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Assessment of sand drift potential along the Nile Valley and Delta using climatic and satellite data

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ABSTRACT

Sand encroachment is a significant environmental hazard prevailing across the western fringes of the Nile Valley and Delta due to the occurrence of many dune fields in the adjacent Western Desert. Climatic data acquired from five meteorological stations were used to assess drifting sand and dune activity along this heavily populated and cultivated region. Dune forms and rates of dune advance were extracted from remotely sensed images. Results showed that wind environment and topography are the significant factors for the distribution of aeolian deposits. Wind energy and sand drift are maximum in the Middle Egypt and minimum west of the Nile Delta. Transverse (barchan) dunes are the dominant throughout the study area. Nevertheless, longitudinal (linear) dunes are observed west of the Nile Delta. The southern one-third of the study area is bordered by an elevated plateau from the west that hinders significant dune clusters from reaching the Nile Valley. Development projects in the contiguous fringes west of the Nile Valley would respond negatively to sand encroachment.

Introduction

Aeolian sand deposits account for 6% of the globe with 97% of these deposits occur in arid lands (Pye & Tsoar, 2009). Aeolian deposits comprise sand seas, dune fields and sand sheets. Sand seas refer to the largest sand-covered area more than 100 km^2 and dune fields are generally less than 100 km^2 (Lancaster, 2013). Sand sheets are sand bedforms void of significant dune accumulations. The term sand sea involves not only an area covered by sand dunes, but these dunes should cover at least 50% of the total area (Embabi, 2000). In Egypt- the eastern part of the Sahara- aeolian deposits represent about 16% of the country's area (Hereher, 2009) and they significantly exist in two regions: the Western Desert and the North Sinai (Fig. 1). The Western Desert includes a huge sand sea (the Great Sand Sea) and many dune fields (South Qattara, Abu-Muharik, Farafra, Kharga and west Asyut). Scattered dune assemblages are frequent in the vicinity of the Nile Delta and Nile Valley.

The Nile Valley and its Delta, which occupy about 4% of Egypt's area and host the majority of the country's population and agricultural land extend for about 1000 km long in a north-south direction between two deserts; the Eastern and the Western. These two deserts completely differ in their origin and landforms as well as dominant natural hazards affecting the Nile Valley and Delta. The Eastern Desert (22% of Egypt) is generally a massive and rugged mountainous terrain composed of Pre-Cambrian basement (igneous and metamorphic) rocks, which are dissected by numerous dry streams that drain either toward the Nile Valley or at the Red Sea coast. Flash floods are, therefore, the most significant environmental hazards impacting the eastern side of the Nile Valley. On the other hand, the Western Desert (66% of Egypt) is an immense plateau desert extending from the Mediterranean Sea at the north to the Sudanese and the Libyan borders from the south and west, respectively. The Western Desert is covered by several dune fields and, hence, drifting sand is the conspicuous environmental threat affecting the western side of the Nile Valley. The predominant wind direction across Egypt's Western Desert is generally northwest, with minor occurrence of southwest winds during winter. This pattern of wind regime has a tremendous effect for rendering the force to sands in the vast Western Desert to move southeastward (Hereher, 2010). Desert sands have been reported to settle upon fluvial soils of the Nile Valley (Gifford, Warner, & El-Baz, 1979; Kishk, 1985). Settlements and highways have been exposed to encroachment of sands along the western side of the Nile Valley (Abu El-Ennan, Dalsted, & Salem, 1990; El-Gammal & El-Gammal, 2010).

Assessment of aeolian sand movement is not new, fortunately early attempts for sand transport estimations were carried out in

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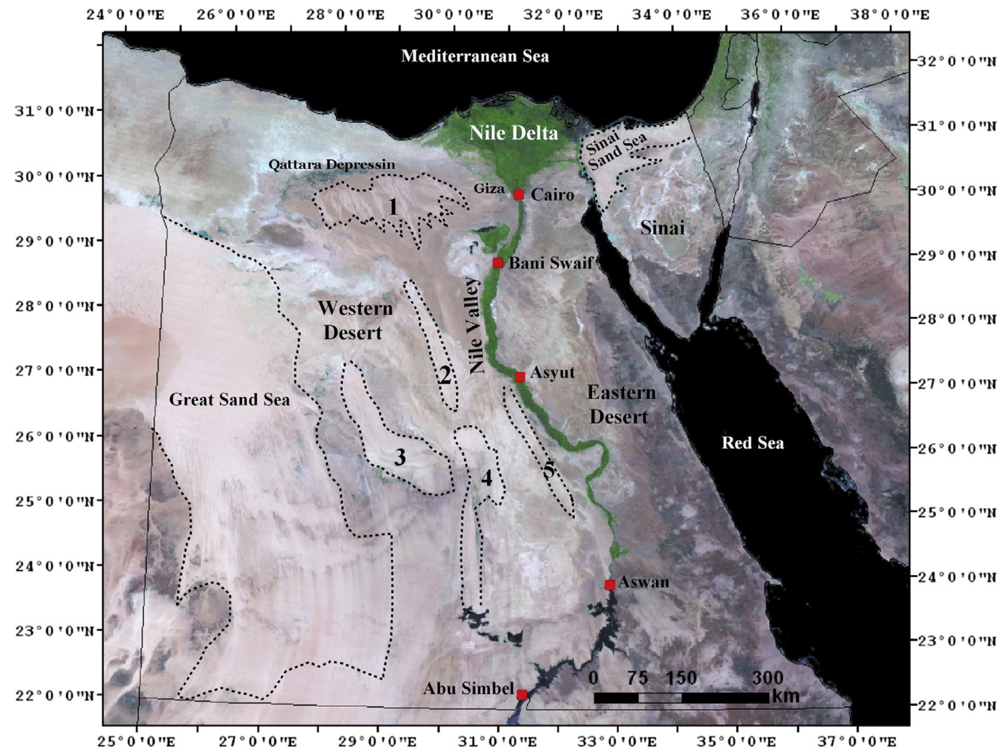

Fig. 1. Sand dune accumulations of Egypt as appear in satellite data. Major sand seas are represented by the Great Sand Sea in the Western Desert and the north Sinai Sand Sea. Dune fields include South Qattara (1), Abu-Muharik (2), Farafra (3), Kharga (4) and west Asyut (5).

the Western Desert of Egypt by the British desert explorer Ralph Bagnold in 1930s. He introduced the physical principles of aeolian blown sands and desert dunes (Bagnold, 1941). Other studies, such as Lettau and Lettau (1969), Wilson (1972), Fryberger and Ahlbrandt (1979), Fryberger, Al-Sari, Clishman, Rizvi, and Al-Hinai (1984) have theorized the basics of mega dune advance and formations of aeolian sand sea. One of the most widely and efficient models used to assess sand drift potential was developed by Fryberger (1979). The model incorporates standard wind data provided by meteorological stations to estimate the amount of loose sand moving across dry surfaces. The equation used by Fryberger (1979) was basically modified after Lettau and Lettau (1978). Fryberger (1979) equation is as follows:

$$Q = V^2\left(V - V_t\right)*t \qquad (1)$$

where Q is the annual rate of potential sand drift expressed in vector units (VU) and it is a measure of the wind energy, V is the horizontal wind speed measured at a standard height (10 m) in knots, V_t is the impact threshold wind velocity (12 knots), and t is the frequency of wind blowing above the threshold velocity. The number obtained from this equation is termed the "drift potential" (DP), which correlates to the wind energy at the location being investigated. The combination of $V^2\,(V - V_t)$ in Eq. (1) is termed the "weighting factor", in which strong winds are given high weighs and weaker winds have lower weights. Fryberger (1979) classified the wind energy depending on the amount of DP in Eq. (1), as: low-energy wind environments (DP < 200 VU); intermediate-energy wind environments (200 VU < DP < 400 VU) and high-energy wind environments (400 VU < DP). Gross sand drift potential from all directions occurring upon a given station should be analyzed by vector analysis to determine: the net amount of sand movement, which is called the resultant drift potential (RDP); and the net trend of sand movement, which is called the resultant drift direction (RDD). The DP and RDP were used by Fryberger (1979) to determine the directional variability of wind and dune forms present in any dune field (Table 1). When wind blows from the same direction this means that RDP/DP is high (>0.7) and transverse dunes predominate. When bi-modal winds prevail (0.7 ≤ RDP/DP ≥ 0.3), linear dunes occur. Regions characterized by multi-direction winds (RDP/DP < 0.3) are dominated by star dunes. Although Pearce and Walker (2005) reported a concern about the bias of Fryberger (1979) model, particularly in complex wind regimes, the wind pattern of the study area is consistent all the year round and follows a clockwise direction (El-Baz, 1986; Hereher, 2010). Moreover, Fryberger (1979) model is extensively used to measure sand drift potential in arid regions similar to the study area (e.g. Al-Awadhi, Al-Helal, & Al-Enezi, 2005; Blumberg &

Table 1
Fryberger (1979) classification of dune forms, wind regimes and drift potential.

Drift potential (VU)	Drift potential[a] ($m^3\ m^{-1}\ year^{-1}$)	RDP/DP	Wind energy	Wind regime	Dune form[b]
<200	<13	<0.3	Low	Obtuse bi-modal	Star
200–400	13–28	0.3–0.8	Intermediate	Acute bi-modal	Linear
>400	>28	>0.8	High	Uni-modal	Barchan

[a] Fryberger et al., 1984.
[b] Lancaster, 1995.