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Sand dune distribution and related impacts on agricultural resources of Sinai Peninsula, Egypt, using integrated remote sensing-GIS techniques

Gad, A

National Authority for Remote Sensing and Space Sciences (NARSS), 23, Josef Brows Tito, El-Nozha El-Gededa, Cairo, Egypt P.O Box 1564-Alf Maskan
Email: abdallagad1@gmail.com; agad@narss.sci.eg; Tel: +/20122/3568182

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Sinai Peninsula, as a vital strategic region, is prioritized in the recent government sustainable development program. Availability of potable water is essential for any effort of cultivation or implementation of new societies. Arc-GIS system was used for building the thematic layers model, including contour lines, wells locations, roads, urban areas, agriculture and main wadies. Analyzing the SPOT images (acquired in year 2011) and Landsat ETM+ (acquired in 2000) made it possible to define four dune movement rate categories. The lowest movement rate (2.54 to 3.72 m/year) characterizes the coastal areas, dominated by cultivations and vegetated land use pattern. The moderate movement category (4.0-5.5 m/year) dominates the south and southeast of Lake El Bardaweel. The moderately high category (5.5-7.0 m/year) characterizes the south of Kantara Shark and south El Sheikh Zwied city. The highest movement rate category (7.0-9.0 m/year) influences the south of cultivated El Salam Canal command area. It was found that the road network influenced by the high dune movement risk represents 37.78 % of Sinai roads network, located south of El Kantara Shark and East of Wadi El Arish. Most of urban areas (82.62 %) are located under a low risk of sand dunes movement. The cultivated lands located under the high risk of sand dunes represent 33.37 % of cultivated lands. It could be concluded that the sand dunes movement rate is controlled by the climate, vegetation cover and topography. The northern district of North Sinai is the most affected by sand dunes activities.

Keywords: Remote Sensing, GIS, Sand dunes, Sinai, Egypt

INTRODUCTION

Sinai is a vital strategic east frontiers Egyptian region; it is considered the northeastern national gate towards the continent of Asia. Moreover, Sinai opposed to Africa, effectively serving as a land bridge between two continents. It is considered as an important area in the current stepwise rural development program. Egypt, in general, is facing a water scarcity due to over- population, industrialization and agricultural expansion. Sinai is suffering from water shortages, which represent the major natural resource limitation. Increasing the water resource in Sinai by transporting the Nile water is expensive and competes with other more productive uses possibility in the

Valley and Delta. Water desalination is also quite expensive, the cost of which can only be borne by selected tourism activities, industrial, and domestic uses. Present agriculture in Sinai Peninsula includes date palms in depressions between sand dunes and near the coast; scattered rain-fed agriculture includes primarily watermelon, vegetables, and barley, in addition to limited drip-irrigated crops near El Arish.

Sinai may geologically be divided into three areas as follows (Misak and ElShazly 1982);

1. The northern region, consisting of sand dunes and fossil beaches, was formed by changing Mediterranean Sea levels during the glacial periods, two million years ago. The landscape is flat and uniform, interrupted only by some vast sand- and limestone hills.
2. The scarcely inhabited Al Tih Plateau is the central geological area with limestone dating from the Tertiary Period.
3. The highlands extend towards the south, where Limestone and sandstone sediments are replaced by granite and basalt.

The assessment and detection of sand dune migration in North Sinai are based either on ground survey or remote sensing techniques. The ground based techniques include sand traps (Misak and ElShazly 1982 and Hermas et. al. 2012), steel, iron, and plastic rods (Asaal 1999, Aql 2004 and Khidr 2006). Although these techniques show high level of accuracy, however lack the capability to monitor wide coverage, in addition of being expensive and time consuming. The classical remote sensing techniques for monitoring sand dune migration are normally carried out comparing multi-temporal aerial photographs or satellite images (Gad and Ali 2011, Kamel et al. 1982; Hereher 2000, and El Bana 2004).

Unlike field measurements, remotely sensed data show regular and wide coverage for analysis and measurement. Aerial photographs are, however, expensive, and analyzing them manually is time consuming. Furthermore, although satellite imagery provides multi-temporal coverage of large areas at low cost, the classical definition of sand dune boundaries is highly affected by satellite geometry, sensor parameters, and illumination conditions. This makes determination of sand dune movements from satellite images difficult (Liu et al., 1997).

MATERIALS AND METHODS

Satellite Image processing

A number of 19 SPOT satellite scenes, covering the whole territory of North Sinai (Figure 1) imaged during the year 2011, were collected and processed to be included in the GIS land resources database***.*** Image pre-processing was applied to reduce the undesired variations/noises and enhance desired features. In the current study, different functions of ENVI 4.7 were used for all processing steps.

Histogram equalization stretching technique was applied for obtaining the maximum contrast between features of different sub-scenes. False color composite images of the enhanced sub-scenes were produced using the combination of bands 3, 2 and 1 rendered in red, Green and Blue, respectively.

Radiometric correction of satellite imagery (Normalization) takes into account the combined, measurable atmospheric reflectance, aerosol and earth’s surface scattering and absorption. The process was applied according to Hall et al (1991), to get all images appear as if they were acquired from the same sensor.

Geometric rectification of the imagery resamples the pixel grid to fit that of a map projection or another reference image. This becomes especially important when scene to scene comparisons of individual pixels in applications such as change detection are being sought (ERDAS, 1999).

Separate images were registered to the Egyptian Transverse Mercator (ETM) system. Ground Control Points (GCP's) collection, first order transformation, and nearest neighbor resembling of the uncorrected imagery was performed. The nearest neighbor resembling method was selected to transfers original data values, using the closest pixel value without losing the extremes and subtleties of the data values (ERDAS, 1999). Each GCP was ordered by the residual error it contributed to the polynomial fit. Points with high error were discarded before registration. Image fit was considered acceptable if the RMS error was < 15 m or one-half pixel wide (RMS = 0.5). Overall, RMS errors of less than 0.5 pixels were achieved for each transformation.

The supervised classification was elaborated according to Lillesand and Kiefer (1994), using ground checkpoints and digital topographic maps of the study area. Then accuracy assessment was carried out using 300 points from topographic and existing land cover maps. In order to increase the accuracy of land cover classes, ancillary data and the result of visual interpretation was integrated with the classification result using GIS-ENVI 4.7 software.

Building GIS database

Arc-GIS 10.1 software was used for producing the digital forms of a thematic model which includes contour lines, wells locations, roads, urban, agriculture and main wadies in North Sinai. Digitizing specifications of the maps were defined according to the available themes. A number of 9 topographic maps at scale of 1: 100,000, produced by the Egyptian General Survey Authority (EGSA), were used for this purpose. Different digital maps were corrected from different errors and edge-matched “rubber sheeting” after the geo-referencing processes, according to Tomlin,

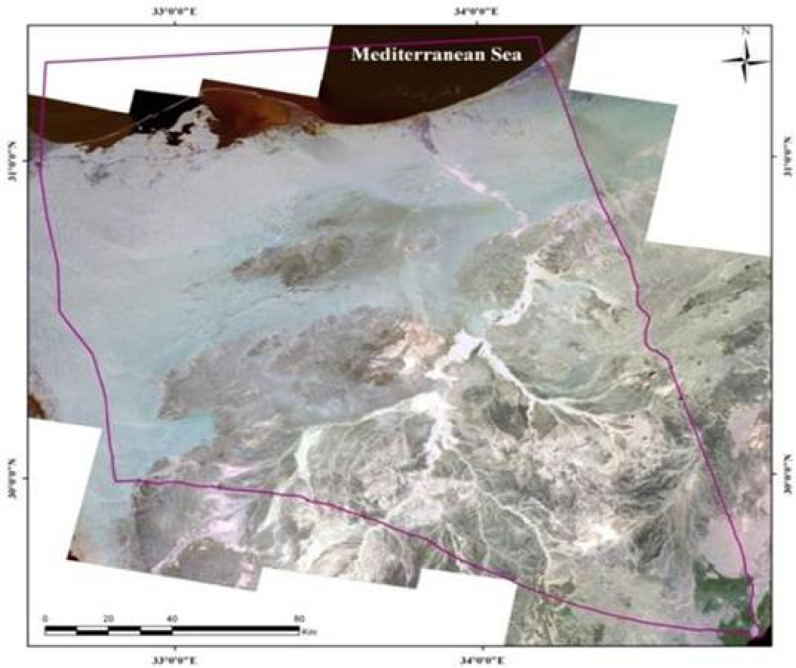

Figure 1: SPOT mosaic of North Sinai

(1990). Layer with least accurate features is adjusted, and the adjoining layer is used as the control.

Change Detection Using Write function memory insertion (WFMI)

The Write function memory insertion (WFMI), as described by Jensen (2005) is a simple effective method of visualizing land-cover change between two or three dates. WFMI is used to qualitatively inspect change in any type of registered, multi-date imagery. The technique operates by creating a red-green-blue (RGB) colour composite image based on co-registered imagery from two or three dates.

In this study, using the Add layer in ENVI, through the RGB Color Model, an 8 bit".pix" file was generated using multi-bands image includingETM-band 7, imaged in year2000 and SPOT- band 3, 2011 (Jenson, 1996). Band 7 of year 2000 in the Red, Band 3 of 2011 in both green and blue. The resulted image file was exported to ArcGIS and was made into final professional map with all the required map cartographic information (Jenson 1996). This method didn't require any quality control because it is just a visual tool.

The result is an image where the areas of change are displayed as red (date 1 is brighter than date 2) and cyan (date 1 is darker than date 2), and areas of little change are represented in grey-tones. The larger the change in pixel brightness between dates, the more intense the resulting colour will be.

RESULTS AND DISCUSSIONS

Land use/cover classification

SPOT satellite scenes, imaged during the year 2011 were used to classify different land use/cover classes in North Sinai using ENVI4.7 software. It was possible to identify a number of 12 classes (Figure 2 and table 1).

The obtained data indicate that the land use/Land Cover classes include sabkhas, fish farms, urban areas, sand beaches, complex active dunes, stable dunes, rain-fed agriculture, newly reclaimed areas, salt marches, wadies and Rockland.

This land cover class "Sabkha" is usually found at the north of the study area near to the Mediterranean coast and El Bardaweel Lake. It represents very small frequencies (0.59%) of the total territory (168.05 km^2). The most important part of the sabkhas is located in the northern part of El Gharaneeq protected area. These sabkhas are found in wet status along the coastal line, while dry in creating parts of the desert playas. The Fish Farms are located in the North West part of the study area, exhibiting about 1 km^2 (i.e. 238 feddans).

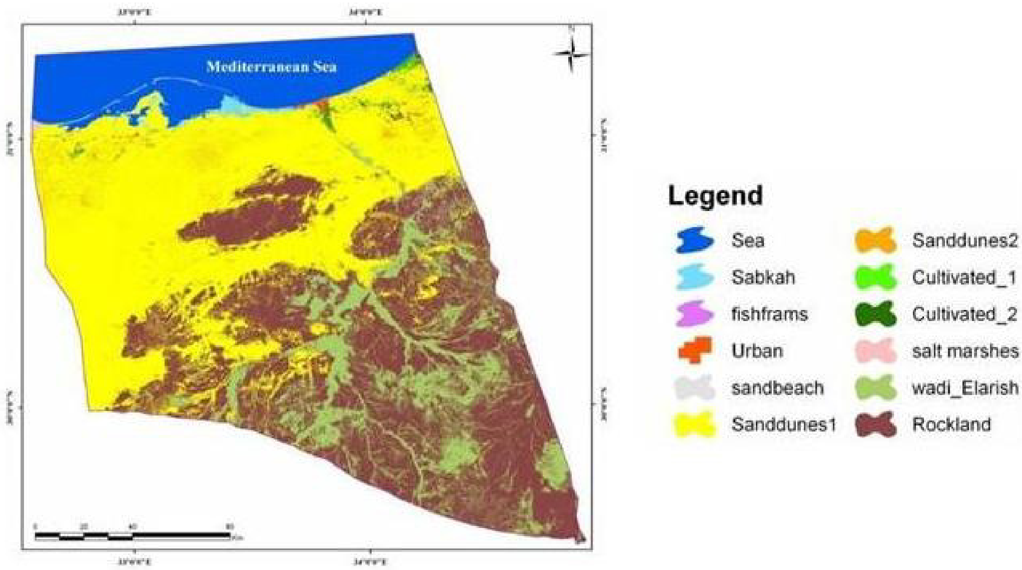

Figure 2: Land Use/Land Cover classes of North Sinai, based on SPOT image 2011

Table 1: Areas of Land Use/ Land Cover classes, North Sinai, 2011

Land Use/Land Cover Class	Area	
	Km^2	%
Urban	46.713	0.16
Sabkha	186.052	0.59
Sand Dunes 1	12070.674	42.60
Sand Dunes 2	490.094	1.73
Sandbeaches	111.644	0.39
Clay Plain	32.282	0.11
Fish Farms	0.854	0.00
Cultivation 1	64.437	0.23
Cultivation 2	161.164	0.57
Wadi El-Arish	4257.583	15.03
Rockland	10931.338	38.58
Total	28334.8352	100

It is remarked that the fish ponds are limited to El Tina Plain and are not observed in other locations at north Sinai. This type of land use resulted from the high salinity of the soils at El Tina Plain where the local farmers try to decrease the soil salinity. The urban class covers small area (46.7 km^2) concentrated at the northern parts of the study area, El Arish city is an ideal example. The salt marches take place in the northeastern part of the study area, covering 0.11% of the total territory. The great importance of the salt marches is related to their economic value and possibility of establishing industrial areas.

The sand beach area is extending, in a narrow strip, along the coastal line representing about 0.39% of the study area (i.e. 11106 km^2). The class "Sand dunes1"refers to the complex active dunes and sand sheet. They exhibit an area of 12070 km^2, representing 46.6 % of the total area. The developed areas around El-Salam canal are subjected to the risk of the dynamic activity of the dunes. It must be pointed out that the supervised classification of SPOT images didn't allow the separation of different dune types, due to the similar reflectance characteristics of sand particles, composing different dune types. It can be

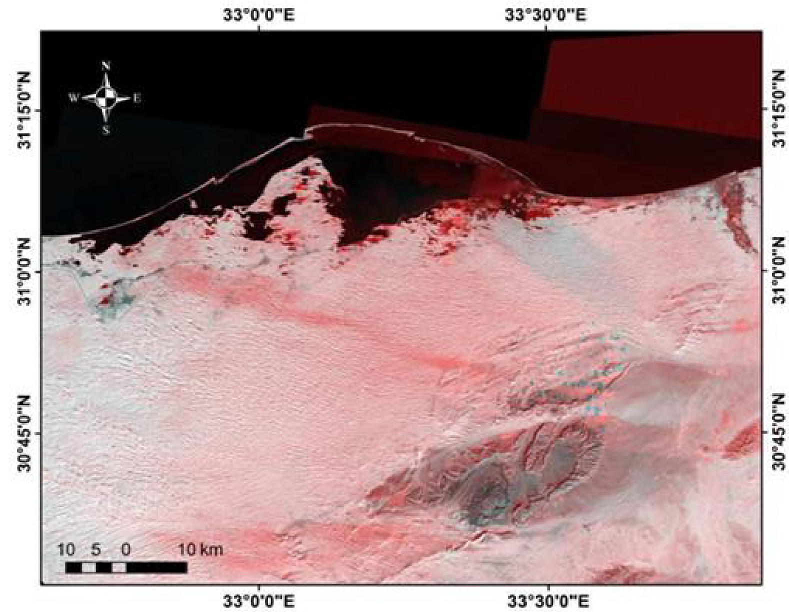

Figure 3: Change detection of sand dunes movement between 2000 and 2011, North Sinai.

outlined that the movement of sand dunes in the study area affects the following agriculture and native vegetation, Protectorates, urban areas, roads networks and Irrigation canals. The class "Sand dunes 2" refers to the stable dunes, which cover an area of 490.09 km^2, representing 1.73% of total area.

This type is usually located south of El Bardaweel Lake and around Wadi El Arish tributaries. The class**"**Cultivation1" indicates the rain-fed cultivation which is concentrated in the coastal plain from El Arish to Rafah, covering an area of 64.4km^2. In general, orchards are the main cultivations in the coastal plain. Sand dune encroachment is one of the most environmental hazards facing this type of cultivation in North Sinai. The study of sand dune movement is the cornerstone for sustaining these areas. The class "Cultivation 2" refers to the newly reclaimed areas, which are located mostly in the northwestern parts at the south of El-Salam canal and El-Arish area. This type of land use represents the main pillar of development in North Sinai occupying an area of 161.2 km^2 (i.e. 0.57% of the total area).

The class "Wadies" covers an area of 4257.58 km^2 (15 % of the total area), representing the most promising sustainable development land in North Sinai. This type mainly includes Wadi El Arish and its tributaries which descend from the south east to the north. It is worthwhile to mention that Wadi El Arish and its tributaries are surrounded by active sand dune fields. The class "Rockland" is located at the middle and southern parts of the study area, exhibiting 38.58 % of the territory. The main importance of this type is related to the mining and tourism activities

Sand dune movement rate

Over Sinai it is found that the northern district is affected by sand dunes, the movement rate of sand dunes is controlled by the climate, vegetation cover and topography. SPOT images (acquired in year 2011) and Landsat ETM+ (acquired in year 2000) images were used to estimate the rate of sand dunes movement at northern Sinai, using the Write Function Memory Insertion (WFMI) technique (Figure 3). The red colors, in the produced image, represent areas swept by moving frontiers of sand dunes.

According to Figure 3, the movement rate values were categorized into four classes (i.e. Low, Medium, High and very High), as shown in figure (4). Areas suseptable to different dune movement rates categories, are shown in table (2). Characteristics of each category can be explained as follows;

Category I*"Very High"*: the rate of sand dune movement in this category is rather high as it ranges between 7.30 and 9.30 meters per year. It characterizes an area of 1858.31 km^{2}representing 19.05% of the studied territory, located south of El Salam Canal.

Category II "*High*":: this category dominates areas of about 3811.75 km^{2}representing 39.14% located to the south of Kantara Shark and south El Sheikh Zwied cities.

Table 2: Areas susceptible to different sand dune risk categories

Rate class	Area (km^2)	Frequency (%)
Very high	1858.31	19.08
High	3811.75	39.14
Moderate	1530.84	15.72
Low	2537.42	26.06
Total	9738.33	100.00

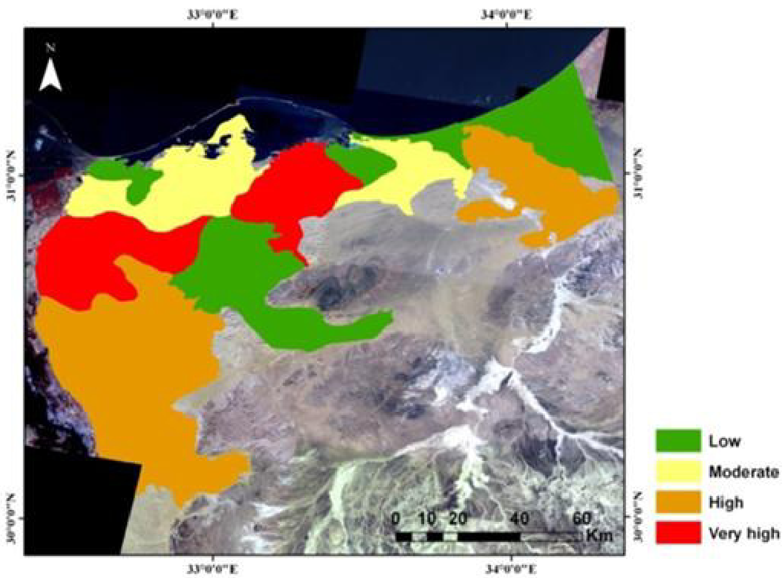

Figure 4: Categories of sand dunes movement rates at north Sinai area

The movement rate was classified as high where it ranges between 5.50 and 7.00 meter per year.

Category III "Moderate": Sand dunes movements in this category are characterized by a rate of 4.00 to 5.50 meter per year. This category dominates the areas located at the south and southeast of Lake El Bardaweel exhibiting an area of 1530.84 km^2 representing 15.72% of study area.

Category IV "*Low*": the rate of movement in this category is low where it was estimated that most of sand dunes movement direction is from NW to SE with a rate of 2.54 to 4.0 m per year. This category characterizes the coastal areas representing about 7979 km^2. Cultivations and vegetation are the main land use/cover in these areas.

Sand dune impact on the development projects and infrastructure

Table (3) demonstrates the impacts of sand dune movement activity on the development projects and infrastructural elements, represented by roads network, urban and vegetated covered areas.

Sand dunes impact on roads network

On bases of sand dune movement rate and their geographic distribution, the impact of sand dunes on Roads networks, urban areas and cultivations have been extracted. The results of this study are demonstrated in Figure (5).

Table (3) shows that the total length of roads network in north Sinai is 2776.93 km. The density of this network is high in the northern part of study area, while low in the southern one. It is noticed that 125.23 km of road network lengths (i.e. 4.51 %) are located under a very high risk of sand dune movement, located mostly at the south of Lake El Bardaweel and the southwest of El Kantara Shark.

The results reveal that 1049.23 km (37.78 %) of the roads network are located under a high risk, as they are

Table 3: Road network length and areas of urban and vegetated land under different dune movement risk categories

Layer	Measures	Very High	High Risk	Moderate Risk	Low Risk	Total Area
Hazard Area (Km^2)	Area (km^2)	1858.31	3811.75	1530.84	2537.42	9738.32
Roads Network Length (Km)	Length	125.23	1049.23	372.31	1230.16	2776.93
	%	4.51	37.78	13.41	44.30	100
Urban Area	Area (km^2)	0.11	0.24	11.25	55.16	66.76
	%	0.17	0.36	16.85	82.62	100
Cultivated Land	Area (km^2)	1.24	92.49	24.88	158.59	277.20
	%	0.45	33.37	8.97	57.21	100

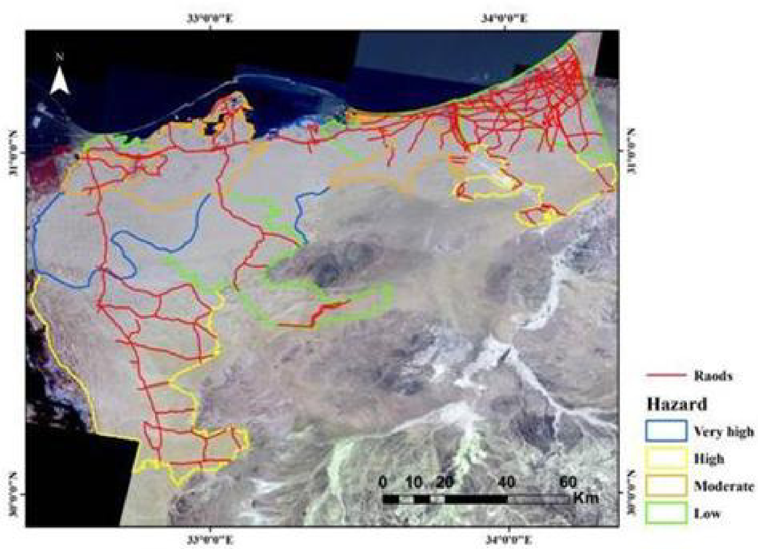

Figure 5: Sand dune encroachment risk on road network, North Sinai

located at an area characterized by sand dune movement rate of 5 –7 meter per year. Most of these roads are located at the south of El Kantara Shark and East of Wadi El Arish. A total of 372.31 km (i.e. 13.41 %) of the roads network are located under moderate risk of sand dunes encroachment. These parts are found mainly east of El Tina plain and west of Wadi Al Arish. The roads network susceptible to low risk of sand dune movement, characterize 1230.16 Km, representing 44.30 % of the total roads network. This risk category is found at the southern part of study area and small parts east of El Tina plain.

Sand dunes impact on urban areas

Regarding the urban areas, it is found that they exhibit an area of 66.76 km^2. These areas are mostly located closed to the Mediterranean Sea shore line. The obtained data (Figure 6 and table 3) indicate that most of these areas (82.62 %) are located under a low risk of sand dunes movement. About 16.85 % of urban areas are located under the moderate risk, as they are found near to the southern border of Lake El Bardaweel Lake.

The urban areas located within the high and very high dune movement risk cover 0.36 and 0.17 % of study area respectively. They are mainly found at the south of El Kantara Shark and east of Wadi Al Arish.

Sand dunes impact on cultivated areas

The cultivation represents the main pillar of sustainable development in Sinai. The results (Figure 7 and table 3) show that the total cultivations, in the study area cover 277.20 km^2 (i.e. 66113.5 feddans). The area located within the low risk of sand dunes movement represents 57.21 % of the cultivated area. These areas are mostly concentrated east of Sahl El Tina, Wadi Al Arish and east

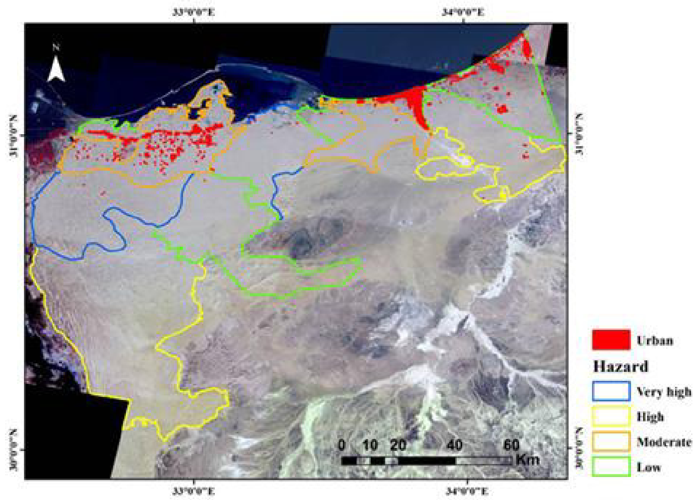

Figure 6: Sand dune encroachment risk on urban areas of North Sinai

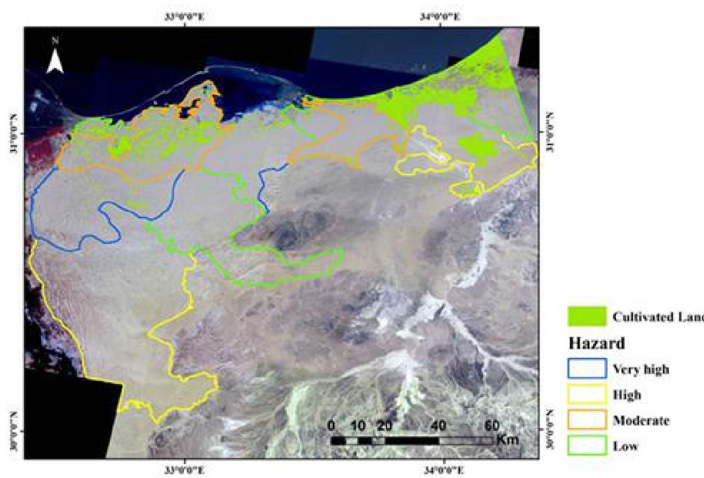

Figure 7: Sand dune encroachment risk on cultivated areas of North Sinai

Wadi Al Arish. The cultivated areas located within a moderate risk represent 8.97 % of the cultivated lands.

They are mainly located South El Bardaweel Lake where the rate of dunes movement ranges 4.00 – 5.5 meter per year. It is also found that about 33.37 % of the cultivated lands are located under a high risk of sand dunes. These areas are concentrated east and south east of Al Arish city. The cultivation located under a very high risk represents very small areas (i.e. 0.45 %) concentrated South El Kantara Shark.

CONCLUSIONS

It is possible to conclude that the sand dunes movement rate is controlled by the climate, vegetation cover and topography. Due to variable landscape at North Saini, different sand dune movement rat categories exist. However, as the northern coastal zone is inhibited by different sustainable development activities as urban, agricultural, roads and tourism, it proved to be the most affected by sand dunes activities.

It is obvious that Sinai is a vital strategic area, which needs intensive efforts towards sustainable development. North Sinai has potential importance supporting the national development programs. Integrating remote sensing data with digital land resources maps, using GIS, lead to point out the priorities for elaborating successful sustainability. Sand dunes activity hazards have to be analyzed, where precautions must be considered.

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