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Landscape Evolution and Human Alterations of the Aeolian Sediment Dynamics in the Jandía Isthmus (Fuerteventura, Spain)

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Abstract: Analysis of the landscape evolution in the isthmus of Jandía (Fuerteventura, Spain) between 1963 and 1992 has been carried out using Geographical Information System (GIS). The effect of human alterations on the aeolian sediment transport across the isthmus is considered using GIS data, as well as from the spatial and temporal variability of the sediments. Measurements of the aeolian transport rates by means of sediment traps have allowed us to determine the predominant pathways of the aeolian sediment flux.

Key words: aeolian sediment transport, human alterations, landscape evolution, Fuerteventura

Introduction

The Jandía isthmus presents the most important aeolian sedimentary deposit in the Canary Islands. Sediments are transported across the isthmus by trade winds until they reach the Sotavento beaches, located on the southern coast of the isthmus. These beaches reach up to 20 km in length, and sediments are moved southward by waves and currents. Therefore, both the Jandía isthmus and the Sotaviento beaches are considered parts of the same sedimentary system.

As in many other places around the world, economic interests often conflict with those of conservation. The former mainly refers to two important tourist resorts located along the aforementioned beaches; a wind station which has recently been located in the centre of the area and a marina that is planned to be built. On the other hand, a large area of the isthmus is included within the limits of the Jandía Natural Park whose geomorphological characteristics are defined by its complex evolution (Criado, 1991). Apart from that, the area is important from the point of view of palaeoclimatic evolution, since three kinds of marine deposits (Mio-Pliocene, Upper Pleistocene and Holocene) are evident. These are representative of a warm climate which has been followed by dune formations and palaeosoils from a humid climate (Meco, 1993).

Previous studies in the area have been undertaken by Carracedo (1989), whose purpose was the evaluation of available arids to be extracted. Fernández (1990) was the first to estimate the sediment transport across the isthmus; Höllermann (1990) considered the evolution of two longitudinal dunes at the south of the area, and Alcántara-Carrió *et al.* (1996) obtained several transport rates at different locations of the isthmus.

Description of the Study Area

The isthmus of Jandía is located in the Southern part of the island of Fuerteventura (Canary Islands). It is oriented NE-SW and covers an extension of 54.5 km^2. The general topography is quite flat, since the highest point is Loma Negra at 322 m. There are small wadis which are dry most of the time, except just after sporadic heavy rains. These wadis tend to cross the isthmus in a shore-normal way.

Two coasts limit the isthmus. The Barlovento coast to the north is quite steep with sandy cliffs that reach up to 40 m in certain areas. On the other hand, the Sotavento coast to the south presents a mainly basaltic cliff 20 m high, which is broken by the different wadis that end at the coastline. In front of the cliffs there is a very wide coastal sedimentary environment, which consists of areas of beach, lagoon, littoral barrier and marsh.

Most of the isthmus is covered by sands, which spatially present different degrees of consolidation. There are wide areas of mobile sediments, important deposits of slightly stabilized sediments, as well as basaltic stony places and more reduced areas of carbonated crusts. The semi-arid and nearly desert-like climate determine that the vegetation is sparse, but isolated bushes or small groups of individuals may be found all across the isthmus.

Landscape evolution

As human activities may determine certain geographical changes on a given region, human alterations should be viewed as an integral component of landscape evolution (Nordstrom, 1994). A landscape unit map has been made from aerial colour photographs taken on April 1992. As the photograms scale of 1:50,000 has defined the resolution of the final map, this map should be considered as a first approximation which could be improved using higher scale photograms. The general criteria used to make this map are: characteristics of the sandy basement, topography, vegetation and human activities. The resultant map shows 6 groups with 16 types of landscape units, the designation and surface (in km^2 and percentage of the area) of which is shown in Table 1.

Another landscape units map derived from 1963 photograms was made in order to determine the recent landscape evolution. Since the scale of these ones was 1:18,000, they had to be corrected to 1:50,000 in order to use the same scale in both series. The final landscape evolution map (Figure 1) results from the comparison of both maps, which were digitised and introduced into the IDRISI GIS program from the Graduate School of Geography of the Clark University, (Massachusetts, USA). Table 2 shows the detected changes and its extension.

Figure 1 shows a significant change in nearly 20 % of the area. The main superficial changes are due to extractive activities (3.7 km^2) while almost 3 km^2 of the moving sands have shown a certain degree of stabilisation, probably due to a long term tendency for an increase in vegetation, or perhaps due to seasonal changes

Table 1 Classification of the landscape units from the 1992 aerial photograms

Landscape Unit	Area (km^2)	Area (%)
Group I: Deposits of mobile aeolian sand		
Deposits of mobile aeolian sand on high slope area	6.21	11.45
Littoral dunes	0.14	0.26
Deposits of mobile aeolian sand covering small wadis	0.75	1.38
Deposits of mobile aeolian sand on domical hills	1.90	3.50
Group II: Deposits of slightly stabilised aeolian sand		
Deposits of aeolian sand filling small holes	0.48	0.88
Deposits slightly stabilised by vegetation on moderate slope areas	10.26	18.92
Deposits slightly stabilised by vegetation on domical hills	2.53	4.67
Microbasins covered by clayed-sandy deposits	5.42	10.00
Deposits of aeolian clayed-sandy sediments on domical hill slopes	0.84	1.55
Serir type deposits	6.00	11.07
Group III: Deposits of compacted aeolian sand		
Deposits of compacted aeolian sand on moderate slopes	4.33	7.99
Deposits of compacted aeolian sand with carbonated crust on plain	6.00	11.07
Group IV: Tidal units		
Marsh lagoon and littoral barrier	2.64	4.87
Group V: Sandless units		
Basaltic rocks	1.50	2.76
Group VI: Human affected units		
Extractive areas and rubbish dumps	3.94	7.27
Resorts isolated buildings and aeolian park	1.28	2.36
Total	**54.22**	**100.00**

Table 2 Extension of the different changes detected from the evolution landscape maps

Cartographic categories	Area (km^2)	Area (%)
No significative changes	43.61	80.43
Decreased bush coverage	0.05	0.09
Increased mobile sand	2.51	4.63
Stabilised sand	2.95	5.44
Extracting areas for construction	3.67	6.77
New developed areas and isolated instalations	1.43	2.64

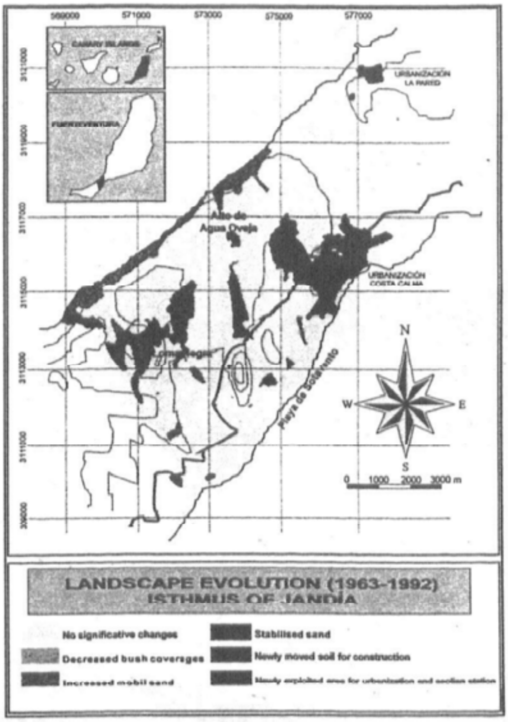

Figure 1 Map of landscape evolution between 1963 and 1992

between the flights in which the photograms were taken. The area of moving sands have shown a significant increase of 2.5 km², while the extension of new urban areas (excluding new roads) covers around 1.4 km² (Table 2).

Analysis of the human alterations

At present there are numerous human actions on the isthmus, particularly affecting the Natural Park and the Sotavento beaches. Due to the complexity of the system and the multiple interactions, it was not possible to quantify each effect. Therefore, the evaluation of each human alteration was only qualitative, considering the location, the orientation, and the rate of horizontal and vertical extension of the alteration (Figure 1).

The most important alterations are the resorts. Buildings, all kinds of service installations, and dense vegetation planted by humans form an impermeable obstacle to the sediment flux. As Fernández (1990) stated, an increase in the resorts extension without proper planning will affect the sedimentary stability of the Sotavento beaches. Furthermore, the presence of ruined buildings and uncontrolled rubbish dumps disturb the aeolian transport of sediments.

During the last decades a considerable demand for sand used for construction purposes has lead to the apparition of numerous non-controlled extractive areas. These can be observed in Figure 1. In order to control this activity, since 1994 sand extraction has been allowed only from one location in the South of the isthmus. This has resulted in a significantly sized excavation of 200 x 40 x 7 m. As this hollow is located in the region of major aeolian sediment transport, it is necessary to do a more detailed study of its effects or to find an alternative zone for extraction so that it will not affect the natural flux of sediments.

A road passes through the isthmus perpendicular to the main direction of the sediment transport. It presents an important interaction with the sediment dynamics. The influence this feature has on the sediment dynamics is more significant in the area where the road is more elevated and thus disturbs the movement of sediments. Finally, numerous secondary tracks for leisure activities also affect the natural sediment dynamics, although this effect has not been considered as important as the previous ones.

Characterisation of the aeolian sediment dynamics

As previously described human alterations affect the natural dynamics of the sediments in the isthmus which has been analysed from two points of view: the spatial and temporal distribution of sediments, and the effective aeolian sediment transport.

Spatial and temporal variability of sediments

In order to characterize the aeolian sediments, two surveys were conducted in August and December, 1995, to collect superficial sediment samples across de isthmus. Sampling spots were selected according to the different units defined from the 1992 landscape units map. Grain size parameters were computed using the statistical moments method, which can de found elsewhere (e.g. Carver, 1971; Pettijohn *et al.*, 1973; Friedman & Sanders, 1978). From Friedman's diagram (1961) of mean size versus sorting, where the classification of Gläser is applied (for a further explanation on Gläser's classification, refer to Höllermann, 1990), we have defined the aeolian moving (M), the aeolian stability (S), the aeolian residual (R), or the fluvial character (F) for each sample.

Sediments with residual aeolian properties (R) are predominantly found in the region where there are basaltic rocks or carbonated crusts. Samples taken from dunes are considered as aeolian mobile (M).

By comparing the grain size properties of the samples taken in August and December (Figure 2), it can be observed that samples taken initially tend to be in the aeolian mobile sector, while those of December better fits into the stable sector, and even some samples show a residual aeolian character. The difference in grain size is due to the seasonal variability of the aeolian dynamics of the area.

With regard to the spatial distribution of the sediments, three main areas can be distinguished. In the southern part of the isthmus there are sediments which are transported by wind during throughout the year. The southern part is thus the largest and the most important region of mobile aeolian sediments (M). Alternatively the northern sector is characterized by mainly stable sediments (S), with less aeolian transport. However some exceptions can be found at the borders of the

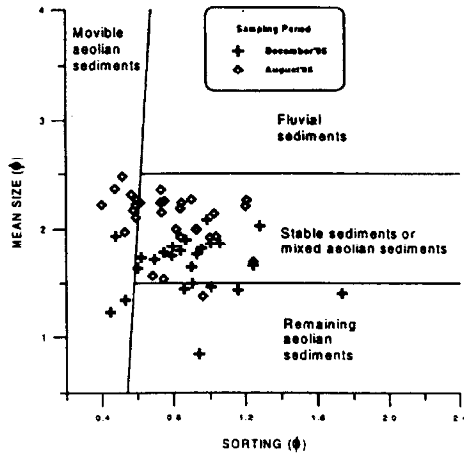

Figure 2 Classification of sediments according to Gläser method (1987)

small wadi, where sand accumulations are present due to the sudden changes in topography. The third area corresponds to the central region, which presents the largest seasonal variation of sediment characteristics, which are mobile in August and stable in December.

Aeolian sediment transport

There are many equations in the literature which can be used to evaluate the aeolian sand transport (Horikawa *et al.*, 1986). Most of these equations are theoretical and consider the sediment transport in ideal conditions (dry sand, homogeneous grain size, uniform and stationary wind field, logarithmic velocity profile and a plane horizontal and wide bed). Other authors have considered the transport under non-ideal surfaces and have focused on the effect of vegetation, slope, and sediment cohesion due to moisture or crusts (Sherman & Hotta, 1990). Nevertheless in all these works, field measurements require the use of *in situ* traps, to determine the effective transport on that area under that particular environmental conditions (Sarre, 1988; Goldsmith *et al.*, 1990).

In this study, sediment trap stations were made following Leatherman's trap design (Leatherman, 1978) and Goldsmith *et al.* (1990). Each station consisting in four traps orientated to the North, South, West, and East. The ability of these traps stations is that they allow the study of the main direction and magnitude of the aeolian sediment transport, and therefore, directional sediment transport rates may be obtained.

Wind data from the aeolian station of Cañada del Río, located in the centre of the isthmus, show that trade winds from the N-NNE were predominant between April and September, while there is a greater variability in wind direction during the rest of the year. There are also shorter period variations (daily and even hourly) that obviously affect the aeolian transport.

As a resulting of this wind pattern, the sediment distributions previously described and the trap stations placed in the area during the August and December surveys,

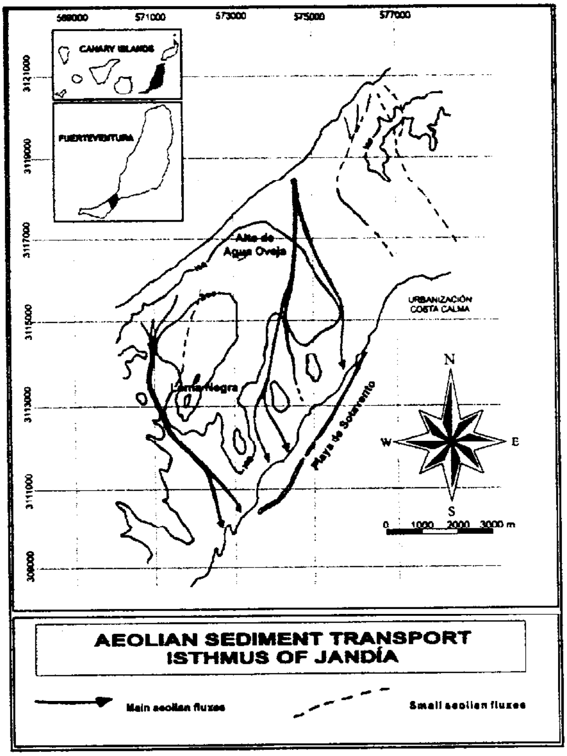

Figure 3 Main pathways of the aeolian sediment transport across the isthmus of Jandía

it has been found that the dominant aeolian transport direction for all stations and for both periods is from the N, with the highest transport rates along the upwind coast (Alcántara-Carrió *et al.*, 1996).

From these results, the main pathways for the aeolian sediment movement are shown in Figure 3, where such pathways are due to the interaction of the natural wind field, sediment dynamics, topography, type of substrate and the human activities. It can be observed that the northern sector presents a decreasing sediment transport which is reduced to no transport near the Sotavento coast. In the central region, sediments pass through various channels, one of which is reduced due to the presence of one of the resorts and some rubbish dumps. Finally, the southern region presents the most important aeolian sediment transport, which flows through the ravine of Pecenescal, and generates two longitudinal dunes at the Sotavento beaches.

Conclusions

From comparisons of 1963 and 1992 aerial photograms using GIS, it has been possible to determine the different physical changes that have occurred in the Jandía isthmus during the last three decades. The results of this analysis show that around 20% of the total area has been significantly altered.

Three areas in the isthmus have been distinguished based on the ability of the sediments to be transported by wind. Sediments in the northern sector have resulted to be mainly stable, those in the southern one are predominantly mobile, while sediments in the central sector are mobile in summer time and quite stable during the rest of the year.

From sediment trap data, the most important pathways of sediment transport have been recognised. These pathways have been altered by human activities, and some of them have even been completely blocked as a result of the development of tourism in the area.

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