Effect of Soil Particle Size Distribution on Sand Dune Formation and Mapping Using GIS in Al-Nile Subdistrict, Babylon Governorate

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Abstract

The study area was selected due to the threat of sand dune encroachment and the resulting damages. This study was conducted in Al-Nile Subdistrict, where clusters of sand dunes are widespread. The subdistrict is located within Babylon Governorate in central Iraq, geographically between longitudes 44° 31′ 18.104″ to 44° 54′ 30.400″ E and latitudes 32° 27′ 33.061″ to 32° 35′ 9.155″ N. The total area of the study region is 3016.49 hectares. The study aimed to investigate the effect of soil particle size distribution on the formation of sand dunes in Al-Nile Subdistrict, Babylon Governorate. Fieldwork was carried out through several repeated site visits to the region, during which the locations of sand dunes were identified and their morphological shapes were described. A total of 33 sites were selected to represent most of the sand dunes distributed within the study area. Soil samples were collected from the dunes using standard sampling tools (auger, shovel, etc.) at a depth of 0–30 cm from each site. The coordinates of the sites were recorded using a GPS device. The collected samples were then transferred to the laboratory for necessary analyses. The results of particle size distribution showed that the dominant soil textures were sandy loam and loam. Sand was the prevailing fraction, ranging between 406–874 g kg^{-1}, followed by silt, which ranged between 62.0–512.0 g kg^{-1}, while clay was the least fraction, ranging between 36.0–302.0 g kg^{-1}. The dominance of sand fraction facilitated the formation of sand dunes in the region.

Keywords: Sand dunes, soil separates, Al-Nile Subdistrict, GIS

Introduction

Sand dunes are geomorphological features formed by the accumulation and movement of wind-transported sand. They pose a threat to agricultural lands, infrastructure, and ecosystems in arid and semi-arid regions [4 ,13]. Dune shapes, including barchan, longitudinal, and nabkha forms, are influenced by wind intensity, sediment availability, and vegetation cover [9,11]. thus, sand dunes are commonly found in desert regions. Wind-driven sands cover large land areas and form long, narrow shapes, crescent forms, or peak-shaped dunes. Vast areas with widespread dunes in deserts are called “sand seas,” and many dunes migrate across lands as wind carries sand grains from one side of the dune and deposits them on the other. [11] explained that sand dunes are either desert sand dunes, where the main source is the surrounding mountains, with wind as the dominant transporting agent shaping desert surfaces, aided by aridity and lack of vegetation cover;

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or coastal sand dunes, where the main source is distant, the transporting agent is water, and the grains are uniform in size but poorly graded and well sorted.[6] stated that sand dunes are geomorphological features formed from accumulations of sands of varying sizes, originating from weathered sedimentary, igneous, or metamorphic rocks through erosion and weathering processes, in addition to the effects of wind and rainfall. They are characterized by sand grains of different sizes and shapes, distributed over wide areas of deserts. Sand dunes often encroach toward agricultural lands and areas with sparse vegetation cover.[13] highlighted that sand dunes are a major landform type within sand seas, formed from sand accumulations sculpted by prevailing winds. They take diverse shapes, with wind being the principal factor in their formation under conditions such as sparse vegetation cover, soil salinity, and topographic features of the region where dunes develop. In Iraq, sand dunes are widespread across desert and alluvial plains, but few studies have linked their formation directly to soil particle size distribution. Most previous research focused on dune morphology or climatic factors separately. The novelty of this study lies in analyzing the quantitative relationship between sand, silt, and clay fractions and the formation of barchan and nabkha dunes in Al-Nile Subdistrict, combined with GIS mapping for spatial representation.This study aims to:Examine the distribution of sand, silt, and clay fractions in sand dune soils of Al-Nile Subdistrict.Investigate the relationship between soil particle size and dune morphology and Generate spatial maps of soil fractions using GIS to support land management decisions.

Materials and Methods

This study was conducted in Al-Nile Subdistrict, where clusters of sand dunes are widely distributed. The subdistrict is located within Babylon Governorate, central Iraq, geographically between longitudes 44° 31′ 18.104″ to 44° 54′ 30.400″ E and latitudes 32° 27′ 33.061″ to 32° 35′ 9.155″ N. The subdistrict lies southeast of Al-Mahawil District center, bordered by Al-Musayyib District to the north, Al-Kifl District to the east, Al-Hashimiyah District to the south, and Al-Mahawil District to the west. The study area covers 3016.49 hectares (Figure 1).

After obtaining the satellite imagery, fieldwork was carried out through several repeated visits to Al-Nile Subdistrict in Babylon Governorate to identify the locations of sand dunes and describe their morphological characteristics. A total of 33 sites were determined, covering most of the sand dune locations distributed within the study area. Soil samples were then collected from the dunes using standard sampling tools (auger, shovel, etc.) at a depth of 0–30 cm for each site. The coordinates of each site were recorded using a high-accuracy in Germa GPS device for the purpose of linking field data with satellite data. The study area was delineated on the imagery, a shapefile was created, and the area of interest was clipped. The collected samples were then transported to the laboratory for necessary analyses.The samples were brought to the postgraduate laboratory of the Department of Soil Science and Water Resources, College of Agriculture, Al-Qasim Green University. They were manually disaggregated and sieved through a 2 mm mesh sieve. The following parameter was determined:

Soil particle size distribution.

Samples were air-dried, sieved through 2 mm mesh, and analyzed for particle size distribution using the hydrometer method [7]. Soil texture classes were determined using the USDA soil textural triangle. Additional soil parameters, such as bulk density and organic matter, were measured to assess their influence on dune formation.

GIS Mapping

Coordinates and laboratory results were integrated into GIS. The Inverse Distance Weighting (IDW) interpolation method was

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used to generate spatial maps of sand, silt, and clay distribution. Dune morphology was analyzed in relation to particle size fractions and prevailing wind data from a nearby meteorological station.

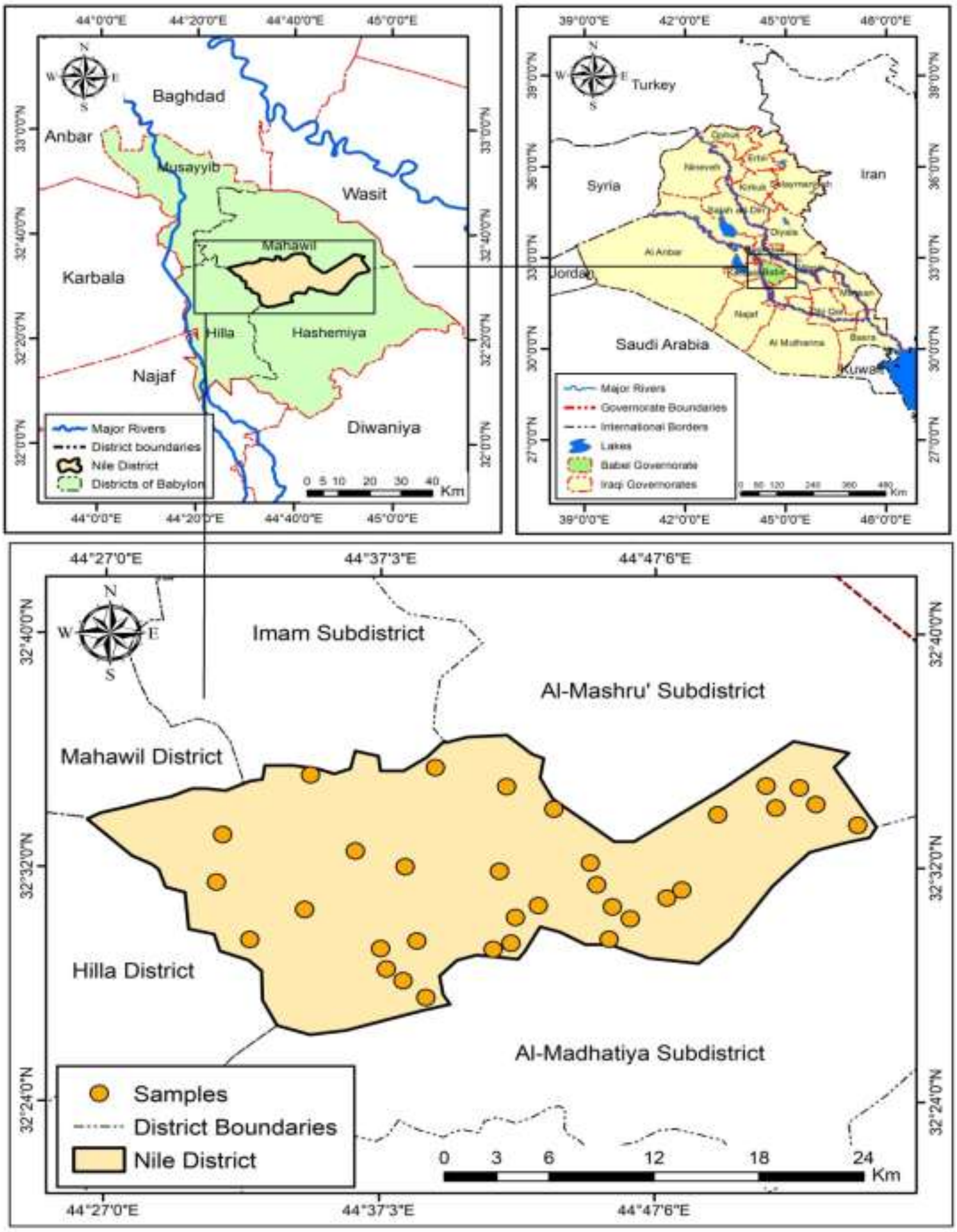

Figure 1. Map of Iraq, Babylon Governorate, and Al-Nile Subdistrict showing the locations of the studied soils.

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Results and Discussion

Morphological description of sand dunes in the study area

Sand dunes in Al-Nile Subdistrict represent distinctive geographical features of arid and semi-arid regions, formed by wind that transports and accumulates sand into mounds. Several types of sand dunes are present, the most prominent being barchans and nabkhas. Recent studies indicate that barchan dunes are formed as a result of sand accumulation under prevailing wind conditions, whereas nabkhas are formed by sand deposition around plants, leading to the development of low, stabilized mounds [9].

The most common types of sand dunes prevailing in the study area are:

Barchan dunes

The barchan dunes in Al-Nile Subdistrict are characterized by a sharp crest and inclined arms, which help in identifying the direction of prevailing winds in the region . Their dimensions range between 1–3 m in height, 3–50 m in width, and 3–25 m in length. They are irregularly distributed, reflecting the role of prevailing winds in shaping their forms (Figure 2).

Nabkha dunes

Nabkha dunes are formed as a result of sand accumulation around plants, leading to the development of low and relatively stable mounds (9). These dunes are more stable compared to the mobile barchans, indicating the significant role of vegetation in stabilizing sands and preventing their movement (Figure 3).

a

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b

Figure 2. (a, b) Images showing the Barchan dunes in the study area

Figure 3. Photograph showing Nabkha dunes in the study area.

Spatial distribution of the characteristics of sand dune soils and their effect on dune formation

The soils of the sand dune areas in Al-Nile Subdistrict are characterized as coarse-textured, consisting mainly of sand, with high water drainage capacity, which makes them unsuitable for cultivating most traditional crops [12]. However, these soils provide a favorable environment for certain desert plants adapted to arid conditions. In the sand dune areas of Al-Nile, some natural vegetation adapted to harsh environmental conditions is present, including grasses and shrubs tolerant of drought and high temperatures. These plants contribute to stabilizing the sand and preventing its movement [9].

The soil separates that influence the formation of sand dunes are:

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- Particle size distribution of sand dune soils
- Sand

Results of Table 1 indicate that the sand fraction in the soils of the sand dunes was high, ranging between 406.0–874.0 g kg^{-1}. The lowest content was recorded at Site 31, which was classified as silty loam, while the highest content was found at Site 25, classified as sandy soil. The high proportion of sand in these soils is attributed to fluvial deposits, as the study area lies within the Mesopotamian alluvial plain influenced by seasonal riverine sedimentation, in addition to the dominance of northwesterly winds that contribute to the transport of sand particles. This is consistent with the findings of [4].

Results of Table 2 and Figure 4 showed that the sand fraction was spatially distributed in the soils of the study area within four ranges. The range 525.0–650.0 g kg^{-1} occupied the largest area of 1620.42 hectares, representing 53.72%. In contrast, the range 775.0–995.0 g kg^{-1} occupied the smallest area of 76.94 hectares, representing 2.55%. This is attributed to high temperatures and aridity that cause water evaporation, leaving behind solid residues including sand. Additionally, wind plays a role in the transformation and partial transport of barren lands into sand dunes, which agrees with the findings of [2].

Table 1. Some properties of sand dune soils.

Texture	Clay	Silt	Sand	S.No.
	g Kg^{-1}			
LS	45.00	94.00	861.00	1
SL	63.00	177.00	760.00	2
LS	59.00	161.00	780.00	3
SL	150.00	254.00	596.00	4
SL	133.00	243.00	624.00	5
SiL	71.00	509.00	420.00	6
SiL	60.00	512.00	428.00	7
SL	124.00	224.00	652.00	8
SL	100.00	214.00	686.00	9
L	192.00	335.00	473.00	10
L	186.00	334.00	480.00	11
SL	196.00	131.00	673.00	12
SCL	205.00	113.00	682.00	13
CL	291.00	283.00	426.00	14
CL	286.00	290.00	424.00	15
SL	54.00	222.00	724.00	16
SL	84.00	225.00	691.00	17
SL	75.00	311.00	614.00	18
L	183.00	331.30	485.70	19
L	176.70	408.30	415.00	20
L	166.00	316.00	518.00	21
SCL	202.00	94.00	704.00	22
CL	302.00	263.00	435.00	23
CL	256.00	297.00	447.00	24
S	41.00	85.00	874.00	25
S	36.00	62.00	902.00	26
LS	49.00	128.00	823.00	27

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SL	63.40	322.80	613.80	28
L	273.00	283.00	444.00	29
L	162.00	318.00	520.00	30
SiL	90.00	504.00	406.00	31
SiL	65.00	510.00	425.00	32
SiL	82.00	501.00	417.00	33

Table 2. Spatial distribution of the sand fraction in the soils of the sand dunes in the study area

%Percentage	Area (hectares)	Ranges (g kg^{-1})
29.56	891.64	525.0 – 400.0
53.72	1620.42	650.0 – 525.0
14.17	427.49	775.0 – 650.0
2.55	76.94	905.0 - 775.0
100	3016.49	Sum

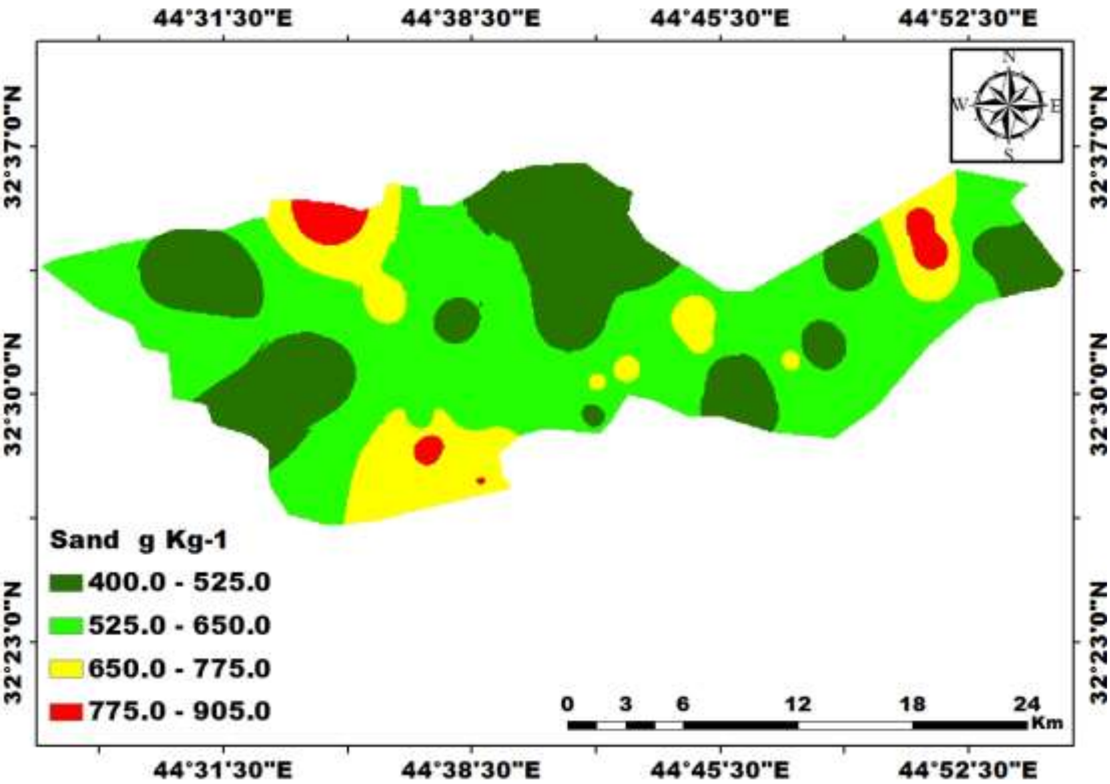

Figure 4. Spatial distribution of the sand fraction in the soils of the sand dunes

- Silt

Results of Table 1 indicate that the silt fraction in the soils of the sand dunes was low compared to the sand fraction, ranging between 62.0–512.0 g kg^{-1}. The lowest silt content was recorded at Site 26, classified as sandy soil, while the highest content was found at Site 7, classified as silty loam. This variation is attributed to a combination of geological, environmental, and climatic factors. Silt represents a medium-sized fraction between sand and clay; its particles are lightweight but more cohesive than sand. Since wind plays a major role in transporting

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sediments depending on particle size and density, the high-energy winds were more effective in transporting sand. Silt, being finer, is carried farther distances or remains suspended in the air, which leads to sand accumulation and a reduction in silt content, as reported by [2].

Results of Table 3 and Figure 5 show that the silt fraction is spatially distributed in the soils of the sand dunes across three ranges. The range 200.0–360.0 g kg^{-1} occupied the largest area of 1961.98 hectares, representing 65.04%, while the range 60.0–200.0 g kg^{-1} occupied the smallest area of 383.36 hectares, representing 12.71% of the total study area soils. This confirms the low silt content in sand dune soils, likely due to the nature of the sedimentary source. [2]. indicated that the sand dunes in this region were formed from ancient riverine deposits that were subjected to drying and subsequently redistributed by wind. These deposits are primarily sandy, originating from environments with medium to high fluvial energy, which led to the winnowing of fine particles (silt and clay) away from the sand dunes. Consequently, these soils exhibit low silt content due to the characteristics of the original sedimentary source.

Table 3. Spatial distribution of the silt fraction in the soils of the sand dunes in the study area

%Percentage	Area (hectares)	Ranges (g kg^{-1})
50.40	1520.20	200.0 – 60.0
42.87	1293.26	360.0 – 200.0
6.73	203.04	520.0 – 360.0
100	3016.49	Sum

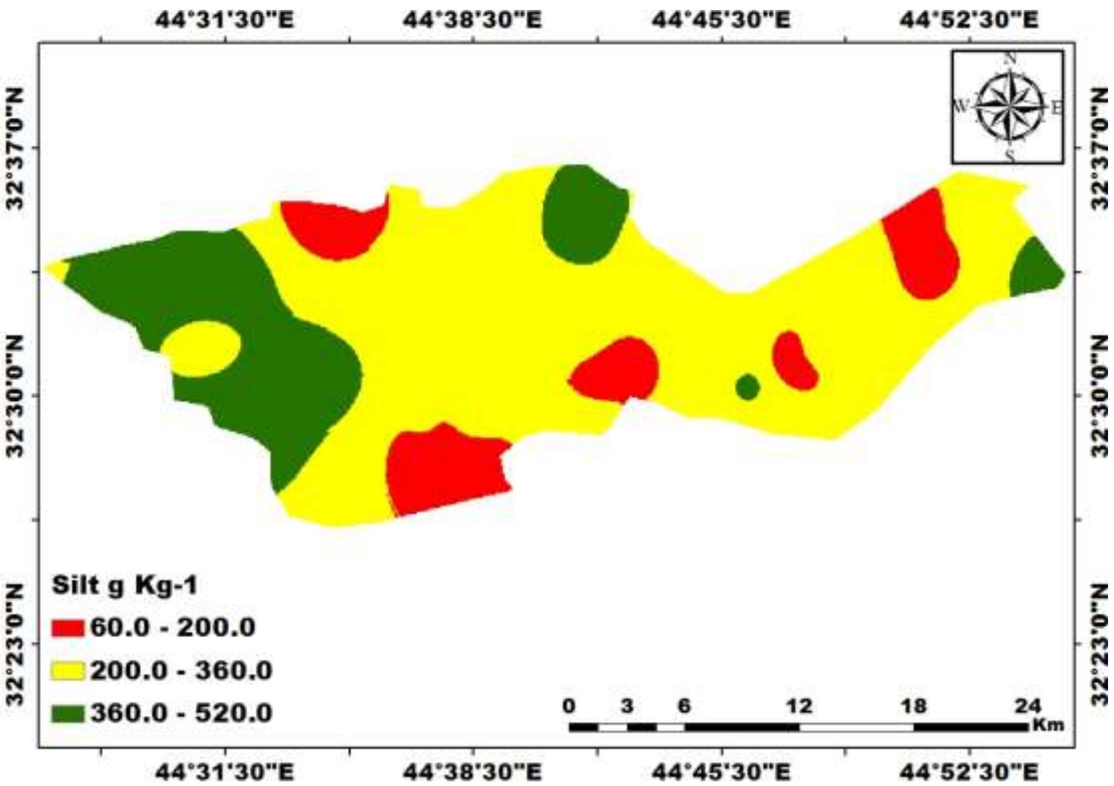

Figure 5. Spatial distribution of the silt content in the soils of the sand dunes in the study area

- Clay

Results of Table 1 indicate that the clay content in the soils of the sand dunes was low, ranging between 36.0–302.0 g kg^{-1}. The lowest content was recorded at Site 26, classified as sandy clay, while the highest

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content was found at Site 23, classified as clay loam. This variation is attributed to dry climatic conditions, including high temperatures and low rainfall, which increase evaporation rates, contributing to soil drying and moisture loss. Consequently, clay and silt particles are transported away from the area by wind. Dry conditions reduce the cohesion of clay particles, making them more susceptible to wind transport, as reported by [8].

Results of Table 4 and Figure 6 show that the spatial distribution of clay content in the soils of the sand dunes occurred across three ranges. The range 35.0–125.0 g kg^{-1} occupied the largest area of 1520.20 hectares, representing 50.40% of the total study area. The range 210.0–302.0 g kg^{-1} occupied the smallest area of 203.04 hectares, representing 6.73%, while the range 125.0–210.0 g kg^{-1} covered 1293.25 hectares, representing 42.87%. It is notable that the largest area was occupied by the lowest clay content range. This is due to the interaction of several natural and anthropogenic factors, including prevailing winds, dry climatic conditions, desertification effects, and human activities such as agricultural expansion, excessive irrigation, tree cutting, and changes in sediment sources. Since the sediment source contains a low proportion of clay, the resulting soils also exhibit low clay content, as reported by [1].

Table 4. Area and percentage of clay content in the soils of the sand dunes in the study area

%Percentage	Area (hectares)	Ranges (g kg^{-1})
50.40	1520.20	125.0 – 35.0
42.87	1293.25	210.0 – 125.0
6.73	203.04	302.0 – 210.0
100	3016.49	Sum

- Soil Texture Classes

Results of Table 1 indicate that the soil texture classes in the study area were relatively homogeneous, ranging from sandy loam (SL), silty loam (SiL), loam (L), clay loam (CL), loamy sand (LS), sand (S), to sandy clay loam (SCL). The dominant classes were sandy loam, loam, and silty loam. The sandy loam texture occupied 30.30% of the texture classes in the study area, appearing 10 times, followed by loam with 21.21% occurrence (7 times), and silty loam with 15.15% occurrence (5 times). Clay loam accounted for 12.12% (4 times), loamy sand 9.09% (3 times), while sandy clay loam and sand each represented 6.06% (2 times).It is notable that there is a degree of homogeneity among the texture classes: the more frequent a certain class appears, the greater the homogeneity, and vice versa. This indicates that the soils of the study area do not show sharp uniformity in their texture composition, as more than 66.66% of the soils fall into three main texture classes. This homogeneity reflects the presence of similar depositional conditions, likely related to the characteristics of riverine flooding in the study area, a typical feature of the alluvial plain [10].

Results of Table 5 and Figure 7 show that the spatial distribution of soil texture classes in the study area spread across seven homogeneous classes. Sandy loam (SL) covered the largest area of 746.44 hectares, representing 24.75%, followed by loam at 711.66 hectares (23.59%). Silty loam occupied 487.86 hectares (16.17%), and clay loam covered 393.57 hectares (13.05%). Loamy sand accounted for 291.92 hectares (9.68%), sandy clay loam 289.78 hectares (9.61%), and sand occupied the smallest area of 95.26 hectares (3.16% of the total area) .The dominance of these classes is attributed to a sedimentary environment rich in riverine deposits. The higher clay content in certain

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locations indicates clay pockets that affect homogeneity in the lower soil layers. Wind-induced particle sorting results in heterogeneous distribution of clay in the sand dunes, creating clay pockets in the lower soil layers, as reported by [3] .

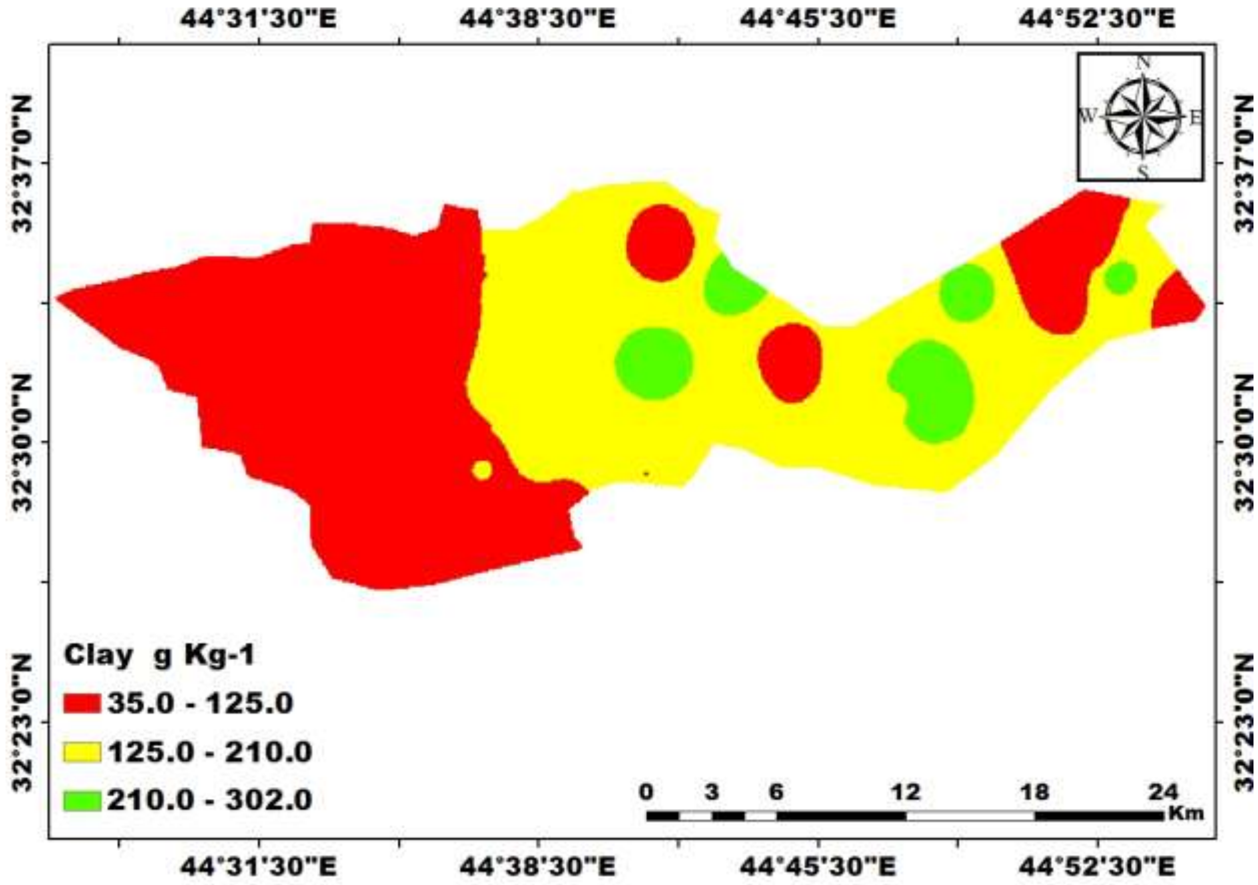

Figure 6. Spatial distribution of clay content in the soils of the sand dunes in the study area

Table 6. Spatial distribution of soil texture classes in the sand dune soils of the study area

%Percentage	Area (hectares)	Texture Class
3.16	95.26	S
9.61	289.78	SCL
9.68	291.92	LS
13.05	393.57	CL
16.17	487.86	SiL
23.59	711.66	L
24.75	746.44	SL
100	3016.49	Sum

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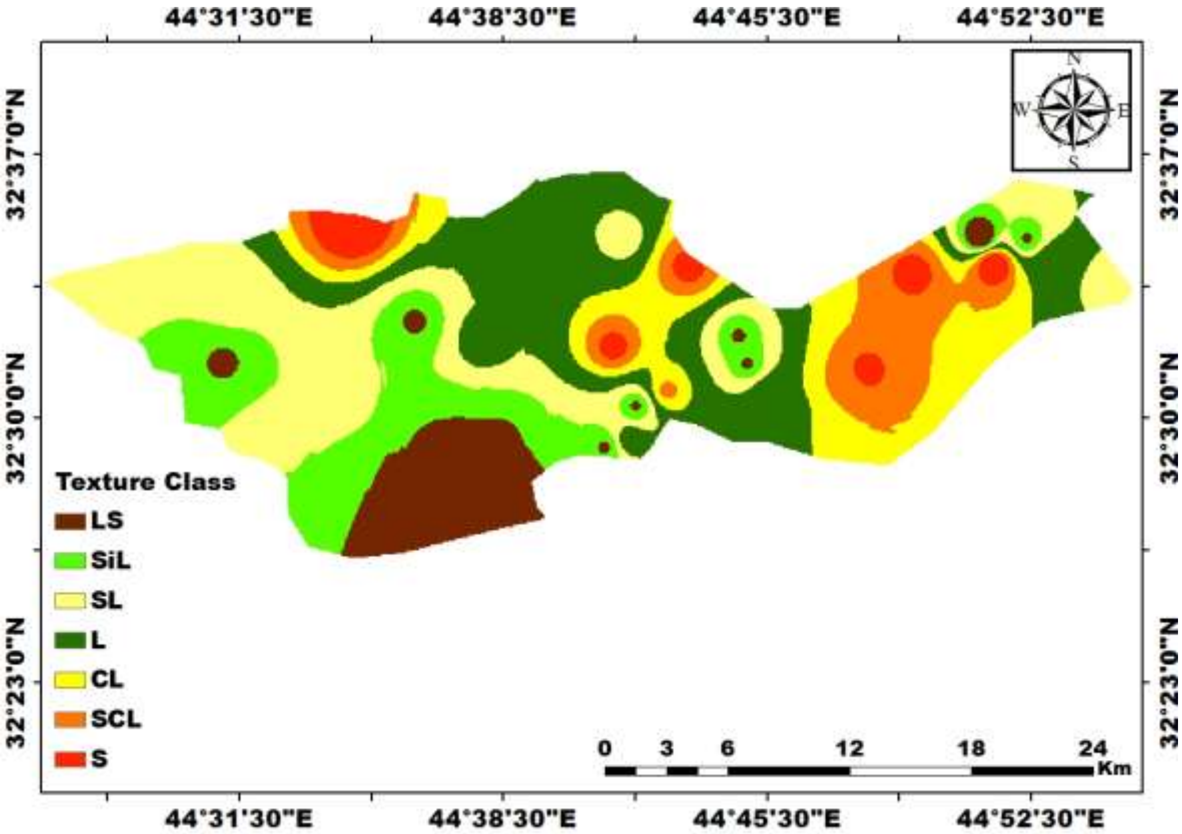

Figure 7. Spatial distribution of soil texture classes in the sand dune soils of the study area

Conclusions

Sand fraction dominates the soil composition of Al-Nile dunes, facilitating the formation of barchan dunes in areas with sparse vegetation.Nabkha dunes are formed around vegetation that stabilizes sand, highlighting the role of plants in dune morphology.GIS mapping effectively visualizes spatial distribution of soil fractions and can inform sustainable land use planning.Integrated field, laboratory, and GIS analyses provide a comprehensive understanding of sand dune dynamics in Al-Nile Subdistrict.

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