

DIACHRONIC ANALYSIS TO DETECT AND MONITOR BARCHAN DUNE MIGRATION IN AIN SALAH (ALGERIA)

DIJAKRONIJSKA ANALIZA U OTKRIVANJU I PRAĆENJU MIGRACIJE BARHANE U AIN SALAHU (ALŽIR)

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The aim of this work is to analyse deposit patterns and their effect on urban and agricultural areas in Ain Salah region in southern Algeria. A supervised classification of Landsat images over a 13-year period (2005, 2009, 2013 and 2017) was applied to create land cover maps which were used for a spatiotemporal monitoring of barchan migration by dune feature changes. The results show that sand dunes covered area increased between 2005 and 2017 with direction movements from northeast to southwest and represents the potential of using time series imagery for a better understanding of dune migration and sand encroachment.

KEY WORDS: Landsat, multi-date, barchans, migration, Ain Salah

Cilj ovoga rada je analizirati uzorke depozita i njihov učinak na urbana i poljoprivredna područja u regiji Ain Salah u južnom Alžiru. U istraživanju je provedena nadzirana klasifikacija Landsat snimaka u razdoblju od trinaest godina (2005.; 2009.; 2013. i 2017.) radi izrade karata zemljišnog pokrova koje su korištene za prostorno-vremensko praćenje migracije bahrana kroz praćenje obilježja dina. Rezultati pokazuju da se područje prekriveno pješčanim dinama povećalo između 2005. i 2017. godine sa smjerom kretanja od sjeveroistoka prema jugozapadu te da primjena niza vremenskih snimaka omogućuje bolje razumijevanje migracije dina i prodiranja pijeska.

KLJUČNE RIJEČI: Landsat, vremenski niz, bahrane, migracija, Ain Salah

INTRODUCTION

Sand dune movement is considered as one of the most serious environmental and socio-economic problems. In Algeria, nearly 20 million hectares are threatened by wind erosion. For a long time, the phenomenon of wind erosion and its adverse effects on environment presented a serious difficulty, especially in the arid areas of the country (BENSAID, 2006).

Ain Salah region suffers from barchan dune migration and sand encroachment over urban and agricultural areas due to wind corridors coming from northeast and bringing particles of sand from the Grand Erg Oriental.

Barchan dunes move according to a unidirectional-wind mechanism, while the amount of available sand for wind transportation causes the difference between their shape and size. Barchans are isolated mounds of sand, formed in limited sand supply areas that overlie coarse sand or non-sandy surfaces (Tsoar, 2001). Barchans usually do not stay isolated but belong to rather large fields (Lettau, Lettau, 1969).

Yohannes et al. (2021) showed that remote sensing techniques were useful to evaluate the response of hydrological ecosystem services to structural landscape changes. Multi-temporal Landsat satellite data were used to understand the drivers of land use and land cover changes which are often monitored and quantified using remote sensing imagery. Landsat data and geospatial techniques were very effective to quantify the channel characteristics of the Ganges system in Bangladesh during 38 years including the volume of erosion and deposition (Dewan et al., 2017). Annayat, Sil (2020) combined Landsat images with the statistical model ARIMA to investigate the morphometric parameters and temporal shifting of the Barak river in India which obtained good results of the synoptic view of the river course over the study period. Dewan et al. (2012) used landscape metrics derived from satellite data to map the dynamics of land cover and land use changes and the quantification of landscape patterns.

Remote sensing imagery played an important role in the analysis of barchan dune fields. The use of remote sensing started with the first stud-

ies on mapping and classifying sand dunes (McKee, 1979). Change detection technique is one of the most useful applications of remote sensing. Change detection includes multi-temporal data application in order to specify the regions in which land cover and use changed considering various times of imaging (Rabiei, 2005).

DATA AND METHODS

Description of the study area

The study area presented in Figure 1 is located in the south of Algeria in Tamanrasset county and covers an area of approximately 937 km², at 28°:5' to 25°:16' in latitude and from 2° to 4°: 10' in longitude.

The climate of the region is arid Saharan climate, cold in winter, hot and dry in summer. The yearly average of precipitation ranges between 2.86-0.95. Generally speaking, this region remains dry most of the year. The average temperature ranges from 46.09 °C in summer and 27.27 °C in winter. Physiographically, this area is characterized by a low relief with an average of 300 m in altitude and is composed of three types of relief; Tadmit Plateau in the northern side, Tidikelt Plain in the middle and Adrar Nahenet Mountains in the south with a predominantly sandy soil texture.

The wind speed and direction data were collected from the Algerian Meteorological National Office over a period of 10 years (from 2008 to 2018) at 10 meters above ground level. The northeast direction represents 32% of wind frequencies when the monthly average speed was higher in July and August and reached its maximum in August, as well as the number of days where the maximum wind speed was over 6.59 ms⁻¹.

Remotely sensed data

Multi-date dataset of satellite imagery of Landsat images was used to understand and analyse the barchans displacement trend and dynamics; for better results, images were taken in the same season over a period of 13 years (2005-2017); these images were obtained from

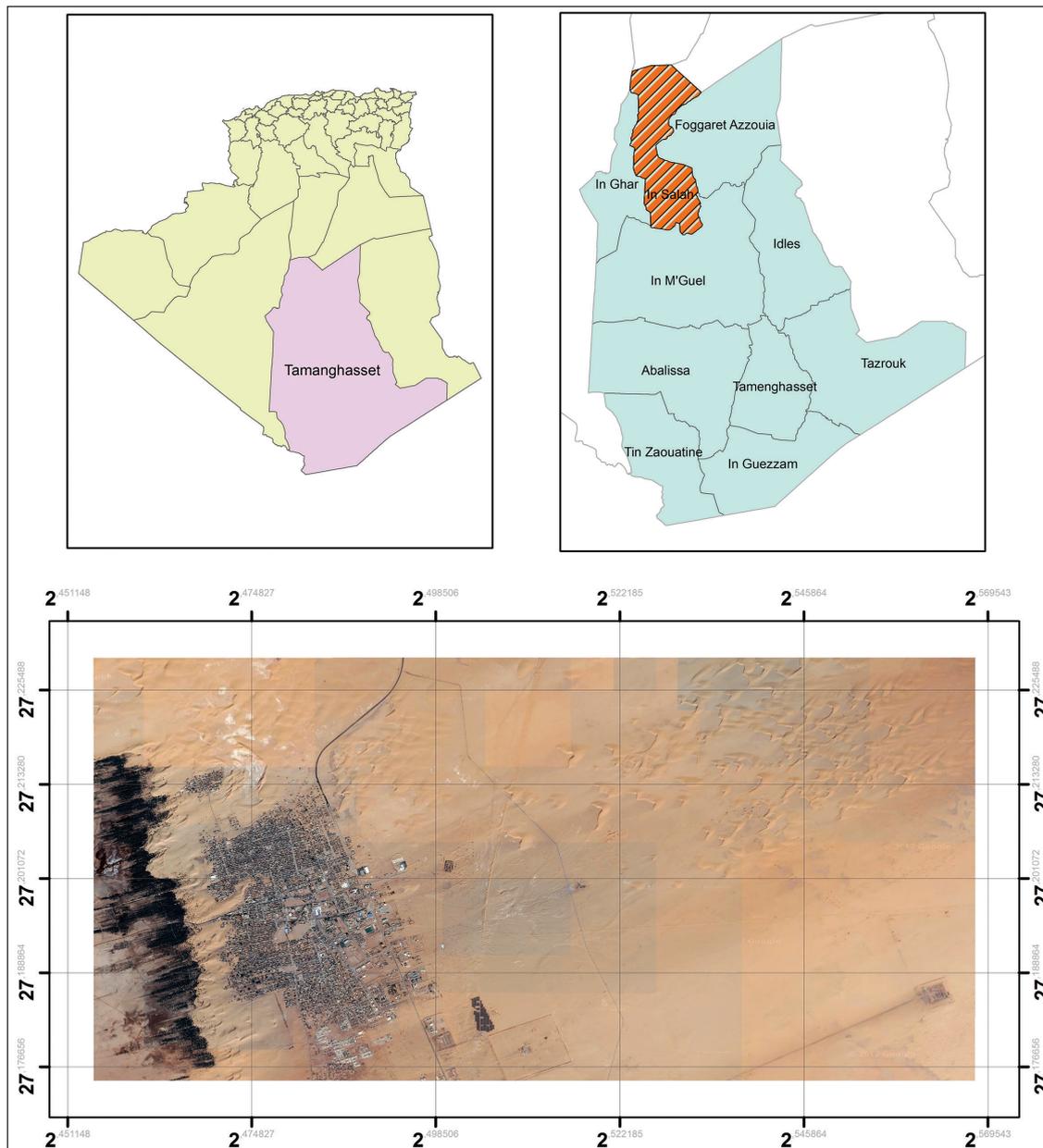


FIGURE 1 Location of the study area

the United States Geological Survey data base (see Tab 1.).

Data pre-processing

A geometric correction was applied to all images using ground control points that transformed coordinate system to UTM, zone 32

(SEYMOUR, 2014). Then all images were resampled to a 30 m spatial resolution using an automated tie-point program (KENNEDY, COHEN, 2003).

Radiometric calibration was used for all images to convert 8-bit satellite quantized calibrated digital numbers (DN) to at-satellite reflectance (SCHROEDER, 2006). For full absolute correction,

TABLE 1 Landsat images used in this study

Satellite data	Target	Image ID	Acquisition date
Landsat TM	WRS2, Path195, Row41	LT51940412005223MTI00	2005-08-11
Landsat TM	WRS2, Path195, Row41	LT51940412009218MPS00	2009-08-06
Landsat OLI_TIRS	WRS2, Path194, Row41	LC81940412013213LGN01	2013-08-01
Landsat OLI_TIRS	WRS2, Path195, Row41	LC81950412017231LGN00	2017-08-19

at-satellite reflectance was converted to surface reflectance (HADJIMITSIS ET AL., 2004).

The Optimum Index Factor (OIF) was used to select the optimum combination of three bands for the satellite image (CHAVEZ ET AL., 1984). The OIF is a statistical tool to measure the dispersion of pixel value and the correlation among different bands, where the combination of the high dispersion of pixel value and the lowest correlation considered as the band combination of highest amount information.

For each combination of three bands, the OIF is calculated as follows:

$$\text{OIF} = \frac{\text{Std}i + \text{Std}j + \text{Std}k}{\text{Corrij} + \sqrt{\sum_{i=1}^n (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}} \quad (1)$$

where: Std*i* = standard deviation of band I, Std*j* = standard deviation of band j, Std*k* = standard deviation of band k, Corrij = correlation coefficient of band i and band j, Corrik = correlation coefficient of band i and band k, Corrjk = correlation coefficient of band j and band k

Data processing

Each image was classified using the supervised maximum likelihood classification applied on the colour composite images (BOUZEKRI, 2017). In addition, ground control points during fieldwork were used as training sites to estimate probabilities and consider the variability of brightness values in each class. This classifier is based on Bayesian probability theory, which is one the most powerful classification methods when accurate training data is provided and one of the most widely used algorithms (PERUMAL, BHASKARAN, 2010). The likelihood classification expressed as follow:

$$Lk = P(k/X) = P(k) * P(X/k) / P(i) * P(X/i) \quad (2)$$

where: P(k) = prior probability of class k, P(X-/k) = conditional probability to observe X from class k, or probability density function

Usually P(k) are assumed to be equal to each other and P(i)*P(X/i) is also common to all classes. Therefore, Lk depends on P(X/k) or the probability density function. By applying the classification on the colour composite using QGIS software, four major classes of land cover categories were delineated in this study; bare land, sand dunes, vegetation and urban area. The post-classification comparison approach is very advantageous when using data from different sensors with different spatial and spectral resolutions (ALBOODY ET AL., 2008).

Accuracy assessment of land changes

In order to measure land cover change and classification accuracy assessment, we used the intensity analyses method developed by ALDWAIK, PONTIUS (2012), this approach is based on the analysis of land cover change modelling maps from 2005 to 2017 conducted by using Pontius-Matrix42. This matrix was intended to measure the size and speed of changes over time on the one hand and to analyse the losses and gains of each class between two dates on the other.

RESULTS

Twenty band combinations were calculated for each image Landsat 8 by using ILWIS software. Table 2 shows the highest OIF values which means the highest amount of information provided by band combination. For all dates the OIF suggests that out of twenty-band combinations, the combination of bands blue, green and short-wave infrared 1, which ranks first, provides the

TABLE 2 The highest values of OIF for each date

Date of satellite image	Highest OIF	Combination
2005-08-11	18.93	blue, green and short-wave infrared 1
2009-08-06	18.12	blue, green and short-wave infrared 1
2013-08-01	18.54	blue, green and short-wave infrared 1
2017-08-19	18.23	blue, green and short-wave infrared 1

TABLE 3 Confusion matrixes of supervised classification of Landsat data

Class	Bare land	Sand dune	Urban area	Vegetation	User's accuracy %
Bare land	10708	19	4	0	99.79
Sand dune	1065	37	0	0	39.66
Urban area	205	1	1780	2	89.54
Vegetation	0	0	14	219	93.99
Prod accuracy %	92.49	95.62	99.00	99.10	
Class	Bare land	Sand dune	Urban area	Vegetation	User's accuracy %
Bare land	21064	97	101	0	99.07
Sand dune	684	4473	2	0	86.70
Urban area	789	7	4063	45	82.85
Vegetation	0	0	130	702	84.38
Prod accuracy %	93.46	97.73	94.58	93.98	

TABLE 4 Percentages of land cover over time

Classes	11-08-2005	06-08-2009	01-08-2013	19-08-2017
Bare land	70.81	63	59.24	52.2
Sand dunes	18.03	27.16	26.01	35.16
Urban area	9.81	9.12	11.58	11.11
Vegetation	1.34	1.82	2.04	1.57

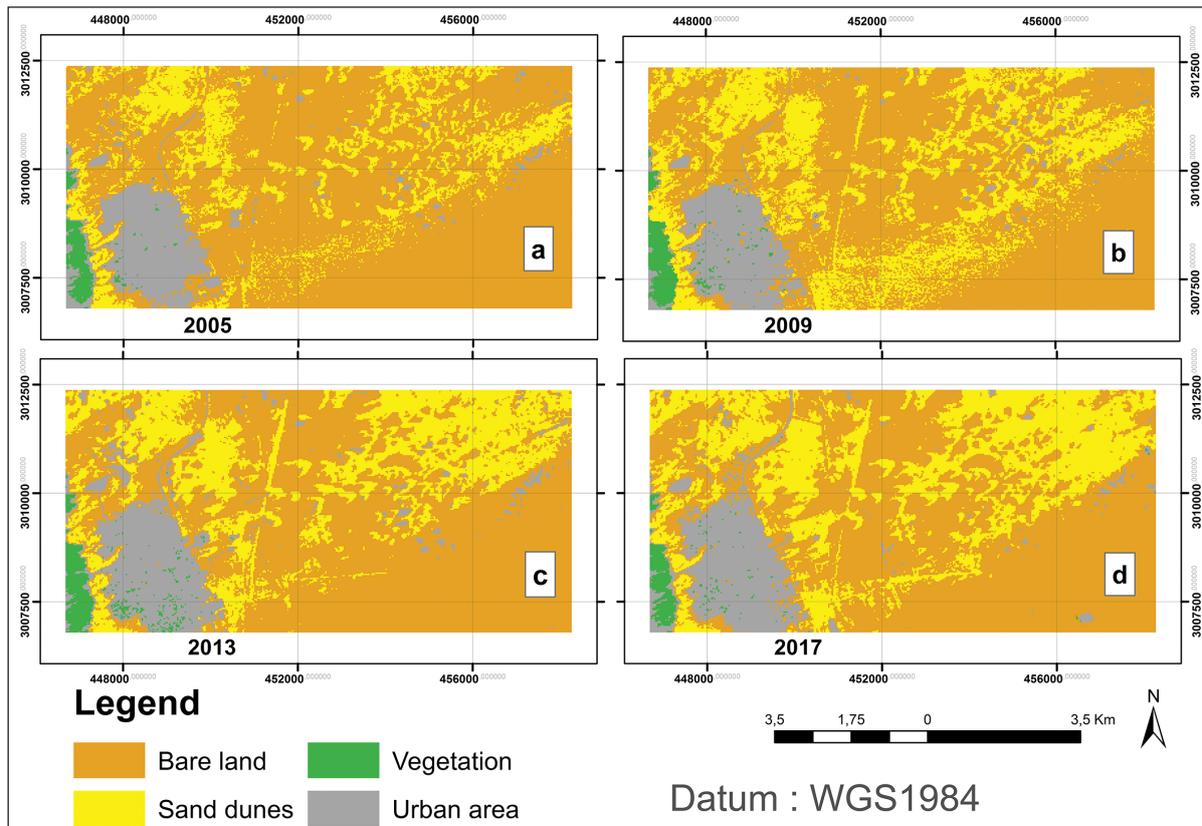


FIGURE 2 Land cover maps for the four defined periods

greatest amount of information and colour contrast.

Table 3 presents the confusion matrixes of

2005 and 2019 supervised classification respectively. The value of Kappa coefficients is 0.81 for 2005 and 0.82 for 2019 and the number of

corrected classified pixels indicate that the results of these LCLU classifications are acceptable and accurate.

The results of image processing revealed a significant change in land cover feature classes in Ain Salah area over the study period (see Tab 4. and Fig. 3).

DISCUSSION

When comparing the surfaces of sand dunes for the four different dates it appears that there was a remarkable increase. In 2005, sand dunes occupied 18.03% of the total study area, in 2009 this area increased to 26.16%, there was a slight increase again between 2009 and 2013, followed by an increase reaching 35.16% of the total area during the last period (2013-2017). Over the study period from 2005 to 2017 the annual rate of increase of sand dunes area was 1.7%.

Bare land showed an opposite trend of change having an initial decline from 70.81% to 63% during the first period followed by a decrease that caused a loss of 3.76% of its area in 2013. In 2017 it decreased to nearly 52%; overall, bare land cover lost an area of 18.61% to other classes, and especially to sand dunes.

The increase in sand dune surfaces at the expense of other land use classes and the changes in bare land, vegetation and urban area over time will lead to more encroachment by sand dunes and more acceleration of its movements.

The transition matrix (see Tab 5.) represents the loss and gain for each category of land cover and land use, where the rows represent the state of LU/LC at the beginning of the study (2005) whereas the columns represent the categories at the end of the study (2017) and the diagonal cells show their persistence size.

Figure 3 shows the loss and gain size and intensity in each class, divided into three components: quantity, exchange and shift using PontiusMatrix42 to indicate the change patterns dynamic.

Figure 3a shows the size of loss and gain in each class, the focus here is on the largest losses and gains, where bare land surface change is nearly similar to the one in sand dune areas and its quantities are the most distributed component.

The exchange is nearly the total component for vegetation and urban area categories. Figure 3b illustrates uniform change intensity for bare land and sand dunes while the urban area category has 15% of shift component and 75% of exchange component.

GIS tools were used to estimate barchan dune migration rate and direction by measuring the distance between the same barchan acquired at different dates. The overlapped barchan dune layers (see Fig. 4) resulting from different dates allowed us to monitor dynamics and patterns of dune migration. The visual interpretation of the obtained results showed that the barchans migration is characterized by a constant direction from the northeast to the southwest. The migration rate of barchans depends on their individual size, and wind velocity.

The highest dune migration rate belongs to the central and northwest parts of the study area especially between 2013 and 2017, where there were no obstacles against the wind blowing from the Northeast. Also, the smallest barchan dunes are located in the north-western region having a fast migration rate of 120 m per year with changing in their size and shape. However, the larger dunes migrate more slowly with a rate of 30 m per year keeping the same size and shape.

The analysis of sand dune migration by using the multi-date images was considered as an

TABLE 5 Pontius Matrix 42 between 2005 and 2019

Category	Bare land	Sand dunes	Urban area	Vegetation
Bare land	47	21	2	0
Sand dunes	3	13	1	0
Urban area	1	1	7	1
Vegetation	0	0	1	2

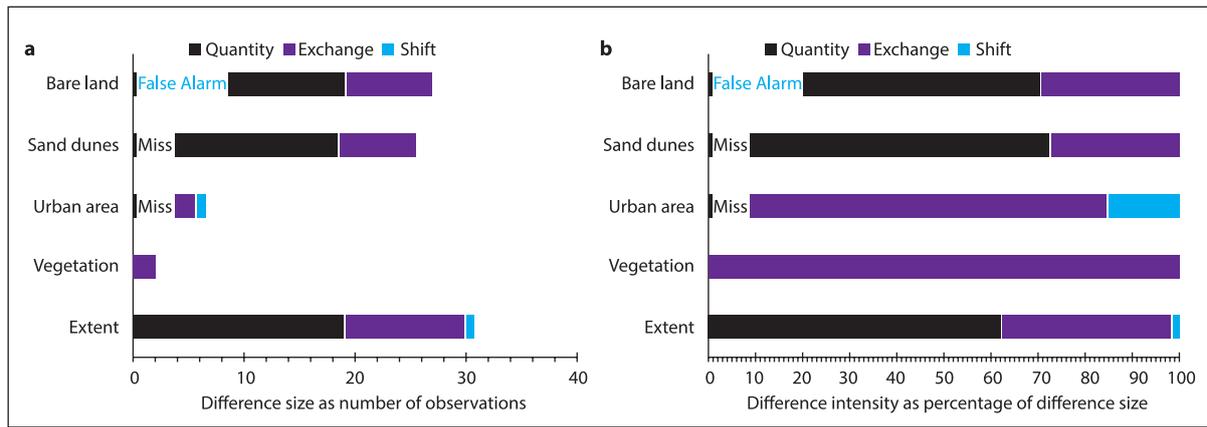


FIGURE 3 Interval level change components in terms of (a) size and (b) intensity

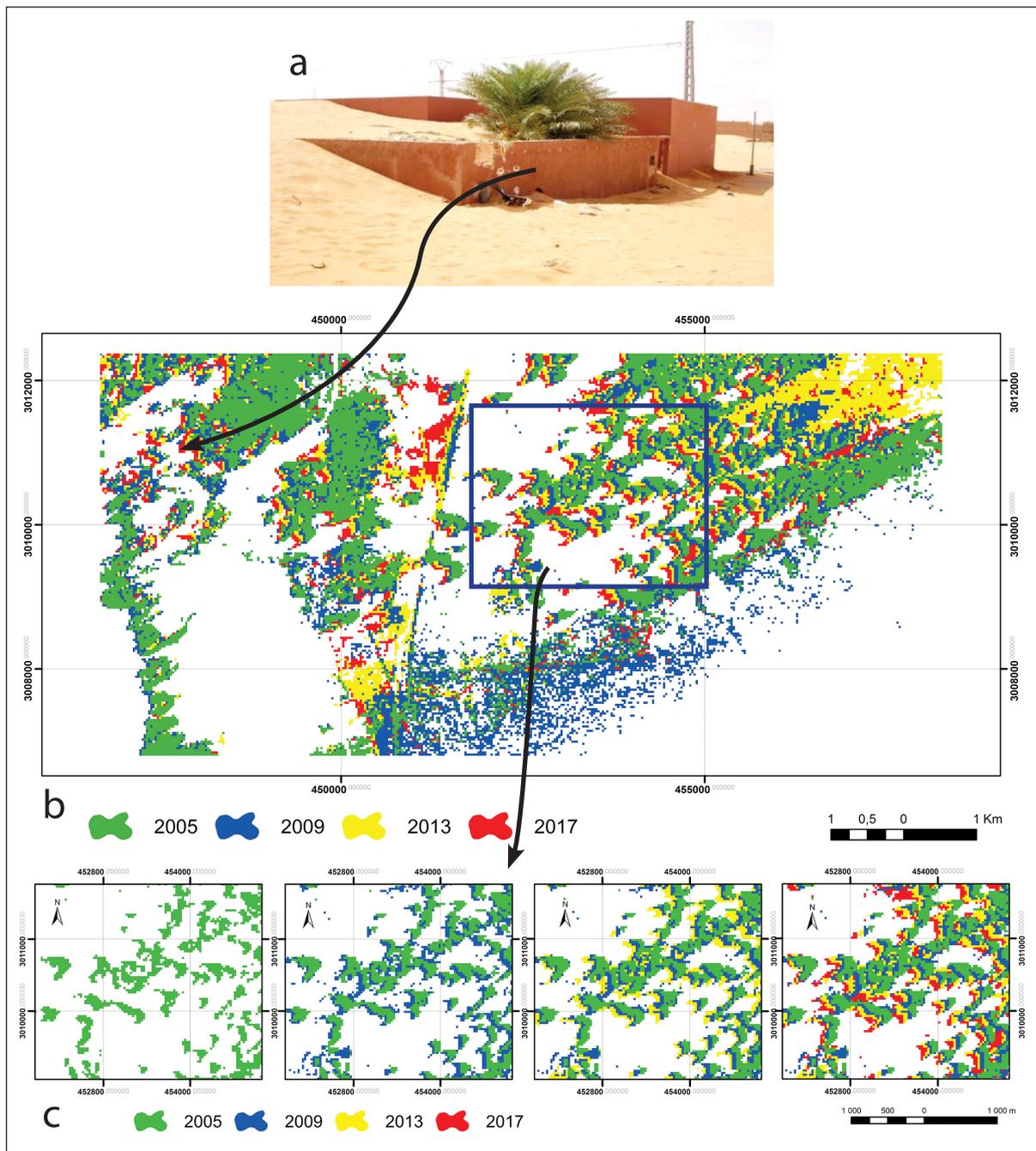


FIGURE 4 (a) Sand dunes encroachment on urban area; (b) Overlapped sand dune layers for the study period, (c) Migration of barchan dunes over time

efficient approach to understand the local and regional sand movement and the patterns of deposit. The results showed that the source of sand is from north east which is the Grand Erg Oriental and created also by the wind erosion actions on Tadmait hill, then the sand transported was accumulated in Tidekelt region to form barchan dunes and to deposit over the urban area and agricultural lands as the mapped results showed on Figure 4.

In the southwest part of the study area sand dunes were stable from 2005 to 2017 due to the vegetation cover that formed an obstacle against Northeast winds forming a sand accumulation zone, in addition to the Ergs of Sidi Moussa that presents a topographical obstacle which is the reason of the dune migration stability in this region.

CONCLUSION

The main purpose of this research was to understand deposit patterns in the region of Ain Salah in south Algeria and to monitor this environmental and socioeconomic problem. We used the approach of post-classification comparison based on supervised classification of a multi-date data of Landsat images and monitor the movement of sand dune features through time. Satellite imagery is a useful technique to monitor barchan dune migration and to calculate its distance between two dates.

Results obtained showed that the migration rate was variable over time and space, ranging from 30 m to 120 m per year, depending on the barchan shape and size besides the wind velocity.

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