The Role of Wind Dynamics in Sand Mobility in the Tafilalet Oasis (Southeast Morocco)

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Abstract. Wind plays a crucial role in the movement and accumulation of sand in the Tafilalet Oasis. It is the primary driver of variations in the morphological forms of sand accumulation, as well as the direction of dune development and movement. This dynamic has significant socio-spatial consequences for the region. This study emphasizes the fundamental role of wind dynamics in shaping and moving sand formations. The methodology is based on an analytical approach, tracking the evolution of various sand accumulation dynamics over a 12-year period using remote sensing techniques, geographic information systems (GIS), and field data. The results reveal notable differences in the mobility of specific dune forms. For instance, the displacement reached 15 meters at sites 6 and 7, and 45 meters at site 8—values considered low compared to the mobility observed at sites 1 to 5, where displacement reached up to 130 meters at site 1 and 70 meters at site 5. The study also highlights variations in the mobility of dunes with similar characteristics, influenced by many factors such as the size of sand accumulations, wind speed, and other natural elements like topographical flatness.

Keywords: Oasis, Dynamics, Sand Movement, Tafilalet, Morocco.

1 Introduction

The study area serves as a remarkable example of wind dynamics, which result in the formation of various sand morphological forms with diverse size distributions and varying levels of development and mobility. Extensive sand fields are present, covering large areas where land is buried and rendered unusable, causing significant damage to properties. This phenomenon has profound socio-spatial impacts on the oasis system, leading to its degradation and imbalance.

This study investigates the role of wind dynamics in sand mobility within the region. It aims to understand the relationship between creeping dunes and wind speed and direction, while also highlighting the differences among sand accumulations, their patterns of evolution, and their measured sizes.

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2 Study Area

Wind is one of the key climatic elements contributing significantly to the aridity of the region. Its dynamics have a pronounced impact, primarily through sand ablation, which is the dominant and most frequent phenomenon. This is a natural outcome of the region's semi-desert conditions, characterized by a combination of water scarcity and soil degradation.

This phenomenon is evident in the presence of Ergs, Regs, and vast bare surfaces. Moreover, the region experiences strong, dry, and multidirectional winds that intensify during the hotter months. In winter, strong northern winds prevail, while during the other three seasons—particularly in summer—dry southern winds dominate. The average monthly wind speeds recorded include 2.38 m/s at the Foum Zabel station (5 km north of Errachidia) between 1982 and 2016, 3.74 m/s at Yerdi, 3.84 m/s at Tingheras, and 4.15 m/s at Merzouga from 2011 to 2023.

Wind speed increases as one moves southward, driven by the Chergui winds originating from the southeast and moving northwest (Fig. 1.). These are followed by westerly winds, moving from the southwest to the northeast, which play a significant role in dune formation due to their dominant frequency [1]. In this region, wind speeds can become exceptionally strong, occasionally reaching over 20 to 30 m/s [2].

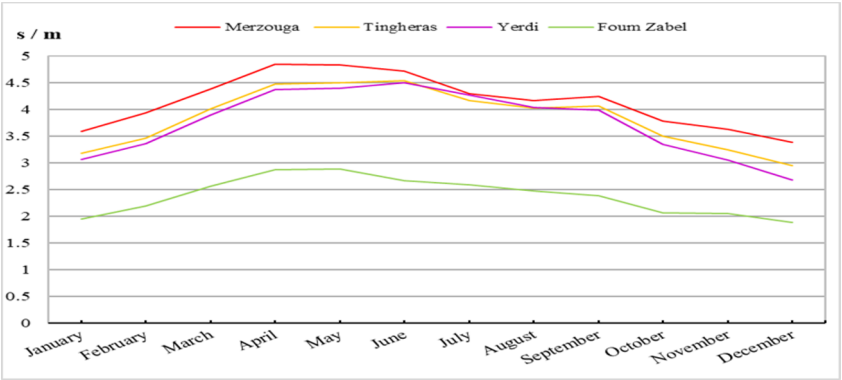

Fig. 1. Average monthly wind speed at the Foum Zabel station (1982-2016) and in the study area (2011-2023) m/s.

The study area is situated in southeastern Morocco, to the southeast of the eastern High Atlas Mountains. It is bordered to the west by the Small Atlas Mountains (Saghro and Ougnat), to the east by Hammada Guir, and to the south by Hammada Kem Kem. Administratively, as of the 2015 division, the study area falls within the Draa-Tafilalet region and the province of Errachidia (Fig. 2).

3 Research Method

The method adopted in this study is based on an analytical approach. We used the Google Earth Pro application as an effective tool, providing high-resolution images to identify and select areas for tracking and monitoring the developments and changes in sand accumulation forms between 2011 and 2023. Additionally, field visits and observations were conducted to better understand the nature of sand movement and highlight the resulting impacts.

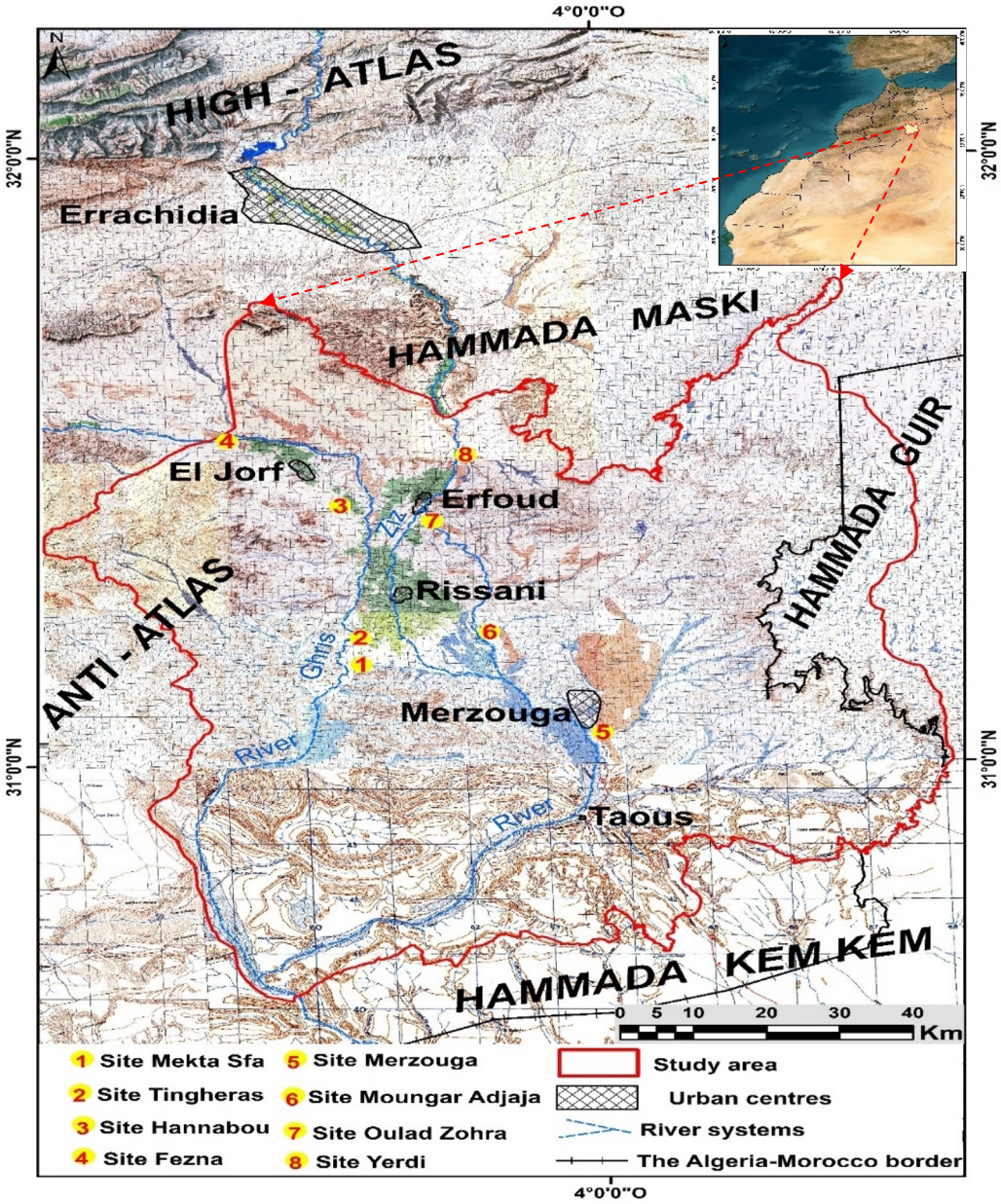

Fig. 2. Situation of the study area.

4 Results and Discussion

The study demonstrated the diversity and variety of sand accumulation forms, which reflect the direction and speed of the wind in the area. Differences and variability in sand mobility were also observed, depending on the size of each sand accumulation. Additionally, barchan accumulations exhibited significant development compared to longitudinal or transverse accumulations in the region (Fig. 3).

Fig. 3. Monitoring the variability and mobility of sand accumulations in the region (2011 - 2023).

It should be noted that even homogeneous forms, such as barchans, show differences in mobility and dynamics due to many factors such as their size, wind speed, and the nature of the surface (Fig. 4). In this regard, smaller sand surfaces play a crucial role in their evolution, and vice versa [3].

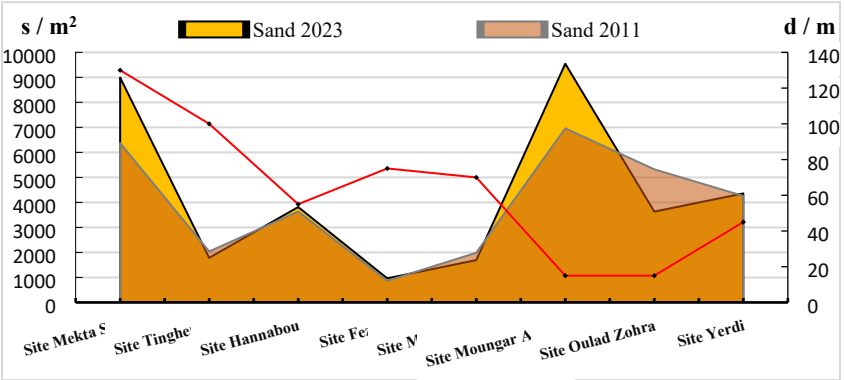

Fig. 4. Evolution of the area of sand forms in the region between 2011 and 2023.

Furthermore, the study found that the sand mobility at sites 6, 7, and 8 was low during the period from 2011 to 2023, with the evolution of these forms measuring 15 meters for sites 6 and 7, and 45 meters for site 8. This can be attributed to the dominant wind system, the size of each accumulation, and the surface characteristics.

In contrast, the forms at sites 1, 2, 3, 4, and 5 showed significant sand mobility over the same 12-year period, with substantial and uneven evolution. The dune forms reached 130 meters at site 1, 100 meters at site 2, 55 meters at site 3, 75 meters at site 4, and 70 meters at site 5. These differences are due to wind strength, topographical surface factors, and the type of sand accumulation forms, as these sites predominantly feature barchans of varying sizes and areas.

During the period from 2011 to 2023, some sites experienced an increase in their area, while others shrank, due to wind dynamics that led to changes in sand morphological forms, thereby causing socio-spatial impacts in the region.

Sand accumulations move in accordance with the direction of the dominant wind, with their evolution varying from year to year due to the influence of multiple wind directions. The Chergui wind, which blows from the south and southeast during the hot seasons, with maximum intensity in summer, is primarily responsible for the evolution and mobility of sand forms at sites 1 to 6. Additionally, winds from the north and northeast during winter [4], play a role in the dynamics of sand forms at sites 7 and 8.

A study conducted at the El Kraïr site showed that the creep of barchans aligned with the SW/NE wind direction. Over a 6-month period, the dunes advanced 9 meters toward the northeast. After a year of observation and monitoring 7 barchans, it was concluded that the dune creep reached 15 meters toward the northeast.

Similarly, in the El Jorf area, between 1986 and 1995, similar results were recorded, with dune creep evolving by 125 meters toward the northeast and 15 meters toward the northwest [5]. This confirms the convergence and similarity of results and conditions with the present study.

Additionally, a study conducted in Bouarafa between 2013 and 2023 revealed that a dune's creep was recorded at 47 meters toward the northeast at Chott Tigri [6].

Although the duration of this study (10 years) is shorter than that of the present study (12 years), it was concluded that there is a delay in the evolution of sand movement, both in terms

of direction and distance. This delay can be attributed to the nature of the dominant wind in each region.

5 Conclusion

The various forms of sand accumulation in the region between 2011 and 2023 showed significant variation in their evolution and mobility, ranging from a maximum of 130 meters to a minimum of 15 meters. These values reflect the imbalances of the area faces due to the studied phenomenon, primarily driven by wind dynamics as the main controlling factor. The study also highlights the strong correlation between the movement of different dune types and the direction and speed of the prevailing wind, as well as the geographical distribution and surface features of each form.

It is important to note that this morphological risk, resulting from dune creep, has considerable impacts on the Tafilalt Oasis system, leading to land degradation, loss, and damage to properties due to the continuous mobility of sand. Furthermore, the failure and ineffectiveness of certain measures to combat or mitigate this phenomenon exacerbate the problem.

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Author Contribution
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Ethics approval and consent to participate
Not applicable.

Consent for publication
All the authors have agreed to publish this article.

Competing interests
The authors declare that they have no competing interests.

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