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# Climatic Factors Affecting Mobility and Stability of Sand Dunes

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## Introduction

Sand dunes are known to be: (i) free of vegetation and active (ii) partly vegetated and active (iii) fully vegetated and fixed (Wilson, 1973). Low rainfall and high potential evaporation result in sparse or nonexistence vegetation (Thornthwaite, 1931) and hence active sand dunes. The amount of vegetation on sand dunes is also checked by sand transport when winds are strong enough. Several wind erosion or sand mobility indices have been developed for various parts of the world (Ash & Wasson, 1983; Talbot, 1980), all of which are based on these two factors that influence dune mobility. The first one deals with the degree of windiness (expressed as the average annual wind velocity to the third or fourth power, or as the annual percentage of days experiencing winds above the threshold for sand movement). Most dunes will be mobilized if windiness is increased. The second factor is the vegetation growth cover that is taken as a function of the ratio between the average precipitation (P) and evaporation (E).

Considering the above two factors, an equation was developed by (Lancaster, 1988) that is widely used by many geologists and geomorphologists, to determine whether sand dunes would be active or fixed and the expected effect of climate change.

$$M = \frac{W}{P/PET} \quad (1)$$

where: $M$ = sand mobility index, $W$ = percent of days during the year with sand moving winds, $P/PET$ = the ratio of mean annual precipitation to mean annual potential evapotranspiration.

The critical values of equation 1 for Southern Africa are: $M$>200 for fully active dunes with no vegetation and $M$<50 for inactive vegetated dunes. These values are performed very well for the Great Plains sand dunes (Muhs & Maat, 1993) but they are not in accord with the results from many other sand dunes areas in the world. There are many examples of unvegetated active sand dunes in humid areas and of vegetated fixed dunes in arid regions (Cooper, 1958; Tsoar & Möller, 1986).

## The physical properties of dune sand and its effect on vegetation

Precipitation and evaporation are not very effective on sand dune vegetation. Dune sand is devoid of runoff and is known to have high rates of infiltration because of its relatively big pore spaces. As a result, sand quickly reaches its field capacity, which is less than 5%, and with abundant rainfall water infiltrates to the groundwater where plants cannot reach. A profusion of rain will only leach the sand of its nutrients. Because easy and deep percolation occurs in dune sand, moisture is stored at depths where it is protected from evaporation during the long dry periods. Hence, precipitation and evaporation have a different effect on vegetation, which grows on sand, as opposed to on other soils.

Wind power is the most important factor in sand dune mobility because of the non-cohesiveness of the sand. Wind above a certain wind power can erode sand to such an extent that it prevents seeds from germinating in the sand and stabilizing it. According to the sand transport equations (Bagnold, 1941), the sand flux (q) is directly proportional to the cube of the wind. The wind factor in equation 2 only refers to the percent of days during the year with sand moving winds and not to the wind magnitude. In addition it does not refer to the wind directionality.

A much better index for the wind magnitude is the drift potential (DP) of the wind (Fryberger, 1979), which refers to the sand transport equation:

$$DP = \sum q = \frac{U^2(U - U_t)}{100} t \tag{2}$$

where U is the wind velocity, measured at a height of 10 m, $U_t$ is the threshold wind velocity and t is the time the wind blew (in percent).

DP is a parameter of the potential maximum amount of sand that could be eroded by the wind during a year. DP, being roughly proportional to the rate of sand transport and the time the transport happens, is a measure of the wind power. The index of the directional variability of the wind is the ratio of the resultant drift potential to the drift potential of the wind (RDP/DP).

By analyzing rainfall data it was found that there is no correlation between rainfall and dune mobility and stability. Because of the low field capacity of dune sand, rain is effective for plants only if it falls very frequently and in amounts small enough to bring the sand moisture to field capacity level most of the time. The frequency of the rainfall can be determined by the arithmetic mean of the monthly rainfall deviation from the monthly average. There is no link between this deviation and the amount of vegetation on sand dunes.

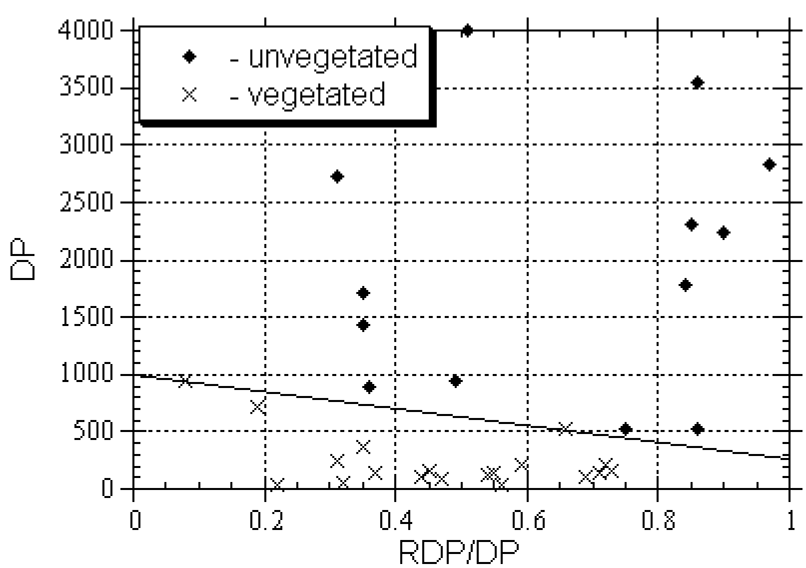


Figure 1. DP versus RPD for stations with and without vegetation.

By process of elimination, it remains that the predominant factor affecting sand dune mobilization is wind erosion, as expressed by the drift potential (DP) and the annual wind direction variability (RDP/DP). Analysis of the relationship of DP versus RDP/DP for vegetated and unvegetated dunes from several sand dunes all over the world can highlight the effect of wind power on the vegetation cover of sand dunes (Fig. 1). When RDP/DP is low, wind energy is distributed on more than one slope of the dune and the energy exerted on each slope is lower. Sand dunes in areas where the annual average rainfall is ≥ 50mm are unvegetated and mobile under wind conditions in which M (according to Equation (3)) exceeds 1.

$$M = \frac{DP}{1000 - \left(750\frac{RDP}{DP}\right)} \qquad (3)$$

Other factors that influence the mobility and stability of sand dunes are related to human activity. There are many examples of the destruction of vegetation by grazing, trampling and wood gathering. These actions are known as processes of desertification. On the other hand, human are also making efforts to artificially stabilize sand dunes because of their apprehension of shifting sands. Most of the coastal sand dunes in Europe have been undergoing processes of fixation for the last 200 years (Favennec, 1996).

The relationship between wind power and vegetation cover can be recapitulated by a hysteresis curve (Fig. 2). When climate changes in the form of a decrease in wind power, vegetation will start covering the sand dunes in increasing numbers as the wind power decreases below 1000 DP. However, when this process is reversed, increase of wind power over vegetated dunes will not cause the extinction of vegetation when DP increases above 1000. There is a threshold for the destruction of vegetation by tempest winds but the value of the wind power for this occurrence is not known. The artificially stabilized sand dunes along the coasts of Europe have DP values above 1000 and they are in the upper reverse side of the hysteresis curve.

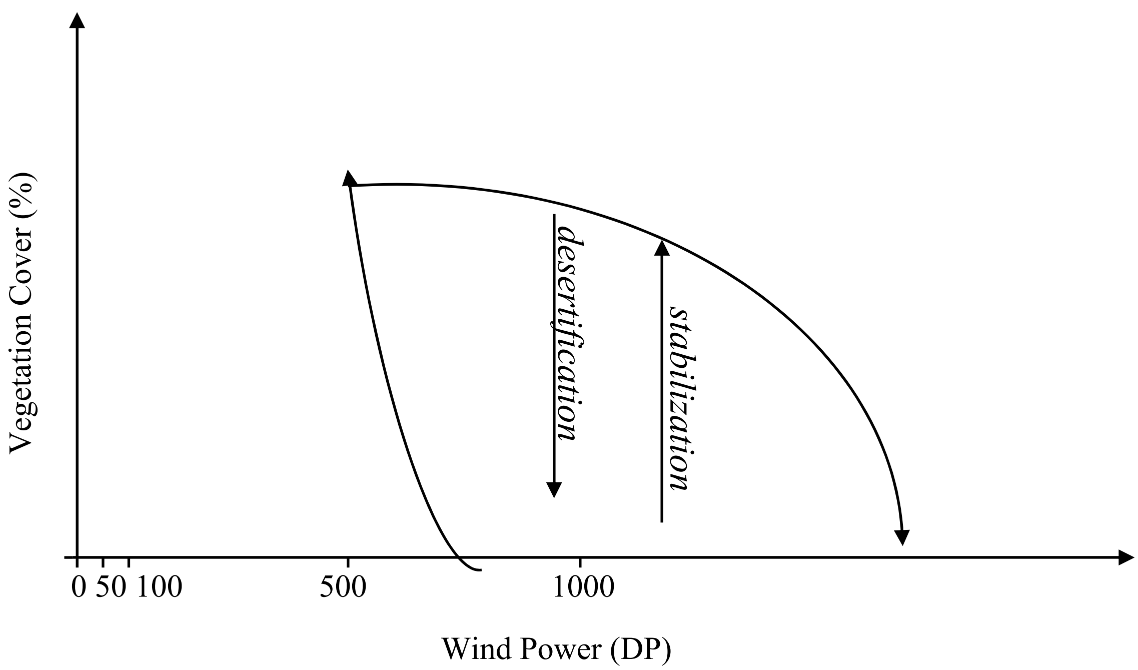


Figure 2. Hysteresis curve related to changes in wind power and vegetation cover.

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