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Chemical and Morphological Characteristics of Phytogenic Mounds (*Nabkhas*) in Kuwait

الخواص الكيميائية والمورفولوجية لتلال النباتية (*النباك*) في الكويت

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Abstract: Natural accumulation of wind-borne sediments within or around the canopies of plants plays an important role in the ecological and evolutionary dynamics of many coastal and desert ecosystems. The formation of such phytogenic mounds (nebkhas) creates patches that can strongly influence the spatial distribution of plant and soil resources. Nabkhas are common, and are dunes formed around plants. Individual plants must reach 10 - 15 cm in height before they can effectively trap sand. The largest nabkhas accumulate around trees, and can reach 10 meters in height. Nabkhas can be composed of sand, silt, or pelletized clay, the grains of which can be cemented by organic materials. Once trapped in a nabkha, these cemented particles do not readily become wind re-entrained. This paper examine some aspects of the development, morphological and ecological characteristics of nabkhas formed around perennial dominant plant. Nabkha area develop mainly under the control of Aeolian process**.** The study focused on eleven dominant plant species covered desert of Kuwait. Each plant have special character. *Cyperus, Haloxylon and Rhanterium* lied in highly degraded area. *Haloxylon* speciesis more efficient in trapping sand compared to other desert plants. *Astragalus sp* have highest carbonate percentage of all nabkha. *Citrullus sp* have lowest hight of nabkha. Sabkha plant such as *Nitraria*, *Tamarix*, *Halocnemum* and *Salicornia* have low pH and carbonates and high in moisture content and electrical conductivity. *Lycium* sp is characterized to have the longest distances between branches and plants in comparison to other plant specie.
Keywords: *Nabkha, Dominant plant, Morphology characteristics.*

المستخلص: للرواسب الريحية حول النبات دور مهم في ديناميكية النظام البيئي الصحراوي والساحلي. مقدرة النبات في تكوين النباك مهم في اصلاح وانتشار الغطاء النباتي ومحافظة على التربة. النبكة هي كثيب يتكون حول النبات. كل نبات يجب ان يصل ارتفاعه الى 10-15 سم لكي يستطيع ان يحتجز ويصيد الرمال. والنباك الكبيرة تتراكم حول الاشجار، وقد تصل الى ارتفاع 10 أمتار. النبكة تتكون من الرمل والطين حبيباتها متماسكة بالمواد العضوية . هذه الورقة العلمية تدرس اهم الخصائص المورفولوجية والبيئية النباك المتكونة حول احدى عشر نوعا من النباتات السائدة المنتشرة في الصحراء الكويتية. لكل نبات خاصية تميزه عن غيره. فمثلا نبات الثندى متواجد فى مناطق شديدة التدهور و ذات نشاط ريحي شديد. نبات الرمث يتميز بقدرته العالية على حجز وصيد الرمال، ونبات الشداد يحتوى على نسبة عالية من الكربونات الكالسيوم. نبات الحنظل ينتشر أفقيا لذلك ارتفاع جسم الرملي قليل. المسافات البينية لأفرع نبات العوسج كبيرة بالنسبة لنباتات الاخرى. أما النباتات المالحة التى تنمو فى السبخات مثل الغردق، ثالوث والاثل والخريزة تتميز بانخفاض درجة الحموضة وكمية كربونات الكالسيوم وبارتفاع معدل الرطوبة وكمية الاملاح الذائبة ودرجة التوصيل الكهربائي.
كلمات مدخلية: *النباك، النباتات السائدة، الخصائص المورفولوجية.*

INTRODUCTION

In physical geography, a dune or Nabkha is a hill of sand built by eolian processes. Whereas Nabkha in specific is an Arabic term given to mound of wind-brone sediment that accumulated around shrubs (Cooke, *et al*. 1993) and (Khalaf, *et al*. 1995). Dunes are generally mobile, but may anchor to topographic obstacles or vegetation to form Nabkha. Anchored dunes do not change position, but their surfaces are mobile; stabilized dunes are immobilized by cementation or vegetation after they have formed, and consequently their surfaces are immobile and the dunes themselves do not change position. Phytogenic mounds (nebkhas) – the natural accumulation of wind-blown sediments within or around the canopies of plants. Vegetation plays an important role in shaping the morphology of aeolian dune landscape in coastal and semiarid environment. Each plant must reach 10 - 15 cm in height before they can effectively trap sand. Once trapped in a Nabkha, these cemented particles do not readily become wind re-entrained. Individual plant can form Nabkha with unique morphological and sedimentological characteristics. Moreover, Nabkhas around the same plant in one area exhibit variable morphological features according to local wind regime.

Nabkhas are subject to different forms and sizes based on their interaction with the wind. It is defined a body of coarse sand shaped by ambient wind conditions and the grain-by-grain deflation of sand. Standing as much as 400 meters high (the tallest reported), with a lower height limit around 30 cm, dunes are typically between 1 m and 1 km wide. Quartz is the most common type of sand material. Study on Nabkhas has been widely reported.

In Kuwait, anchored dunes are differentiated into: Nabkhas and falling dunes. Accordingly, in this study the efforts will be directed towards one type of anchored dune, which is Nabkha dune. Nabkhas varied in sizes and rates of development from one area to another. However, a typical Nabkha is a convex mound of sand with a flat top and steep sides (Langford, 2000). Moreover, Nabkhas around the same plant in one area exhibit variable morphological features. These variations are due to remarkable differences in local wind regime, rates of sand supply, depth and quality of subsoil water and plant morphology (Khalaf, *et al*. 1995). On the basis of their sizes, single Nabkhas are differentiated into two main classes: large and small. Large sized Nabkhas are developed around *Nitraria retusa, Tamarix aucheriana and lycium shawii*. On the other hand, small Nabkhas are accumulated around *Zygophyllum qatarense, Panicum turgidum* and other species. Nabkhas are varying considerably in size and shape. Coastal Nabkhas are developed around several plant species in the northern and southern coastal plains of Kuwait. Moreover, they are scattered in local hollows at the extreme southeastern strip of the country (Nuwaisib – Wafra, along Saudi Arabia border). These hollows are covered by salt flats where Nabkhas are accumulated around *Nitraria retusa* revealed that they are mainly derived from the sabkha flat sediments (Al-Dousari, *et al*. 1996 and Al-Hemaid, 2002).

This paper will focuse on studying ecological and sedimentological parameters of selected Nabkha dune in Kuwait for eleven dominant perennial plant species.

METHODOLOGY

Field Investigation

To address the research objective, field studies investigated the sedimentological and morphological properties of different perennial plant species developed around Nabkhas. These Nabkhas were selected within different areas in the Kuwait's desert as shown in Table (1) and Figure (1). Twenty representative soil samples were collected from top surface and root in each type of the investigated plant species in order to define the correlation between sediment and morphological characteristics of Nabkhas with different plant species. Vertical samples were collected, vertically every 10 cm from two representative Nabkhas of each plant species in order to measure PH, electrical conductivity (EC), soil moisture and calcimeter determination. Five hundered soil samples were collected from surface and root in all studied Nabkhas. Morphometic parameters of different selected Nabkhas were measured (Length, width and height…etc).

Table 1. List of dominant perennial plant species within different areas in the desert of Kuwait.

Perennial Plant Species	Vernacular Name	Areas
Rhanterium epapposum	Arfaj	Kabd, Dubaiyah
Haloxylon salicornium	Rimth	Bhyith, Abdulli, Dubaiyah, Jal-Azur
Lycium shawii	Awsaj	Jal-Azur, Liyah
Nitraria retusa	Ghardaq	Dubaiyah, Jal-Azur
Halocenum strobilaceum	Theluth	Bubyain Island
Salicornia europaea	Khraiza	Bubyain Island
Astragalus schimperi	Kidad	Liyah, Abdulli
Panicum turgidum	Thamam	Al-Dhabiaya
Tamarix aucheria	Tarfa	Al-Doha
Citrulus colocynthis	Hanthal	Kabd, Liyah, Jal-Azur
Cyperus conglomeratus	Thandah	Kabd, Liyah

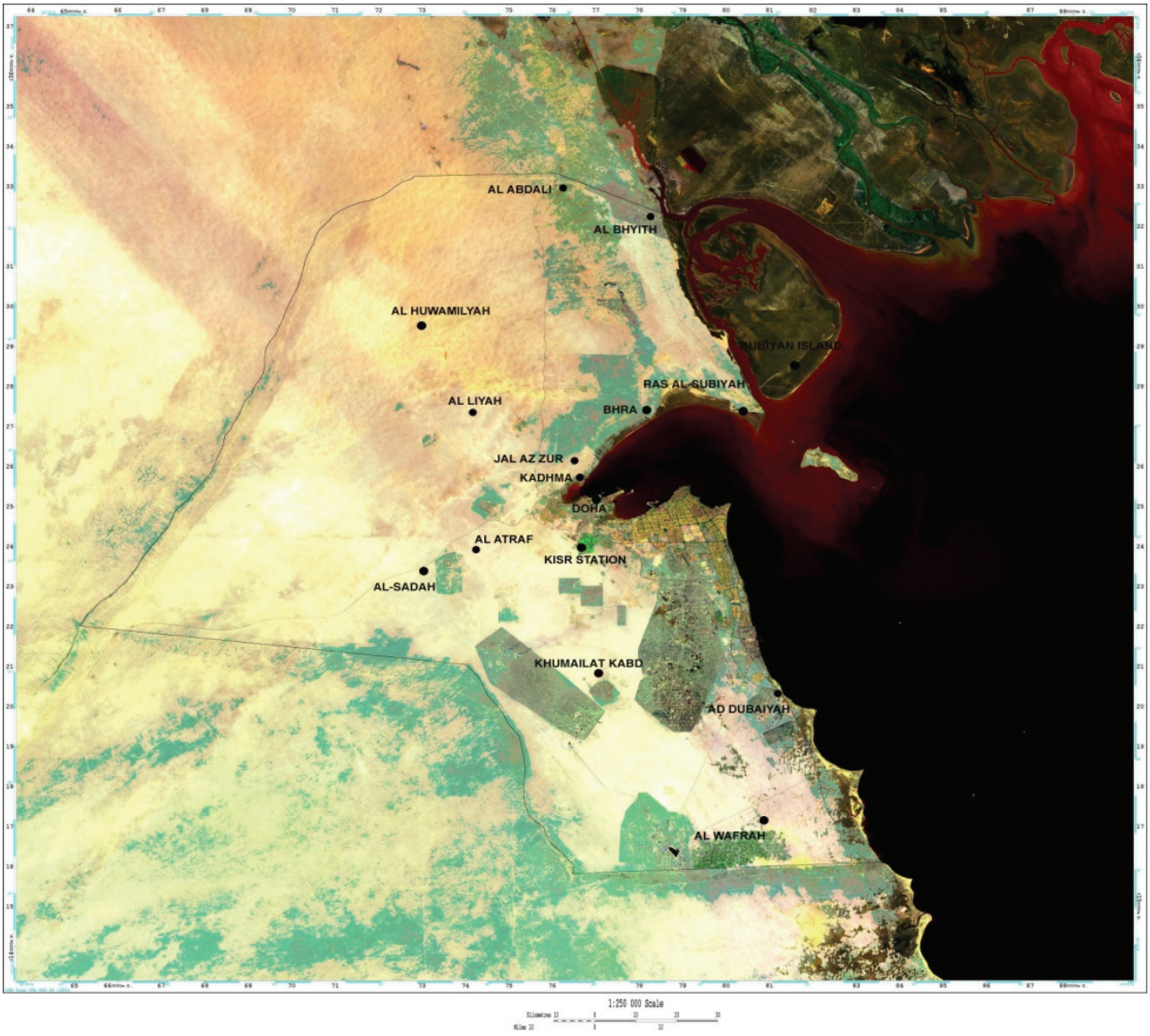


Fig. 1. Sites location marked on landsat image of Kuwait for April-May 2003 (Baby, 2004).

Morphology of Nabkha

For a better understanding of the pattern of Aeolian sediment accumulation on different plant species, the various morphometric parameters of Nabkhas were measured. The Nabkhas in Kuwait are typically low (rarely exceeding 105 cm in height) and of varying lengths, forming under different perennial plant species. There is inherent variability in the morphology of nebkhas a cross the region. The variability is likely to be associated with land-use histories, geomorphological setting and, in particular, the ecological community characteristics. Nabkhas formed under *Lycium shawii, Nitraria retusa* and *Tamarix aucheria* are significantly large. *Haloxylon salicornicum*, *Halocenum strobilaceum* and *Salicornia europaea* have ability to form medium sized Nabkhas. Much smaller Nabkhas occur under *Astragallus spinosus, Citrillus colocynthis, Panicum turgidum* and *Rhanterium epapposum*. Low Nabkhas due to the height of the canopy and the size of bush are effective in trapping sediment moving by creep and saltation close to the ground surface. The large Nabkhas are able to grow and trap large volumes of sediment. The Nabkha around 11 plant species were morphologically studied. They are varying in shape and size. They generally have triangular shape due to the presence of the long southeasterly tail and shorter nose resulted from the dominant northwesterly wind. On the other hand, Nabkhas in Boubyan Island, northern and southern coast of Kuwait are elongated and some with a mound shape. The Nabkha morphology interrelationship is well observed within height of the shrub and Nabkha height. There are four types of coastal Nabkhas were studied these are *Halocnemum strobilaceum, Salicornia europaea*, *Tamarix aucheriana* and *Nitraria retusa*. The former two are developing large Nabkhas while the others are smaller Nabkhas.

RESULTS AND DISCUSSION

Nabkha Dimension

There is a direct relationship between Nabkha height and shrub height for most of studied plants. Figure (2A) illustrates large similarities between smaller plants such as *Haloxylon salicornicum, Cyperus conglomerates, Rbanterium epapposum, Astragallus spinosus, Halocnemum strobilaceu* and *Salicornia europaea*. They show common Nabkha and shrub height interrelationship. On the other hand, Figure(2B) shows clear differences in most of these plants in terms of Nabkha width and length interrelationship. In all morphological units, the two halophytes *Halocnemum strobilaceum* and, *Salicornia europaea* form the smallest nabkas. Five morphological traits were measured for all Nabkhas,namely: Nabkha height, Nabkha width, Nabkha length, shrub height and shrub length.

There are a poor interrelationship between Nabkha height and other Nabkha morphological units (Figure 3). Each plant species has its own morphological characteristics, for example, both *Nitraria* and *Panicum* are showing the highest Nabkha length in comparison to other plant species, while *Salicornia europaea* and *Halocnemum strobilaceum* are the smallest. The *Nitraria* retusa also has highest shrub and longest shrub which resulted in trapping a huge body of sand. On the other hand, *Salicornia europaea* and *Halocnemum strobilaceum* are showing the lowest morphological units of all plant species. *Tamarix aucheriana* and *Lycium shawii* characterized by huge shrub but the spacing between the branches are wider than *Nitraria* retusa that resulted in lower sand body trapped around these two plant species. Figure 2 (A-B) clearly differentiates between dominant plant communities. It is evident from the bivariate diagram that width is playing an important role in developing the sand body of the Nabkhas. The wider the plant the longer the sand accumulation will be. There are four types of plant species are developing wider (> 250cm) and longer (>350cm) Nabkhas, namely: *Tamarix aucheria*, *Lycium shawii*, *Nitraria retusa* and *Haloxylon salicornicum*, but Nabkhas that develops around *Tamarix aucheria* is shorter (<50cm) than previous plants.

Nabkha Spacing

The Nabkhas takes three morphological forms, namely: single, compound and complex. Single Nabkha is a sand body developed around single plant species. Compound Nabkha is a two

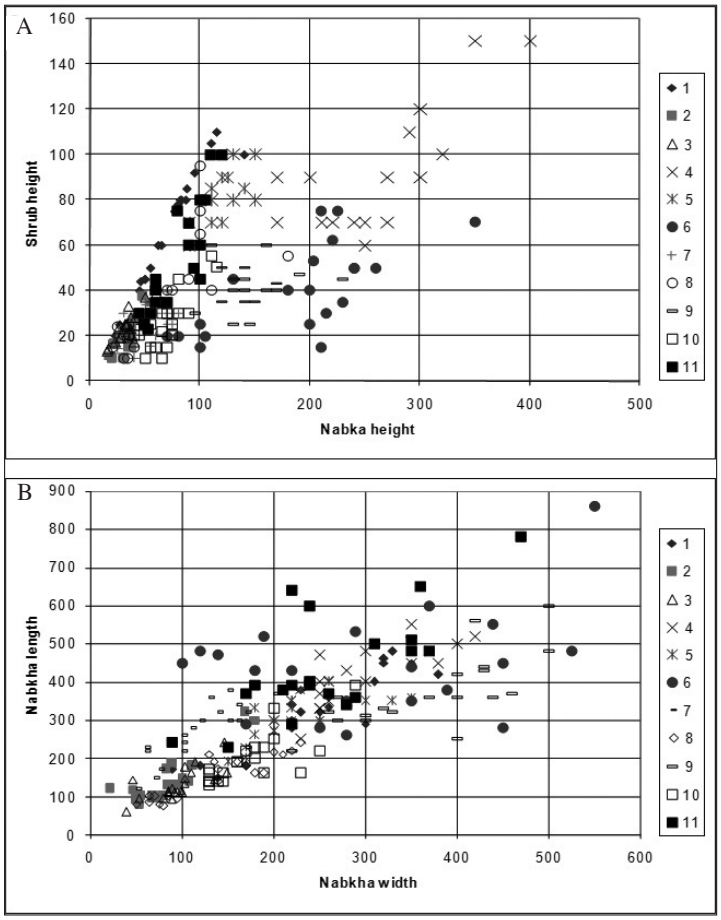


Fig. 2 (A-B)
(A): Bivariate diagram's of Nabkha height versus shrub height
(B): Bivariate diagram's of Nabkha width versus Nabkha length
In: 1. *Citrulus colocynthis*, 2. *Salicornia europaea*, 3. *Halocenum strobilaceum*, 4. *Nitraria retusa*, 5. *Panicum turgidum*, 6. *Lycium shawii*, 7. *Astragalus schimperi*, 8. *Cyperus conglomerates*, 9. *Tamarix aucheria*, 10. *Rhanterium epapposum*, 11. *Haloxylon salicornium*.

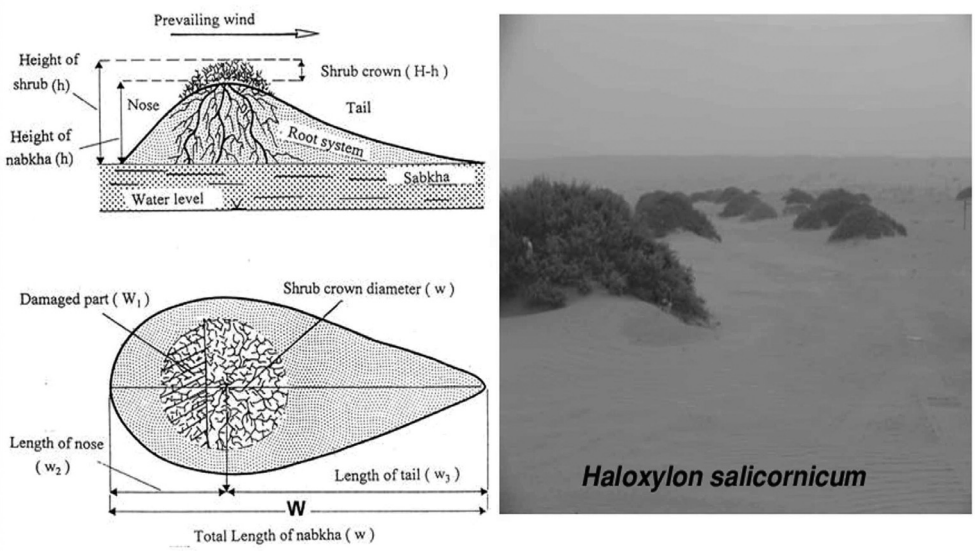


Fig. 3. Photos and schematic diagram illustrate the morphometric parameters of Nabkhas.

Nabkha dune attached by one sand body forming a saddle like feature, while complex Nabkha is a group of Nabkhas attached together by one sand body. The distances between single isolated Nabkhas from each other are much greater than compound and complex Nabkhas (Table 2).

The average distance is 9 m, 0.54 m and 0.57 m for single, compound and complex Nabkha dunes respectively. The distance between single Nabkhas from each other is highly related to the Nabkha size, that is the larger the Nabkha, the larger the distance will be. *Tamarix aucheria, Lycium shawi, Nitraria retusa* and *Haloxylon salicornicum* illustrates the highest distances between single Nabkhas (Figure 4A). This might be attributed to the competion between the same plant communities where the root system of larger Nabkhas are covering larger areas compared to smaller Nabkhas. On the other hand, distances of the same plant species between compound and complex Nabkhas are highly correlated (Figure 4B).

Panicum turgidum, Cyperus conglomeratus and *Rhanterium epapposum* are showing the smallest distances to form compound or complex Nabkhas in comparison to other Nabkha dunes.

The distance between Nabkha branches are varying from one plant to another. *Rhanterium epapposum*, *Panicum turgidu Haloxylon salicornicum*, *Cyperus conglomeratus* and *Haloxylon salicornium* respectively showed the lowest distances between plant branches (that is <7 cm) which make them more efficient compared to other plant species like *Lycium shawii*, *Halocenum strobilaceum, Astragalus schimperi* and *Tamarix aucheria* which they show the highest distances between branches (>7 cm).

Carbonate Content, pH, Moisture Contents and Conductivity

The carbonate content varies from one plant to another. It ranges from 0.8% to 24% with an average of 6%. *Citrullus colocynthis, Salicornia europaea, Astragallus spinosus* and *Panicum turgidum, HaLoxylon salicornicum* and Nabkha sediments respectively shows the highest carbonate percentages in comparison to other Nabkha species. The carbonate percentages of these Nabkha sediments are more than 6%. On the other hand, *Halocnemum strobilaceum, Rbanterium epapposum, Lycium shawii* and *Cyperus conglomerates* shows the lowest carbonate percentages with less than 5% (Table 3).

The pH, conductivity and moisture contents vary with depth, but there was no trend observed in variation. The only exception is at depth 70 cm where samples show its lowest pH, EC and moisture content Figure 5 (A - C). It can be detected from these figures that samples at depth 60 cm show higher values of pH, EC and moisture content. Moisture contents are highly correlated to EC values, which might indicate the effect of water in distributing salt in the Nabkha body. The studied sediments are slightly alkaline ranging in pH between 7.2 and 8.7 with an average of 7.9. The highest values of pH are present in *Cyperus*, *Citrullus, Rhanterium* and *Haloxylon* (desert plants), and the lowest in *Halocnemum, Panicum turgidum* and *Lycium shawii* respectively (Figure 6A). All samples (except halophytes) present very low EC levels, and therefore non-saline. The EC levels and moisture content are the highest in *Citrullus colocynthis*, *Halocnemum strobilaceum*, *Tamarix aucheria* and *Nitraria retusa* respectively (Figure 6B,C). It was observed that desert Nabkhas differ from coastal Nabkhas or the halophytes Nabkhas (*Halocnemum strobilaceum*, *Nitraria retusa* and *Tamarix aucheria*). The halophytes Nabkhas are characterized by lower pH but higher conductivity level and moisture content than desert Nabkhas. The lower content of EC within halophytes Nabkhas might indicate that the trapped sediments are originated from surrounded sabkha environment not from the desert environment. *Lycium shawii*, *Citrullus colocynthis*, *Panicum turgidum* and *Astragalus spinosus* as other desert plants are growing at different environmental conditions. *Lycium shawii* and *Citrullus colocynthis* are growing within drainage systems such as valleys and depressions. *Citrullus colocynthis* characterized by high pH, low carbonates, conductivity level and moisture content and the largest mean grain size and longest root system of all desert plants. *Panicum turgidum* and *Astragalus spinosus* are forming dominantly within sandy environment and depressions where it shows the finest mean grain size compared to other desert Nabkhas.

Table 2. Space distances (cm) between Nabkhas and branches for each plant species.

Plant species	Space between Nabkhas			Space between Branches
	Single	Compound	Complex	
Lycium shawii	2757	75	50	14
Halocemum strobilaceum	99	40	61	10
Astragalus spinosus	202	96	94	8
Tamarix aucheria	4056	44	37	7
Nitraria retusa	277	62	85	6
Haloxylon salicornium	271	71	91	6
Cyperus conglomeratus	98	34	27	5
Panicum turgidum	170	29	42	4
Rhanterium epapposum	94	37	28	3
Average	**891**	**54**	**57**	**7**

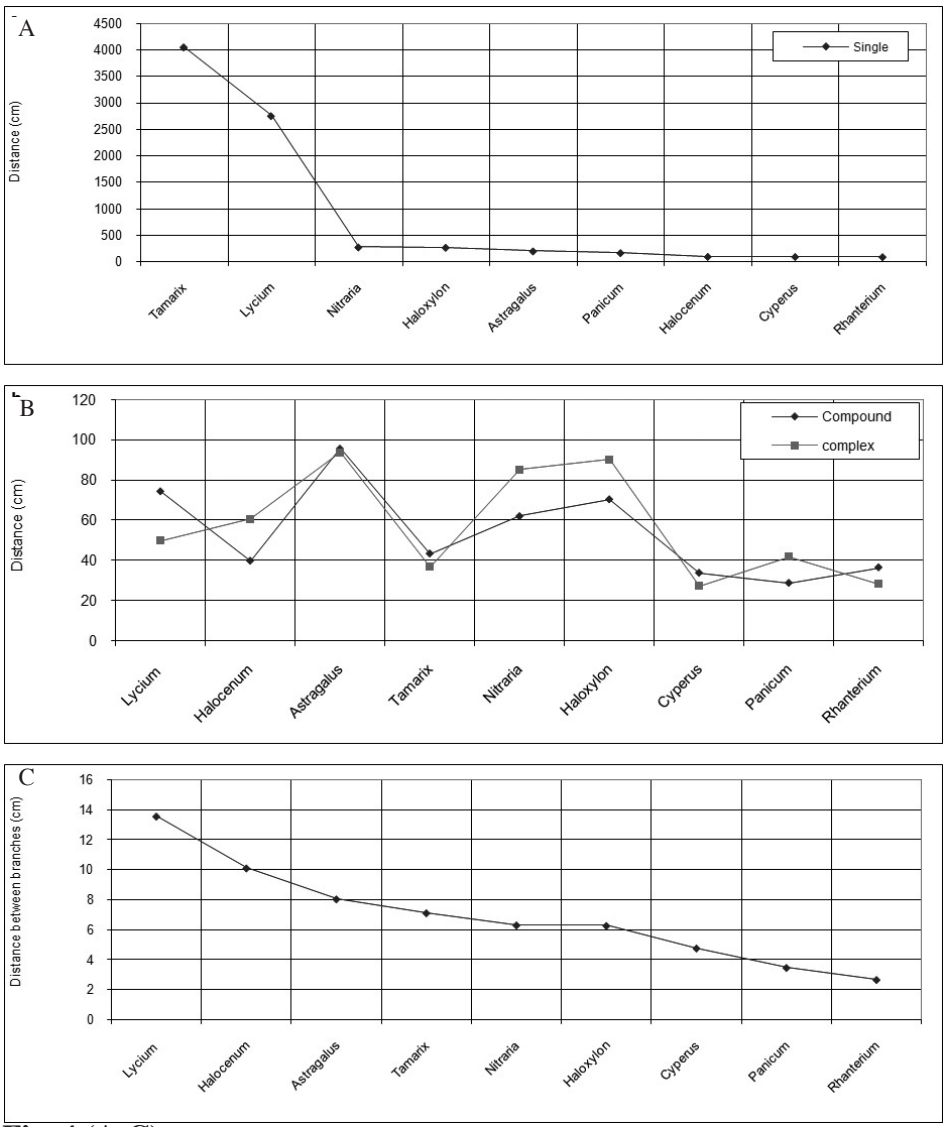


Fig. 4 (A-C)

(A): Distances between single Nabkhas for dominant plant species in Kuwait.

(B): Distances between compound and complex Nabkhas for dominant plant species in Kuwait.

(C): Distances between Nabkhas branches for dominant plant species in Kuwait.

Table 3. Carbonate content in percentage for studied Nabkhas.

Plant Species	Carbonate %
Halocnemum strobilaceum	2.4
Rhanteium epapposum	3.8
Lycium shawii	4.1
Cyperus conglomeratus	4.6
Nitraria retusa	5.2
Tamarix aucheria	6.8
Haloxylon salicornicum	7.6
Panicum turgidum	8.5
Astragalus spinosus	9.6
Salicornia europaea	11.1
Citrullus colocynthis	13.7
Average	**7.0**

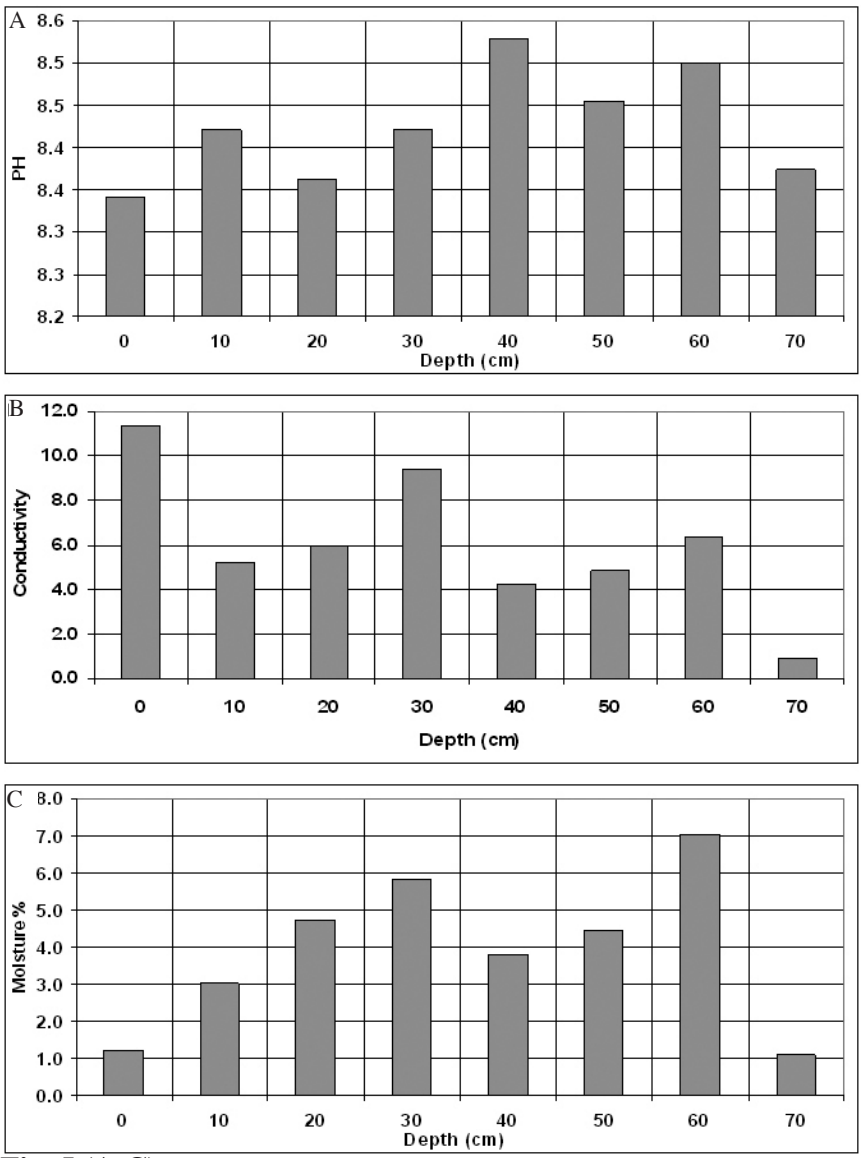


Fig. 5 (A-C)

(A): Average pH in relation to depth (cm).

(B): Conductivity in relation to depth (cm).

(C): Moisure percentages in relation to depth (cm).

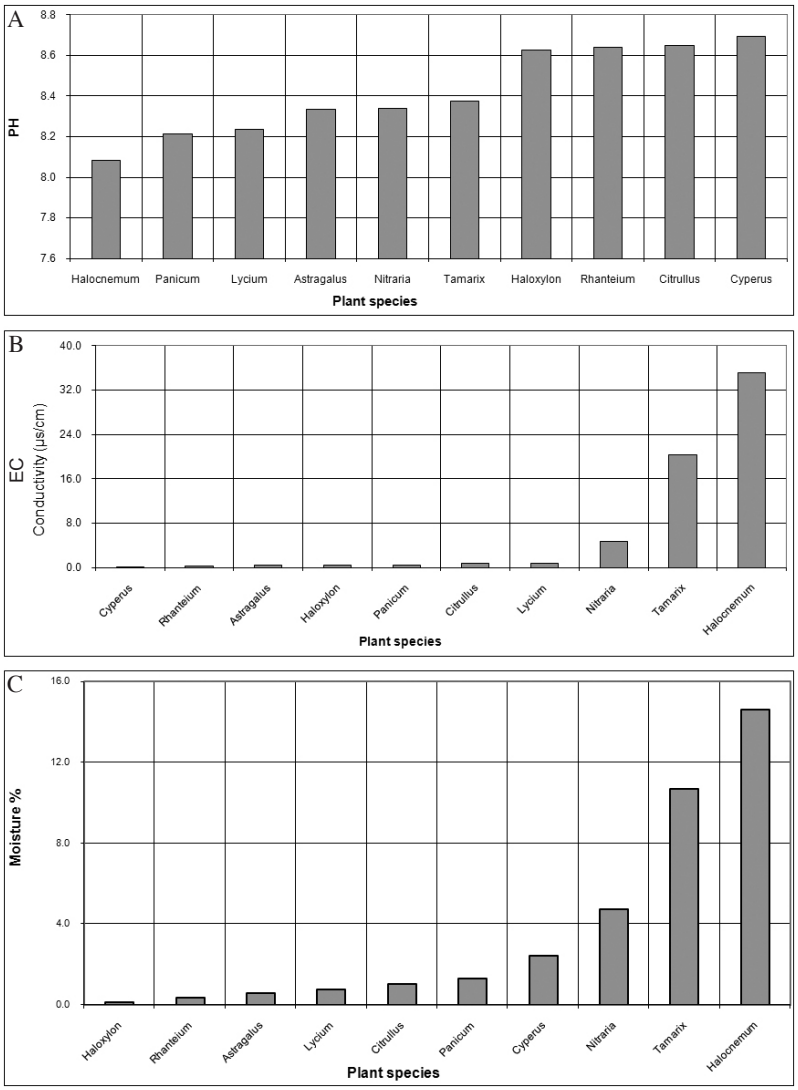


Fig. 6 (A-C)
(A): Variation of pH in relation to plant species.
(B): Variation of EC in relation to plant species.
(C): Variation of moisture contents in relation to plant species.

Grain Size

The majority of the surface sediments consist of coarse or medium sand. Few surface sediments are mainly formed of fine sand. The surface deposits are dominantly unimodal and occasionally biomodal. The graphical method was found to be the most suitable for calculating the statistical parameters for most of the collected aeolian sediments since it shows a lot of uniformity (unimodal). Histograms representing all Nabkha species were prepared for all the samples and averages.

The mean size classification of each aeolian sediment type is represented in Figure (7). It is obvious that medium and coarse sand are the dominant size fractions. Variability in grain size percentages between different Nabkha species are depending on sample locations and in Nabkha species. The histogram in Figure 7 (A) shows no variations were observed on average size classification between surface and root sediments for *Rhanterium epapposum*. On the other hand, variation between surface and root of hallophites Nabkha sediments such as *Halocnemum strobilaceum*, *Salicornia europaea* and *Tamarix aucheria* are well noticed (Figure 7 B, C, D) but *Nitraria retusa* is an exceptional case (Figure 7 E). The desert Nabkhas are showing no variability in size distribution between root and surface (Figure 7 F, G , H , I). *Citrulus colocynthis* is an exceptional

case. It can be seen that the aeolian sediments within the desert environment and the surrounding areas are dominantly similar in being unimodal with modal classes in the medium sand size ranges. The medium sand is the dominant size fraction in most of desert Nabkhas such as *Rhanterium epapposum*, *Haloxylon salicornicum*, *Lycium shawii* and *Cyperus conglomeratus*, while fine sand in *Panicum turgidum, Astragalus schimperi* and *Citrulus colocynthis* (Figure 7 I, J). The later plants are also showing bimodal in comparison to former Nabkhas that present with unimodal type of distribution. Variation are considered in Nabkha species Interrelationships diagram between the different statistical size parameters, but well illustrated within *Halocnemum strobilaceum* and *Tamarix aucheria*

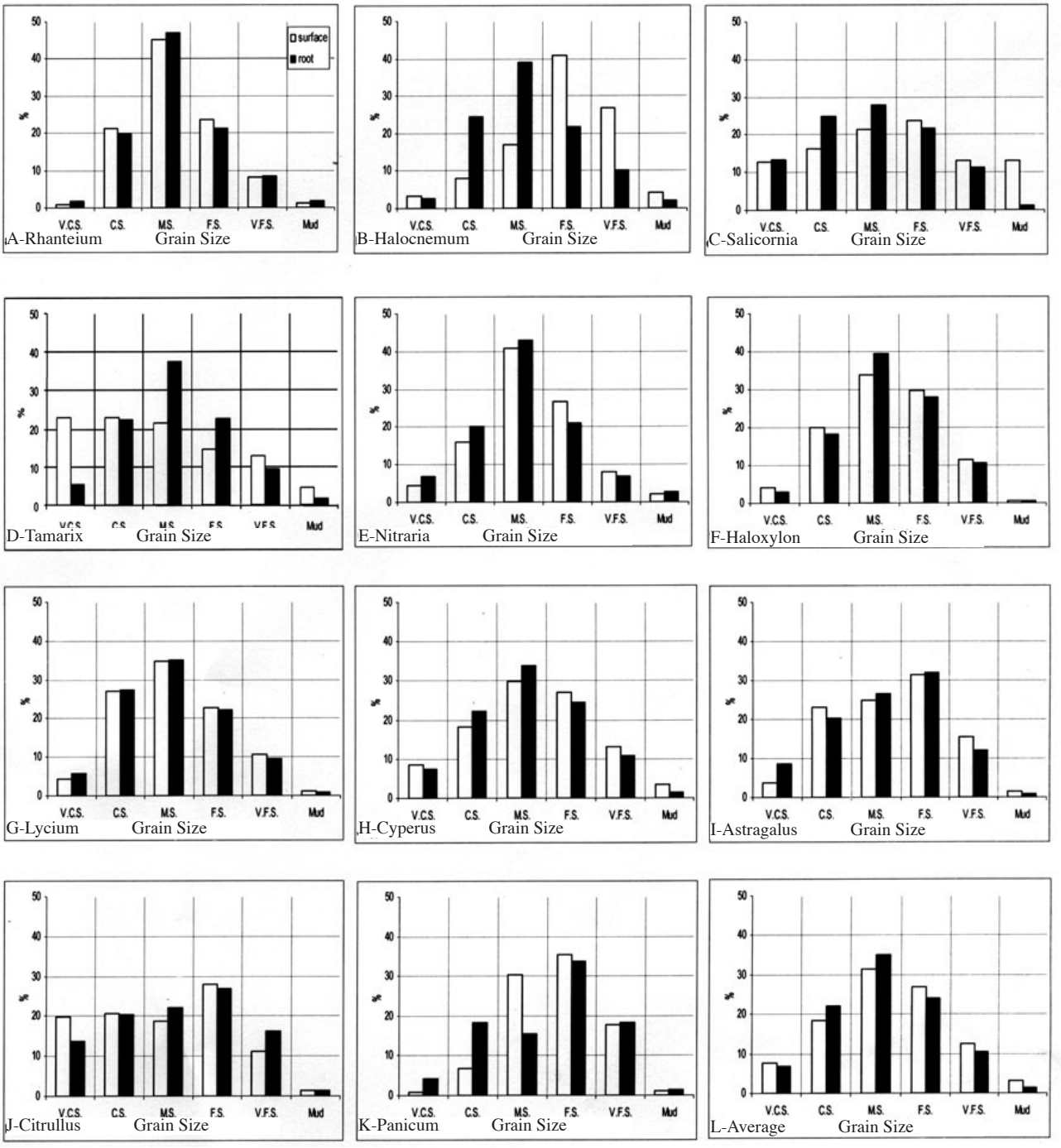


Fig. 7 (A-L) Grain size percentages of *Nabkha sediments* root and surface from (A) *Rhanteium*, (B) *Halocnemum*, (C) *Salicornia,* (D) *Tamarix*, (E) *Nitraria*, (F) *Haloxylon*, (G) *Lycium*, (H) *Cyperus*, (I) *Astragalus*, (J) *Citrullus*, (K) *Panicum* and (L) Average.

CONCLUSION

It is likely that many vegetation mounds are relics of wetter environmental conditions, having started as Nabkha dunes formed around vegetation aligned along old water channels or around moisture-retaining basins. As the sand accumulated, the plants developed an ever more extended root system to reach water stored at the base of the mound. If the mounds build up beyond the ability of the plants to reach water, the vegetation will die. The distribution of Nabkhas is depending on the suitable condition for each plant species. That is each plant species has its own growth environment. For instance the growth of *Cyperus conglomeratus* is dominantly within sandy environment and distributed dominantly within mobile sand corridors and sand sheets environment. The *Cyperus conglomeratus* Nabkha sediments is characterized by highest pH, and moisture content in comparison to all other desert plants but lower carbonates, conductivity level and total dissolved salts (TDS).

The presence of *Cyperus conglomeratus* shows it is a good indicator of highest severity of aeolian processes (Figure 8). *Haloxylon salicornium* and *Rhanterium epapposum* are growing as a plant species on the main bedrock and the accumulated aeolian sand come later which protect, conserve and feed the plant by its water and nutrients needs. These three plant species are characterized by high pH values but lower EC and moisture percentage values. It is also characterized by shorter distances between plant branches and plants compared to other plants. The medium sand is the dominant size fraction within the Nabkha sediments of these plants where there is no variations were observed between root and surface sediments. The *Haloxylon salicornicum* is more efficient in trapping sand compared to other desert plants since it is characterized by developing wider and longer Nabkhas than *Cyperus conglomeratus* and *Rhanterium epapposum*. Table (4) shows the condition that is necessary for growth of each plant species. *Panicum turgidum* is also another plant species that grows in the sandy environment within sandy corridors but develops in unsuitable conditions to the three former plant species that is characterized by finer size fraction and lower pH. On the other hand, other desert plant species such as *Astragalus spinosus , Citrullus colocynthis* and *Lycium shawii* are dominantly found within drainage basins. *Astragalus spinosus* is growing within the lower stage of the wadis downstream on the delta alluvial deposits. It is characterized by the finest mean grain size and highest carbonate percentages of all Nabkha. *Citrullus colocynthis* is the shortest of all desert plants. It is also characterized with low pH, EC level and moisture content. *Citrullus colocynthis* has along root system with long distances between plants. On the other hand, *Lycium shawii* is characterized by longest distances between branches and plants in comparison to other plant species. *Lycium shawii* Nabkha sediments have low pH, EC level and moisture content. Halophytes such as *Nitraria retusa*, *Tamarix aucheria*, *Halocemum strobilaceum* and *Salicornia europaea* have unique morphological and ecological characteristics in comparison to desert Nabkhas. Halophytes characterized by lower PH and carbonates percentages, but higher in moisture, TDS, and EC levels. They also vary in mean grain size from smaller size fractions in smaller Nabkhas (*Halocemum strobilaceum* and Salicornia europaea) and larger size fractions in larger Nabkhas (*Tamarix aucheria* and *Nitraria retusa*. More detailes are well tabulated within Table (4).

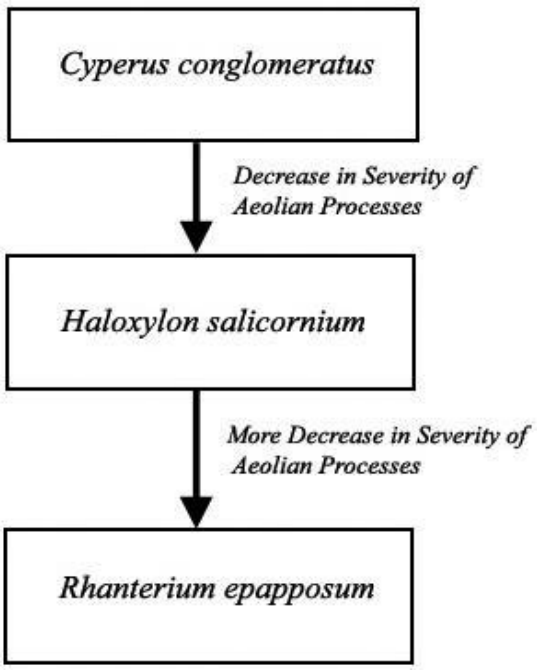
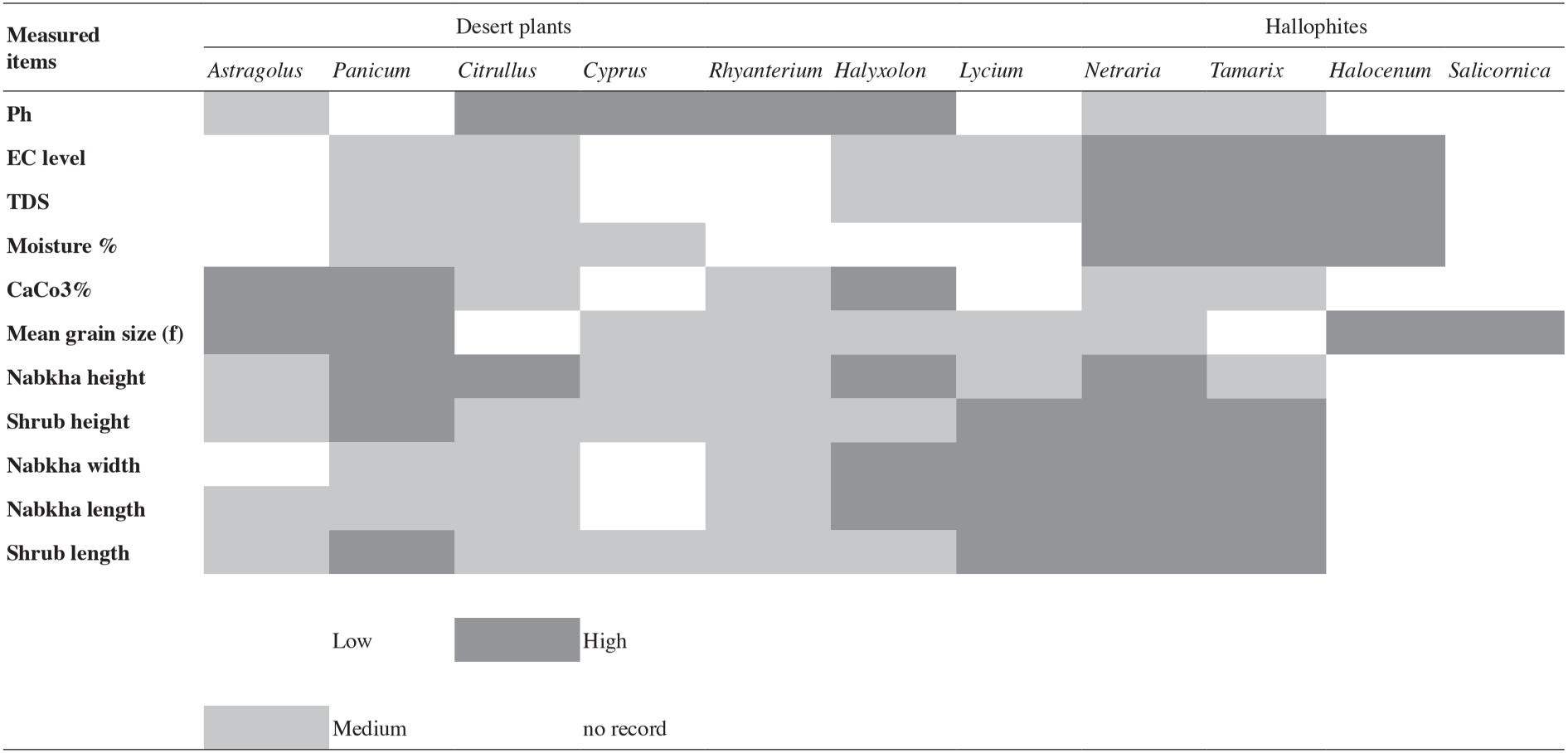


Fig. 8. Relationship between plants species and severity of aeolian processes.

Table 4. Summary of chemical and morphological characteristics of each dominant plant species in Kuwait.



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