

Sand dunes of the Gaza Strip (southwestern Palestine):
morphology, textural characteristics and associated environmental impacts

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ABSTRACT

Sand dunes are wide spread in the Gaza Strip and are present in its northern, central and southern regions. Thirty sand samples were collected at seven locations along the middle region of the Strip. The coordinates for each sampling site were positioned using GPS and processed with ArcGIS software.

Mechanical and chemical properties were examined to determine the textural characteristics and carbonate contents of the dune sands. The mean grain size is fine to medium, and the sands range from moderate- to well-sorting. The skewness is fine to very fine, and the kurtosis ranges from mesokurtic to very leptokurtic. Additionally, the results show that the carbonate content ranges from 1.5% to 5%.

The high permeability, good porosity, and low carbonate content of the sand dunes in the Gaza Strip have led to more groundwater pollution via leachates percolating from the solid waste landfills and basins from wastewater treatments constructed above the sand dunes. Sand quarries have also changed the natural landscape of the Gaza Strip. These quarries were excavated randomly, used for a short period and then disused. This random and unregulated excavation has led to the destruction of natural habitats for flora and fauna.

Key words: Beach dunes, desert dunes, grain size distribution, Gaza Strip, Palestine.

RESUMEN

Las dunas de arena se extienden ampliamente en la Franja de Gaza y hacen presencia en las regiones del norte, centro y sur. Para este trabajo se recolectaron treinta muestras de arena en siete puntos a lo largo de la región media de la Franja. Las coordenadas de cada muestra se marcaron con el GPS y se procesaron con el programa ArcGIS. Se examinaron las propiedades químicas y mecánicas para determinar las características de textura y los contenidos de carbonato de las dunas de arena. El tamaño del grano está entre fino y medio y las arenas oscilan entre moderadas y bien definidas. La asimetría estadística va desde fina hasta muy fina y la variedad de la curtosis se ubica entre mesocúrtica y muy leptocúrtica. Adicionalmente, los resultados muestran que los rangos de contenido de carbonato están entre 1,5 % y 5 %. La alta permeabilidad, la buena porosidad y el bajo contenido de carbonato en las dunas de arena de la Franja de Gaza han permitido una mayor contaminación a través de lixiviados que se filtran desde vertederos de desechos sólidos y desde estaciones de tratamiento de aguas residuales construidas sobre las dunas de arena. Las canteras de arena, además, han cambiado el paisaje natural de la Franja de Gaza. Estas canteras fueron excavadas de manera aleatoria, utilizadas por un tiempo corto y luego cayeron en desuso. Estas excavaciones aleatorias y sin regulación han llevado a la destrucción de hábitats naturales de flora y fauna.

Palabras clave: Dunas de playa, dunas de desierto, distribución del tamaño de grano, Franja de Gaza, Palestina.

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Introduction

Sand dunes cover vast land areas and are primarily located in arid regions. Sand dunes are concentrated in Africa, Australia and Asia, where approximately half of the sand dunes have stable, fixed configurations. Most of the currently fixed dunes were active during the last glacial maximum (e.g., Hesse et al., 2003; Fitzsimmons et al., 2007; Stone & Thomas, 2008; Ashkenazy et al., 2012) when the weather was colder and drier, and air turbulence was strong (e.g., Harrison et al., 2001; Lunt & Valdes, 2001; 2002; Duller & Augustinus 2006).

In Palestine, sand dunes cover an area of approximately 1,600 km²; approximately 81% of the area (1,300 km²) is located in northwestern Negev, and the remaining area is primarily located in the southern coastal plain. The northwestern Negev dunes are older than those on the coastal plain, where they invaded the area more than 15 thousands years ago. The southern coastal plain dunes are younger, approximately 100 - 1,500 years old (Goring-Morris & Goldberg, 1990; Magaritz & Enzel, 1990; Rendell et al., 1993; Tsaor et al., 2004; Singhvi & Porat, 2008; Tsaor, 2009). In the Gaza Strip, sand dunes overlay the Gaza Formation, which consists of alternations of calcareous sandstones and reddish-brown, fine-grained deposits along the middle region of the Gaza Strip between the Coastal ridge and Al Montar ridge. In addition, the sand dunes cover the beach along the western margin of the Strip. The western and middle Gaza Strip sand dunes stabilized at the end of the previous century when land use drastically changed. Stabilization of the Gaza Strip sand dunes contains considerable vegetation coverage, and architectural activities occur in the middle part of the Strip. These dunes stabilized rapidly due to the low wind power in Palestine (Tsaor, 2009).

The aim of this study was to examine the sand dunes in the Gaza Strip, specifically the morphology, textural parameters, and anthropogenic environmental impacts associated with these dunes.

Geography and geology of the Gaza Strip

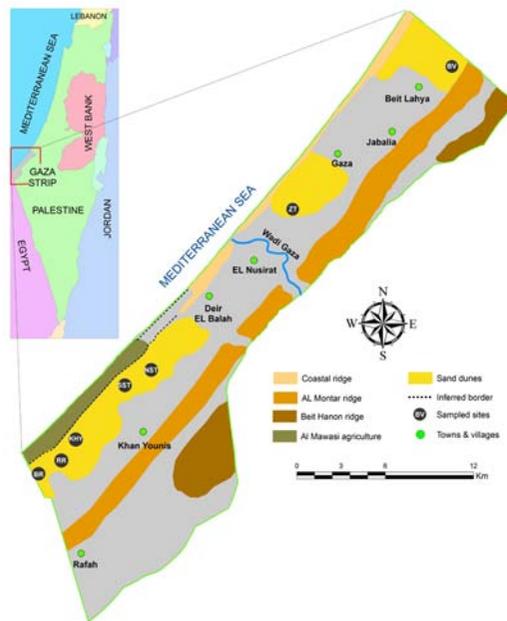


Figure 1. Map of the study area showing the topography and the sand dune locations in the Gaza strip. BV=Bedouin Village; ZT=Al Zahraa Town; NST=North Asdaa Town; SST=South Asdaa Town; KHP=Khan Younis; RR=Rafah Road; and RB=Rafah Border.

The Gaza Strip is located in southwestern Palestine at the southeastern coast of the Mediterranean Sea, between 34° 02' east and 31° 45' north (Fig. 1). The Strip covers an area of approximately 365 km², has a length of 45 km along the coastal zone, and its width ranges from 5 to 8 km in the central and

northern regions to a maximum of 12 km in the south. The Gaza Strip is located in the transitional zone between a temperate Mediterranean climate in the west and north and the arid climate of the Sinai Peninsula on the east and south. The temperature gradually changes throughout the year, reaches its maximum during the summer in August and its minimum in January during the winter. The average monthly maximum temperature ranges between 17.6 °C for January and 29.4 °C for August. The average monthly minimum temperature for January is approximately 9.6 °C and 22.7 °C for August. The mean annual rainfall is 335 mm per year, and the average annual evaporation is 1300 mm.

The topography of the Gaza Strip is defined by three ridges (locally termed kurkar ridges), depressions, dry streambeds and shifting sand dunes (Fig. 1). The ridges and depressions generally extend in the NE-SW direction parallel to the coastline. The surface elevation ranges from mean sea level to approximately 110 m above mean sea level. The depressions, which contain alluvial deposits, are approximately 20 - 40 m above mean sea level.

In terms of stratigraphy, these ridges belong to the Kurkar Group (Bartov et al., 1981). This group is of a Pliocene-Pleistocene age, and within this group, three formations can be distinguished: Ahuzam Fm, Pleshet Fm, and Gaza Fm (Bartov & Arkin, 1980; Frechen et al., 2004; Galili et al., 2007; Ubeid, 2010; 2011b). The kurkar ridges, which belong to the Gaza Fm, consist of calcareous sandstones (locally termed kurkar) alternated with brown-reddish, fine-grained deposits (locally termed hamra) (Horowitz, 1975; Abed & Al Weshahy, 1999; Frechen et al., 2004; Ubeid, 2010; 2011b). In the southern part of the Gaza Strip, these features tend to be covered by sand dunes. The soil in the Gaza Strip is primarily composed of three types: sandy soil, clayey soil, and loess soil (Ubeid, 2011b; 2013). The sandy soil is found along the coastline and middle parts of the Gaza Strip in the form of sand dunes. The clayey soil is found along the northeastern part of the Gaza Strip. The loess soil is found around the Wadis area.

Materials and methods

The dune field was first studied using aerial photographs and Landsat images. The sand dunes were mapped from orthophotos at a scale of 1:5000 in a GIS program and validated with field surveys. Field observations were noted and documented using field photographs. Seven localities, characterized by the presence of a dune field were selected for study, which from north to south, are the following: Bedouin Village (BV), Al Zahraa Town (ZT), North Asdaa Town (NST), South Asdaa Town (SST), Khan Younis (KHP), Rafah Road (RR), and Rafah Border (RB) (Fig. 2). At each location, the length, width and height of the dunes were measured using meter tape, and the slope of the dunes was measured in both the lee and stoss directions. The coordinates for each location were recorded using portable GPS (Table 1). The sand flow direction was determined from ripple marks and dunes using a Brunton compass.

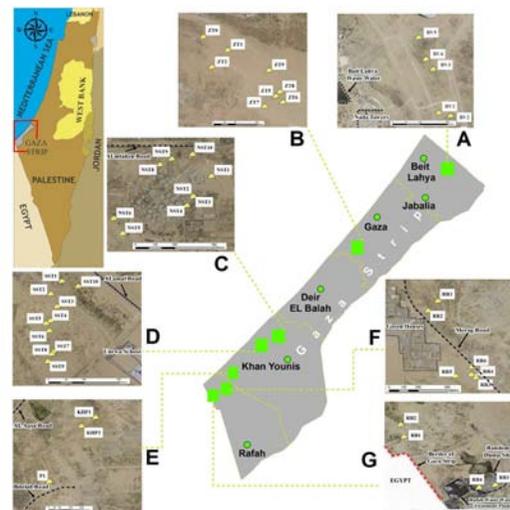


Figure 2. Sampling sites within the study area. (A) Bedouin Village; (B) Al Zahraa Town; (C) North Asdaa Town; (D) South Asdaa Town; (E) Khan Younis; (F) Rafah Road; (G) Rafah Border.

Locality	Station no.	GPS Location		Elevation MSL (m)
		N	E	
Bedouin Village	BV1	31.55894	34.52477	46
	BV3	31.56171	34.52441	37
	BV4	31.56235	34.52396	32
	BV5	31.56373	34.5235	36
Al Zahraa Town	ZT1	31.47526	34.40955	15
	ZT2	31.4749	34.40922	16
	ZT5	31.47428	34.41056	32
	ZT6	31.47415	34.41071	31
North Asdaa Town	NST2	31.37574	34.31407	31
	NST3	31.37567	34.31408	36
	NST5	31.37318	34.30939	38
	NST6	31.37419	34.30879	36
	NST8	31.37782	34.31186	26
South Asdaa Town	SST1	31.36791	34.29184	45
	SST4	31.36607	34.29131	39
	SST9	31.36419	34.2912	42
	SST10	31.36767	34.29259	25
Khan Younis	AM1	31.34307	34.28290	49
	KHP1	31.33433	34.25616	30
	KHP2	31.33375	34.25524	40
	P1	31.33009	34.25315	38
Rafah Road	RR1	31.322	34.24633	36
	RR3	31.31503	34.24973	42
	RR4	31.31529	34.24931	37
	RR5	31.31517	34.24791	38
	Rafah Border	RB1	31.31185	34.22844
RB2		31.31272	34.2282	41

Table 1. GPS coordinates of the sampling sites in the study area.

Thirty samples were collected from the crest, lee and stoss sides of the dunes for sedimentological analysis. Samples were taken during the spring season (May-June 2012).

Approximately 100 g of each sample were used to determine the grain size. The grain size distribution was obtained using the sieve analysis method. The data were processed using GRADISTAT software following Blott and Pye (2001) to determine the grain size parameters. In this software, linear interpolation was used to calculate the statistical parameters as per Folk and Ward (1957). The software also provides a physical description of the textural group that the sample belongs to and the sediment type, which are named according to Folk (1954). The total calcium carbonate content was measured using volumetric calcimetry. The coordinates of each sampling location were integrated onto a digital map using ArcGIS software.

Results

Dune morphology and field relations

During the fieldwork, it was observed that the dunes were of the barchans type (Fig. 3). The dunes had a low-density distribution with tens of meters between dunes. Table 2 presents a summary of the dimensions of the dunes, and Figure 4 shows the morphology of the dunes in the studied area. Dunes differ in their sizes. Smaller dunes (Fig. 4A) had heights ranging from 0.4 m to 1.6 m and widths ranging from 2.4 m to 12 m, whereas relatively larger dunes (Fig. 4B) ranged in height from 1.8 m to 20 m and in width from 25 m to 78 m. There is a direct relationship between the length and width of the dunes and between their length and height (Fig. 5). The relationship between dune length and width is stronger because the fit line of the curve passes through the original point, which suggests that the wind effects that transport the sand were uniform throughout the dunes. The curves also show that the smaller dunes are closer to the line of fit; increased size may lead to some deformation in shape.



Figure 3. Field photograph of a barchans dune, at the southern part of the Gaza Strip.

Locality	Station no.	Back length (m)	Slip face length (m)	Width (m)	Height (m)	Ripple Index
Bedouin Village	BV3/1	10	2.4	4.5	0.5	25
	BV3/2	10.5	5.3	6.8	0.8	19
	BV4	3.4	1.2	2.4	0.4	12
	BV5	70	12	53	10	8
Al Zahraa Town	ZT	160	22	78	20	9
North Asdaa Town	NST1	25	5	31	5	6
	NST7	5	1	6.5	0.6	10
South Asdaa Town	SST4	14	6.6	12	1.6	13
	SST5	12	6	4	0.9	20
	SST9	43	23	25	1.8	37
Khan Younis	KHP2	4	1.7	3.2	0.7	8
Rafah Road	RR1	4	2.3	4	0.4	9
	RR5	5		3	0.6	8
Rafah Border	RB2	5	1.5	4.5	0.6	11

Table 2. The measured field dimensions of the sand dunes.

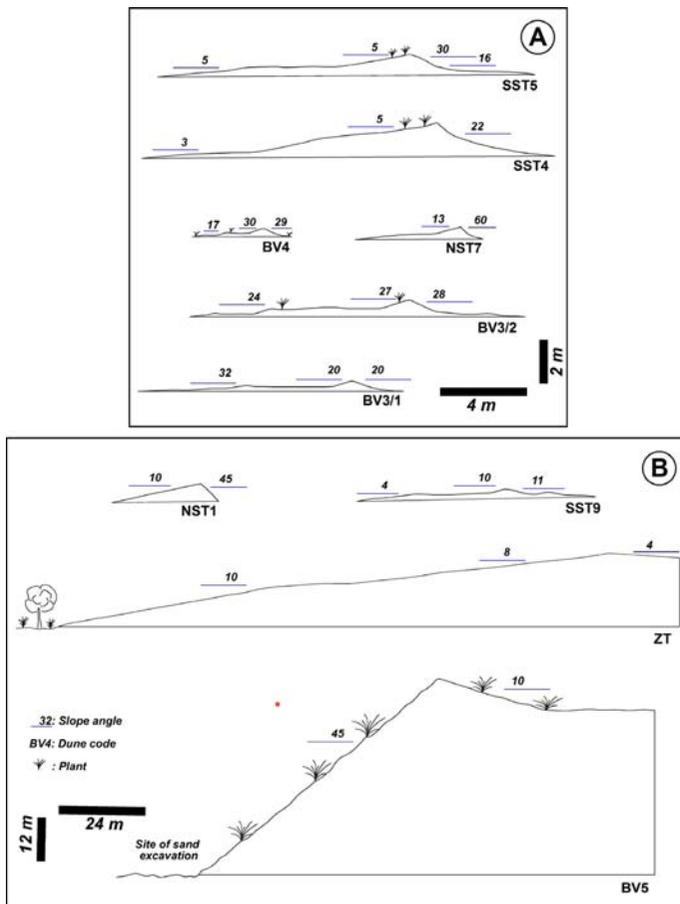


Figure 4. The morphology of sand dunes in the study area. (A) Dunes with a ripple index ranging from 6 to 25. (B) Dunes with a ripple index ranging from 6 to 9 (except SST9 at South Asdaa Town).

The size distributions of the dunes are random and not dependent on their location. It was observed that architectural activities, in addition to sand supplements and wind directions, affected the size and distribution of the dunes. The larger dunes were observed in open areas with low relief and were far from buildings or foundations. Additionally, the larger dunes

were found at localities where the coastal ridge height was at the minimum, such as in the middle and southern parts of the Gaza Strip; these locations experienced maximum wind speeds. Additionally, sand excavation at the sand quarries affected the size of the dunes: the creation of large, flat areas in the quarries allowed sand to move easily through these areas.

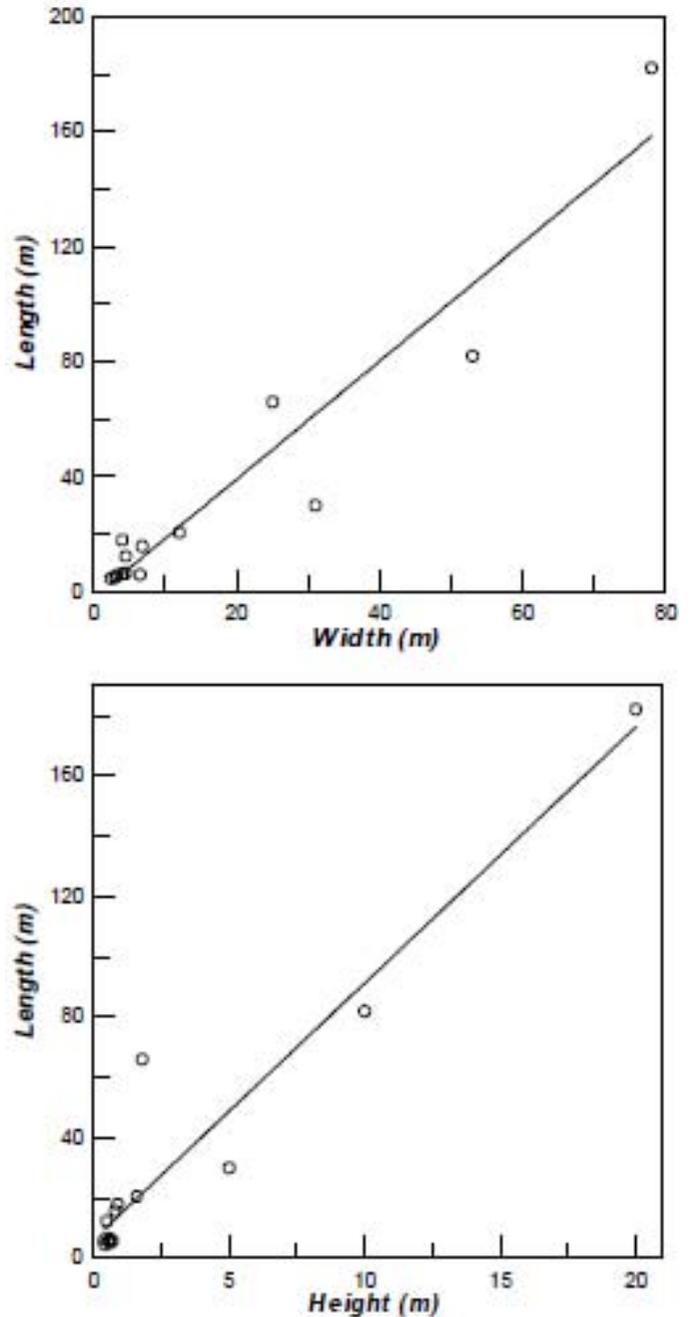


Figure 5. The relationships between the dimensions of the dunes in the study area.

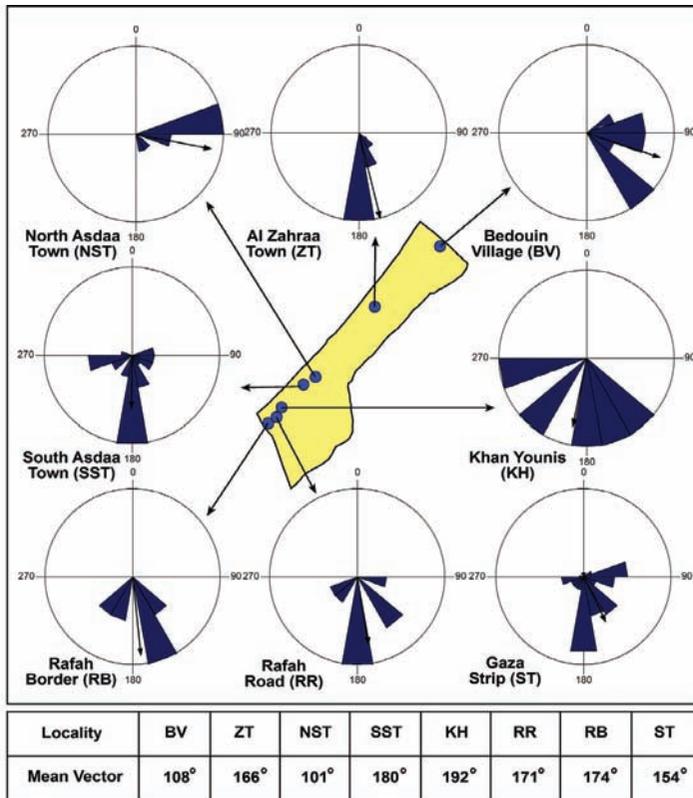


Figure 6. Current flows of dune sands at the study sites in the Gaza Strip. The table below the figure shows the mean vector of the directions at each site.

The wind direction was SSE in most locations, except in the northernmost location (Bedouin Village) and in the southern part (North Asdaa Town), where the wind direction was EES (due to open areas with a low relief at these locations, Fig. 6). The rose diagrams in Figure 6 show the vector mean and dominant direction data separately at all sites in the study area. It was observed that the vector means are not coincident with the maxima of each rose diagram. This could be due to the wind regime, which is affected by the topography of the different sites (Zu et al., 2008). It was observed that the differences are smaller in the southern sites than in the northern sites. Furthermore, the wind energy increases in the south due to the low relief of the coastal ridge in the west (Fig. 1).

However, the density of the vegetation on the sand dunes was low to very low in the northern and middle parts of the Gaza Strip, whereas it was low to moderate in the southern part. The vegetation preserves the stability of the dunes, and the sands accumulate around the plants and form a nabkha, particularly in the south (Fig. 7).

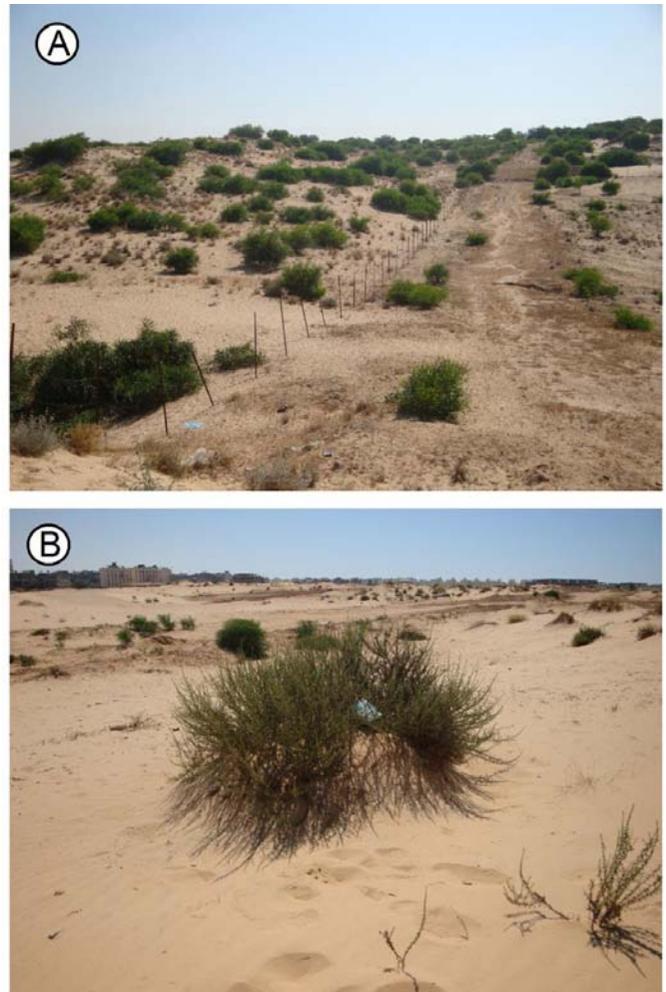


Figure 7. Field photographs of vegetation cover. (A) The vegetation cover on the sand dunes in the south, at the Khan Younis locality. (B) The Nabkha in the southernmost part of the Gaza Strip, at the Rafah locality.

Textural parameters

The grain size parameters of the sands from the seven sampling locations are shown in Tables 3-5. Twenty-two of the histograms that represent the mechanical composition exhibit unimodal distributions in which the modal class falls into the medium grade, whereas eight display bimodal distributions that are of fine and medium grades. The statistical grain-size parameters show that in all the studied locations, the sand dunes are primarily formed by medium sands, except in the North Asdaa Town location in the southern part of the Gaza Strip; there, the sand dunes are mostly formed by fine sands. The dune sands in all the studied locations are primarily moderately well sorted, except those at Al Zahraa Town and Rafah Road, where the dune sands are moderately sorted to well sorted. The skewness of the dune sands of the northern and middle locations is primarily very finely skewed, whereas in the southern part of the Gaza Strip (i.e., in South Asdaa Town, Khan Younis, and Rafah) the dune sands are finely skewed. The dune sands in the northern and middle parts of the Gaza Strip are primarily very leptokurtic, whereas in the middle and southern parts, they are leptokurtic to mesokurtic. The fine grain size at the North Asdaa Town is due to selectiveness of the wind, which is concentrated at the dune. The sorting values suggest that the Al Zahraa and Rafah Road dunes have been subjected to high transport by winds that control the grain size distributions within the dune system; this factor was strongly related to the extremely low height of the coastal ridge at these localities, where the effect of wind is larger.

Locality	Sample no.	M		Q		Sk ₁	K _G	Description			
		μm	Ø	μm	Ø			Mean	Sorting	Skewness	Kurtosis
Bedouin Village	BV1	248.3	2.010	1.618	0.694	0.419	1.563	Fine Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic
	BV3	288.9	1.791	1.466	0.552	0.275	1.522	Medium Sand	Moderately Well Sorted	Fine Skewed	Very Leptokurtic
	BV4	235.1	2.089	1.665	0.736	0.407	1.709	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
	BV5/1	288.9	1.792	1.368	0.452	0.019	0.979	Medium Sand	Well Sorted	Symmetrical	Mesokurtic
	BV5/2	276.3	1.856	1.472	0.558	0.267	1.463	Medium Sand	Moderately Well Sorted	Fine Skewed	Leptokurtic
	BV5/3	257.2	1.959	1.654	0.726	0.427	1.536	Medium Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
Al Zahraa Town	ZT1	297.8	1.747	1.390	0.475	0.047	1.039	Medium Sand	Well Sorted	Symmetrical	Mesokurtic
	ZT2	304.3	1.717	1.408	0.494	0.128	1.120	Medium Sand	Well Sorted	Fine Skewed	Leptokurtic
	ZT5	241.2	2.052	1.679	0.748	0.449	1.514	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
	ZT6	303.1	1.722	1.325	0.406	0.232	0.955	Medium Sand	Well Sorted	Fine Skewed	Mesokurtic
North Asdaa Town	NST2	239.0	2.065	1.679	0.748	0.407	1.562	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
	NST3	237.2	2.076	1.626	0.701	0.365	1.600	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
	NST5	230.8	2.115	1.714	0.778	0.409	1.646	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
	NST6	312.8	1.677	1.523	0.607	0.343	1.625	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic
	NST8	296.3	1.755	1.565	0.647	0.201	1.563	Medium Sand	Moderately Well Sorted	Fine Skewed	Very Leptokurtic
South Asdaa Town	SST1	308.2	1.698	1.564	0.646	0.336	1.586	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Very Leptokurtic
	SST4	226.9	2.140	1.790	0.840	0.295	1.002	Fine Sand	Moderately Sorted	Fine Skewed	Mesokurtic
	SST9/1	306.2	1.707	1.390	0.475	0.248	1.134	Medium Sand	Well Sorted	Fine Skewed	Leptokurtic
	SST9/2	269.8	1.890	1.513	0.597	0.137	1.185	Medium Sand	Moderately Well Sorted	Fine Skewed	Leptokurtic
	SST10	294.6	1.763	1.522	0.606	0.258	1.568	Medium Sand	Moderately Well Sorted	Fine Skewed	Very Leptokurtic
Khan Younis	AM1	252.8	1.984	1.532	0.616	0.304	1.341	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Leptokurtic
	KHP1	302.2	1.727	1.434	0.520	0.383	1.451	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Leptokurtic
	KHP2	307.3	1.702	1.335	0.417	0.228	0.999	Medium Sand	Well Sorted	Fine Skewed	Mesokurtic
	P1	272.1	1.878	1.461	0.547	0.213	1.324	Medium Sand	Moderately Well Sorted	Fine Skewed	Leptokurtic
Rafah Road	RR1	287.0	1.801	1.366	0.450	0.183	1.007	Medium Sand	Well Sorted	Fine Skewed	Mesokurtic
	RR3	274.5	1.865	1.411	0.497	0.164	1.174	Medium Sand	Well Sorted	Fine Skewed	Leptokurtic
	RR4	270.1	1.889	1.394	0.479	0.164	1.017	Medium Sand	Well Sorted	Fine Skewed	Mesokurtic
	RR5	249.6	2.002	1.655	0.727	0.463	1.508	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Leptokurtic
	Rafah Border	RB1	308.8	1.695	1.446	0.532	0.276	1.354	Medium Sand	Moderately Well Sorted	Fine Skewed
RB2		305.2	1.712	1.311	0.391	0.299	1.048	Medium Sand	Well Sorted	Fine Skewed	Mesokurtic

M = mean grain size; Q = sorting; Sk₁ = skewness; K_G = kurtosis

Table 3. Grain size parameters of sands from the dunes.

Locality	M		Q		Sk ₁	K _G
	μm	Ø	μm	Ø		
Bedouin Village	271.78	1.92	1.54	0.62	0.30	1.46
Al Zahraa Town	286.60	1.81	1.45	0.53	0.214	1.16
North Asdaa Town	263.22	1.94	1.62	0.70	0.35	1.60
South Asdaa Town	281.14	1.84	1.56	0.63	0.25	1.30
Agri. Ministry	252.80	1.98	1.53	0.62	0.30	1.34
Khan Younis	304.75	1.71	1.38	0.47	0.31	1.22
Pdolah	272.1	1.878	1.461	0.547	0.213	1.324
Rafah Road	270.30	1.89	1.46	0.54	0.24	1.18
Rafah Border	307.00	1.70	1.38	0.46	0.29	1.20

M = mean grain size; Q = sorting; Sk₁ = skewness; K_G = kurtosis

Table 4. Average values of grain size parameters for each location in the study area.

Locality	Sample no.	V.C. silt (%)	V.F. sand (%)	F. sand (%)	M. sand (%)	C. sand (%)	V.C. sand (%)
Bedouin Village	BV1	0.2	12.7	24.9	60.5	1.5	0.1
	BV3	0.1	10.4	22.3	65.2	2.0	0.0
	BV4	0.4	14.4	26.9	56.1	2.2	0.1
	BV5/1	0.0	1.2	32.7	62.1	3.9	0.1
	BV5/2	0.5	8.4	27.7	62.2	1.1	0.0
	BV5/3	0.1	12.6	21.5	62.2	3.5	0.1
Al Zahraa Town	ZT1	0.3	1.9	28.5	63.6	5.6	0.1
	ZT2	0.3	3.5	24.2	65.5	6.3	0.2
	ZT5	0.4	14.3	23.7	59.2	2.3	0.1
	ZT6	0.0	2.3	23.7	71.2	2.8	0.0
North Asdaa Town	NST2	0.1	14.6	25.4	57.0	2.8	0.1
	NST3	0.5	13.2	31.3	53.2	1.5	0.3
	NST5	0.3	15.9	25.8	55.0	2.8	0.0
	NST7	0.2	8.3	15.6	68.5	7.3	0.1
	NST8	0.3	12.1	20.1	60.5	6.9	0.2
South Asdaa Town	SST1	0.3	10.5	16.0	65.1	7.8	0.2
	SST4	0.5	16.9	31.0	46.9	4.6	0.1
	SST9/1	0.2	3.7	21.8	69.6	4.6	0.0
	SST9/2	0.2	5.5	34.5	55.1	4.7	0.1
	SST10	0.1	11.0	20.6	63.8	4.5	0.1
Khan Younis	AM1	0.1	9.4	34.0	55.8	0.6	0.1
	KHP1	0.1	7.3	19.1	71.0	2.4	0.1
	KHP2	0.0	1.3	23.1	72.2	3.5	0.0
	P1	0.2	6.7	31.8	59.0	2.3	0.0
Rafah Road	RR1	0.2	4.0	29.7	64.2	1.9	0.0
	RR3	0.1	5.1	33.1	59.9	1.8	0.0
	RR4	0.3	4.1	34.8	59.7	1.1	0.0
	RR5	0.6	13.1	22.2	61.5	2.6	0.0
	Rafah Border	RB1	0.2	5.0	20.1	68.9	5.8
RB2		0.0	3.6	19.8	75.9	0.7	0.0

Table 5. Grain size distribution of the different sand samples.

The Gaza Strip sand dunes are rich in quartz with smaller amounts of plagioclase. Bioclasts of land snail shells were found in the middle and southern parts of the Gaza Strip (Fig. 8). The carbonate contents of the sand dunes range from 1.5% -to 5% (Table 6).



Figure 8. The bioclasts of land snail shells (white color), at South Asdaa Town in the southern part of the Gaza Strip.

Locality	Sample no.	CaCO ₃ (%)
Bedouin Village	BV1	3.2
	BV3	2.2
	BV4	1.9
	BV5/1	1.4
	BV5/2	4.9
	BV5/3	2.3
Al Zahraa Town	ZT1	3.3
	ZT2	3.5
	ZT5	3.9
	ZT6	4.2
North Asdaa Town	NST2	1.9
	NST3	2
	NST5	1.6
	NST7	1.8
	NST8	1.7
South Asdaa Town	SST1	3.8
	SST4	2.9
	SST9/1	2.8
	SST9/2	1.9
	SST10	2.1
Khan Younis	AM1	2.4
	KHP1	2
	KHP2	2.6
	P1	1.9
Rafah Road	RR1	2.3
	RR3	1.7
	RR4	1.3
	RR5	2.1
	Rafah Border	RB1
RB2		3

Table 6. Calcium carbonate contents for the different sand samples.

Discussion

Classification and inferred sources of sand dunes

Based on geographic location, two main categories of sand dunes can be recognized: (1) beach sand dunes and (2) desert sand dunes.

Beach sand dunes

These dunes are located along the beach at the western margin of the Gaza Strip. The sand is composed of a high percentage of a light yellow to transparent sugary quartz and approximately 1% dark-colored accessory minerals. The sand grains are characterized by medium-grained sand that is moderately well sorted (Ubeid, 2011a). The sand of this type comes from marine sediments

that were transported along the eastern shore of the Mediterranean Sea from the Nile Delta by longshore currents (Nir, 1989; Goldsmith & Golik, 1980; Goldsmith et al., 1990; Ben-Dor et al., 2006; Zviely et al., 2006; 2007; Ubeid, 2010; 2011a).

Desert sand dunes

The desert sand dunes are located along the middle part of the Gaza Strip (Fig. 1). The characteristics of these dunes are outlined above (see Results) and are presented in Tables 3- 5. The characteristics of the sand reflect the aeolian sediments that were supplied from the Sinai Desert (Neev et al., 1987; Crouvi et al., 2008; Ubeid, 2011b) (Fig. 9). Sediment supply and strong winds are both crucial contributors to the dune encroachment and sand transport from the Sinai Desert to northwestern Negev and the Gaza Strip (Amit et al., 2006; Enzel et al., 2008; 2010; Roskin et al., 2011a & 2011b, 2013).

Associated environmental impacts

The anthropogenic environmental impacts associated with sand dunes in the Gaza Strip are the following:



Figure 10. Field photographs of the sand quarries in the study area. (A & B) The quarries at Bedouin Village in northern part of the Gaza Strip. (C & D) The quarries at North Asdaa Town in the southern part of the Gaza Strip. (E) The trucks used during the excavation sands from a sand quarry in the southern part of the Gaza Strip. (F) An abandoned sand quarry at South Asdaa Town in the southern part of the Gaza Strip.



Figure 9. Regional map showing the distribution of sand dunes in the northern Sinai Desert, which extends from the Nile Delta eastwards into northwestern Negev and Gaza Strip (after Dan & Raz, 1970; Bartov, 1990). The large NE arrow marks the westerly winds prevalent during sand incursion (e.g. Amit et al., 2006; Enzel et al., 2010).

1 - *Sand quarries*. Randomly established sand quarries were distributed throughout most of the studied sites (Fig. 10). Sand was excavated from each quarry for a short period of time; then, workers moved the sand to another place, which left relatively large low-relief areas behind. The mineral composition of the sand dunes (i.e., primarily quartz) encourages people to excavate the sands from these quarries for commercial and industrial purposes. For example, approximately 664,759 m³ of sand was used for construction. Figure 11 shows the amount of sand excavated from the quarries in the studied sites during 2011. The excavation was performed without any plan for the future, which led to the destruction of the natural landscape and the habitat for flora and fauna in the Gaza Strip.

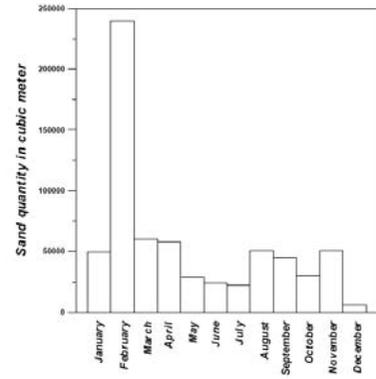


Figure 11. The amount of sand excavated from the sand quarries in the studied sites during 2011.

2 - *Wastewater treatment basins*. Most of these basins were established on the sand dunes (Fig. 12). The geochemical analysis results of the groundwater for the wells around the wastewater treatment basins in the Rafah location at the southernmost tip of the Gaza Strip showed that the groundwater of these wells are polluted, where most of them are not fit for drinking according to the World Health Organization (WHO) (Table 7A and 7B). Therefore, high seepage from these basins could possibly occur. The sand dunes of the Strip are characterized by high permeability and good porosity due to moderate- to well-sorted grain sand and low calcium carbonate contents. These characteristics lead to wastewater leakage into the aquifer and subsequent pollution of the groundwater. In addition, a large amount of rainfall that would otherwise be used to recharge the aquifer is lost; these basins occupy an area of at least 872 km² above the sand dunes (Table 8).

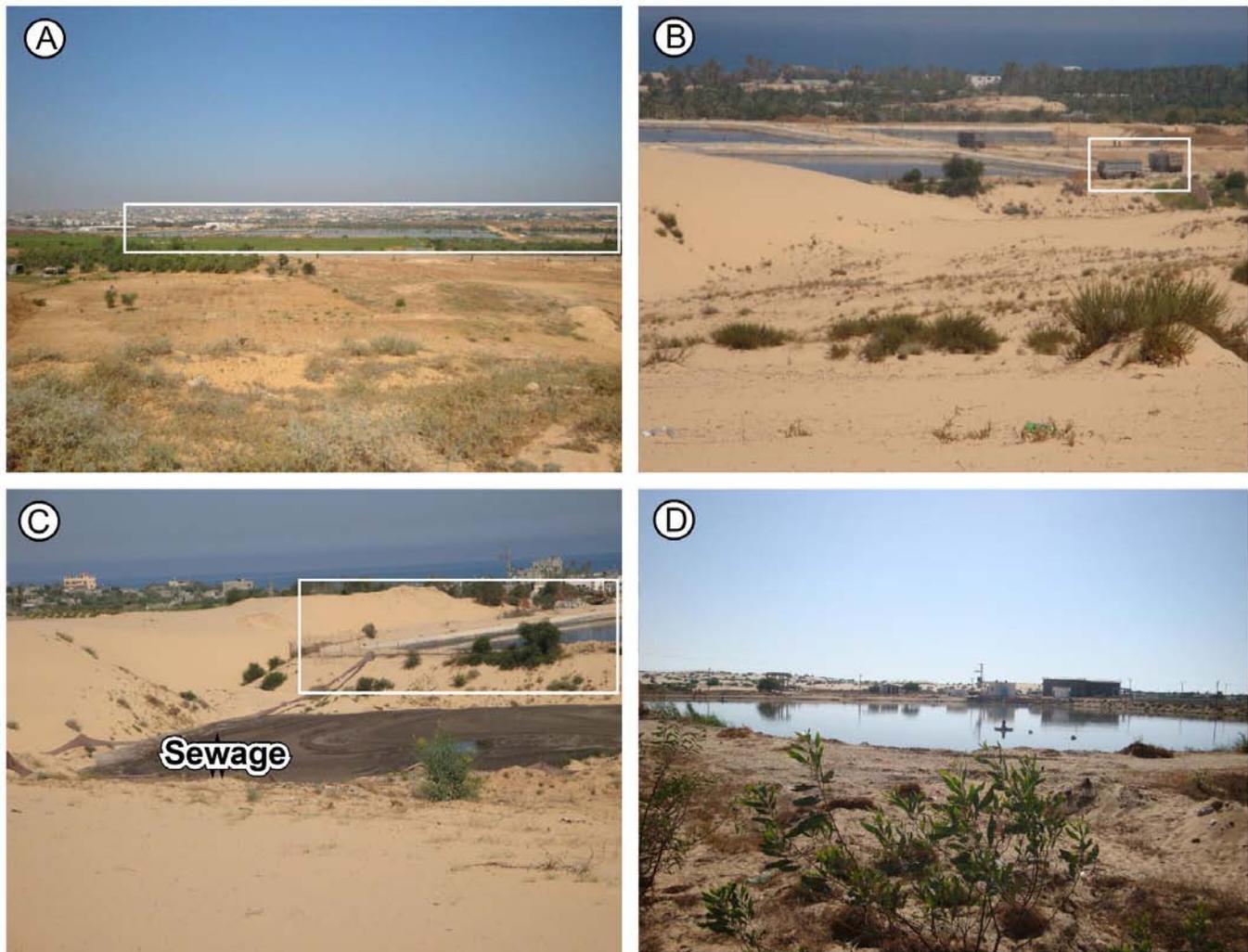


Figure 12. Field photographs of wastewater treatment basins above the sand dunes in the study area. (A) At Beit Lahya locality near Bedouin Village, in the northernmost part of the Gaza Strip (basins are shown in a rectangle). (B & C) At Khan Younis locality in the southern part of the Gaza Strip. Note in (C) the sewage from the basin thrown above the sands. (D) At Rafah Border, in the southernmost part of the Gaza Strip.

(A)

Well ID	Coordinates		pH	EC ($\mu\text{S}/\text{cm}$)	Hardness (mg/l)	Cl ⁻ (mg/l)	NO ₃ ⁻ (mg/l)
	X	Y					
P/124	77599	79414	7.43	2250	320	460	106
P/138	78667	80053	6.6	3070	380	690	22
P/144	78314	80367	7.95	1922	100	440	54
P/145	79368	79856	7.35	2740	380	590	187
P/148	78666	80053	7.33	1380	220	250	186
P/153	77736	80520	7.94	698	50	100	93
P/164	77599	79414	7.64	3230	550	874	16
SAFA	80122	78527	7.29	4440	690	1000	171
SEKA	79583	78520	7.29	4320	420	990	264

(B)

Parameter	WHO values
pH	6.5-8.5
TDS (mg/l)	1000
Mg ²⁺ (mg/l)	60
Ca ²⁺ (mg/l)	100
Na ⁺ (mg/l)	200
K ⁺ (mg/l)	5
HCO ₃ ⁻ (mg/l)	200
Cl ⁻ (mg/l)	250
NO ₃ ⁻ (mg/l)	45

Table 7. Geochemical analysis of the groundwater for wells around the waste water treatment basins in Rafah locality at southern most part of Gaza Strip. (B) WHO's drinking water standards. Note the high concentration of the results in the wells especially chloride and nitrate concentration comparing with WHO's standards.

Location	Area of basin (m ²)	Waste water (m ³ /day)
Beit Lahya (Bedouin Village)	432000	25000
Eshiekh Ejlein	211000	75000
Khan Younis	62000	16000
Rafah	167000	10000

Table 8. Depicts the wastewater treatment basins above the sand dunes in the studied locations.

3 - Landfills. Several solid waste landfills were established in the sand dunes at the abandoned sand quarries above the low-relief area after the sand excavations were terminated (Fig. 13 and Table 9). Solid waste leachate from these landfills causes groundwater pollution in areas where the sand dunes are characterized by high permeability. The landfills also led to the destruction of natural habitats.



Figure 13. Photographs of solid waste landfills above the sand dunes in the study area. (A) At Khan Younis locality, in the southern part of the Gaza Strip. (B) Near Rafah border in the southernmost of the part Gaza Strip. Note that both locations were established at abandoned sand quarries.

Location	Area of landfill (m ²)	Waste solids (Ton/day)
Beit Lahya (Bedouin Village)	70000	280
Khan Younis	60000	200
Rafah	10000	110

Table 9. Depicts some waste solid landfills above the sand dune in the study area.

Conclusions

In Palestine, sand dunes cover an area of approximately 1,600 km². In the Gaza Strip, the sand dunes cover the beach area along the western margin and the middle of the Strip between the Coastal ridge and the Al Montar ridge. According to the sand dune sources, the sand dunes in the Gaza Strip can be classified as either beach sand dunes or desert sand dunes. The beach sand dunes are located along the western part of the Strip between the beach and the Coastal ridge. The origin of these dunes is the Nile Delta, from which the sands are transported by longshore currents. However, the desert sand dunes are found along the middle part between the Coastal and Al Montar ridges. They cover the northern part of the Bedouin Village, the middle region in Al Zahraa Town, and the southern areas from Khan Younis up to Rahah. The sands from these dunes originated from the Sinai Desert.

The sand dunes in the Gaza Strip have a low-density distribution and differ in size, ranging from 0.4 - 20 m in height and 2.4 - 78 m in width. Architectural activities, in addition to sand supplements and wind directions, affect their sizes and their distribution. In addition, vegetation contributes to the stability of the dunes.

The sands from the middle part of the Gaza Strip are primarily medium-grained, except in North Asdaa Town, where they are fine-grained. The sands are primarily moderately well sorted, except in Al Zahraa Town and in the southernmost part of the Strip, where the sands are moderate- to well-sorted. The skewness is very fine to fine, and the sands are very leptokurtic to mesokurtic. The carbonate content in the dune sands ranges from 1.5% to 5%.

There are several wastewater treatment basins and solid waste landfills above the sand dunes in the Gaza Strip. These basins and landfills pollute the groundwater due to the high permeability and good porosity of the sand dunes, which are composed of fine- to medium-grained sands and are moderate- to well-sorting. The random distribution of the sand quarries, wastewater treatment basins, and solid waste landfills have destroyed the natural landscape of the Gaza Strip.

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