Aeolian Sediment Budget of the Dunes of the Peninsula do Ancao

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Publication date
2000

Document Version
Final published version

Published in
Inlet Dynamics Initiative Algarve (INDIA); Report of the Contribution of the Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam

INLET DYNAMICS INITIATIVE ALGARVE (INDIA)

REPORT OF THE CONTRIBUTION OF THE INSTITUTE FOR BIODIVERSITY AND ECOSYSTEM DYNAMICS, UNIVERSITY OF AMSTERDAM

4 AEOLIAN SEDIMENT BUDGET OF THE DUNES OF THE PENINSULA DO ANCÃO

Introduction

Short-term field experiments give some insight in the functioning of an ecosystem. To be able to say something about dune building on the longer term, we need to extrapolate this knowledge and we have to use models.

By using long-term wind data, it is possible to make estimations of the dune building over a longer time period. For the Faro barrier islands wind data are available from Faro Airport. For this study we used wind data of the period July 1997 to March 2000. To be able to estimate the importance of extreme storm events on dune building, it is necessary to study wind data over a much longer period of about 20-30 years. These data are available at the Portuguese Meteorological Office, but were not provided for this study.

Methods

Sand transport was measured with saltiphones, sand traps and erosion pins. Saltiphones give an indication of transport intensity. Those measurements are continuous. Sand traps are used for measuring mass transport, at certain time intervals. Erosion pins give information on changes in height, from which sand transport can be deduced. To calculate total transport during events, sand trap data and saltiphone data are combined. For some days, saltiphone data and sand trap data could be directly correlated. For these days, a ratio was determined between trapped amounts of sand and recorded grain impacts at the beach and dunefoot (Figure 1). This ratio appeared to be variable, and is possibly related to wind speed. At low wind speeds, a larger part of the sand grains move in creep, which is not detected by the saltiphone. At high wind speeds the efficiency of the traps diminishes. There are too few data to investigate this relationship. The spatial variability is limited: the ratio between grain impacts and trapped sand for beach and foredune was more or less the same. With this saltiphone/trap-ratio saltiphone recordings can be converted to mass transport. For all time intervals that saltiphones did record impacts, the total mass was calculated, and with these calculations, daily total transports were computed.

The relationship between saltiphone counts and wind speed is complicated and far from constant. There is an influence of beach width, grain size, local sorting, surface moisture, rainfall and other factors. Because of the influence of many variables, the relationship is very complex. For this reason, and because of the availability of a relative limited data set, it is impossible to set up different equations for different conditions. Therefore we choose too establish an empirical relationship for some “average” conditions, by fitting empirically predicted transport with the total daily transport. This empirical equation with the form of the Kawamura equation uses a fixed threshold velocity.

The equation is:

$$q = \frac{C_{emp} * (U_{Ancao\_4.2m} - U_t) * (U_{Ancao\_4.2m} + U_t)^2}{\eta / 100 * W * 1000 * 600} \qquad (1)$$

with:

C_{emp}	=	constant	(0.12)
$U_{ancao\_4.2m}$	=	wind speed at Ancão dune crest at 4.2 m	($m.s^{-1}$)
U_t	=	local threshold velocity	(6.8 $m.s^{-1}$)
η	=	Efficiency of sand trap	(15%)
W	=	Effective trapping width of sand trap	(0.1 m)
600	=	to convert 10 minute periods to second periods	

and with all constants known:

$$q = \frac{0.12 * (U_{Ancao\_4.2m} - 6.8) * (U_{Ancao\_4.2m} + 6.8)^2}{0.15 * 0.1 * 1000 * 600} \text{ in kg.m}^{-1}\text{.s}^{-1} \qquad (2)$$

Conventional transport equations are used to calculate potential transport. We have used the equations of Bagnold and Kawamura:

$$q = C_B \frac{\rho}{g} \sqrt{\frac{d}{D}} (U_*)^3 \qquad (3)$$

$$q = C_K \frac{\rho}{g} (U_* - U_{*t})(U_* + U_{*t})^2 \qquad (4)$$

with:

q	=	transport in $kg.m^{-1}.s^{-1}$
C_B	=	constant in Bagnold's equation
C_K	=	constant in Kawamura's equation
ρ	=	air density (1.22 kg/m^3)
g	=	gravity (9.81 m/s^2)
d	=	grain size (m)
D	=	standard grain size (0.00025 m)
U*	=	friction velocity (m/s)
U*t	=	threshold friction velocity (m/s)

Transport in m^3/m.hour, assuming a bulk density of 1600 kg/m^3 is calculated with

q_i=3600/1600q (5)

Application of a wind frequency distribution yields the total transport Q_j per windsector j in m^3/m by summation of all calculated hourly transport rates q_i

$$Q_j = \sum_{i=1}^{n_j} q_i \qquad (6)$$

with n_j the total number of hours for wind sector j.

Total landward transport is then calculated with

$$Q = \sum_{i=0}^{360} Q_j \cos[dd_j] \qquad (7)$$

Prediction of transport for days with rain is still very difficult. For the calculation of the long-term sediment budget, we have adopted the following approach. We have used the daily rainfall data for Faro Airport and applied a correction factor, depending on the amount of rainfall, with the equation:

$$Q_{rain}=C_{rain}*Q \qquad (8)$$

with C_{rain}:

daily rainfall	correction coefficient C_{rain}
0-2 mm	1
2-5 mm	0.8
5-10 mm	0.5
10-20 mm	0.2
20-50 mm	0.1
> 50 mm	0

Results

Table 1 shows the results of the transport calculations. Columns "Bagnold" and "Kawamura" give the calculated daily landward transports using the equations 3 and 4. Column "Empirical" gives the estimated daily landward transport based on the empirical equation (equation 2). Column "measured" gives the "measured" daily landward transport rates, based on direct measurements and extrapolations.

Table 1. Sediment budgets for days with aeolian events; predicted and measured.

date	*Bagnold* $m^3m^{-1}.day^{-1}$	*Kawamura* $m^3m^{-1}.day^{-1}$	*Empirical* $m^3m^{-1}.day^{-1}$	*"measured"* $m^3m^{-1}.day^{-1}$	rain (mm)
31-12-98	5.54	9.98	2.46	8.25	2
9-2-99	0.54	0.78	0.16	0.16	0
24-2-99	0.27	0.32	0.09	0.02	0
3-3-99	0.48	0.68	0.16	0.12	0
4-3-99	0.21	0.28	0.01	0.01	0
10-3-99	0.42	0.51	0.10	0.00	1
11-3-99	0.46	0.61	0.12	0.05	23
12-3-99	0.76	1.15	0.39	0.04	10
13-3-99	0.11	0.13	0.05	0.00	16
23-3-99	0.00	0.00	0.00	0.00	0
24-3-99	0.19	0.19	0.02	0.00	0.1
25-3-99	0.38	0.57	0.09	0.09	6
26-3-99	0.19	0.29	0.01	0.01	0
Total	9.55	15.52	3.66	8.75	-
Total 1999	4.02	5.53	1.20	0.50	-

In general the predicted daily transports are much higher than the measured transports. Surprisingly, for the big storm event at 31-12-1998, the "measured" transport is in the same order of magnitude as the predicted transport. The empirical equation predicts a much lower transport. Figure 2 illustrates wind speeds and predicted landward transport for 31-12-1998. For days with a lot of rain, transport is often limited or even zero. For these days, predictions are worst (for example 11 and 12 March).

In total, the measured transport into the dune area over 1999 is approximately 0.5 m^3m^{-1}, which is very low. Compared to the transport at 31-12-1998 of 8.75 m^3m^{-1}, this is even almost insignificant. In the predictions the contribution of the 31-12-1998 event is less important, but still accounts for about 60% of the total transport in the period 31-12-1998 to 28-03-1999.

There are several reasons for the deviation between predicted and measured transport. The two most important reasons are rainfall and restriction to the sediment source. The beach at Ancão is narrow and steep, and the fetch therefore is often limited. In many cases the wind will not be saturated with sand because the distance for saltation to develop is too short. Because of the presence of coarse, badly sorted material, the threshold for transport is variable. During gentle winds, the finest grains will be removed, after which the threshold rises and transport may be limited or even completely restricted. During very strong winds, also thresholds for coarse grains may be exceeded, and transport may be less restricted. Finally, the transport equations use a threshold velocity at which transport on the beach starts. It can be argued, that threshold velocities for landward transport are much higher, because only at higher wind speeds sand is actually moved over the vegetation. At lower wind speeds, sand may be transported on the beach, but transport in or over the vegetation will be zero. All these factors are not taken into account with the use of transport equations. This has to be kept in mind when the results of transport predictions are analysed. The predictions give some upper limit for the aeolian sediment budget. The actual budgets will be lower.

For the prediction of the long-term sediment budget we have used the Faro Airport data from July 1997 to March 2000. We also applied a correction for transport during rainy days, as was explained in the methods. Figure 3 displays the direction of winds that are accompanied by rain. It is obvious that most rain comes with westerly or south-westerly winds, which are also the winds that can transport sand to the dunes. In Table 2 days with rainfall are arranged according to their wind speed. The results of the calculations are given in Table 3.

Table 2. Cross-table, showing combination of wind-rain events. The numbers indicate the number of days in the period July 1997 to December 1999.

	0-5	5-8	8-10	10-12	12-16	16-20	>20	TOTAL
0	130	485	49	52	3	-	-	719
0-1	4	49	8	7	1	1	-	70
1-2	1	6	-	2	1	-	-	10
2-5	6	18	8	7	-	-	1	40
5-10	1	15	3	6	3	-	-	28
10-20	-	6	5	10	3	-	-	24
20-50	-	3	3	6	2	1	-	15
TOTAL	142	582	76	90	13	2	1	906

Table 2 shows that although days without rain are dominant, days with much rain (more than 5 mm) are mostly also days with strong winds. With the given correction factors (see methods) the effect of rain on transport results in a reduction in transport of about 30 to 50%. Figures 4 and 5 prove that mainly the south to southwesterly component becomes less important.

Table 3. Yearly predicted and extrapolated aeolian sediment budgets, Ancão (onshore winds 225 degrees).

	Q_Bagnold m^3m^{-1}	Q_Kawamura m^3m^{-1}	Q_Emperical m^3m^{-1}	Q_Kawamura with rain corr. m^3m^{-1}	Q_empirical with rain corr. m^3m^{-1}
1997 (from July)	29.3	43.9	10.9	21.3	5.3
1998	42.9	60.5	14.8	46.9	11.4
1999	38.0	49.5	12.0	38.3	9.2
2000 (to March)	1.9	1.9	0.4	1.7	0.4

In Table 4 we have made some calculations of landward transport using higher threshold velocities. Only at higher wind speeds (above 8 m/s) sand is actually taken up by turbulence and moved over the vegetation. The stronger the wind, the higher the sand will be lift up and the further it can be transported landward. In this sense it might be argued that for different zones of the dunes different thresholds should be used. In Table 4 the results for three higher threshold velocities are used, corresponding to wind speeds at Faro Airport of 8.0, 9.0 and 10.0 m/s. On days with transport over the dunes, wind speeds at Faro Airport were 10 m/s during part of the day.

Table 4. Yearly predicted and extrapolated aeolian sediment budgets, Ancão (onshore winds 225 degrees) for several threshold velocities (wind speed at Ancão dune crest, 4.2 m height), with rain correction.

	with U_t=8.6 and U_{*t}=0.44		with U_t=10.0 and U_{*t}=0.51		with U_t=11.3 and U_{*t}=0.58	
	Q_kawamura m^3m^{-1}	Q_empirical m^3m^{-1}	Q_Kawamura m^3m^{-1}	Q_empirical m^3m^{-1}	Q_empirical m^3m^{-1}	Q_empirical m^3m^{-1}
1997 (from July)	12.0	2.9	7.0	1.6	3.9	0.8
1998	28.4	6.8	20.1	4.6	14.7	3.4
1999	18.3	4.4	9.8	2.2	4.5	1.0
2000 (to March)	0.5	0.1	0.1	0.0	0.0	0.0

It is obvious that the higher thresholds result in a lower transport and an increasing importance of the 31-12-1998 event. The number of events with landward sand transport decreases dramatically. Figures 6 and 7 visualise the monthly distribution of aeolian transport. Highest peaks are observed in the period October-December, but this also coincides with the largest amounts of rainfall. The predicted transport in the period January to March 1999 is much larger than we observed in the field. In those months there was hardly any transport to the dunes. When applying a high threshold the number of months with significant transport to the dunes declines. Only the winter months contribute to dune building, which is much more conform reality.

Figure 8 shows the different sand roses, using a low and a high threshold velocity.

The predictions with the Kawamura equation can be considered as the maximum possible transport on the beach when all conditions for aeolian transport are optimal. The actual transport will be much lower, and will probably be in the range of the transport predicted with the empirical equation. However, based on the experience during the fieldwork, the deviation between the empirical and measured values, and the experience of researchers of the University of Algarve (O. Ferreira, personal communication) with dune building in the area, we believe that the actual yearly transport is in the order of 0-5 m^3m^{-1}. We can conclude that it probably is much more realistic to use a higher threshold wind speed for sand that is finally transport into the dunes for a more realistic estimation of sediment budgets.

Similar calculations can be made for other parts of the Faro barrier islands. For example, for Culatra the coastal exposition is 135º. In this case the landward component of aeolian transport is much lower, as is evident from Table 4, mostly because westerly winds do not contribute to dune building here. Transport to the dunes on the southeasterly exposed barriers is about 1/3 of the transport at Ancão.

Table 5. Yearly predicted and extrapolated aeolian sediment budgets, Culatra (onshore winds 135 degrees)

	Q_Bagnold m^3m^{-1}	Q_Kawamura m^3m^{-1}	Q_emperical m^3m^{-1}	Q_Kawamura with rain corr. m^3m^{-1}	Q_empirical with rain corr. m^3m^{-1}
1997 (from July)	9.5	14.3	3.8	6.2	1.9
1998	11.8	17.6	5.4	12.3	4.1
1999	6.0	7.1	1.8	3.2	1.1
2000 (to March)	0.7	0.4	0.5	0.4	0.5

Conclusions

It is clear that the calculation of sediment budgets involves many uncertainties. The differences between observations and calculations are high. A best match between observations and predictions is obtained when a high threshold wind velocity is used. The most important arguments to use a higher threshold velocity is that only during very strong winds sand is actually lifted up and moved over the vegetation into the dunes. During gentle winds, transport on the beach is observed, but this is restricted to the bare zone. This sand moves to the upper part of the beach and stays there until very strong winds transport it further landward.

Application of transport equations give more insight in the distribution of transport over the year, the year to year variability and in potential differences in sediment budget between sites in the same region but with a different coastal aspect. When using a high threshold velocity (10 m/s for Ancão crest, 4.2 m height) it appears that most of the dune building occurs in the months October to December (1998, 1999) and sometimes also in the other winter months (winter 1997-1998). Transport in 1998 is much higher than in the other years, which is related to the big storm of 31-12-1998.

For dunes with a southeast exposure, which is the case for most of the easterly barrier islands, the sediment budget is much lower than for Ancão. The estimated aeolian sediment budget is about 1/3 of the sediment budget of Ancão.

Figures

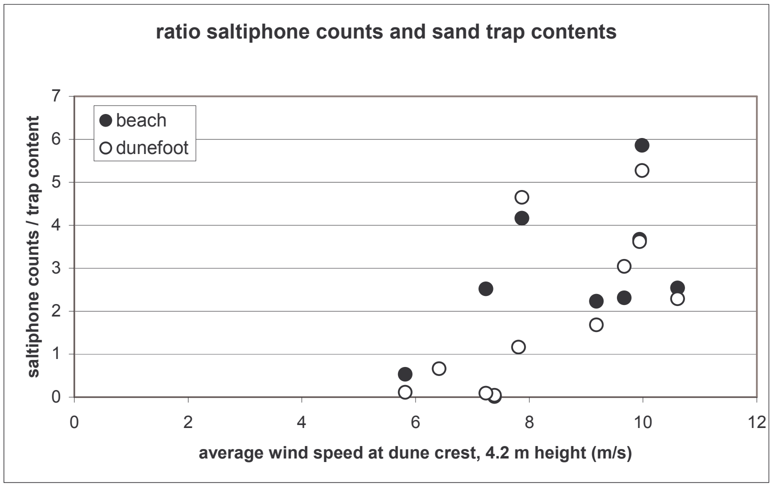

Figure 1. Ratio between saltiphone counts and sand trap content for different periods of time.

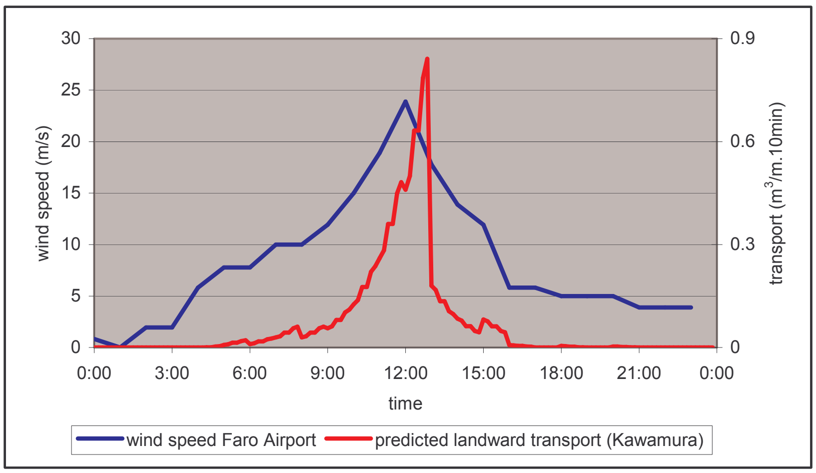

Figure 2. Wind speed at Faro Airport and predicted landward transport with Kawamura's equation for 31-12-1998.

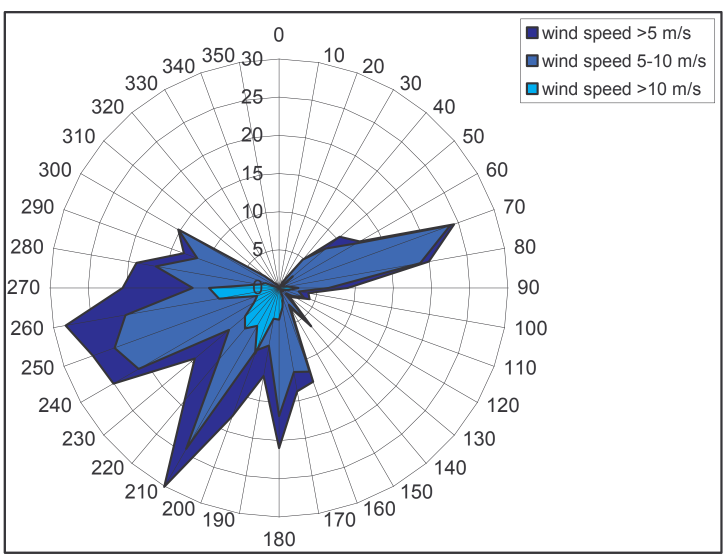

Figure 3. Wind / rain rose showing direction of rain carrying winds, with rain in millimetres.

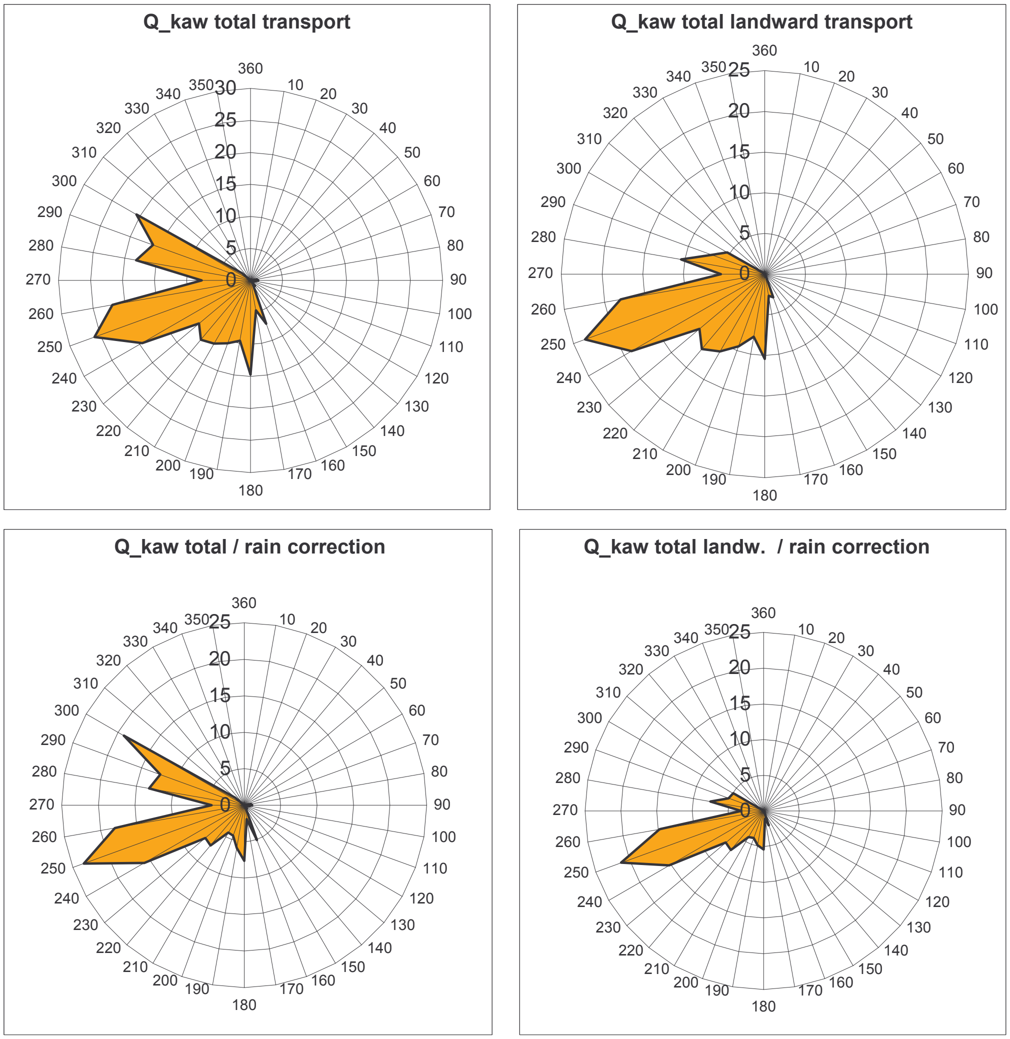

Figure 4. Sand rose showing predicted total (left) and landward (right) transport without (above) and with (below) corrections for rainfall.

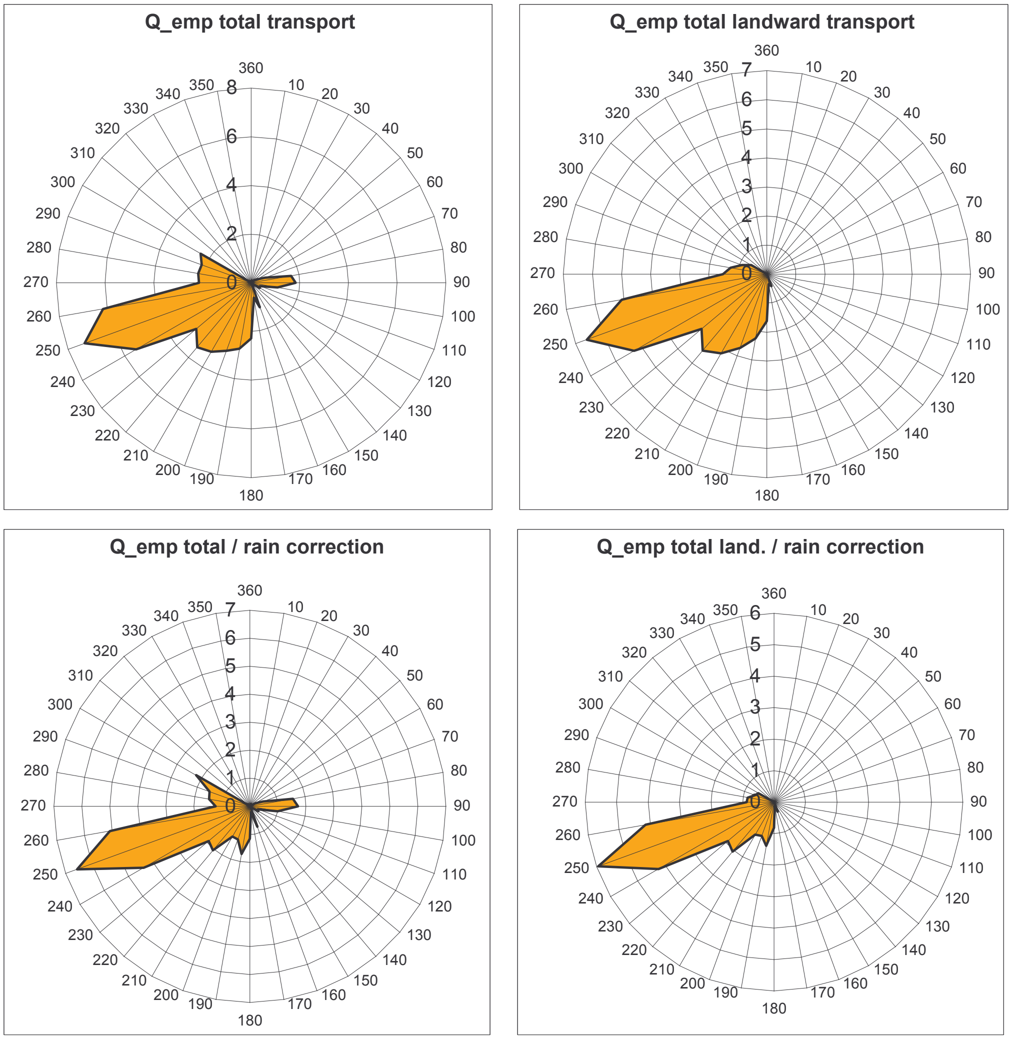

Figure 5. Sand rose showing extrapolated total (left) and landward (right) transport without (above) and with (below) corrections for rainfall.

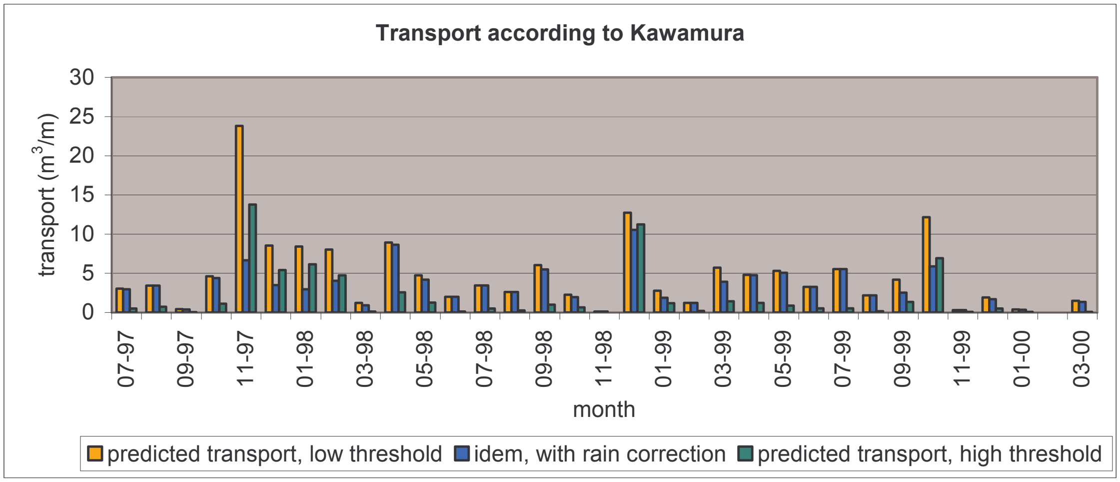

Figure 6. Monthly potential transport calculated with Kawamura's equation, and calculated transport with correction for rainfall.

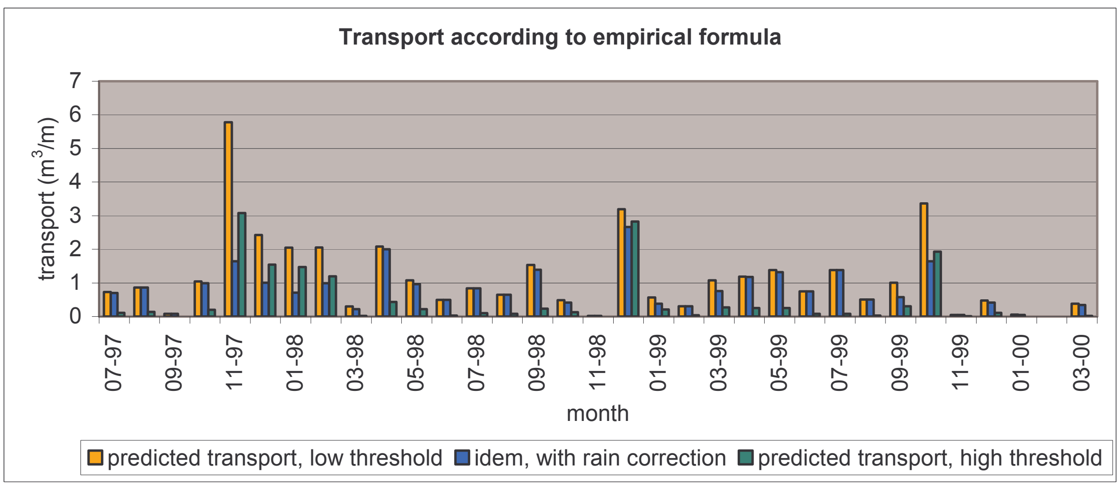

Figure 7. Monthly potential transport calculated with the empirical equation, and calculated transport with correction for rainfall.

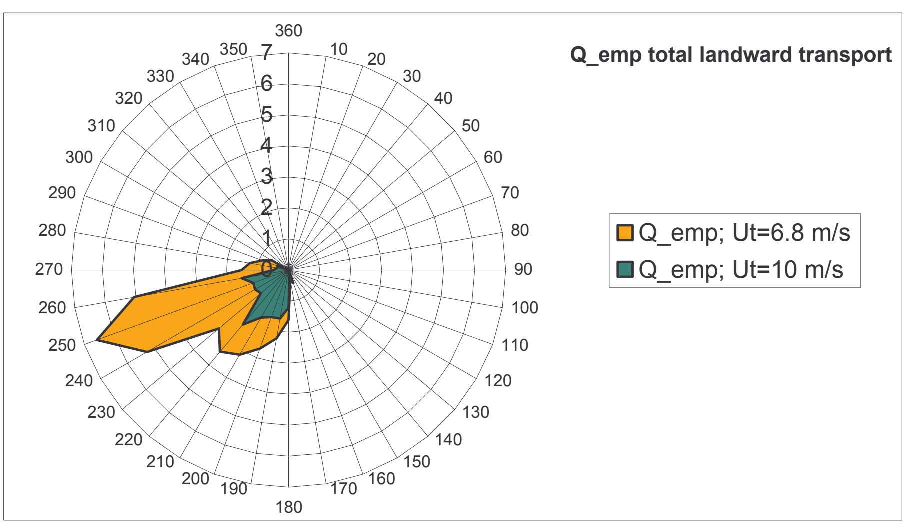

Figure 8. Calculated empirical transport with low threshold (transport on beach) and high transport (transfer into dunes).