Comparative study of the geotechnical properties of the coastal Sabkhas of Saudi Arabia and their hazardous effects

Ammar Amin

Abstract Sabkha is composed of sand deposits mixed with silt and clay intercalated with evaporites. Two types of sabkha are present in Saudi Arabia: the inland sabka, which is found in the northern part of the country and coastal sabkha, which is located along the Red Sea and Arabian Gulf. The main geotechnical hazards include settlement, corrosive action, heave due to salt crystallization/recrystallization and flooding due to the low infiltration rates. This comparative study indicates the engineering properties of the coastal sabkha along the Red Sea differ from those of the sabkha along the Arabian Gulf, which is likely to be more costly to develop.

Résumé Les sebkhas sont constituées de dépôts de sables mêlés à des silts et des argiles, intercalés avec des évaporites. Deux types de sebkhas existent en Arabie Saoudite : les sebkhas intérieures, que l'on trouve dans le nord du pays et les sebkhas côtières, situées le long de la Mer Rouge et du Golfe arabique. Les problèmes géotechniques qui leur sont associés sont les tassements, les actions corrosives, les gonflements dus aux évaporites et les inondations dues aux faibles taux d'infiltration des eaux. Cette étude montre que les propriétés géotechniques des sebkhas côtières le long de la Mer Rouge sont différentes de celles des sebkhas le long du Golfe arabique.

Keywords Coastal Sabkha · Saudi Arabia · Engineering properties · Salt crystals · Jeddah · Jubail · Geotechnical problems

Mots clés Sebkhas côtières · Arabie Saoudite · Propriétés géotechniques · Sel · Jeddah · Jubail · Problèmes géotechniques

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Introduction

The term sabkha is used in the Arab countries as equivalent to the term "salt flat". In general, sabkha is composed of sand deposits mixed with silt and clay and is intercalated with evaporites (Shehata et al., 1990b; Abu Taleb and Egeli, 1981). Ellis (1973) describes the sabkha deposits as the bottom of a closed depression, the zone of evaporation for accumulated run-off from shallow saline subterranean water, characterized by the presence of salt deposits and absence of vegetation. The salt constituent plays an important role in determining the engineering properties of the sabkha soil. During the dry seasons, the salt encrusted surface of the sabkha is strong and durable whereas when the surface is wet due to rain or storms/tides, the sabkha is soft and muddy (Akili and Ahmad, 1983; Shehata Bader and Harari 1990a).
This paper presents an assessment of the engineering properties of the coastal sabkhas of the Red Sea and Arabian Gulf in Saudi Arabia, and compares these.

Types, distribution and formation of Sabkha deposits

Sabkha deposits are classified according to their locations: inland sabkha (continental) and coastal sabkha (Kinsman and Park, 1969).
The inland sabkha is found in basins and typically surrounded by sand dunes. Their salts are related to the evaporation of the continental groundwater, which contains little carbonate but abundant gypsum and anhydrite (Akili and Ahmad, 1983). In Saudi Arabia the inland sabkhas are mainly in the northern area in Wadi As Sirhan.
The coastal sabkha stretches along the coastal plains of the Red Sea and the Arabian Gulf (Fig. 1) and is a highly

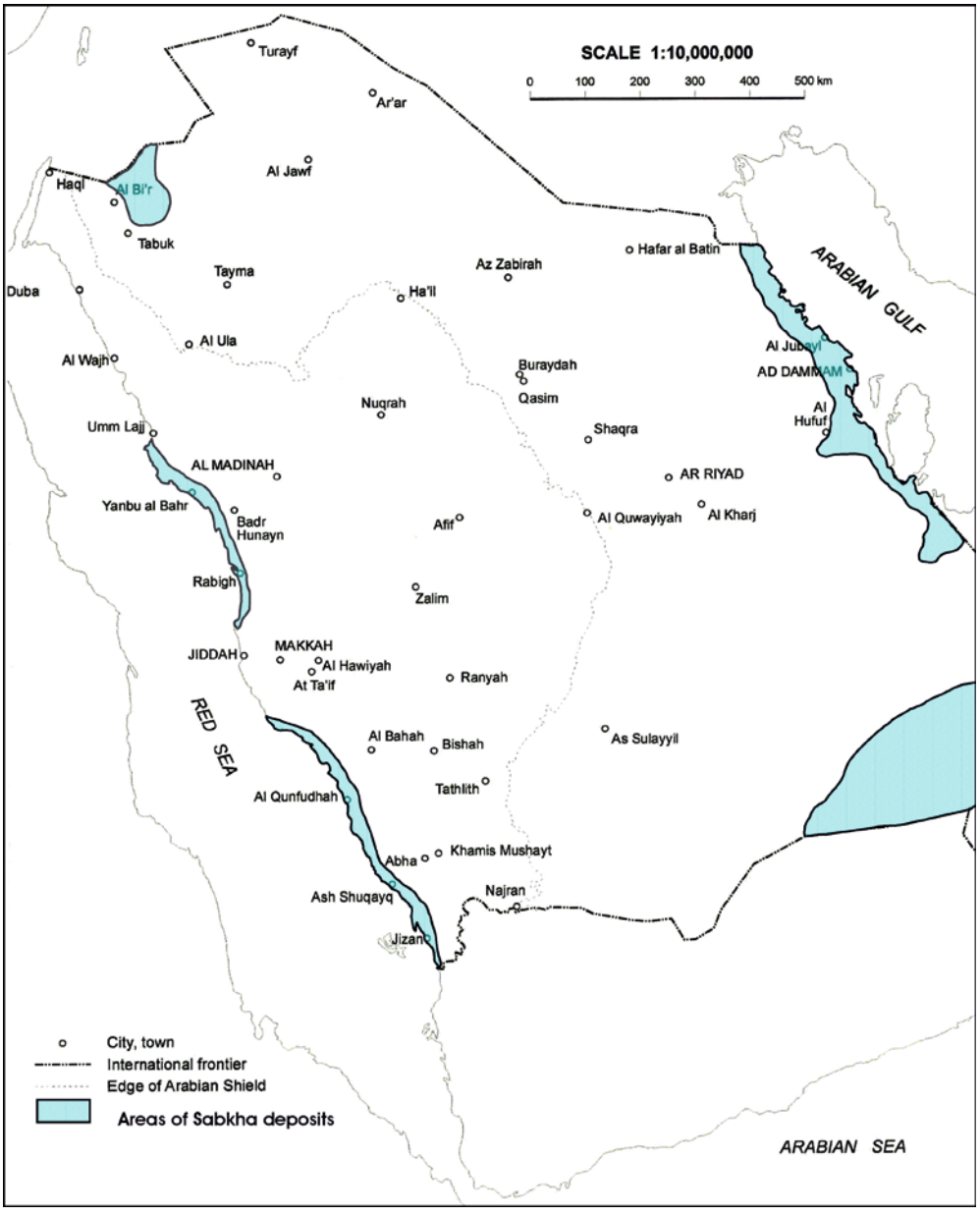

Fig. 1
Distribution of sabkha deposits in the Kingdom of Saudi Arabia

friable material. Geotechnically it is the more important, as most of the residential and commercial structures are along the sea coast (Paterson and Kinsman 1981).

The formation of sabkha deposits, their geological/geomorphological features and their geotechnical properties have been described by many investigators (Kinsman and Park, 1969; Butler, 1969; Ellis, 1973; Fookes and Collis, 1975; Akili and Torrance, 1981; Paterson, 1981; Abu-Taleb and Egeli, 1981, Abou Al Heija and Shehata, 1986, 1989). Shehata et al.,1990b suggest the sabkha deposits were formed as the infill of pre-existing lagoons which were separated from the sea by a barrier as the sea regressed. As the rate of evaporation along the coastal areas exceeds the precipitation, capillary rise results in the formation of a salt-rich crust (Fig. 2) comprised mainly of gypsum, anhydrite, halite and celestine.

Potential geotechnical problems of the coastal sabkha

The main potential problems in sabkha can be summarized as follows:

a) The quick decrease of soil strength due to water flooding (Fig. 3);
b) Variation in the soil compressibility characteristics within a short distance (both vertically and horizontally) which may lead to significant differential settlement;
c) Under hot and humid conditions gypsum ($CaSO_4.2H_20$) undergoes alternating hydration to form anhydrite ($CaSO_4$) and dehydration to form gypsum again — a chemical process which involves significant volume changes;

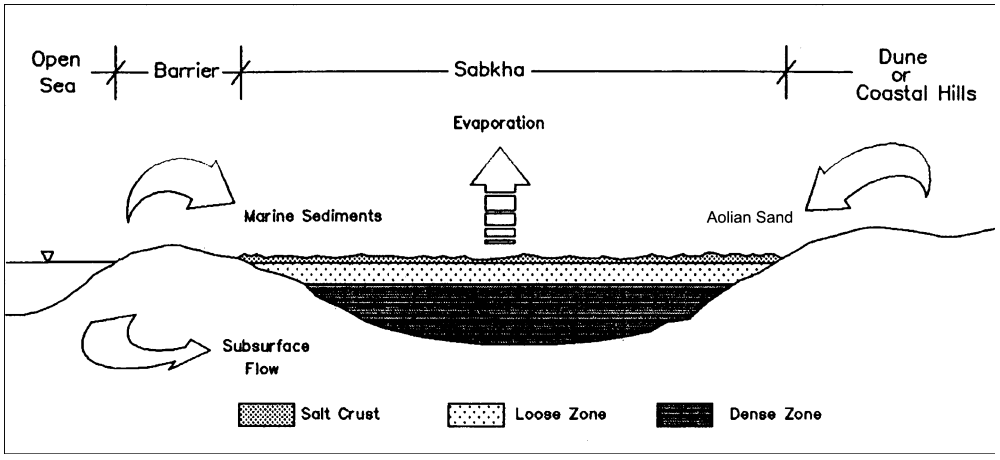

Fig. 2
Formation of coastal sabkhas (after Shehata et al., 1990b)

d) Ground water movement related to evaporation precipates salts at or near the surface. In the hot temperatures, the growth and horizontal expansion of the salts causes small cracks in the pavements. In addition, where gravely soils are present, salts may accumulate in these and cause "heave" (Fig. 4),
e) The salt-rich waters migrate to the surface by capillary rise. The high concentrations of sulphate (SO_4) and chloride (Cl) are corrosive to both concrete and steel (Fig. 5).

Engineering properties of coastal sabkha

Sabkha along the Red Sea coast

The sabkha deposits along the Red Sea coast have been studied and evaluated especially where this deposit occurs in areas of potential urban extension. Comprehensive studies were carried out at several sites along the Red Sea coast in order to understand the behavior of the coastal sabkha e.g. in Jeddah (Ali, Kazi and Al Quahtani., 1985; Ghazali, Fatani and Khan, 1986); Obhor (AIi and Hossain, 1987; Hossain and Ali, 1988); Jizan (Ghazali et al., 1986; Dhowian, Erol and Sultan., 1987) and AI-Lith (Abou Al Heija and Shehata, 1986, 1989). The results of these studies show that the sabkha is argillaceous, comprising mainly of grey silty clay with a light brown surface crust. The groundwater is highly salt-rich and is at a very shallow depth (Shehata et al.,1990b). As seen in the generalized soil profile given in Table 1, sabkhas along the Red Sea coast contain coral fragments and gypsum crystals. Table 2 gives a summary of the geotechnical characteristics of the coastal sabkha soils in the Kingdom of Saudi Arabia. The chemical analysis of the brines from the Obhor sabkha (Table 3) shows that the sabkha water is salty to brine as classified by Davis and De Wiest (1966).

Sabkha along the Arabian Gulf coast

Previous studies along the Arabian Gulf coast (Akili, 1975; Johnson et al., 1978; Abu, Taleb and Egeli, 1981; Shehata et al.,1990a) have revealed that the sabkha can be classified into three types:

a) Arenaceous sabkha composed of loose, medium-grained quartz sand. This type of sabkha occurs mostly in sand dune terrain, such as found in Al Azizia, south of Dammam.

Fig. 3
Photograph showing subsidence pits in the pavement due to subsoil wetting in north Jeddah city

Fig. 4
Photograph showing salt crystals covering the ground surface of soil sabkha in the Al Salamah district

Fig. 5
Extensive corrosion in the concrete developed by salt attack in sabkha soil, north Jeddah

Table 1
Generalized coastal sabkha profile, Red Sea Coast (after Shehata et al., 1990b)

Zone	Average thickness (m)	Description
Crust	0.6	Light brown silty sand with soluble salts. (SPT N-value <5)
Soft/loose	3.0	Light grey soft sand, silt and clay with shells and coral fragments, close to the water level (SPT N-value ranging from 0 to 10)
Stiff/ dense	10.0	Chalky white, medium dense to very dense clayey silt or coarse grained coralline limestone (SPT N-value ranging from 30 to 95)

b) Argillaceous sabkha consisting mainly of marine clays that are derived from decomposing biotic and calcareous materials, such as found in Al Fasl at Jubail.
c) Mixed sabkha composed of both sandy and clayey deposits, such as found in Al Riyas, at Jubail.

Table 2
Summary results of engineering properties of coastal sabkha soils in the Kingdom of Saudi Arabia

Description	Measured Values	
	Red Sea Sabkha (after Abou Al Hejja and Shehata, 1986)	Arabian Gulf Sabkha (after Akili and Torrance, 1981)
Fines <75 μm (%)	10–70	18–97
Moisture Content (%)	15–78	10–84
Liquid Limit (%)	20–60	30–84
Plasticity Index (%)	5–32	NP - 45
Bulk Density (g/cm^3)	1.86–2.25	1.34–1.89
Specific Gravity	2.55–2.75	2.51–2.82
SPT (blows/foot)	0–10	0–30
Cohesion (kg/cm^2)	0.052–0.41	0–0.54
Friction Angle (degree)	22–40	0–22
Initial Void Ratio	0.1–0.88	1.08–2.16
Compression Index Cc	0.17–0.88	0.39–0.95

Table 3
Chemical analysis of coastal sabkha brines

Parameters	Range of values	
	Obhor Sabkha, north Jeddah (after Ali and Hossain, 1987)	Al Fasl Sabkha, Jubail (after Al Saafin and Kidwai, 1984)
pH	7.05–7.6	6.6–7.5
Cl^- (g/l)	22.5–49.6	70–154
SO^{-2}_4 (g/l)	3.21–4.35	1.88 6.82
Na^+ (g/l)	20–95	43–80
K^+ (g/l)	0.5–1.9	1.2–2.8
Ca^{+2} (g/l)	0.44–1.8	0.6–2.8
Mg^{+2} (g/l)	1.83–3.31	1.8–7.5
TDS (g/l)	50–155	140–256

The sabkhas are highly saline and have a puffy surface crust. The groundwater level is usually within 1 m of the ground surface. The results of the geotechnical investigations carried out at several sites along the Arabian Gulf coast are given in Table 2 . The chemical analysis for the groundwater at Al Fasl (see Table 3) shows it to be hypersaline or brine as classified by Davis and De Wiest (1966). This type of groundwater is highly likely to form salt crystals (Al Saafin and Kidwai,1984). A generalized description of the coastal sabkha is given in Table 4.

Comparison between sabkhas along the Red Sea and Arabian Gulf coasts

As shown in Table 5, the engineering properties of coastal sabkha along the Red Sea differ from those of the sabkha along the Arabian Gulf. The coastal sabkha along the Arabian Gulf is thicker than that along the Red Sea and has more saline and sandier constituents. It is also more porous and compressible, thus more costly to treat. Figures 6 and 7 show that the increased Total Dissolved Solids in the sabkha brines in coastal areas have a positive influence on some engineering properties such as plastic-

Table 4
Generalized coastal sabkha profile, Arabian Gulf Coast (after Shehata et al., 1990b)

Zone	**Average thickness (m)**	**Description**
Crust	0.4	Puffy sand crust mixed with soluble salts (SPT N-value <5)
Soft/loose	8.0	Aeolian sand interbedded with clay and silt layers. Soft crystals and shell fragments exist. Water level is present in this zone. (SPT N-value ranging from 0 to 10)
Stiff/dense	>10.0	Cemented and/or uncemented sand, silt, and clay; dense and/or stiff materials (SPT N-value >30)

Table 5
Comparison of engineering properties of coastal Sabkhas along the Red Sea and Arabian Gulf Coasts

Parameter	Red Sea	Arabian Gulf
Depth to Water Table (m)	<1	≈1
GW Quality	Salty to brine	Hyper saline
TDS (g / l)	50–155	140–256
Type of sabkha	Argillaceous	Arenaceous to argillaceous
Main constituents	Silt, clay	Sand, clay
Sabkha thickness (m)	<10	>10
Fines (%)	10–70	18–97
Natural water content (%)	15–78	10–84
Liquid limit (%)	20–60	30–84
Plasticity index	5–32	0–45
Specific gravity	2.55–2.75	2.51–2.82
Bulk density (g/cm^3)	1.86–2.25	1.34–1.89
Initial void ratio	0.1–0.88	1.08–2.16
Friction angle (degree)	22–40	0–22
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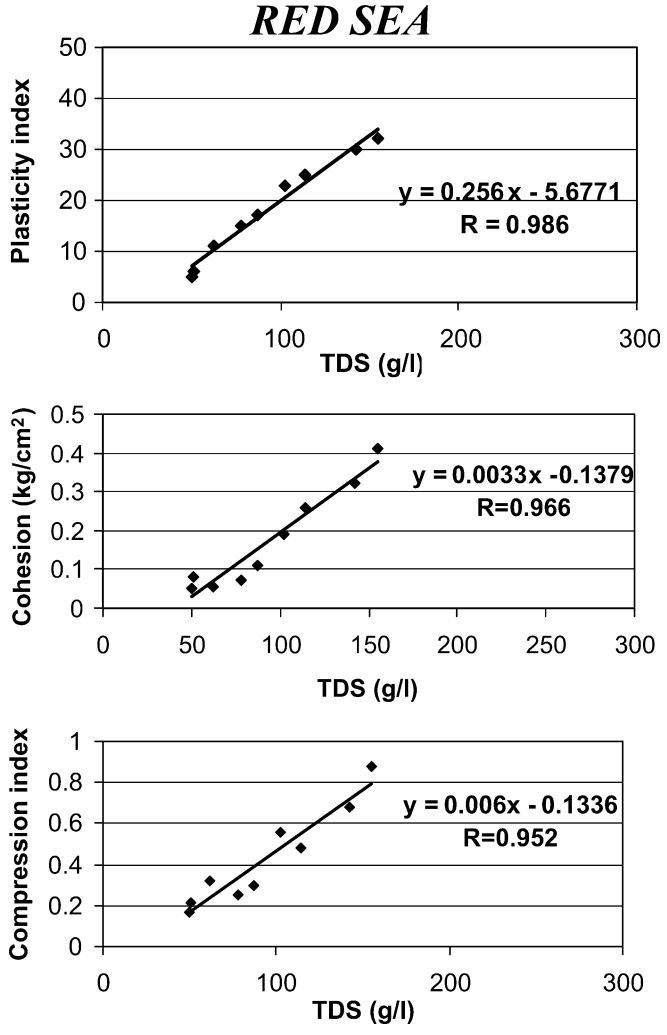

Fig. 6
Influence of TDS of Red Sea sabkha brines on the engineering properties of the sabkha soil

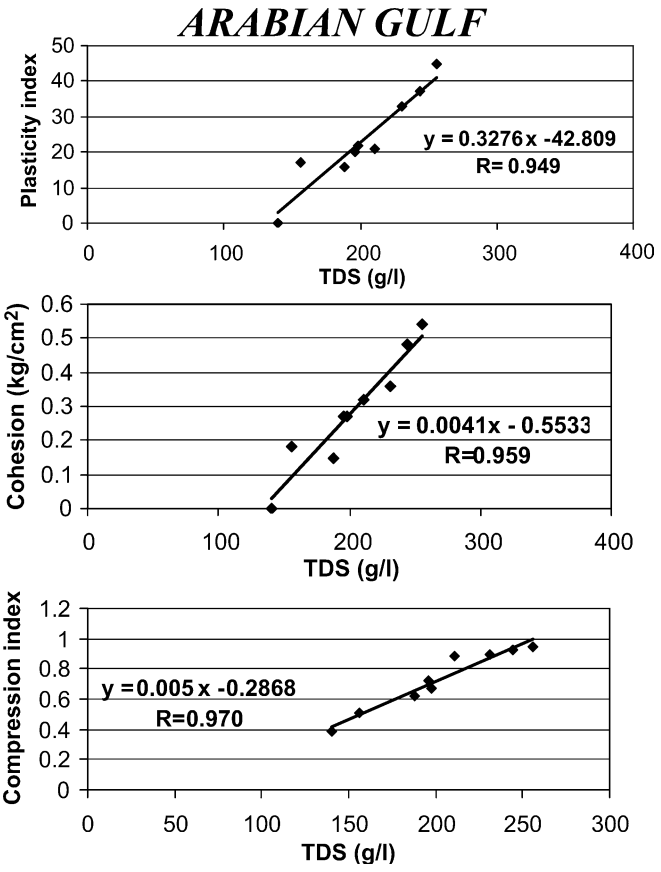

Fig. 7
Influence of TDS of Arabian Gulf sabkha brines on the engineering properties of the sabkha soil

ity, cohesion and compression. The sabkha along the Red Sea shows a stronger correlation between TDS and plasticity/ cohesion, although for compression the sabkha along the Arabian Gulf has the stronger relationship with TDS.

Conclusions

This comparative study was conducted to characterize the coastal sabkha soils in Saudi Arabia. The results indicate that the engineering properties of coastal sabkha along the Red Sea different from those of the sabkha along the Arabian Gulf. The coastal sabkha along the Arabian Gulf is thicker and has more saline and sandier constituents. In addition, it is more porous and compressible, hence it would be more expensive to develop. Further studies are required to evaluate the influence of $CaCo_3$ and SiO_2 on the engineering properties of the coastal sabkha in Saudi Arabia.

References

Abou AI Heija MK, Shehata WM (1986) Engineering properties of AI-Lith sabkha, Saudi Arabia. Proe 5th Inter Congo IAEG 2:935–941

Abou AI Heija MK, Shehata WM (1989) Engineering geological aspects of AI-Lith sabkha, Saudi Arabia. 28th Inter Geol Congo Wash DC

Abu Taleb MG, Egeli L (1981) Some geotechnical problems in the Eastern Province of Saudi Arabia. Proc Sym Geotech Problems in SA 799–811

Akili W, Torrence JK (1981) The development of geotechnical problems of sabkha, with preliminary experiments on the static penetration resistance of cemented sand. Q J Eng Geol London. 14:59–74

Akili W, Ahmad N (1983) The sabkhas of Eastern Saudi Arabia - Geotechnical considerations. Proc 1st Saudi Eng Conf II:300–322

AIi KM, Hossain D (1987) Geotechnical and geochemical characteristics of abhor sub-soil. KAU, FES Bull. 7, Jeddah.

Ali S, Kazi A, AI Quahtani MB (1985) Geotechnical aspects of a recent lagoonal sabkha deposit in Jeddah. 8th Southeast Asian Geotech Conf 2:1–8

Al Saafin AK, Kidwai ZA (1984) Hydrogeological aspects of sabkha at Al Fasl. Saudi Arabia. Unpubl Report KFUPM. RL

Butler GP (1969) Modern evaporite deposition and geochemistry of co-existing brines and sabkha, Trucial coast, Arabian Gulf. J Sed Petrol 39(1):70–89

Davis SN, De Wiest RJ (1966) Hydrogeology. John Wiley, NY 463 pp

Dhowian AW, Erol AA, Sultan S (1987) Settlement prediction in complex sabkha soil profile. IAEG Bull 36:11

Ellis CI (1973) Arabian salt-bearing soil (sabkha) as an engineering material. Transport and Road Res. Lab Rept LR 523. Crawthorne. Berkshire. UK, 15 pp

Fookes PG, Collis L (1975) Aggregates and the Middle East. Concrete 9(2):14–19

Ghazali F, Fatani M, Khan A (1986) Geotechnical properties of sabkha soils of Jeddah and Jizan, Saudi Arabia, Proce of the 2nd Saudi Engineers Conference, Vol. 2, University of Petrolium and Minerals, pp 286–307

Hossain D, Ali KM (1988) Shear strength and consolidation characteristics of abhor sabkha, Saudi Arabia. Q J Engng Geol 21:347–539

Johnson DH, Kamal MR, Pierson GO, Ramsay JB (1978) Sabkhas of eastern Saudi Arabia. In Quater Period in Saudi Arabia. AI-Sayyari SS, Zotl J (eds), Springer, Heidelberg Berlin New York pp 84–93

Kinsman DJ, Park RK (1969) Studies of recent sedimentology and early diagenesis. Trucial Coast Arabian Gulf. 2nd Reg Tech Symp Soc Petr Eng of AIME. Saudi Arabian Section

Levy Y (1977) The origin and evolution of brine in coastal sabkhas, northern Sinai. Journal of Sedimentary Petrology, 47(1):451–462

Patterson RJ, Kinsman DJJ (1981) Hydrogeologic framework of sabkha along the Arabian Gulf. Amer Ass Pet Geol Bull 65:1,457–1,475

Powers RW, Ramirez LS, Redmond CD, Elberg EL (1966) Geology of the Arabian Peninsula — Sedimentary geology of Saudi Arabia. US Geol Surv Prof Paper 560-D

Shehata WM, Bader T, Harari ZY (1990a) Principal geological hazards along the Arabian Gulf coast, J King Abdulaziz Univ Earth Sci 3, pp 289–302

Shehata W, Saafin A, Harari Z, Bader T (1990b) Potential sabkha hazards in Saudi Arabia, 6th International IAEG Congress, 1990 Balkema, pp 2,003–2,010