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Potential of medium-resolution satellite imagery for monitoring sand transport in pre-Saharan urban areas

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Abstract

One of the most spectacular manifestations of desertification is silting up. On a sandy windy day in the Saharan environment, the atmosphere can be so loaded with solid matter that it feels like twilight. It thus presents a danger and a health risk for the population at two levels: i) at the respiratory level, firstly because of the inhalation of solid matter and ii) at the level of sight; solids entering the eye can cause irritation and over time serious infections.

One of the most spectacular manifestations of desertification is silting up. On a sandy windy day in the Saharan environment, the atmosphere can be so loaded with solid matter that it feels like twilight. Wind erosion is the main cause of all silting up, the wind playing the double role of erosive agent and transport agent. However, in pre-Saharan environments, sand can also be transported by bedload in wadis; in some cases, the sand can also be of very local origin (erosion of soft sandstone for example); some popular cultures then speak of a “source of sand” which they describe as “inexhaustible”. The silting up of a territory can be accelerated (climatic conditions, existence of favorable transport corridors) or slowed down by natural screens (vegetation or relief, for example). Studying the silting up and trying to understand its causes and evolution requires having a multi-date synoptic view of the territory; satellite imagery then appears to be the most appropriate means to provide adequate basic information.

The present study has three main objectives: i) delimit areas covered with sand or likely to be; ii) delimit the potential foci (or sources) of supply for the silting up phenomenon and finally iii) hypothesize on the progression of the silting up phenomenon for a pre-Saharan area where we are witnessing a significant and rapid extension to the both urban space and cultures on the outskirts. It mainly concerns the city of Laghouat, a former oasis in the southern foothills of the Saharan Atlas, and its periphery. The population of Laghouat increased from 42,800 inhabitants in 1977 to 119,043 inhabitants in the year 2003 (estimate), i.e. a variation of 178% (i.e. a multiplication by a factor of 2.8) in 26 years resulting in increasingly important consumption needs of all kinds and a profound change in space. It is estimated at 170,693 in 2021. Data from the National Statistics Office are only available until 2019 for overall statistics.

For the present work we used several satellite images at different spatial resolutions: a Landsat MSS image from April 1972 at 80 meters resolution, two Landsat TM images at 30 meters from April 1987 and April 2000 and finally an image extract. ASTER from 2004 to 15 meters. We applied a specific index combining some of the channels to accentuate the perception and the distinction of the zones of transfer and accumulation of sand.

The comparative analysis of the images makes it possible to specify, firstly, the preferred directions of sand transport and, secondly, the directions of transport and then the areas likely to be most affected.

Keywords: satellite images, silting up, pre-Saharan environment, laghouat

Introduction

The supply of sand by wind transport presents a danger and a health risk for the population on two levels: i) at the respiratory level, firstly because of the inhalation of solid matter and ii) at the level of sight; solids entering the eye can cause irritation and over time serious infections. By delimiting the sand accumulation zones and specifying the directions of the prevailing winds, it is possible to provide natural dams (vegetation, for example) to protect populations from these risks. The urban extensions could also be proposed in spaces naturally protected by the mountains. The main objective of this work is to delineate the areas of sand accumulation and the prevailing wind directions.

Laghouat or El-Aghouat (according to Latin transcriptions used at different times in the history of the city) is the plural of Ghaout which is a poetic name originating from the nature and the very configuration of the region. The most commonly accepted meaning is “houses surrounded by gardens”; another probable meaning, but less poetic, would be “box”, probably in reference to the parallelepiped exterior appearance of the traditional house without a garden. Primarily, and until quite recently, Laghouat was made up of an aggregate of ksours (plural of kasr): Boumendala, Nedjal, Sidi Mimoun, Benbouta. Subsequently, a rampart surrounding the oasis was erected to guard against raids and attacks by other tribes. El-Ayachi, historian and great traveler from the Maghreb, mentions in his “Rihla” the existence of this rampart in 1663. This rampart was subsequently “rebuilt” in stone after the occupation of Laghouat in 1850 with seven gates, the most Popular were the Algiers gate, bab el Oued, or the Hajjaj gate (the only one still present) and bab Dhalaa which has disappeared but whose adjoining part of the rampart still exists.

The birth of the city of Laghouat, as an urban locality, dates back to the beginning of the 19th century. But Ibn Khaldoun reported the existence around the 11th or 12th century of a qasr (town or village surrounded by a stone wall for protection against invasions) in a site which appears to be that of the present city, housing a faction of Béni Laghouat, branch of the famous Berber tribe of Maghraouas. Rock engravings and tumuli, however, attest to centers of prehistoric life that had spread over almost the entire Wilaya (prefecture). However, the date on which the city of Laghouat was founded remains unclear. We only know that it was one of the extreme points of ancient Gétulie (The Gétule people are direct descendants of the branch of the Capesian civilization having immigrated to the Sahara around 3000 BC) and that the Maghraouas, fleeing the tyranny and exactions, found refuge there. In the fifth century of the Hegira, eleventh century, portions of the great tribe of the Hilalians made their permanent home there and kept the name of Laghouat.

Laghouat is located on the southern foothills of the Saharan Atlas, 400 km from Algiers, on the national road 1 as shown in Figure 1. It occupies a strategic position of transition between the Highlands and the Sahara which it rightly constitutes one of the entry points; in the past, it was the obligatory passage for commercial caravans or herders on seasonal transhumance towards the Tell or back to the South. The main peripheral urban centers are Bordj Senouci, El Assafia, El Fetha and el Kheneg; Figure 2 shows the configuration. The discovery of the Hassi Rmel gas field about 80 km south of Laghouat and then the policy of forced sedentarization of nomads thinking of the 1950s generated an influx of population increasing housing needs and significantly modifying the configuration of the space. urban; this transformation was also marked by the restructuring of urban development in traditional neighborhoods under gardens during the dark years of the 1990s.

Figure 1 Localisation.

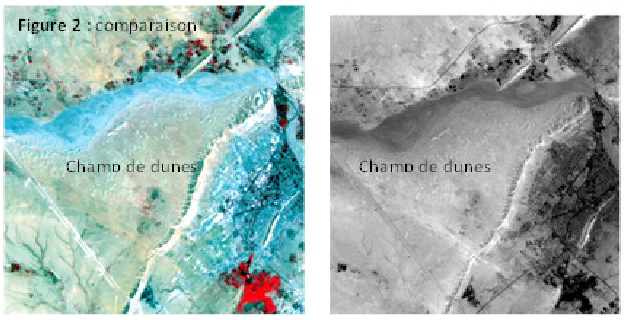

Figure 2 Comparision.

The population of Laghouat increased from 42,800 inhabitants in 1977 to 119,043 inhabitants in the year 2003 (estimate), i.e. a variation of 178% (i.e. a multiplication by a factor of 2.8) in 26 years resulting in increasingly important consumption needs of all kinds and a profound change in space. In 2021, the population of Laghouat is estimated at 170,693, an increase of 51,650 inhabitants over 17 years, representing 43.3% compared to 2003; thus over 17 years the population has multiplied by 1.43. From 1850 (capture of Laghouat), the city is under military administration and did not have any extension land. The new constructions were done mainly at the expense of the gardens or the palm grove which gradually disappeared, but in a way hardly noticeable at the beginning because of the slow demographic growth and the health conditions. The demographic boom of the 70s and 80s, then the cession of land under military administration to the civil authorities and the pressure in demand for housing caused a rapid expansion of the city and the appearance of real urban centers such as Mamourah, the Oasis. North, es Sadikia, Kasr el Bézaim, etc. The national agricultural development program has also generated the development of land reclamation areas for agricultural production, particularly on the road to el Assafia, Ksar el Hirane, Aflou and el Haouita.

The great pressure of demand for housing, the improvement of living conditions allowing faster access to land ownership and the desire to make up for delays in urbanization and infrastructure have often generated the appearance of subdivisions that do not take not take into account the environmental aspect, whether it concerns public or private operations, individual or collective dwellings. On the one hand, we are witnessing the gradual disappearance of vegetation when the mineral takes root in garden or palm grove areas and the absence of green or vegetated spaces in the case of constructions outside gardens or palm groves. The various development plans certainly provide for green spaces; but these green spaces rarely see the light of day; more serious still, very often we see a reconversion of the initial function of space. On the other hand, the development of agricultural development areas creates significant pressure on the water table because of the many wells dug here and there without concerted action with the services in charge of protecting water resources.

We also note the presence of sandy formations and dunes in the region; this is confirmed by Taibi.[1] In terms of climate, the region is subject to winds from a dominant NW-SE direction which creates real sandstorms, especially in April and July-August. Since there is no longer a plant screen, the effect of the sandstorm can be significant on the health of populations and the quality of life of households. The displacement of dunes and sandy formations will also have consequences on agricultural development areas.

The question then is to know to what extent the use of imagery can help to delimit the zones of sand transfers and to predict the evolution of the landscape and therefore to map the vulnerability of spaces and populations. The present work mainly concerns the use of medium resolution satellite imagery to delineate the zones of transfer and accumulation of sand. Figure 1 tells us the location of Laghouat. Laghouat occupies a strategic position between both the north and the south, the High Plateaux - Sahara transition of which it is one of the gates, and the east and west of Algeria. It is thus a real crossroads.

We often associate silting, desertification, dunes. Many authors have dealt with the process of desertification, the silting up of steppe areas and drought in arid and semi-arid areas. Thus, Marius C[2] deals with the problem of silting up and its negative impacts on the mangroves of Senegal; Callot et al.[3] analyzes the geodynamics of aeolian sands in the Saharan northwest; Taibi[1] uses Landsat MSS images from 1977 and TM from 1989 as well as SAR-ERS images from 92 and 93 to carry out diachronic monitoring of three main themes: dense and steppe vegetation and sandy formations at five sites in Piedmont. south of the Saharan Atlas. More recently, Benmohammadi et al.[4] analyzed anthropogenic and natural interrelationships and their impacts on the resurgence of silting up and desertification phenomena in south-eastern Morocco; Desjardins et al.[5] highlighted the advance of dunes in several areas of south-eastern Morocco using high spatial resolution civilian and military images to understand the progression of dune structures over a four-year period; more recently, Bensaid A[6] used satellite imagery for the study of silting up in the wilaya of Naama (Algeria) in an arid zone. In order to separate the zones covered by the sand (transfer or accumulation zones, we tested several classic algorithms such as vegetation indices, soil index. None of these algorithms gave us full satisfaction for our study area; which was expected because of the thematic proximity of the spectral responses of the themes present and the objectives that we have set for ourselves, namely: i) confirm (or deny) the dominant direction of the winds (and therefore the phenomenon of transfer of sand); ii) delimit the directions of transfer and the areas conducive to accumulation; forecast the risk areas.

Material and methods

For the present work we have used several satellite images at different spatial resolutions: a Landsat MSS image from April 1972 at 80 meters resolution, three Landsat TM images at 30 meters from April 1987, April 2000, April 2006 and finally an extract. ASTER image from 2004 at 15 meters. We applied a specific index combining some of the channels to accentuate the perception and the distinction of the zones of transfer and accumulation of sand.

The comparative analysis of the images makes it possible to specify, firstly, the preferred directions of sand transport and, secondly, the directions of transport and then the areas likely to be most affected.

We then started with a building index developed by **Abdellaoui et al.**[7] which we modified to obtain an index of the following form:

$$IBM = (b1 + u * b2 + v * b3) / b1$$

In this formula: b1, b2, b3 denote respectively the Blue, Red and near IR channels; for TM and ETM + we took channels 1, 3 and 5; we set the constants u and v to 1.5 and 2.5 respectively. The image obtained has the advantage of highlighting very clearly 4 well-differentiated themes on separate gray scales:

- Vegetation in black; consolidated or wet sand in dark gray and built in lighter gray
- Sand veil or in motion in white very separated from the rest. Figure 2 gives a comparison between a colored composition and the same grayscale window obtained with the IBM index. This image can also be thresholder to isolate the sandy haze and transfer zones as shown in Figure 3. Figure 3 is obtained from an excerpt from the image from April, 2006; the thresholding of the index made it possible to accentuate in clear white the presence of sand on the sides of the reliefs, as shown by the arrows in yellow.

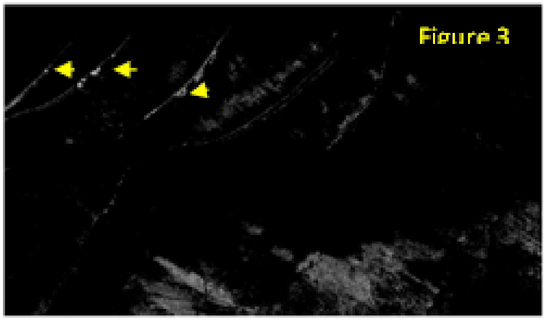

Figure 3 Isolate the sandy haze and transfer zones.

Results, interpretation and discussion

The field of experience: The land includes a sandy formation field to the North East of Laghouat between Jebel Ahmar and the Mzi Wadi and dune fields to the South and South West of Laghouat. A dune formation is also present south of El Kheneg near Wadi Messaad and Jebel El Kheneg. Figure 4 shows the location of the sandy formations in the Laghouat region. Sandstorms were observed in the Laghouat region mainly in February – March or even April; for some time they have been used almost all year round, especially in July and August, in addition to the traditional season of February and March. During these storms, the atmosphere is so laden with solid matter that it feels like twilight in the middle of the afternoon in August.

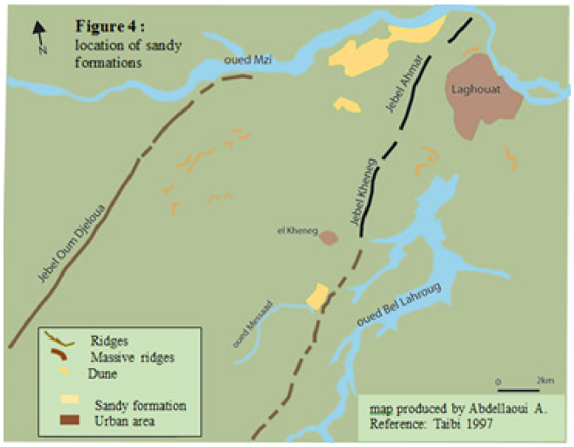

Figure 4 Location of sandy formations.

Figure 5 gives an idea of such a situation; it is taken one afternoon in August of the year 2006. It shows a sandstorm situation, one afternoon in August 2006. The image (a) gives an idea of the birth of the storm north-west of Laghouat, on the road to Aflou; photo (b) shows the arrival of the storm in the city; we are here already in the south of Jebel Ahmar. Photo (b) is taken around noon, but it is so dark that the clarity of the sky looks like a sunset. Photos are taken by the author.

According to J Dubief,[8] a sand wind is a turbulent wind, of any force, carrying a large quantity of particles with an average diameter greater than 1/16 of a millimeter above a surface of several square

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kilometers. At Laghouat, Dubief measured sand winds with an average duration of 4.7 hours; the average is calculated from 94 observations. Taibi (1997) notes in 1997 that the annual average of sand winds is 37.1 hours at Laghouat. It also notes that the number of days with sand winds is lowest from November to January; peaks of occurrence are found in spring and fall.

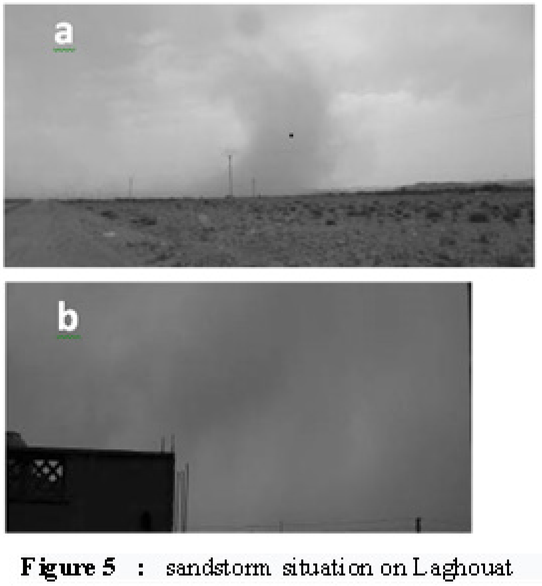

Figure 5 Sandstorm situation on Laghouat.

Figure 6 gives the resultants of the volumes of sand carried by the wind in one year through a line 1m long over the period 1931-1940 according to Dubief's data. Piedmont is an important wind energy transit area. Taibi notes that the hamadas are covered almost everywhere with an almost continuous "red film", more or less thick which progresses from the northwest to the southeast, driven by prevailing winds over these unobstructed surfaces. This sandy veil is, according to Taibi,[1] essentially allochthonous and has a very low dependence on the substrate for both fine and coarse fractions.

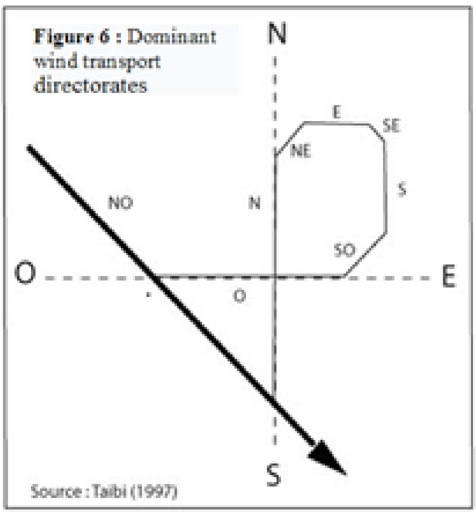

Figure 6 Dominant wind transport directorates.

Image analysis: We wish to answer three specific questions leading to specify: i) the location of the sandy formations; ii) the sustainability of the dominant directions of wind transport and iii) the activity of the phenomenon of transport of solid materials. The result of the processing of the images of April and November 1987 shows us that the direction of the prevailing winds is perennial NW-SE (Figure 7). We then looked at images from April (the windiest month for the region) over different years (1972 to 2004); we also obtain a stability of the directions as it is also shown in Figure 8. We can thus confirm the NW-SE direction. We thus find the predominant direction indicated by Taibi[1] and repeated in Figure 6. The different dune formations are clearly discernible on the "Modified Building.

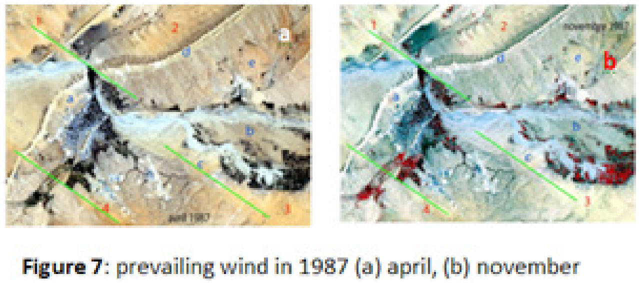

Figure 7 Prevailing wind in 1987.

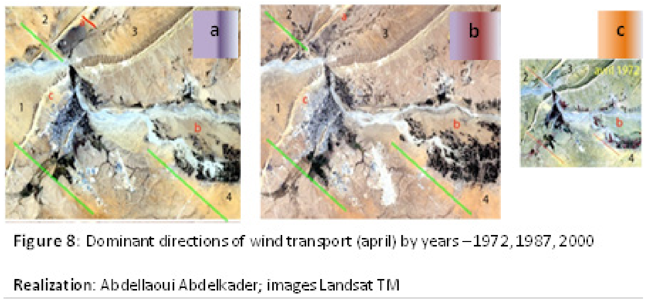

Figure 8 Dominant directions of wind transport (april) by years – 1972, 1987, 2000.

To confirm the sustainability of the direction of the prevailing winds, we were interested in the evolution of the directions of the prevailing winds for different years. Figure 8 confirms the sustainability of the NW-SE direction over the years 1972 (a), 1987 (b) and 2000 (c). Modified Building Index applied to the Landsat image of April 7, 2000 shows the position of the dune fields and mini dunes that exist or are being formed on the outskirts of the city of Laghouat (Figure 9).

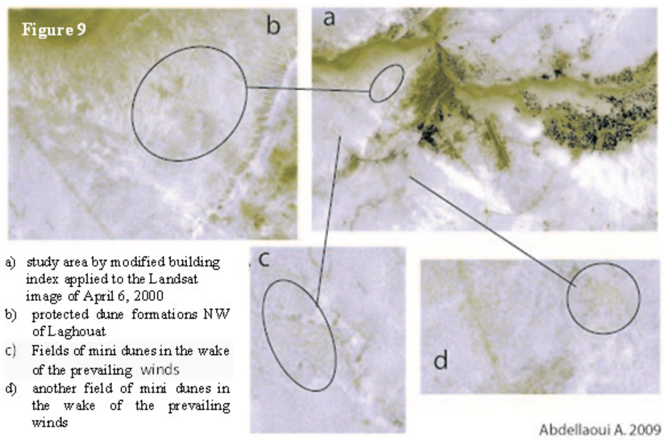

Figure 9 Dune Fields.

In Figure 9, photo (a) confirms the highlighting of dune fields by the modified building index. Photo (b) shows the existence of a

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protected mini dune field east of Jebel Lahmar; this dune field is very probably the result of a local formation by erosion. Photos (c) and (d) show the dune fields due to wind transport; these fields are found in the wake of the prevailing winds; they are therefore due to a transfer of sand from NO accumulation reserves (oued bed or others).

To analyze the activity of the phenomenon, we focused on the images of April 1987, 2000 and 2006, respectively 11, 6 and 7, analyzed by the modified building index. Figure 10 shows a summary map on which the following remarks can be made: i) the NW-SE sandy spit south of Laghouat and the airport, which extends to Jebel Lahmar and which is mentioned by Taibi[1] is present in all three images; ii) the 2000 image shows us an evolution of the sandy veil south of the El Fetha crop area, north of El Kheneg and south of Laghouat; iii) the image of 2006 confirms this evolution of the deposit of sandy veil towards the south of Laghouat and el Fetha with, however, an even greater extent in 2006; this may suggest on the one hand that the displacement is in the NW-SE direction in the NW to SE direction and, on the other hand that the cultivation area of el Fetha may be, in the long term, threatened by silting up. ; iv) the NW direction seems to be responsible for the placement of the sandy trails; v) the potential sources of solid matter can be the various dune fields as well as the river bed of the Mzi wadi, the sandy material of which seems to accumulate rapidly on the right bank, blocked by vegetation (el Fetha in particular which continues to grow get bigger) or topographical obstacles.

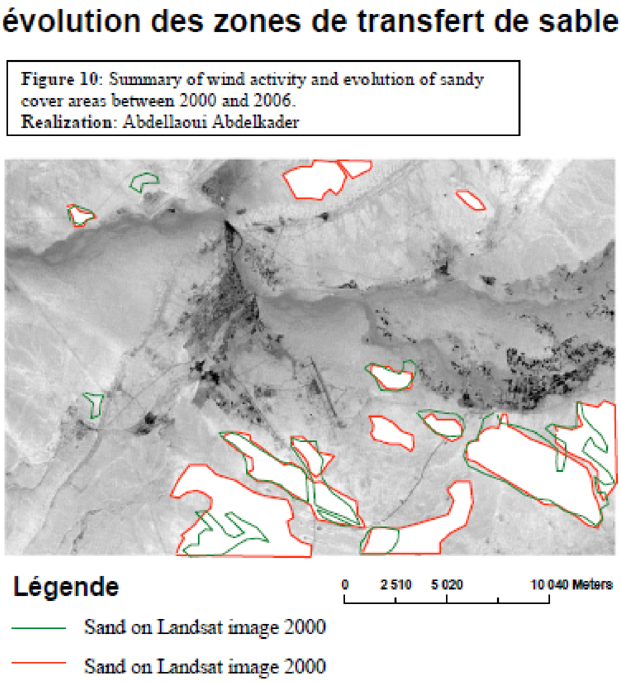

Figure 10 Summary of wind activity and evolution of sandy cover areas between 2000 and 2006.

Realization: Abdellaoui Abdelkader.

Figure 10 shows a synthesis of wind activity from the images of 1987, 2000 and 2006. Two observations can be made: i) the areas in the wake of the prevailing winds are increasing significantly, ii) those near Wadi Mzi appear to be more stable.

We also note the appearance of new sand accumulation zones (presence in the 2006 image and absence in 2000). They appear in green especially east of Jebel Kheneg and north of Wadi Mzi. These two new zones are in the wake of the prevailing winds and could be explained by a sand supply coming from much further away, reflecting a permanent activity of wind transport.

Conclusion

This work has shown that medium resolution satellite imagery (30m) gives interesting results in the monitoring of sandy formations, especially in semi-arid environments. Conventional colored compositions on images pretreated by contrast enhancement already make it possible to identify these formations, although confusion between themes can generate misinterpretations. The use of a specific algorithm (Modified Building Index) made it possible to isolate more finely the sandy formations, in particular the areas of veil or sandy trails present in a large part of the space studied.

The present work also made it possible to follow wind activity over a long period and to follow the evolution of sand accumulation zones or spaces which are beginning to be covered with a sandy veil. The identification of new areas should make it possible to predict threatened areas and therefore to produce predictive maps of the risk of silting up. Monitoring wind activity over a long period from satellite images thus makes it possible to predict areas at health risk for populations.

Using very high resolution images would allow finer resolutions to be achieved.

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