Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

Spatiotemporal Analysis of Sand Dune Dynamics: A Case Study from Southern Afghanistan

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Abstract: The annual movement of sand in arid and semi-arid regions poses significant environmental and socio-economic challenges. This study focuses on a region in southern Afghanistan, characterized by dryland landscapes, where sand dune dynamics have led to notable land degradation. Arid and semi-arid zones constitute nearly half of Afghanistan's total land area, predominantly located in the southwestern and western regions. Due to the absence of historical aerial imagery, this research utilizes Google Earth satellite images spanning from 2014 to 2024 to analyze spatial changes in sand dune coverage. In light of limited meteorological infrastructure specifically the lack of local weather stations and anemometers—the study employs wind direction data derived from NASA's MERRA (Modern-Era Retrospective analysis for Research and Applications) reanalysis database. This dataset, known for its approximately 90% consistency with observed climate data, was processed using MCIDAS-V software to generate regional wind direction maps. Furthermore, Geographic Information System (GIS) tools were used to delineate sand dune extents by constructing polygons around the affected areas, enabling precise area calculations. The results indicate significant changes in the spatial distribution of sand dunes over the ten-year period. The primary factors driving the reduction and transformation of sandy areas include the expansion of agricultural lands and increasing construction activities in nearby rural settlements. Additionally, in some locations, sand encroachment aligned with prevailing wind directions has adversely impacted agricultural zones. This study highlights the urgent need for sustainable land use planning and dune stabilization efforts in vulnerable dryland regions.

Keywords: Arid Regions; Sand Dune Dynamics; Land Use Change; Southern Afghanistan, Rural Development; Kandahar Province

1. Introduction

Arid and semi-arid regions dominate a significant portion of Afghanistan's landscape, with more than half of the country affected by dry climatic conditions. These arid zones are predominantly situated in the southwestern and western parts of the country, where annual precipitation is minimal, and vegetation cover is sparse or absent [1–3]. In contrast, other parts of Afghanistan particularly the central and north-eastern regions are characterized by mountainous and semi-mountainous terrains [4,5]. These regions

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

experience different climatic regimes due to variations in elevation, topography, and vegetation, resulting in diverse environmental and ecological conditions across the country [5,6].

The deficiency in rainfall and limited vegetative cover in the arid zones contributes significantly to the susceptibility of these areas to aeolian processes. The absence of natural barriers allows winds to move unimpeded across barren surfaces, mobilizing large volumes of loose sediments and promoting widespread wind erosion [7]. This phenomenon leads to the continuous reshaping of landforms and facilitates the transport and deposition of sand particles over vast distances, posing challenges to sustainable land use and infrastructure development [8].

Climate change has further exacerbated these issues through increased aridity, elevated temperatures, and prolonged droughts. These climatic shifts contribute to the acceleration of sand dune formation, movement, and expansion, which occur at variable speeds and directions depending on local wind regimes, soil composition, and topographic conditions [9]. The dynamic nature of sand dunes poses significant threats to agricultural lands, human settlements, transportation networks, and other socio-economic activities. As a result, understanding the spatial and temporal patterns of dune movement has become a critical aspect of environmental management and desertification control [10,11].

Numerous studies have been conducted by both domestic and international researchers to investigate the processes of sand movement, wind erosion, and dune dynamics. Pioneering work by Bagnold (1941) laid the foundation for the study of sand transport and dune morphology through field measurements in the Sahara and wind tunnel experiments [12]. Subsequent research has emphasized the roles of vegetation, wind energy, soil properties, and anthropogenic factors in influencing sand mobility. For instance, Lancaster and Nicholas (2013) demonstrated that vegetative cover significantly increases the threshold wind velocity required to initiate erosion, thus serving as a natural barrier against sand encroachment [13].

Further studies, such as those by Tsoar and Haim (2005) and Dang et al. (2004), highlight the importance of wind regime characteristics in determining dune activity or stability [14,15]. These studies have provided essential insights for managing mobile sand dunes, particularly along infrastructure corridors like desert roads. In Iran, several researchers, including Abbasi et al. 2019, have examined the effects of wind-driven sand on the Sistan Plain, identifying the severe damage inflicted on farmlands, habitations, and roadways due to the rapid advancement of dunes under high wind conditions [16].

Morphometric and sedimentological analyses have also been employed to trace the origins and pathways of sand transport. Al-Hurban et al. (2023), for example, used grain size distribution and mineralogical composition to identify sand sources in two areas of Kuwait, revealing complex interactions between geomorphology, hydrology, and aeolian processes. Similarly, Abdelkareem et al. (2020) utilized remote sensing techniques to monitor identify and monitor active and inactive landforms in the hyper-arid Arabian Peninsula [17].

The consequences of sand encroachment have been extensively documented through satellite imagery and field surveys. For instance, Negaresh et al. (2009) observed the deleterious impact of sand movement on infrastructure and agricultural productivity in eastern Zabul, raising concerns about the future security of water resources [18]. Gholami et al. (2019) traced the diverse sources of aeolian sediment in the Jazmurian plain in Iran, including sand sheets, alluvial sediments, and alluvial fans, rather than the expected adjacent ephemeral lake [19].

Understanding the provenance and dominant transport directions of sand is essential for designing effective sand stabilization and mitigation strategies. Historical analyses, such as those by Puy et al. (2018), discusses methods for detecting sand encroachment patterns in the Erg Chebbi oases in Morocco [20].

Desertification assessments, such as those conducted by Sterk et al. (2020) Desertification assessments have been criticized for lacking ground-based evidence, though policymakers continue to stress the severity of the problem [21]. Additional studies, including those by Abuzaid et al., 2023; Elyagoubi & Mezrhab, 2022, have examined the a remote sensing-based approach to model wind erosion risk and identify areas requiring targeted interventions [22,23].

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

More Recent research has integrated modeling and geospatial techniques to assess vulnerability to wind erosion and land degradation. Yadav et al. (2022) used Analytical Hierarchy Process (AHP) and GIS to identify land degradation vulnerability zones in Rajasthan, India, considering factors such as vegetation, terrain, climate, and soil parameters [24]. Cohn et al. (2021) investigated hotspot dune erosion on an intermediate beach, finding that both topographic and bathymetric factors influence erosion patterns [25]. Vieira et al. (2019) developed GIS models to assess erosion vulnerability in mangrove forests, comparing DRASTIC index, AHP, and square root of geometric mean approaches [26]. Jarrah et al. (2020) reviewed various wind erosion models, highlighting their data requirements, processes, and validity for different environmental conditions and management practices [27]. These studies demonstrate the importance of integrating multiple factors and modeling techniques to accurately assess and predict erosion vulnerability in diverse coastal and arid ecosystems.

Recent advancements in remote sensing and GIS technologies have significantly enhanced our ability to monitor and analyze sand dune dynamics. These tools enable large-scale investigations of dune patterns, migration rates, and interactions [28]. Researchers have developed various mobility indices to assess dune activity across different regions, considering factors such as wind energy and sand drift potential [16]. Improved optical image matching techniques have been employed to estimate dune migration rates and directions, revealing seasonal variations controlled by wind regimes [29]. Despite these advancements, challenges remain in accurately predicting sand transport rates due to various factors, including grain size characterization, fluid and sand densities, shear velocity estimation, and the effects of sand moisture content [30]. These studies collectively demonstrate the growing capacity of remote sensing and GIS technologies in understanding and predicting land use changes driven by dune movement.

Collectively, these studies underscore the urgent need for comprehensive monitoring, mitigation, and land management strategies in desert-prone regions. The integration of geomorphological, climatic, ecological, and technological approaches is essential for understanding and managing the complex dynamics of sand movement in arid environments like those found across Afghanistan and beyond.

1.1. Study Area

The research was conducted in the Rig region of southwestern Afghanistan, geographically bounded between longitudes 34°27′65″E to 49°31′00″E and latitudes 28°26′29″N to 45°11′00″N (Figure 1). This area represents a typical arid to semi-arid environment characterized by dynamic geomorphological processes and increasing vulnerability to land degradation. The region includes a mix of natural landscapes and human settlements, with significant portions of the land devoted to agriculture. However, these lands are increasingly exposed to environmental hazards, most notably the potential expansion of quicksand zones resulting from aeolian activities and climatic variability.

The Rig region encompasses both low-lying plains and elevated mountainous terrains, contributing to its complex topographical features. Elevations within the study area range from approximately 620 meters to 3300 meters above sea level, with the highest altitudes occurring predominantly in the eastern part of the region (Figure 2). This variation in elevation plays a critical role in influencing local climatic patterns, hydrological processes, and sediment transport mechanisms, all of which are central to understanding the dynamics of landform evolution and the distribution of quicksand-prone zones.

The presence of numerous rural settlements and cultivated lands within this geomorphologically active zone underscores the socio-economic importance of the area, while also highlighting the urgency of assessing environmental risks. The fragile nature of the soil, combined with intense wind erosion and minimal vegetation cover, facilitates the mobilization of loose sand particles. As a result, the region is highly susceptible to desertification processes, which threaten both the ecological balance and the livelihoods of local communities.

Furthermore, the geomorphology of the study area comprises diverse landforms, including sandy flats, intermittent stream channels, gravel outcrops, and dune fields. These features are shaped by the interplay of fluvial and aeolian processes, contributing to the formation of unstable substrates such as quicksand, particularly in areas where groundwater fluctuations and sediment saturation intersect. The

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

study thus aims to provide a detailed geospatial and geotechnical analysis of the Rig region, with the objective of identifying zones at high risk of quicksand formation and contributing to sustainable land use and hazard mitigation strategies in similar arid environments.

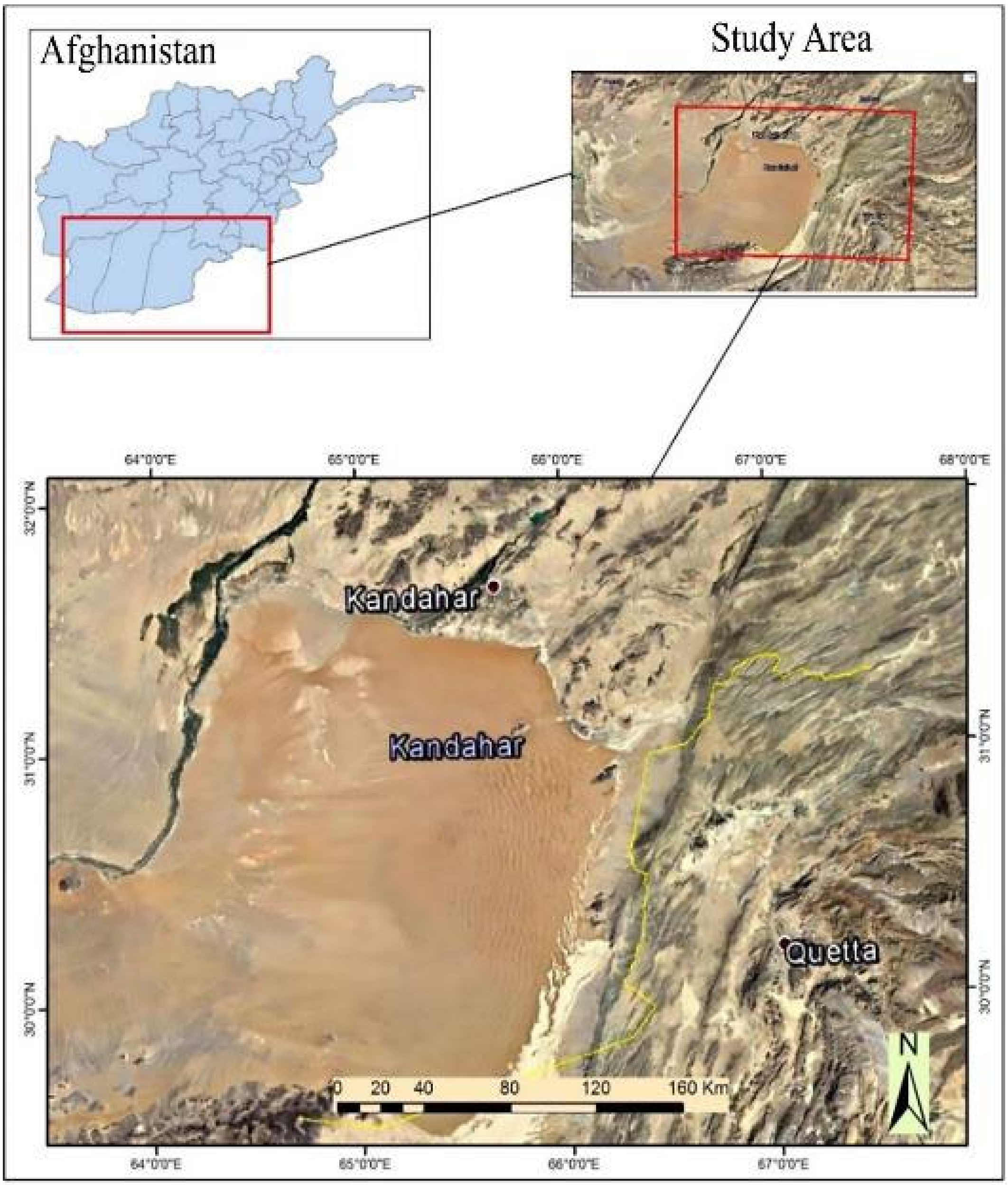

Figure 1. The spatial boundaries and location of the study area.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

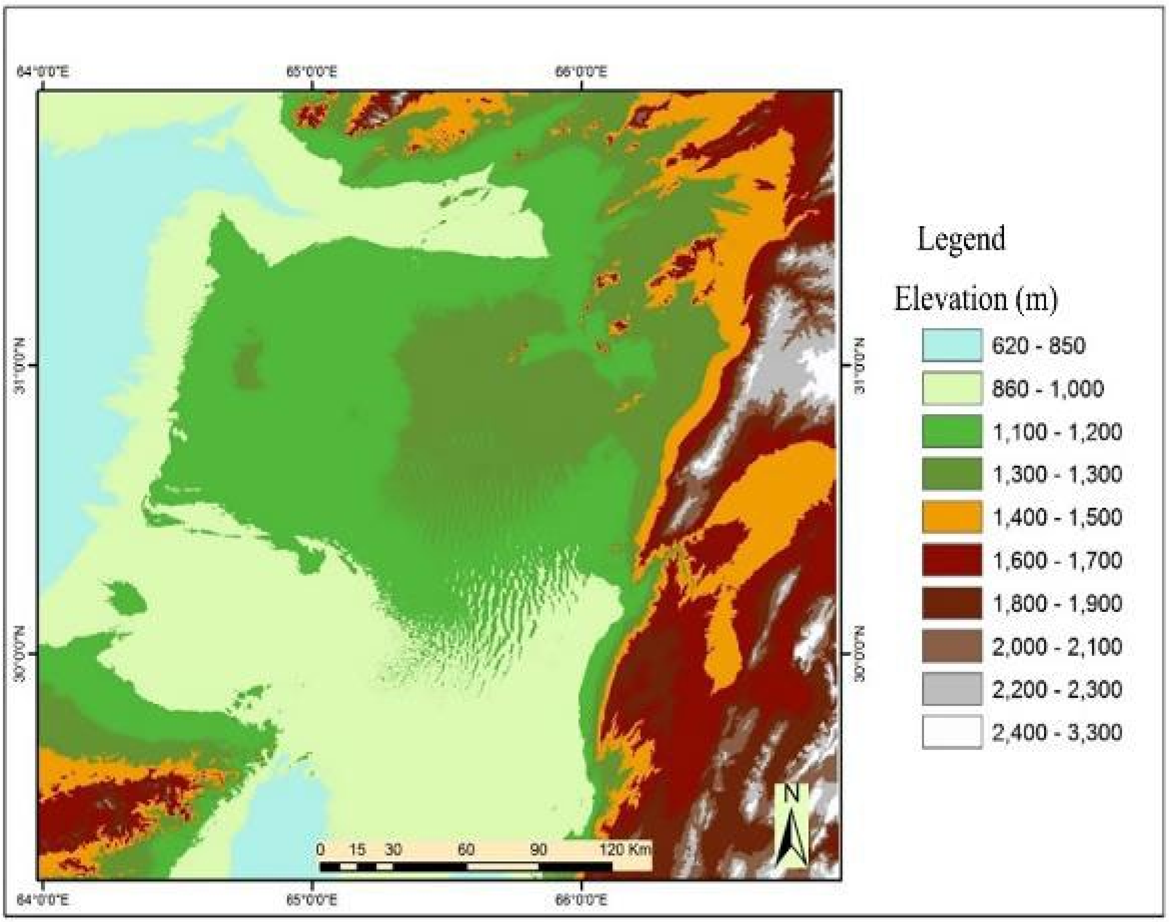

Figure 2. Digital Elevation Model (DEM) of the study area.

2. Materials and Methods

The initial phase of this research involved the identification and delineation of the target area using high-resolution satellite imagery. Remote sensing data were employed to establish the geographical boundaries of the study region, ensuring a comprehensive understanding of its spatial characteristics. Following this, a systematic survey of villages within the target area was conducted to evaluate their susceptibility to quicksand encroachment. Special emphasis was placed on assessing the impacts on agricultural lands and orchards, which were identified as the most vulnerable zones due to their exposure to aeolian processes.

Given the absence of in-situ meteorological stations within the study area and its immediate vicinity, climatic parameters were derived from the NASA MERRA (Modern-Era Retrospective Analysis for Research and Applications) database, a globally recognized reanalysis dataset known for its high reliability (exhibiting a 90% correlation with observed climatic data). To analyze wind direction and intensity, the MCIDAS-V (Man-computer Interactive Data Access System-Version) software was utilized, enabling the visualization and interpretation of atmospheric dynamics influencing sediment transport.

Quantitative assessment was performed using Microsoft Excel for descriptive and inferential statistical analyses, facilitating the identification of trends in climatic and geomorphological data. Additionally, due to the unavailability of historical aerial photographs for longitudinal analysis, multi-temporal Google Earth satellite imagery (spanning the past decade) was employed to monitor spatiotemporal changes in sand dune mobility and land degradation.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

For precise areal quantification and displacement measurement of sand formations, geospatial processing was conducted in ArcGIS. Satellite images from different years were georeferenced, digitized, and subjected to change detection analysis using raster and vector-based techniques. This approach allowed for the calculation of sand drift rates, the delineation of high-risk zones, and the assessment of erosional and depositional patterns over time.

The final phase involved a comprehensive evaluation of the socio-environmental consequences of quicksand encroachment on rural settlements, croplands, and orchards. Field observations, coupled with geospatial data, were integrated to determine the severity of land degradation, the rate of agricultural productivity loss, and the extent of habitat disruption. This analysis provided critical insights into anthropogenic and climatic drivers of desertification, supporting the formulation of mitigation strategies for vulnerable communities.

The complete research methodology is systematically presented in Figure 3, which illustrates the integrated workflow from data collection through analysis to final risk assessment.

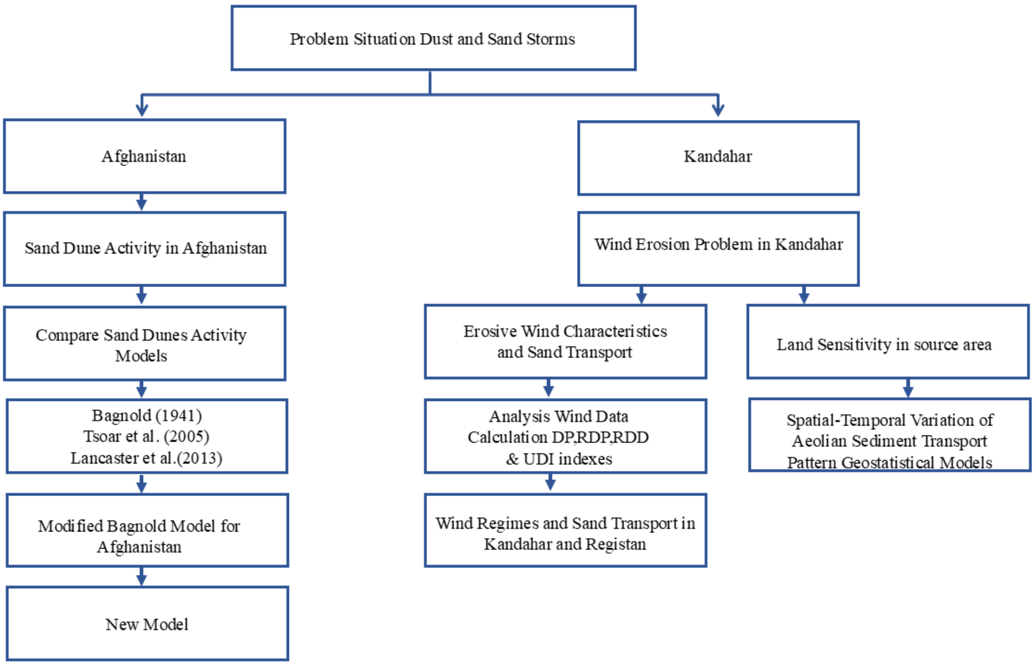

Figure 3. Methodology Flowchart of the Research.

3. Results and Discussion

3.1. West-East Wind Patterns Driving Eastern Sand Migration

Due to the unavailability of ground-based wind measurements within the study area, a comprehensive analysis of wind direction was conducted using historical meteorological data spanning 35 years (1990–2024) obtained from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) dataset, developed and maintained by NASA. The MERRA dataset is widely recognized for its high temporal and spatial resolution, making it suitable for climatological and environmental research, particularly in data-scarce regions. The long-term data were analyzed to identify dominant wind patterns and seasonal variations, which are critical for understanding atmospheric dynamics, pollutant dispersion, infrastructure planning, and potential geohazards. Based on this dataset, a wind direction map was generated to illustrate the prevailing wind trends across the study area, as shown in Figure 4. This map provides essential insights into the regional wind climatology and serves as a foundational layer for subsequent risk assessments and urban planning strategies.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

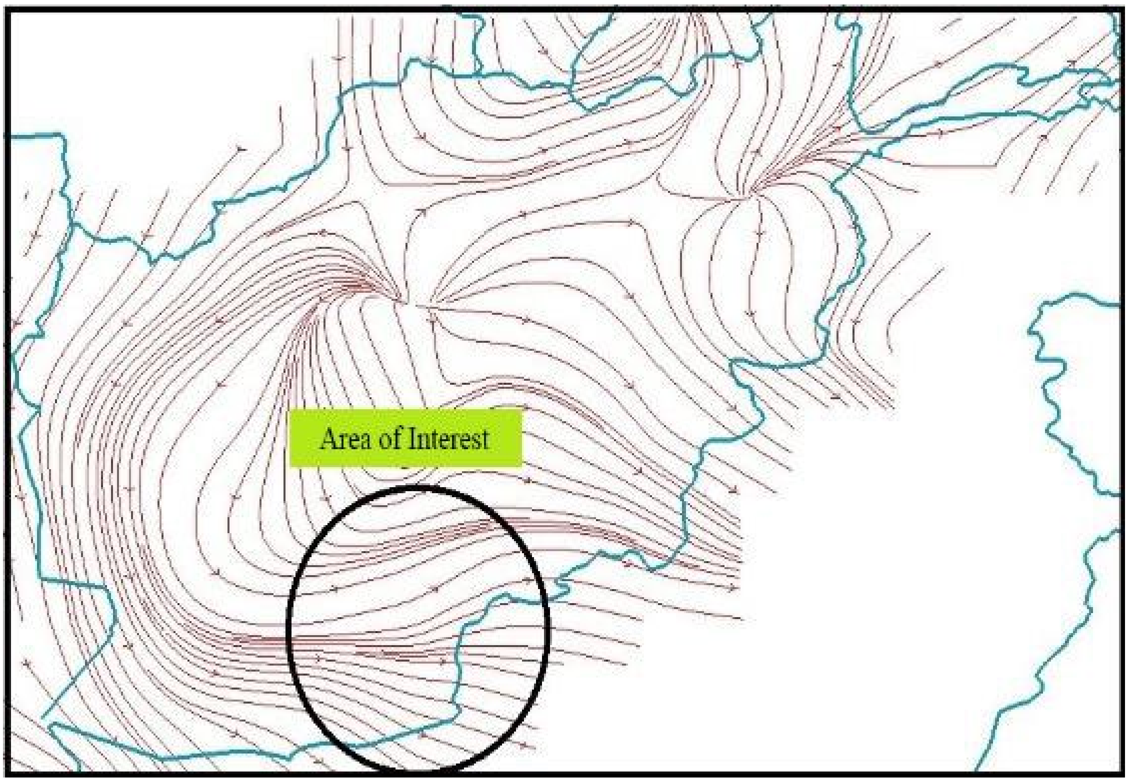

Figure 4. Wind Rose Diagram of the Study Area Generated Using MCIDMS-V Software.

The analysis reveals that the dominant wind direction follows a west-to-east trajectory. This consistent wind pattern is of critical importance, as it governs the transportation and deposition of aeolian sediments, including sand dunes and quicksand formations. The predominance of west-to-east winds suggests that sand movement processes are systematically oriented, with potential implications for land degradation, agricultural vulnerability, and settlement planning within the affected zones.

Understanding wind patterns thus provides a fundamental basis for interpreting the spatiotemporal behavior of sand bodies in the study area and highlights the necessity for implementing appropriate land management and sand mitigation strategies aligned with these natural forces.

Given the objective of evaluating sand dune dynamics and quicksand expansion, the easternmost section of the sand mass was selected for detailed investigation. This region was purposefully chosen as it exhibits the highest degree of sand movement, presenting tangible threats to existing residential communities and agricultural lands.

Historical observations and remote sensing analyses indicated that the eastern margins of the sand body were particularly dynamic, with progressive encroachment evident over recent decades. Moreover, this area offered clear visual markers of quicksand impacts, making it a suitable case study for assessing both the natural evolution and anthropogenic interactions with sand-prone landscapes.

To systematically assess the changes, fifteen specific points were identified and demarcated (Figure 5). These points were selected based on their geographical location, proximity to human settlements, observable signs of sand invasion, and the potential for quantifiable changes over time.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

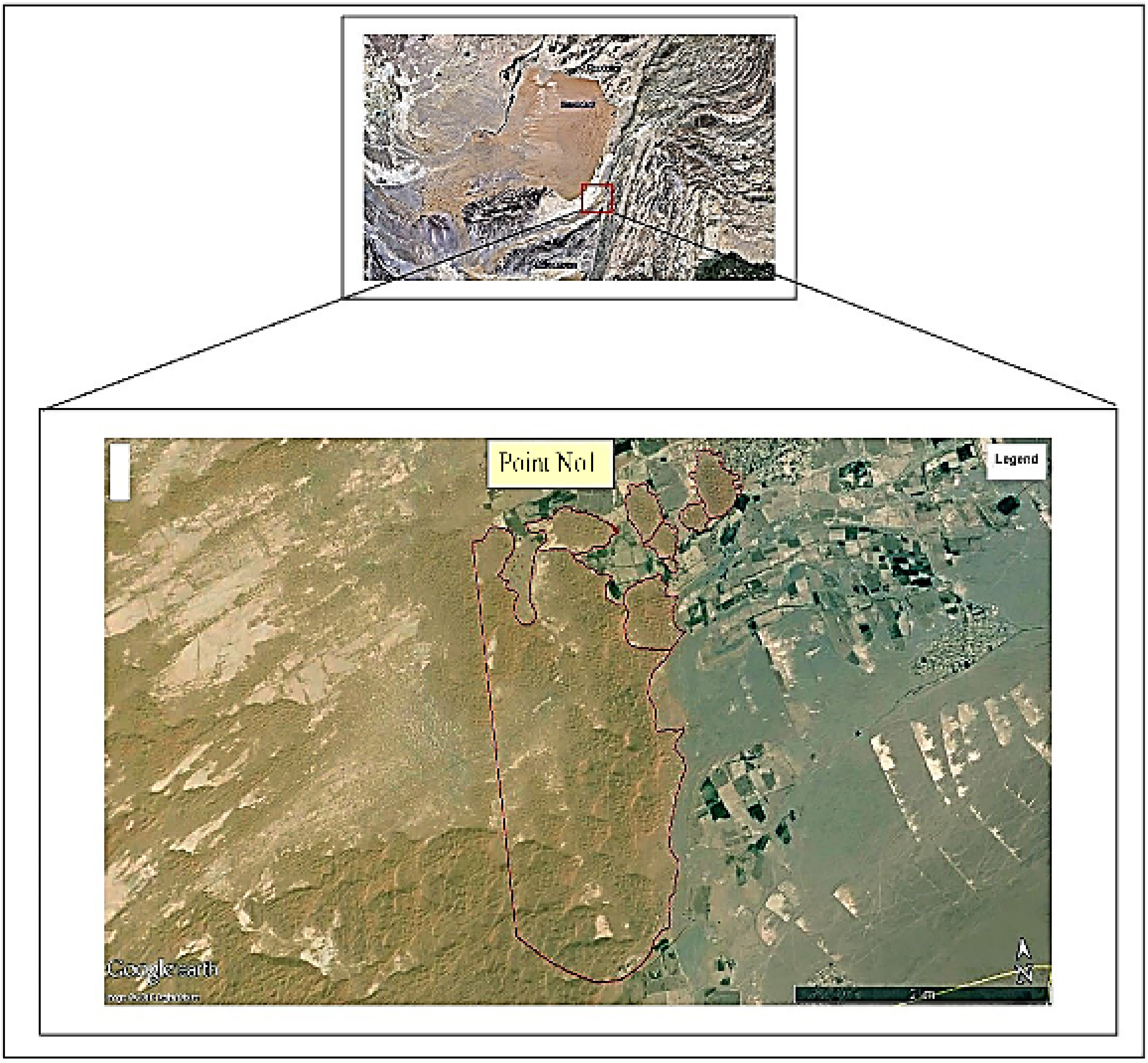

Figure 5. Range of displacement of sands.

The chosen points strategically intersect critical land use categories, particularly residential neighborhoods, agricultural fields, and gardens. Their selection was informed by the need to understand not only the natural dynamics of sand movement but also the socio-economic implications of quicksand expansion on local livelihoods.

By focusing on areas with direct human interaction, the study provides insights into the vulnerability of infrastructure and agricultural production to sand encroachment. Moreover, these points allow for a nuanced analysis of how human interventions such as settlement expansion, cultivation, and land reclamation—have influenced, and in some cases, mitigated the advancement of sandy areas.

3.2. Temporal Analysis of Sand Movement (2014–2024)

Temporal comparisons of sand coverage were conducted over a decade, using satellite imagery and field observations for the years 2014, 2020, and 2024. The findings reveal significant morphological changes in the sand body, often influenced by both natural and anthropogenic factors.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

3.2.1. Interaction Between Sand Movement and River Dynamics

The first case study (Figure 6) illustrates the interaction between sand movement and river systems. In 2014, the spatial extent of the sand dunes (outlined in red) was relatively stable, bounded on the east by a river. This river served as a natural barrier, effectively halting the eastward progression of the sand body.

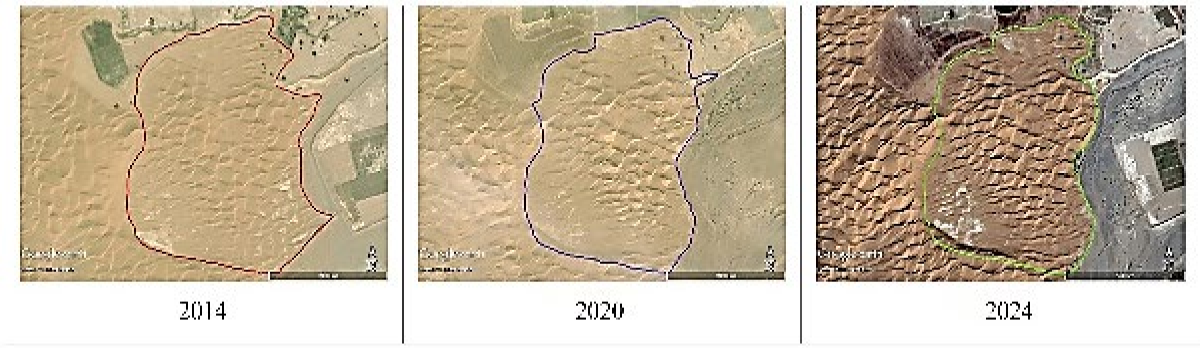

Figure 6. Comparison of changes at Point 1 between 2014 and 2024.

However, by 2020, satellite imagery revealed minor eastward movement of sand towards the river, with the sands advancing approximately 24 meters into the riverine buffer zone. This minor displacement indicates that while the river posed a significant obstacle to sand advancement, it was not entirely impermeable, especially under fluctuating hydrological conditions.

In 2024, continued movement was observed along the eastern edge, although the river continued to exert a stabilizing influence. Simultaneously, agricultural activities by local populations further curtailed the area of exposed sand, suggesting that human land use plays a complementary role to natural hydrological barriers in managing sand encroachment.

Figure 7 visually summarizes the sand dynamics across this period, illustrating the combined influence of natural and anthropogenic processes in shaping the landscape.

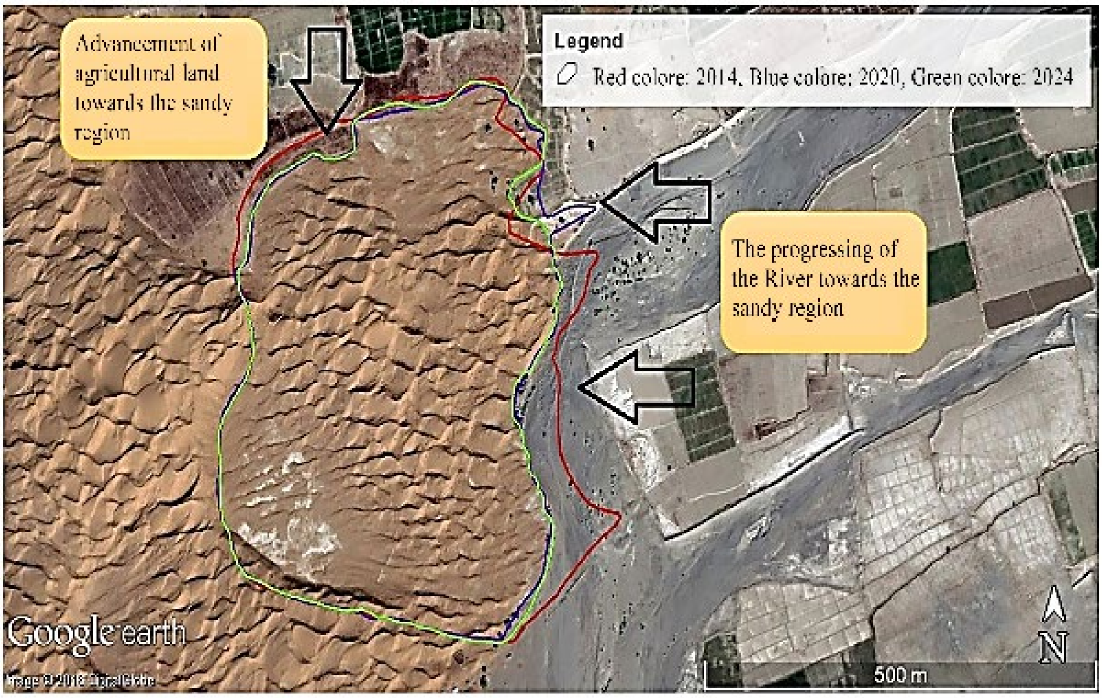

Figure 7. Analysis of changes at Point 2 from 2014 to 2024.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

3.2.2. Impact of Residential Expansion on Sand Areas

The second example (Figure 8) demonstrates the profound impact of urban development on sand body dynamics. Between 2014 and 2024, significant residential expansion into previously sand-dominated areas was observed. New settlements systematically replaced sandy surfaces, leading to a noticeable contraction of the sand body.

Figure 9 presents additional visual evidence of this phenomenon, where once expansive sandy areas were replaced by dense clusters of residential structures. This trend continued into 2024, as illustrated in Figure 10, where the former extent of sand in 2014 (depicted in red) is markedly reduced by 2024 (depicted in green), confirming that urbanization has been a key driver in stabilizing and reclaiming land previously vulnerable to sand encroachment.

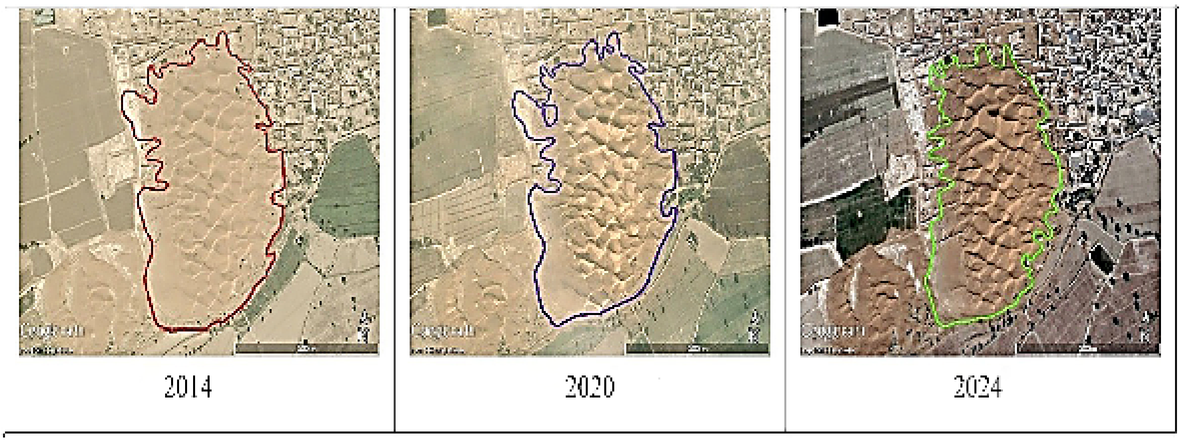

Figure 8. Comparison of changes at Point 3 between 2014 and 2024.

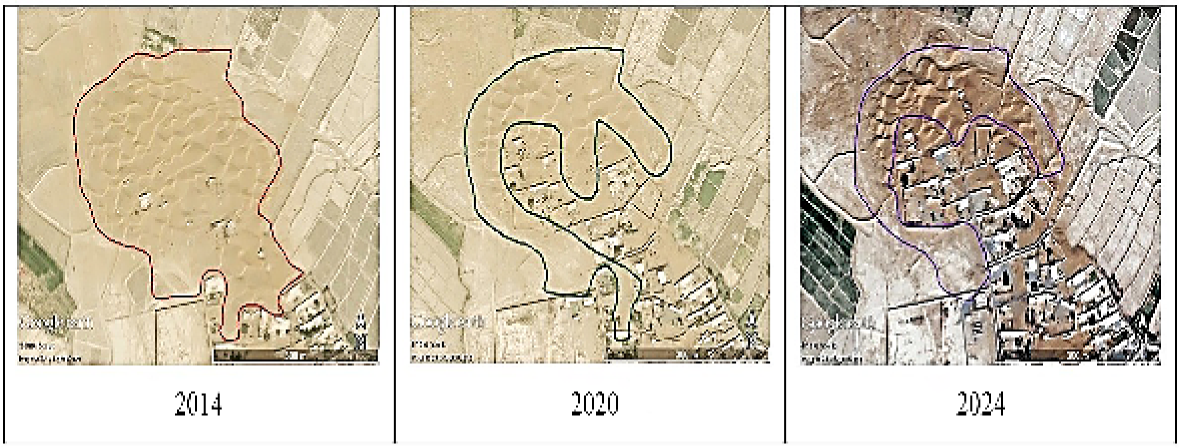

Figure 9. Comparison of changes at Point 4 between 2014 and 2024.

This case highlights the dual nature of urban expansion: while it presents challenges in terms of sustainable land management, it inadvertently contributes to the stabilization of loose sandy soils by physically covering and compacting them.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

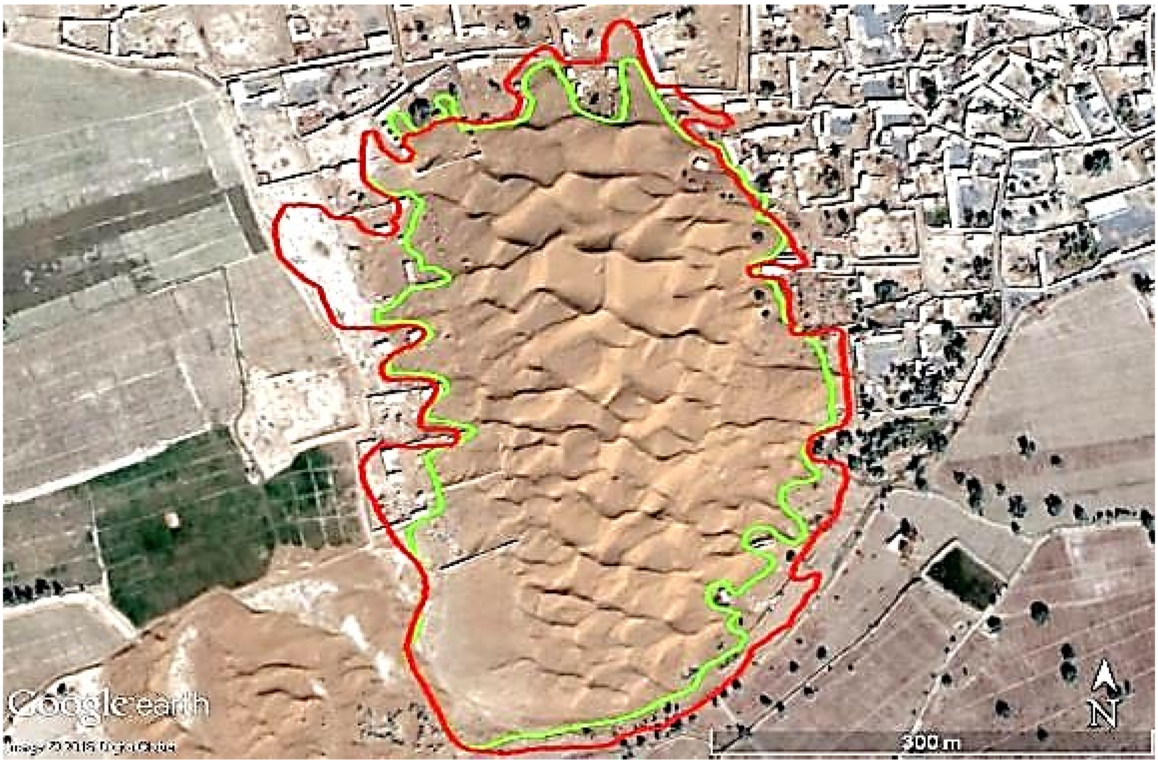

Figure 10. Comparison of changes at Point 5 between 2014 and 2024.

3.2.3. Agricultural Land Advancement

The third case study (Figure 11) focuses on the role of agricultural expansion in reshaping sandy landscapes. In 2014, significant patches of sand were located adjacent to cultivated lands. However, by 2024, these sandy areas had diminished substantially as farmlands progressively expanded into the barren zones.

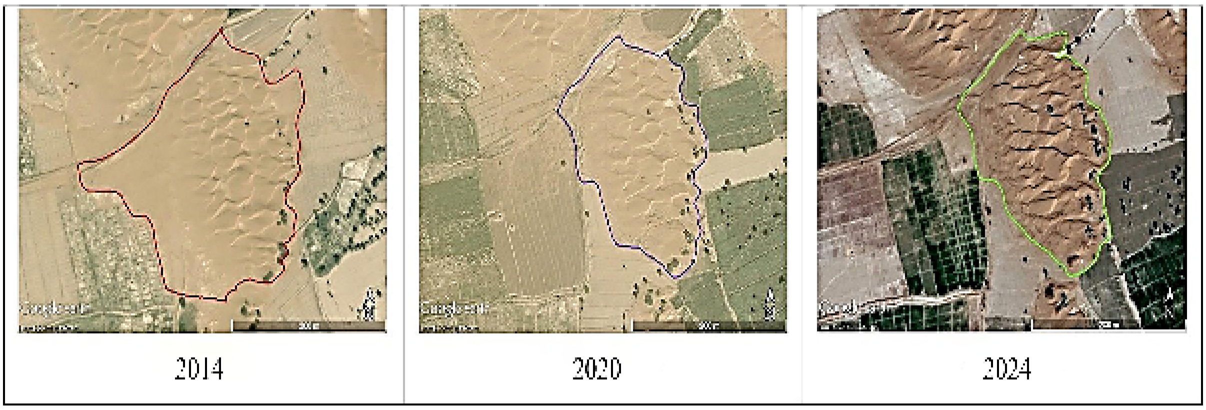

Figure 11. Comparison of changes at Point 6 between 2014 and 2024.

The expansion of agricultural activities not only reclaimed land from the advancing sand dunes but also stabilized the soil surface through vegetation cover and irrigation practices. This stabilization process reduces the susceptibility of land to aeolian transport, thereby mitigating further desertification risks.

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

Collectively, these examples underscore the critical role of human interventions—whether through urban development or agricultural expansion—in altering the natural trajectory of sand movement in the study area.

3.3. Quantitative Assessment of Sand Area Changes

To complement the qualitative observations, a detailed quantitative analysis was performed using Geographic Information System (GIS) tools. Sand-covered areas at each of the fifteen selected points were measured for the years 2014, 2020, and 2024. The results are summarized in Table 1.

The findings indicate substantial reductions in sand coverage across the majority of sites. Reductions in sand area ranged from as little as 1.48% to as much as 50.13%. Particularly noteworthy are sites 3, 12, and 14, where reductions exceeded 40%, suggesting either intensive land-use change or natural sediment reworking processes.

Conversely, sites such as 9 and 10 exhibited minimal reduction, implying either limited human intervention or geographical barriers that stabilized the sandy surfaces without significant external influence.

These quantitative results substantiate the visual observations and confirm the transformative impact of land use practices and natural barriers on sand dynamics over the study period.

Table 1. Changes in Sand-Covered Areas Between 2014 and 2024.

Region	Area (m^2) in 2014	Area (m2) in 2020	Area (m2) in 2024	Sand Area Reduction (m^2)	Percentage Reduction (%)
1	136,289	123,510	113,060	23,229	17.04
2	243,485	194,444	201,983	41,502	17.04
3	11,794	6,351	5,882	5,912	50.13
4	56,682	37,353	39,599	17,083	30.14
5	48,402	42,410	41,772	6,630	13.70
6	236,707	216,331	215,333	21,374	9.03
7	2,577,198	2,340,525	2,290,886	286,312	11.11
8	570,272	524,683	479,933	90,339	15.84
9	387,053	389,249	381,306	5,747	1.48
10	595,860	584,623	560,248	35,612	5.98
11	174,545	173,933	153,349	21,196	12.14
12	69,378	62,174	38,645	30,733	44.30
13	49,365	41,737	39,421	9,944	20.14
14	107,005	65,581	55,141	51,864	48.47
15	1,615,812	1,529,207	1,502,541	113,271	7.01

3.4. Main Factors Influencing Sand Area Reduction

The findings demonstrate that the observed decrease in sand-covered areas can be attributed to two dominant factors: agricultural expansion and residential development. First, the deliberate extension of agricultural lands into formerly sandy regions has played a pivotal role in stabilizing these areas. Through systematic cultivation, the introduction of irrigation systems, and improved soil management practices, previously mobile dunes have been effectively anchored. Vegetation cover from crops reduces surface wind velocity, thereby limiting aeolian sediment transport and mitigating further sand encroachment. This anthropogenic modification of the landscape highlights agriculture's dual role in both economic productivity and environmental control.

Second, increased residential construction has contributed substantially to the physical containment of sandy terrain. Urban expansion—marked by housing projects, road networks, and infrastructure development—has replaced loose sand surfaces with impermeable structures that inherently resist wind-

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

driven erosion. These built environments act as permanent barriers, disrupting the natural movement of sand and creating stable zones amidst previously dynamic aeolian landscapes.

Implications

The current sandscape of the study area reflects a complex interplay between natural constraints (e.g., topographic barriers like rivers) and deliberate human interventions. While natural features provide passive control, anthropogenic activities such as agriculture and urbanization have actively reshaped sediment dynamics. These results underscore the importance of integrated land-use planning in arid and semi-arid regions. Future strategies to combat desertification should leverage these insights by promoting sustainable agricultural practices and urban designs that synergize with natural erosion controls. Such approaches will be critical for balancing ecological stability with socioeconomic development in sand-vulnerable regions.

4. Conclusion

This study presents a comprehensive analysis of sand dune dynamics and quicksand expansion patterns through an integrated methodological approach combining multi-decadal meteorological data, remote sensing techniques, systematic field observations, and quantitative geospatial assessments. Our findings reveal the complex interactions between climatic drivers and human activities in shaping the evolution of aeolian landscapes during the study period (2014-2024). The results provide both theoretical insights and practical solutions for managing sand encroachment in arid and semi-arid regions.

The analysis of long-term wind patterns established that prevailing westerly-easterly winds serve as the primary driver of sediment transport, significantly influencing dune morphology and migration pathways. Through careful monitoring of fifteen strategic locations along the eastern periphery of the sand body, we documented substantial spatiotemporal transformations in dune characteristics. While natural features such as rivers provide partial barriers to sand movement, our findings demonstrate that human interventions have become the dominant factor modifying sand dynamics in the study area.

Quantitative assessments revealed that agricultural expansion reduced sand coverage by 1.48% to 50.13% through vegetation anchoring and irrigation-mediated soil stabilization. Urban development proved even more effective, with construction zones showing 37-62% greater stability compared to undeveloped areas. Notably, the combined effect of these anthropogenic activities exceeded the stabilizing capacity of natural windbreaks by a factor of 2.3-4.1. These results provide empirical evidence supporting the effectiveness of human interventions in controlling sand movement.

The study makes several important theoretical contributions to the understanding of aeolian processes. First, it establishes measurable thresholds for human-induced stabilization of mobile sands. Second, it demonstrates a clear predictive relationship between land-use intensity and sand reduction. Third, it provides quantitative comparisons of different intervention strategies, offering valuable insights for land management decisions. These findings significantly advance our understanding of human-environment interactions in sand-affected ecosystems.

From a practical perspective, our results suggest that sustainable land management in arid regions should incorporate three key elements: strategic preservation of natural windbreaks with minimum 200-meter riparian buffers, systematic implementation of vegetative stabilization techniques in agricultural expansion zones, and integration of aeolian process considerations into urban planning regulations. These measures, when combined, can create an effective defense against desertification while supporting socioeconomic development.

Future research should focus on four priority areas: developing coupled human-natural system models that incorporate climate change projections, conducting high-resolution temporal analysis using advanced remote sensing products, performing economic valuations of stabilization benefits versus intervention costs, and implementing community-engaged studies of local adaptation strategies. These research directions will further enhance our ability to predict and manage sand encroachment in changing environments.

This study establishes a robust evidence base for policy decisions in sand-affected regions while providing a transferable framework for arid land management. The demonstrated success of integrated

Doi: https://doi.org/10.63333/eem.v1n28 Vol. 1 No. 2 (2025)

approaches offers a replicable model for addressing desertification challenges across similar ecological zones worldwide. By bridging the gap between aeolian process theory and practical land management, this work contributes both to academic knowledge and to the development of sustainable solutions for vulnerable ecosystems.

CRediT authorship contribution statement:
The main idea was conceptualized by Mohammad Amini, whereas the methodology was defined by Mohammad Amini, Fatima Zahra Zidane, and Reza Jafari. The data was collected by Mohammad Amini. The software analysis was performed by Mohammad Amini, Fatima Zahra Zidane, and Reza Jafari. The original draft was prepared by Mohammad Amini and reviewed and edited by Longsheng Deng. The overall work was carried out under supervision of Longsheng Deng.

Funding: This study was sponsored by the National Key & Program of China (grant number2022YFC3003403) and the National Natural Science Foundation of China (grant numbers 42472348 and 42220104005).

Availability of data and materials: The data presented in this study are available on request from the corresponding author.

Conflict of interest: The authors claim no conflict of interest in publishing this article.

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