of Algeria. Boulghobra et al. (2016) investigated the aeolian risk in the Touggourt region situated in the south of Algeria. Bouarfa and Bellal (2018) investigated the concentration of sand buildup beneath Algeria's western mountain foothills between 1985 and 2015. All this previous research provided in Algeria, focused mostly on the desert domain, with no studies have been conducted to determine the Aeolian sand deposits in our study area. This research aims to learn more about the textural properties of sand dunes in the region of Ksour Mountains and particularly the region of Ain Sefra and to investigate the source of aeolian sand deposits in this part of Ksour Mountains. This research could help us better understand the factors that influence the shape and size of dunes and the methods in which eolian sand bodies accumulate.

2. Materials And Methods

2.1 Geographical context

The Ain Sefra is part of the Ksour Mountains, and it covers about 3851 Km². It is situated in the southwest of Algeria, it's limited to the north by Chott-Chergui and Chott-Gharbi watersheds, to the west by Morocco, to the south by the region of Bechar, and to the east by El-Bayadh (Fig. 1). This arid region is surrounded by mountains, where the altitude of some summits can reach 2000 m, such as Djebel Aissa (2236 m), Djebel Mzi (2187 m), Djebel Morghad (2136 m), Mir El djebel (2109 m), and Djebel Mekther (2035 m) (Derdour & Bouanani, 2019). The meteorological data of 30 years (1985-2015) gathered from Ain Sefra weather station by Bouarfa and Bellal (2018) revealed that the average precipitation is about 196.73 mm with strong seasonal and annual variations. The annual average number of rainy days is 55 days, and the annual average temperature is 17.79°C. The south sector and west-southwest winds are effective and able to cause movement of sands according to the annual wind rose, where the more frequent winds are between 4 and 6 m/s. Furthermore, according to the effective wind threshold speed, sand movement quantity is between 23.03 and 15,224 m³/m/year. The soils are shallow and less fertile, with an organic matter level that does not exceed 3 percent (Aidoud & Touffet, 1996). From a geological standpoint, the geological series of the region range from the Triassic to the recent Quaternary, and the geological facies that dominate the region are Jurassic and Pliocene sandstones and limestones (Derdour et al., 2021). The analysis of the land use revealed that the forests represent 7.05 percent of the surface of the study area, the rocky outcrops represent 15.06 percent, the very degraded ranges represent 24.06 percent, the steppe ranges represent 29.14 percent, the wind accumulations represent about 17.94 percent, and the sand dunes represent only 6.74 percent (Derdour et al., 2018). The region of Ain Sefra suffers from serious environmental problems linked to wind erosion and dune migration which further accelerate the process of desertification (Fig. 2).

2.2. Data acquisition.

In our study area, eleven (11) samples were collected for granulometry, calcimetry, and morphoscopy analyses to cover all the watershed (E01-E02- E03 E04 –E05-E06- E07-E08-E09-E10-E11), as shown in Table 1 and Fig. 3. In fact, on each side, the most representative dunes were the subject of sand samples (500 g) taken from their crest. And on a dune of each site, we sampled on the right and left toes, on the middle of the right and left flanks (Fig. 4), on sand accumulations, and on the sands inside the city of Ain Sefra. All Samples of sands were taken simultaneously with

wind measurements made at the same height as the samples. It is to find a correlation between the particle size of the moving sand and the wind speed and compare them to the sand taken in this position.

Table 1
Samples distribution in the watershed of Ain Sefra.

Sample	Y LAT	X LONG	Position
E01	32°44'8.98"N	0°34'18.20"W	Right dune toe
E02	32°43'44.99"N	0°34'54.26" W	Right dune flank
E03	32°43'43.74"N	0°35'55.19"W	Sand accumulations
E04	32°43'12.36"N	0°35'47.23"W	Crest of dune
E05	32°45'18.24"N	0°36'39.97"W	Sands inside the city of Ain Sefra
E06	32°42'51.85"N	0°36'33.29"W	Left dune toe
E07	32°41'32.02"N	0°36'52.34"W	Right dune toe
E08	32°42'6.53"N	0°37'10.46"W	Left dune flank
E09	32°42'20.68"N	0°40'40.67"W	Sand accumulations
E10	32°42'24.30"N	0°36'39.65"W	Crest of dune
E11	32°47'57.41"N	0°36'13.86"W	Sands in the city of Ain Sefra

2.3 Granulometric analysis

For this research, the granulometric examination was carried out according to the classical method described by Berthois (1959) and Verger (1963) in relation to the AFNOR standards (AFNOR, 2018). The samples were rinsed, dried in an oven, weighed, and sieved on a column of twelve sieves with mesh sizes ranging from 500 μ m to 0.075 μ m for twenty minutes. The purpose is to create particle size curves (frequency, cumulative) and calculate particle size characteristics that provide information on the degree of sediment categorization, such as mean, sorting (standard deviation), skewness, Kurtosis and standard deviation. These parameters can be calculated by using the software of GRADISTAT developed by Blott and Pye (2001). The semilogarithmic particle size curves' form enables for the identification of different particle size facies, then interpreted according to the work of Folk and Ward (1957) who used different percentiles in ϕ -units: ϕ_{50} (the median), ϕ_{16} and ϕ_{84} (the percentiles at the points of curvature of a Gaussian distribution). The Median corresponds to the 50percent of the total frequency, and this parameter characterizes the coarseness of the sediment (Trask, 1931; Wu et al., 2021). The analyzes were carried out in the Laboratory of Eremology and Combating Desertification (IRA) of Medenine in Tunisia. Table 2. Show the size scale adopted in the GRADISTAT program, used in the discussion section.

Table 2
Size scale adopted in the GRADISTAT software, adapted from Udden (1914) and Wentworth (1922).

Grain size (µm)	Descriptive term	
1000-2000	Very Coarse	Sand
500-1000	Coarse	
250-500	Medium	
125-250	Fine	
63-125	Very fine	
31-63	Very Coarse	Silt
16-31	Coarse	
8-16	Medium	
4-8	Fine	
2-4	Very Fine	
0-2	Clay	

2.4 The calcimetric determination

The calcimetric determination (CaCO_3) was carried out using the Bernard Calcimeter Method which allows the identification of carbonate levels in the sediments. The analyzes were carried out in the Laboratory of Eremology and Combating Desertification (IRA) of Medenine in Tunisia. This analysis allows establishing the detrital or bio detrital origin of the sediments. Various scientists have researched and developed this method (Hulseman, 1966; Muller & Gatsner, 1971). The assay estimates the CO_2 produced when a sample of soil or rock is treated with hydrochloric acid (HCl) on the calcium carbonate (CaCO_3). This principle is well known for laboratory tests. This calcium carbonate and hydrochloric acid reaction is a total and exothermic reaction releasing carbon dioxide (CO_2). Eq. 1 obtains the percentage of carbonates:

$$\% \text{CaCO}_3 = \frac{V_1}{V_0} \times 100 \quad (1)$$

2.5 Organic matter content

Stable organic matter in soil results from the gradual decomposition of crop residues, and plants, animals and other living biological organisms in the soil. The organic matter content of a soil is determined indirectly, from the determination of the organic carbon content, according to the international standard method NF ISO 14235 (ISO, 1998). The organic matter (OM) rate is calculated by multiplying the organic carbon (OC) content by a stable coefficient in regional cultivated soils, set at 1.72, as mentioned in Eq. 2.

$$\text{OM}\% = 1.72 \times \text{OC} \quad (2)$$

2.6 The morphoscopic determination

Morphoscopy, which was determined by Ribault (1975), as being “the statistical determination of the different types of quartz in sandy deposits”, the proportions of each type and the variations of these proportions during transport. Then during these counts, the most representative particles were selected to be observed with a Scanning Electron

Microscope (SEM). The morphoscopic assessment of the sand grains in this zone also provides information on their deposit habitats, transport conditions, and environmental effect. The analyzes were carried out in the Scientific and Technical Research Center on Arid Regions (CRSTRA).

3. Results And Discussion

3.1 Laboratory analyses

The calcimetric study reveals the selective calcium loss from an impure parent limestone (Derdour et al., 2020). Eleven samples from the commune of Ain Sefra were calcimetrically analyzed (Table 3). The calcium carbonate concentration of these samples ranged from 1.85 percent in sample E04 to 7.4 percent in sample E01. Analysis of the calcimetric results shows a very low percentage of calcium carbonate content in the samples, which means that the samples have a low limestone content.

Table 3
Results of lime content in the samples.

Samples	CaCO ₃ percent	Observation
E01	7.4	Low carbonate content
E02	3.7	Very low carbonate content
E03	3.7	Very low carbonate content
E04	1.9	Very low carbonate content
E05	5.6	Low carbonate content
E06	7.0	Low carbonate content
E07	6.7	Low carbonate content
E08	3.0	Very low carbonate content
E09	3.3	Very low carbonate content
E10	1.9	Very low carbonate content
E11	5.9	Low carbonate content

Organic matter greatly enhances the cation exchange capacity of the soil and retains nutrients that plants can assimilate. Thus, organic matter constitutes a reservoir of slowly assimilable nutrients. As shown in Table 4, the analysis of the composition of the sandy material within the dune system of Ksour Mountains shows a very low content of fine fraction and organic matter (silt, clay and organic matter). However, this overall trend is interrupted in places. It may be related to the presence or absence of plant cover capable of providing organic matter and subsequently increasing the percentage of the fine fraction.

Table 4
Organic matter content in the samples.

Samples	C percent	OM percent	Observation
E01	0.56198347	0.96661157	Very low organic matter content
E02	0.09917355	0.17057851	Very low organic matter content
E03	0.42975207	0.73917356	Very low organic matter content
E04	0.42975207	0.73917356	Very low organic matter content
E05	0.16528926	0.28429753	Very low organic matter content
E06	0.59504132	1.02347107	Very low organic matter content
E07	0.52892562	0.90975207	Very low organic matter content
E08	0.0661157	0.113719	Very low organic matter content
E09	0.46280992	0.79603306	Very low organic matter content
E10	0.39669421	0.68231404	Very low organic matter content
E11	0.1322314	0.22743801	Very low organic matter content

The cumulative semi-logarithmic curves of the sands samples taken from our study presented in Fig. 5 show a sigmoidal (hyperbolic) type pattern. The curves have the shape of a "S" more or less spreading which indicates fine sands, which means that the sands are stretched, well classified with a well-developed rectilinear sector in its middle part more and more towards the east. This facies also indicates that the sands were transported in a more or less disturbed environment with fine particle evacuation.

Table 5 gives the complete information of measured and calculated values of different samples analyzed. Median results denote that at particular value of d_{50} , half of the particles are fine sands. Inclusive graphic median (d_{50}). The values in our samples range from 197.3 μm to 256.8 μm , averaging 228.3 μm (Fig. 6-A). The mean values range from 201.5 to 245.5, with an average of 226.5 which shows that the samples mostly belong to fine sands. These results are comparable with those given by the median. We noted that this average, in general, tends to decrease according to the position of the samples (Table 6). The measures of the sorting (Standard deviation) or uniformity of the grains indicating energy conditions that prevailed during transport and deposition. It ranges from 1.22 to 1.90, with an average of 1.31 (Fig. 6-B). This indicates the well-sorting of the sediments, according to the classification of Folk and Ward (1957). The majority of samples (08 samples) are very well sorted, representing smooth and stable currents, followed by moderately sorted species of 03 samples (E05, E07, E011) which can be attributed to slight variability in current velocity. The Skewness measures the degree of asymmetry in the frequency curves regarding the predominance of grains fractions. The kurtosis values range from 0.79 to 1.5, with an average of 0.93. Where 64 percent of samples are Mesokurtotic and 36 percent are Platikurtotic (Fig. 6-C). The skewness value in our samples ranges from -0.4 to 0.66, with an average of -0.06, ranging from near symmetrical to strongly fine skewed. According to the classification of Folk and Ward (1957), we remark that most of the samples are symmetrical, and the rest are coarse skewed and very fine skewed (Fig. 6-D). It shows the symmetry of the curves in the part of the dune system. It explains that the deposition of sediments takes place suddenly and without subsequent reworking by excess load and / or by a decrease in the competence of the carrier current. While in the other parts, the curves show an asymmetry towards the fine elements, with a negative asymmetry, which means that the sediments are deposited in a turbulent medium which deprives them of the fine elements which fill the void left between the coarse elements after disposal is the process of deflation, the main driving force behind aeolian sands deposits.

Table 5
Granulometric parameters of sands in the study area.

	Median (d50)	Mean	Sorting Index		Skewness		Kurtosis		
Sample	Value	Value	Description	Value	Description	Value	Description	Value	Description
E01	253.4	243.8	Fine Sand	1.23	Very Well Sorted	-0.31	Very Fine Skewed	0.89	Platykurtic
E02	197.3	202.4	Fine Sand	1.25	Very Well Sorted	0.13	Coarse Skewed	0.99	Mesokurtic
E03	197.7	201.5	Fine Sand	1.24	Very Well Sorted	0.10	Symmetrical	1.01	Mesokurtic
E04	211.9	212.0	Fine Sand	1.22	Very Well Sorted	0.05	Symmetrical	0.89	Platykurtic
E05	235.9	239.0	Fine Sand	1.50	Moderately Well Sorted	0.02	Symmetrical	1.01	Mesokurtic
E06	256.8	241.2	Fine Sand	1.24	Very Well Sorted	-0.40	Very Fine Skewed	0.79	Platykurtic
E07	245.1	245.5	Fine Sand	1.50	Moderately Well Sorted	-0.02	Symmetrical	0.95	Mesokurtic
E08	197.3	203.4	Fine Sand	1.25	Very Well Sorted	0.13	Coarse Skewed	0.99	Mesokurtic
E09	197.7	201.8	Fine Sand	1.60	Very Well Sorted	0.46	Symmetrical	1.38	Mesokurtic
E10	211.9	212.6	Fine Sand	1.83	Very Well Sorted	0.66	Symmetrical	1.50	Platykurtic
E11	235.9	239.4	Fine Sand	1.90	Moderately Well Sorted	0.42	Symmetrical	1.41	Mesokurtic
Average	228.3	226.5	Average	1.31	Average	-0.06	Average	0.93	

Table 6
Distribution of sand classes in percentage.

	Medium Sands (percent)	Fine Sands (percent)	Very Fine Sands (percent)
E01	52.78	46.27	0.83
E02	17.23	81.60	1.11
E03	15.98	82.47	1.52
E04	19.59	79.78	0.54
E05	42.91	48.30	5.75
E06	56.27	42.15	1.39
E07	46.55	46.06	5.28
E08	17.50	81.40	1.11
E09	16.00	82.50	1.10
E10	20.00	79.00	1.50
E11	42.5	48.8	0.1
Average	35.90	60.95	2.34

Morphoscopic analysis of the quartz particles in sediments from the Ksour Mountains identified several forms, including fresh and angular (NU), round mat (RM), and rounded and shiny (EL) quartz grains. The fresh and angular (NU) shape of the grains could result from low transport. The presence of round mat (RM) grains suggests the impact of aeolian transport. The rounded and shiny (EL) grains indicate the long aquatic mechanical mixing probably of hydrological origin. Fig. 7 shows the Scanning Electron Microscopy (SEM) observation of sands of the study area. The preliminary examinations of the sands in our study area showed that 73 percent of sand are in RM category, i.e. round mat grains are frosted and rounded by aeolian transport and it has a high carbonate content 47 percent CaCO_3 and a low percentage in organic matter, silt and clay, from a dynamic point of view, that the wind transport is done mainly by saltation and affects 98 percent of the sand grains, while the deposit is dune. Otherwise, the rounded and shiny (EL) category represents about 19 percent of samples, while 08 percent are represented by the fresh and angular (NU) category, which have undergone low transport. The morphoscopic study of the sands of the research area asserts that the grains of the sands in our study area are blunt and shiny grains with a dominance of rounded edges, and can sometimes acquire the shape of almost perfect spheres. Their surface appearance is always very polished, shiny, gleaming under the light of the binocular magnifying glass. They are characterized by long transports due to an allochthonous origin, with a very high probability. According to Bouarfa and Bellal (2018), the primary winds are from the south and north, with the east and west coming in second and third, from the unidirectional sandy transport regime. Only the winds from the South and WSW sectors are effective and the most frequent, they are capable of generating a sandy displacement.

On the other hand, outside the region we can count outcrops and source areas providing allochthonous sand. Therefore, we suggest that other reservoirs supplying the sands containing large quantities of sand are located on Moroccan territory such as Chott Tigri, Oued Maader, the corridor between Figuig, Bouarfa and Massa Daraa, are the dominant sources of sands in the region of Ksour Mountains. Chott El Gharbi as example covers an area of more than 140,000 ha, and a large part of its supply comes exclusively from Moroccan territory. The entire transit corridor connecting the two Chotts (El Gharbi and Ehergui) is covered by a sandy veil about thirty kilometers wide which gives us very explicit

information on the passage taken by the sand during its transfer from the South-West (Chott El Gharbi) to the North-East (Chott EChergui).

5. Conclusions

The region of Ksour Mountains is suffering in many localities from significant aeolian sand deposit problems, which result from the severity of climatic and soil conditions, and the non-rational usage of natural resources constitutes the most spectacular desertification phenomenon. The comprehension of the sand deposit phenomenon was achievable by the combined effect of geological, climatic, edaphic and geomorphological factors. The regional wind transport process plan is sand between source zones and deposit zones. The wind remains the primary element responsible for modeling the landform where the wind regime, including direction, magnitude, and frequency, identifies shape, migration, dynamics, and accumulation of dunes of sands. Granulometric testing of samples from 11 locations showed that sand size was mainly very fine to fine grained, with mean grain value of 226.5 μm , sorting ranged from 1.22 to 1.90 indicating well sorting of the sands and skewness values ranges from -0.4 to 0.66, being mainly negative with an average of -0.06, indicated symmetrical to fine skewed values. The kurtosis values range from 0.79 to 1.5, with an average of 0.93, where 64 percent of samples are Mesokurtotic and 36 percent of samples are Platikurtotic. Calcimetric results show a very low carbonate percentage, ranging from 1.85 percent to 7.4 percent, and illustrate a very low fine fraction content and organic matter. The preliminary examinations of the sands in our study area by morphoscopy showed that 73 percent of sand are in RM category, 19 percent in the rounded and shiny (EL) category. In comparison, 08 percent are represented by the fresh and angular (NU) category. The sands of our study area are characterized by long transports due to an allochthonous origin from Moroccan territory, with a very high probability. Despite the success demonstrated, a significant limitation is the lack of prior research studies on the topic in the Moroccan side. Further work to improve on these new developments is suggested. However, selecting the best aeolian sand stabilization method looks to be a difficult process that necessitates a thorough experimental investigation involving a variety of additives as well as other significant variables such as agent quantities and aging duration.

Declarations

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Figures

Figure 1

Study area

Dust storm in Ain Sefra city (24 May 2021)

Blowing sands in the road of Ain Sefra (28 May 2021)

Figure 2

Problems caused by wind-blown sands in Ain Sefra city.

Figure 3

Sample's location in Ain Sefra.

Figure 4

Positions of the samples in the dunes of Ain Sefra.

Figure 5

Cumulative curves of samples of sands in the study area.

(c)

(d)

Figure 6

Histograms of all samples plotted with the respect to statistical parameters calculated by the GRADISTAT program: A- Median, B-Sorting, C-Kurtosis, D-Skewness.

Sample	X4	X10	X40
E01
E02
E03
E04
E05
E06
E07
E08
E09
E10
E11

Figure 7

The Scanning Electron Microscopy (SEM) observation of sands of the study area.