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# Relative Occurrence of Soil Transport Mechanisms and its ranking: At Al-Wafra and Al-Jahra-Subiya Area Situated Along the Major Sand Corridors of Kuwait

# انتقال الرمال السائبة وتواجدها النسبي و تصنيفها، دراسة ميدانية لمنطقتي الجهراء و الوفرة الواقعين في الممر الرئيسي لحركة الرمال بدولة الكويت

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**Abstract:** The purpose of this study is to evaluate the occurrence, mechanisms and ranking of aeolian sand particle movement through particle size analysis of recently deposited wind-blown soil materials in the sensitive and selected desert areas of Kuwait (Al-Wafra and Al-Jahra-Subiya). These areas fall in the two major sand corridors of Kuwait. The aeolian movement mechanisms were evaluated through particle size analysis of recently deposited sand sediment. Soil samples were collected from two areas Al-Wafra area in the southern part of Kuwait and Al-Jahra-Subiya area in the northern eastern part of the state. The particle size analysis of the soil samples revealed the dominance of aeolian particles. Saltation of sand particles movement was concluded to be dominant, followed by creep and then suspension. In the Al-Wafra area, the percentage of particles distribution in the saltation was calculated to be 41.0 to 90.0% with an average of 72.4%. This was followed by creep which ranged between 8.0 and 57.0%, with an average of 25.1%, and a suspension of 0.5 to 5.0%, with an average of 2.36%. In Jahra-Subiya area, the percentage of particle distribution in the saltation ranged between 65.0 to 94.0%, with an average of 85.8%. Creep ranged between 4.0-33.0%, with an average of 11.6%, and the suspension ranged between 0.2-4.0% with an average of 1.8%. The results suggest that the control of the saltation movement in the desert of Kuwait could lead to reducing the mass movement of sand particles. This could be achieved by using soil stabilization processes or windbreaks.

**Key words:** aeolian sand, creep, saltation; suspension, soil stabilization, windbreaks.

**الملخص:** إن الهدف من هذه الدراسة هو تقييم حركة الرمال السائبة وتواجدها وظروف انتقالها وتصنيفها على حسب حجم الحبيبات بالمواقع المتأثرة بالممر الرئيسي لحركة الرمال، وذلك بمنطقتي الوفرة و الجهراء بدولة الكويت، وقد تم جمع العديد من العينات الرملية الحديثة الترسيب لكل من منطقتي الوفرة الواقعة في جنوب دولة الكويت، ومنطقة الجهراء الواقعة في شمال دولة الكويت. وتشير نتائج الدراسة الميدانية بأن معظم الرمال المتواجدة من أصل ريحي، وان الانتقال عن طريق قفز الحبيبات هي حركة الانتقال الدارجة، وبعدها تأتي حركة الزحف وأخيراً الحركة و الانتقال بالتعلق. وجاءت النتائج أن نسبة المواد المنقولة بالقفز في منطقة الوفرة تقدر بـ 41 إلى 90 وبمعدل 72.4, وبعدها أتت نسبة الحركة بالزحف بحدود 8 إلى 57 وبمعدل 25.1 و أخيراً الحركة عن طريق التعلق بحدود 5 إلى 0.5 وبمعدل 2.36. كما تشير النتائج الحقلية إلى أن نسبة و انتقال المواد الرملية في منطقة الجهراء - الصبية على النحو التالي: الانتقال بطريقة القفز تتراوح ما بين 65 إلى 7.94 وبمعدل 85.8 وعن طريق الزحف فالنسبة تتراوح ما بين 4 إلى 33 وبمعدل 11.6, وعن طريق التعلق فالنسبة تتراوح ما بين 4 إلى 2 وبمعدل 1.8. إن النتائج الميدانية للدراسة تقترح بأن يتم استخدام مصدات أو تثبيت الرمال السائبة وعلى الأخص تلك المتحركة بواسطة القفز وذلك للتقليل من نسبة حركة الرمال السائبة في دولة الكويت.

**كلمات مدخلية:** الكثبان الرملية، زحف الرمال، قفز الحبيبات الرملية، المواد العالقة، تثبيت التربة، مصدات الرياح.

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## Introduction

The state of Kuwait lies in the Arid zone. Drifting of sand is becoming a menace around cultural areas around the desert and coastal area of Kuwait. The very fragile natural soil resource in Kuwait is required to be conserved to enhance the environment quality. Due to the general sandy nature of the land surface large areas are prone to wind erosion. The surface is usually underline by recent sediment deposits that include aeolian, residual, playa, dunes, desert plain, slope, and coastal deposits. Aeolian deposits are the dominant and account for 50% of the surface deposits (Khalaf, 1989; Al-Awadhi and Misak, 2000; Al-Sarawi, 1995). Dune deposits in the area comprise quartz, feldspar, fragments of volcanic rocks, carbonates and gypsum. The average grain size ranges from 0.22 mm to 0.27 mm. The dunes vary in size with dimensions ranging 150-200 m long, 3-4 m high and 25-35 m width (Al-Dabi *et. al.,* 1997). Khalaf *et al.* (1984) estimated that mean monthly dust deposition is 191.3t $km^{-2}$, while the mean monthly maxima and minima were recorded in July 1002.7t $km^{-2}$, and November 9.8t $km^{-2}$, respectively. Wind erosion causes serious problems in Kuwait, where loose, dry, sandy soils, poor vegetation protection of the soil, and periods of strong winds prevails.

Fig. 1 shows, three different mechanisms of transport of soil particle in the wind erosion process which can be distinguished as: creep, saltation and suspension (Bagnold, 1937; Cheplin, 1945). However with the transition of two modes, particles of a particular size may be moved by both modes, depending on the differences in density and wind speed.

### Creep

Particles (> 500$\mu$m diameter) are usually set in motion by the impact of saltating particles. They are large enough and generally cannot be lifted up by the wind, and tend to roll or slide and creep along the surface. During the rolling process, they lose their sharp edges and become rounded.

### Saltation

The particles (63-500 $\mu$m diameters) are lifted from the surface. This lift occurs when, initially, particles are rolled on the surface; a vacuum is created at the rear of the moving particle, whereas, in the front, the air is compressed below the particle. The bounce of these particles over the surface reach maximum heights of about 1m, but the bulk of the saltation particles move just over the soil surface.

### Suspension

Saltation particles, when reaching to the surface, can dislodge the soil particles (< 63 $\mu$m diameter) and push them to the atmosphere. They remain in the atmosphere for a longer period, causing dust storms, and reach the soil surface with rain and clog the soil surface to form a surface crust.

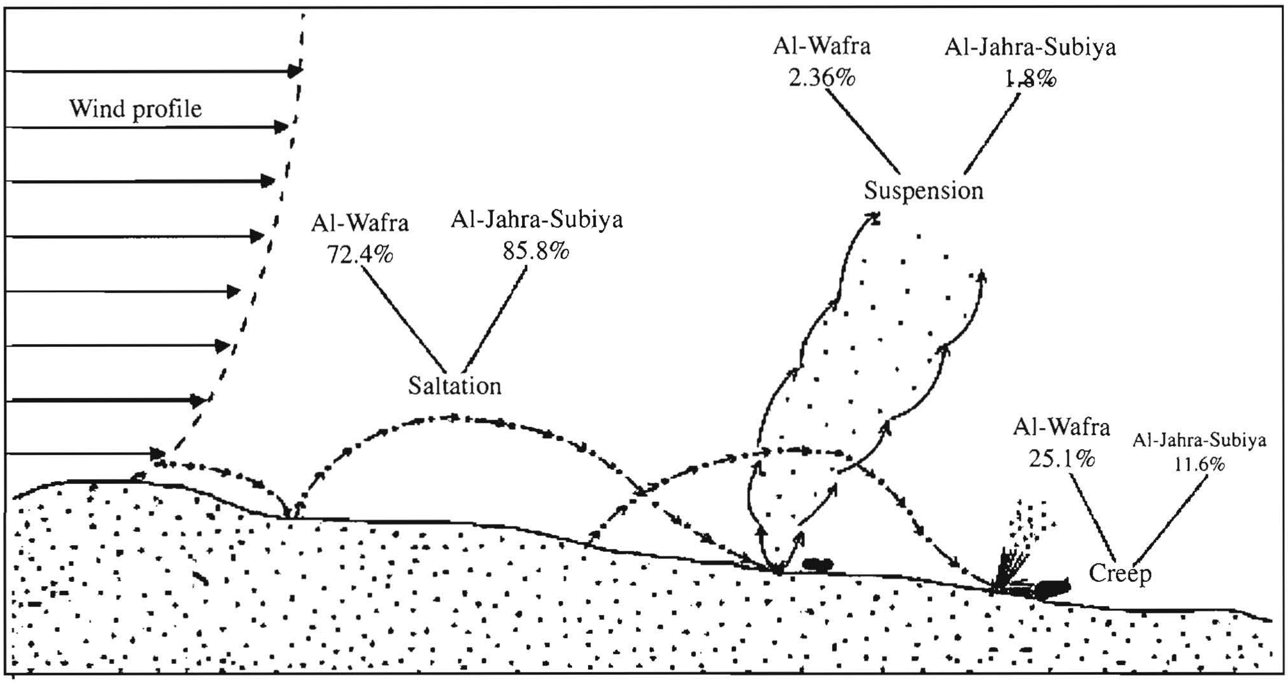


**Fig. 1.** Typical diagram showing three modes of wind blown particle transport and it's contribution to Al-Wafra and Al-Jahra-Subiya area.

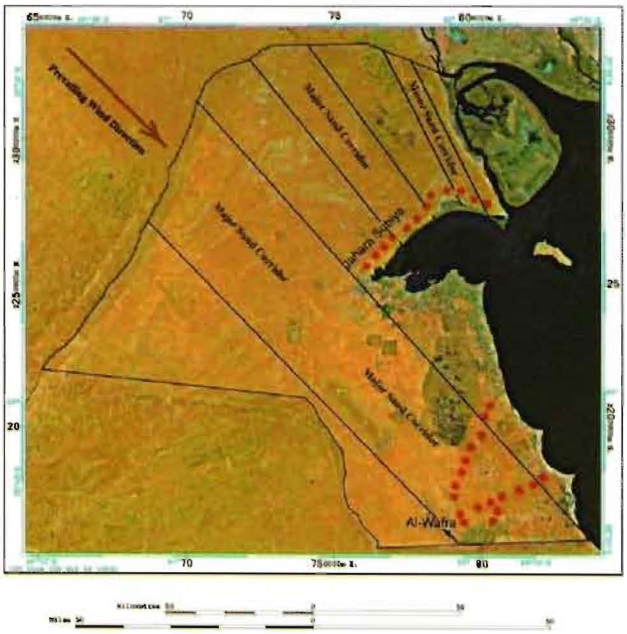


**Fig. 2.** Landsat image showing site Al-Wafra area and Jahra Subiya area, sampling location, sand corridors and prevailing wind direction.

Wind erosion is the process of detachment, transportation and deposition of soil material by wind. Chepil (1957) explains that the basic causes of wind erosion are few and simple. They are: (i) when the soil is loose, finely divided and dry; (ii) when the soil surface is smooth and bare; and (iii) when the wind is strong. Wind erosion damage includes loss of soil, textural change, loss of nutrients and soil productivity, abrasion, air pollution and sedimentation (Troeh, *et al.* 1991).

Bagnold (1937) reported that finest grains move in suspension, intermediate sizes in saltation, and the coarsest erodible grains in surface creep. Finer and coarser sizes are difficult for even strong winds to dislodge, but intermediate-sized grains are relatively easy to move. The tiny dust particles on the ground are swept up by turbulent winds and forced into suspension high above the ground, resulting in dust clouds i.e., toze (Foda, *et al.* 1984). However, the surface winds are not able to raise the much heavier sand grains higher than a few meters from the ground (El-Baz and Al-Sarawi, 1996). This results in a commonly observed, thick, low-lying sand cloud that drives across the country during a sand storm (Al-Awadhi, *et al.* 1998).

In Kuwait, sand control measures are widely discussed by Omar *et al.* (1989) and Al-Enezi (1996). However, these measures have not been applied in Kuwait correctly, even though many installations suffered from sand encroachment problems as reported by Ahmed *et al.* (1996). For example, about 1,417,723 $m^3$ of sand have been removed from Kuwait Oil Company facilities in the last five years at a total cost of KD.1,003,369. About 1,301,400 $m^3$ of sand was removed in Ali Al-Salem air base at a total cost of KD.100,000 in only two years (from April 1993 to June 1995), where as the total sand removed from Al-Wafra roads was 1,205,380 $m^3$ (from 1996 to 2001). The northwest wind results in the activation of large dune fields in the western part of Kuwait (El-Baz, 1994). The main aeolian action includes dust storms that carry fine grain particles in suspension and sand storms which are active winds loaded with sand particles (Khalaf and Al-Ajmi, 1993; Khalaf *et. al.*, 1995).

## Materials and Methods

1. Study Area

Wafra Transect: The transect is located in southern part of Kuwait (Fig. 2). The samples were collected from two transects. One transects starting from King Fahed AbdulAziz road to New Wafra city and the second from New Wafra city to Mina Abdullah Road. Morphologically the Wafra transects run in the following landscape units:

- Stabilized sandy ridges (mostly separated by sabkha)
- Corrugated Plain (alteration between shallow depressions and flat gravelly terrain).

Al-Jahra-Subiya Transect: The transect stretches in the Northern east part of Kuwait (Fig. 2). It extends along the road from Jahra to Subiya near to Bubiyan Bridge.

The present study focused on evaluating the aeolian movement at Al-Wafra and Al-Jahra-Subiya area with respect to soil particle movement mechanisms (saltation, creep, and suspension) and their rank importance in the desert of Kuwait. The aeolian movement mechanisms were evaluated through particle size analysis of recently deposited sand sediment.

2. Sampling procedure

A total of 33 surface sand samples were collected from the two areas; 19 samples in Al-Wafra and 14 samples in Al-Jahra-Subiya, in the manner shown in Fig. 2. About 1.5 kg of representative sand sample was collected from each site at a distance of 5 km. The samples was collected in polythene bags and transferred to the soil laboratory for further processing (drying and sieving

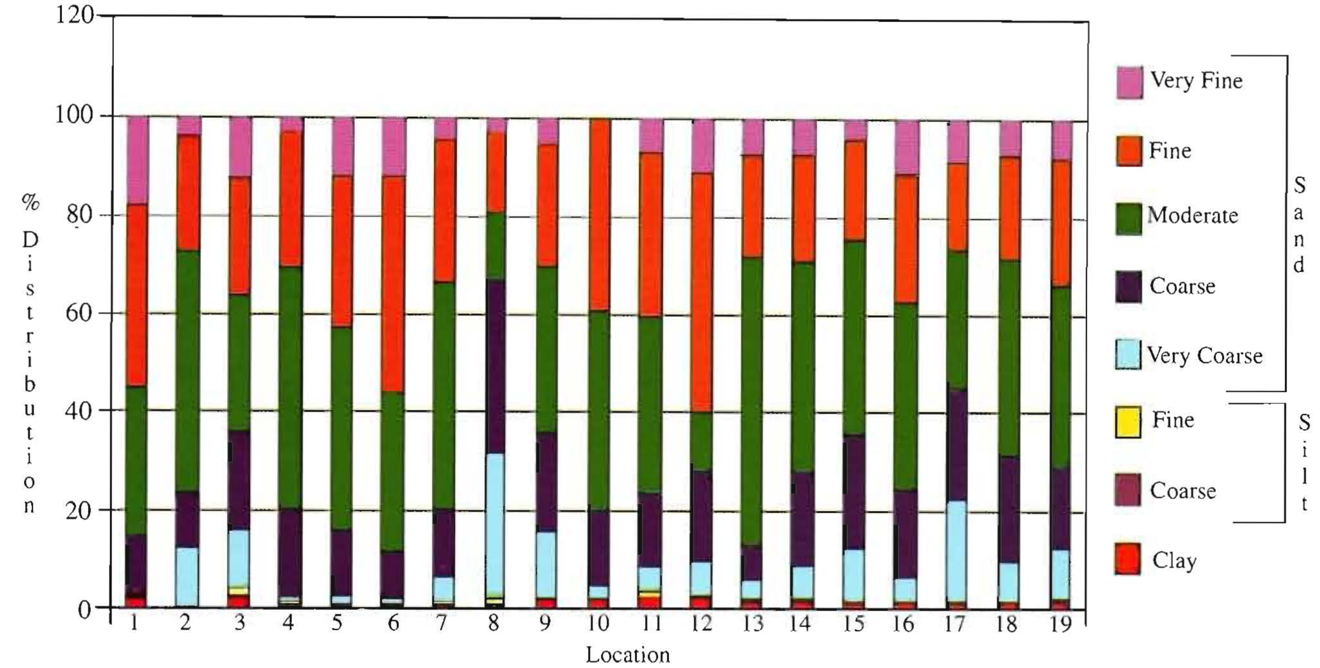


**Fig. 3.** Particle size distribution of fine earth fraction (< 2 $\mu$m) from the Al-Wafra area.

through 2 mm sieves) and analyses. The sieved samples were stored in polythene bottles, labeled and the quantity of fine earth fraction (< 2 $\mu$m) and coarse fractions (> 2 $\mu$m) were recorded and presented as a percentage on whole soil basis. The sand samples were subjected to particle size analysis by Bouyoucos hydrometer method supplemented with wet sieving to separate sand fractions.

3. Soil texture analysis

Soil texture was determined through particle size distribution analyses using the modified hydrometer method (Shahid, *et al.* 1992), which is suitable for arid region soils with low organic matter contents. One hundred grams of soil (< 2 $\mu$m) was dispersed in 100ml 4% sodium hexametaphosphate solution overnight and stirred in a mechanical shaker for 5 min. The dispersed soil suspension was transferred to a standard particle size analysis cylinder and made the volume up to one liter. Readings were recorded after 0.5 and 1 min without removing the hydrometer. Further readings were recorded after 3, 90, 150, 270, and 1080 min after shaking the soil suspension.

4. Wet sieving

After the mechanical analysis was completed with the hydrometer, the suspended sand particles were passed through 630 $\mu$m, 200 $\mu$m and 63 $\mu$m sieves and the retained material on each sieve was oven-dried (105°C) and weighed to calculate percentage on a less than 2mm soil basis. Both the calculated values from hydrometer and the wet sieving were used to obtain a cumulative particle size distribution curve; these were then used to obtain quantities of different sized particles (sand, silt and clay). The present values of sand, silt and clay were plotted onto a textural triangle to obtain textural class (Soil Survey Division Staff, 1998).

## Results and Discussion

Al-Wafra area

From the particle size distribution analysis from Al-Wafra area it was evident that the sediments are dominated by sand particles with a range between 96.0 to 99.5% with an average of 96.7%. To a lesser extent clay particles ranged between 0 to 3.5% with an average of 1.53% while silt ranged between (0-1.0%) with an average of 0.37%. The fine silt ranged from 0 to 1.0% with an average of 0.24% and coarse silt ranged 0 to 0.5% with an average of 0.13%.

The sand particles had variable distribution in Al-Wafra area (Fig. 3). The fine sand ranged from 16.0 to 49.0% with an average of 28.1% while the medium sand ranged between 13.0 to 49.0% with an average of 36.3%. Coarse sand ranged between 7.0 to 30.0% with an average of 17.3% and the very coarse sand ranged between 0 to 30.0% with an average of 7.82% and very fine sand (0-18.0%) with an average of 7.09%. The predominant classes are medium, fine sand and coarse sand.

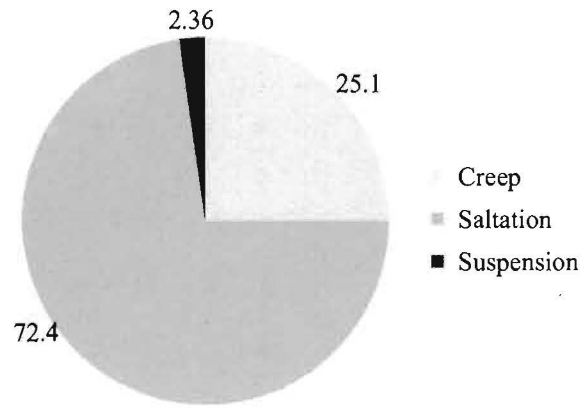


**Fig. 4**. Average percentage of soil transport mechanism at Al-Wafra area.

The mechanism of wind transport of sand particles in Al-Wafra was studied from the above statistics. The study showed that the main mass of wind blown particles represented saltation mode with an average of 72.4% of total mass movement. This is followed, to a lesser extent by creep mode (8.0-57.00%) with an average of 25.1% and to a least extent by suspension mode (0.5-5.00%) with an average of 2.36% (Fig. 4). The suspension movement is thought to be caused by salting particles when bouncing at the surface (Chepil, 1945).

Al-Jahra-Subiya area

Particle size distribution analysis (see Fig. 5) showed that all 14 samples were dominated by sand particles ranging from 96.0 to 100% with an average of 98.5%. The silt percentage in the samples ranged from 0 to 3.5% with an average of 1.1% while clay ranged from 0 to 1.0% with an average of 0.4%. The silt particles consist of fine silt (0-2.0%) and the coarse silt (0-1.5%). The highest proportion of sand is distributed in fine sand fraction (30-60.0%) with an average of 43.3%. This is followed by medium sand (11.0-44.0%) with an average of 25.9%. The least portions are coarse (3.50-16.0%) with an average of 10.1% and very coarse sand (0-17.0%) with an average of 2.23%. The main textural classes of sand particles are sand, fine sand and coarse sand.

The study showed that the saltation mode of sand particle movement was dominant in the range of 65.0 to 94.0% with an average percentage of the total mass movement of 85.8%, followed by creep mechanism mode ranging from (4.0 to 33.0%) with an average of 11.6% (Fig. 6). The least is suspension mechanism mode ranging from 2.0 to 4.0% with an average of 1.80%.

## Conclusion

Sand blown by wind is a natural phenomenon. The results of the present study strongly concluded the saltation mechanisms are the dominant one in removing soil particles in the deserts of Kuwait.

Whenever there is a supply of cohesionless sand particles exposed to wind that reaches a certain threshold velocity, the sand particles are set in motion either through suspension, saltation or creeping.

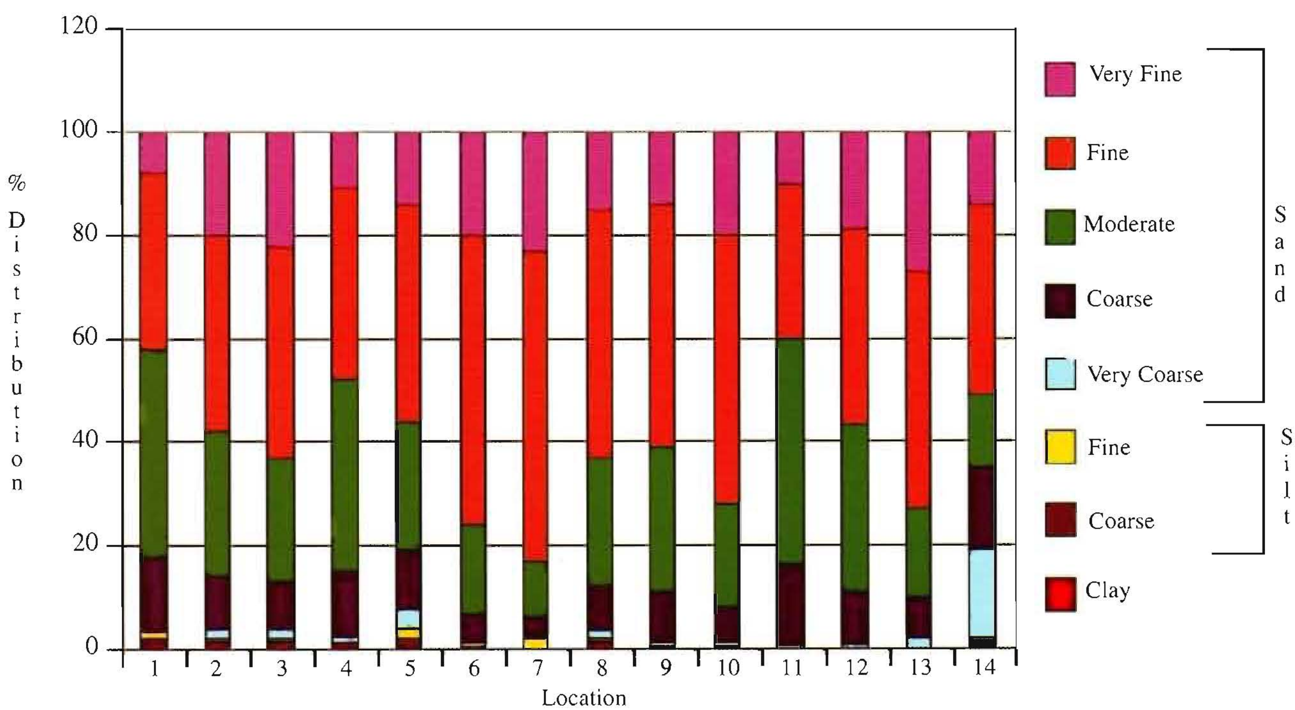


**Fig. 5**. Particle size distribution of fine earth fraction (< 2 $\mu$m) from the Jahra-Subiya area.

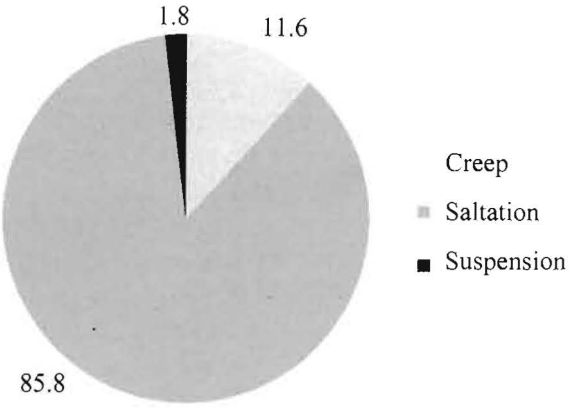


**Fig. 6**. Average percentage of soil transport mechanism at Al-Jahra-Subiya area.

The above lines can be technically described with the mass source algorithm (Marticorena, *et al.* 1997) which defines the vertical mass flux of dust (F) as function of friction velocity ($u_f$) and threshold friction velocity ($u_t$). Coefficient k, ($m_{-1}$), air density (Ú) and acceleration due to gravity (g) are constants.

$$F = k\frac{\rho}{g}\left(u_f^2 - u_t^2\right)$$

The friction velocity is dependent on meteorological condition and surface roughness of the place at that particular time. Threshold velocity and soil coefficient are only dependent on space relating to the surface roughness, soil, and land-use characteristics Rainfall is one of the important meteorological parameter, which affects the surface roughness (Baby and Al-Sudairawi, 2004).

Finer particles are transported in suspension, whereas courser ones generally creep on the ground surface and are subjected to bombardment by salting particles. The saltation is the critical mode of transport and the grain size most easily moved by the wind usually accounts for 75% of sand transport and may increase up to 95% depending on the grain size.

Saltation of sand particles movement was concluded to be dominant, followed by creep and then suspension (Fig. 1). In the Al-Wafra area, the percentage of particles distribution in the saltation was calculated to be 41.0 to 90.0% with an average of 72.4%. This was followed by creep which ranged between 8.0 and 57.0%, with an average of 25.1%, and a suspension of 0.5 to 5.0%, with an average of 2.36%. In Jahra-Subiya area, the percentage of particle distribution in the saltation ranged between 65.0 to 94.0%, with an average of 85.8%. Creep ranged between 4.0-33.0%, with an average of 11.6%, and the suspension ranged between 0.2-4.0% with an average of 1.8%. The results suggest that the control of the saltation movement in the desert of Kuwait could lead to reducing the mass movement of sand particles. Using soil stabilization processes, windbreaks, etc could achieve this.

## Recommendations

Wind erosion occurs whenever conditions are favorable for transportation of sand material by wind such as soil erodability, surface roughness, climatic conditions (wind velocity and humidity), length of exposed surface and vegetation cover influence how much erosion will take place.

The results of the present study strongly concluded the saltation mechanisms are the dominant one in removing soil particles in the deserts of Kuwait, therefore, it is important to control saltation movement. This can be achieved either by increasing the size of the particles to big enough that the wind cannot pick easily, or to stabilize the surface of the deserts of Kuwait. These can be accomplished by using different management strategies including the wind breaks and factors which promote soil stabilization.

The first important factor appears to be the cohesion of the soil surface. Breaking a crusted surface and dislodging a grain of sand, whether by aerodynamic forces or by impact (threshold velocity for continuation of saltation). Surfaces highly resistant to wind erosion are characterized by crusts having a high salt, clay or silt.

The second important factor in producing a higher energy threshold is the sorting of particle sizes, associated to some extent with the absence of a crust in the saltation formations. The threshold velocity for maintaining saltation can be expected to be significantly lower in the well sorted saltation than in an unsorted soil, since energy is saved by not having to dislodge dust-sized particles that do not contribute to maintaining saltation.

A third factor is an increase in surface roughness. Vegetation and algae play an important role in stabilizing the surface (bio-crusting). Plants increase the surface roughness sharply and act as mechanical obstacles that reduce the velocity and alter the direction of the wind. As a result, sand grains near these obstacles drop out from the saltating flow and accumulate near the plants. It is important it can be accomplished by adapting the practices which maintain soil structure and conserve moisture should be followed to control saltation movement rather minimize it.

The above paragraphs can technically be applied by understanding the mass source algorithm. It is understood from the mass source algorithm that the friction velocity is dependent on meteorological condition and surface roughness of the place at that particular time. Threshold velocity and soil coefficient are only dependent on space relating to the surface roughness, soil, and land-use characteristics. Rainfall is one of the important meteorological parameter, which affects the surface roughness with:

- enhanced or developed vegetation
- changing the soil moisture

Change in vegetation and soil water content brings significant changes in friction velocity thus altering the threshold friction velocity. The surface roughness absorbs the part of the momentum of the blowing wind. Ronald *et al.* (2001) has indicated that rain leads to the formation of Cyano-bacterial Lichen soil Crusts (CLC) which resists the wind. The smaller soil particles agglomerate to form much bigger particles due to cohesive properties of water, thus altering the size of soil particles and its distribution and reducing the outbreak of dust storm.

In dry regions such as Kuwait plants with low water requirements should be planted, particularly before high intensity winds, this may be accomplished by introducing wind breaks. The vegetation used should have the ability to grow on sandy soils, the ability to grow in the open, firmness against the wind, and long life and should provide an obstruction to wind to reduce its velocity. The filtering brush matting, debris, rock and gravel may be suitable in stabilizing sandy areas.

To stabilize such drifting sand planting of selected species of plants is necessary to provide proper shelterbelts (longer) or wind breaks (shorter). Baby (1998) says the aim in creating such greenbelts should be:

- to shelter population in a city from hot wind blast
- to arrest particulate matters as much as possible
- to shelter live-stock
- to protect agricultural land
- to control sand movement and
- to provide healthy habitat

Best results of greenbelts can be achieved if it is properly designed. The design depend on the local conditions related to objectives, particulate and pollutant characteristics, wind direction and speed, the essential height, density, species of the tree, the spacing between the belts, shape, porosity and orientation of the belts (Baby, 1998; Baby and Al-Sudairawi, 2004).

The uses of mulches are another option, they can be organic or inorganic, the main objective of adding mulch material is to conserve the soil moisture, and protect the soil surface from erosion. The best way of mulching is to incorporate partially to the soil so that it reacts with soil, this usually enhances the soil binding forces and also enhance the soil absorption of moisture, in addition it also increases organic matter and nutrients in the soil if are organic based.

The uses of synthetic "hydrophylic polymers" are another option. They effectively increase soil stabilization, decrease both wind and water erosion of soil, increase final infiltration rate and water holding capacity and also act as "Soil Conditioner" (Ben-Hur and Keren, 1997). The polymers induce flocculation of clay particles, bridge soil particles and therefore develop soil structure. In addition, these polymers can be used in turfgrass landscaped areas under Kuwait Municipality and therefore would be very attractive technology.

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