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Assessment of the Erosion Risk in Humid Mediterranean Areas

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1 INTRODUCTION

The soil erosion is one of the main problems for agriculture in the Mediterranean countries of the EU (Giordano & Marchisio, 1989). Several works have been done about erosive status mapping at regional scales in Spain (ICONA, 1983; ICONA, 1988) or in other places (Bougonoviae *et al.*, 1999). The soil erodibility has frequently been calculated from the lithological nature of the substrate (ICONA, 1983; ICONA, 1986; Díaz-Fierro & Benito, 1991; Moreira, 1991). Some authors have made some contributions relating the concept of erosive states and the acting geomorphic processes (Perles, 1994-95). Bellinfante *et al.* (1999), Martínez-Zavala *et al.* (2000) and Jordan *et al.* (2000) have carried out some interpretations of the erosive processes geomorphologically active in the area, as well as of their intensity in connection with the erosion risk.

During the last years, the Department of Crystallography, Mineralogy and Agricultural Chemistry of the University of Seville has followed a research trend based on the cartography of geomorphoedaphic units in protected natural spaces (Paneque *et al.*, 1997; Paneque *et al.*, 1999). The characterization of geomorphoedaphic units includes the description of main variables (lithology, slope, land use, morphogenesis and soil type) and several secondary variables (as the geomorphologic processes or the physiography). As a result of these investigations, and using GIS, diverse thematic maps have been made, helping to define erosive status maps at a semi-detailed scale. At the present time, studies on the erosion risk are being developed in several points of SW Spain, as the Campo de Gibraltar (135498 ha) in Cádiz or the district of the Andévalo (102443 ha) in Huelva.

The mapping of erosive status of the study area was carried out following the methodology proposed by PAC/RAC (1997). It shows that a great part of the land presents apparently low levels of erosion risk, which are not adjusted to the intensity of the active erosive processes, as observed in the field. This fact has been observed so much in the area of the Strait of Gibraltar like in the Andévalo. In humid and subhumid areas, as some natural spaces of SW Spain, where the erosive effects of the rainfall can be extremely high at a local scale, estimations about potential erosion risk cannot be accurate if climatic aggresivity is not considered. So, in the case of the Campo de Gibraltar, the use of the Fournier Modified Index (FMI) allowed to map the erosion risk, relating it to the intensity of the erosive processes observed in the field. Pluviometric data are easily available, and the GIS technology allows its integration in the assessment of the erosion risk.

2 STUDY AREA

The Campo de Gibraltar is a natural area where the irregularity of the climate, the performance of the chemical processes, the degradation of the vegetation cover, the lithology and the high slopes constitute a group of specially aggressive erosive factors (Ibarra, 1993). Most of the territory is constituted by marginal lands or with a low use capacity (de la Rosa & Moreira, 1987).

The Campo de Gibraltar area is the most southern portion in the European continent (Figure 1). It includes part of the Sierra of the Algibe, constituted by siliceous sandstone, included in Los Alcornocales Natural Park; although the mountain is not very high (the highest point is the pick Algibe, 1091 m) the relief is extremely sharp. Inserted in the valleys and in the periphery of the mountains are presented clays and basic materials as calcareous sandstone and loams. The climate is humid or subhumid mediterranean (annual 600-1400 mm), with strong Atlantic influence (Figure 2). The maximum and minimum temperatures are softened due to sea proximity and the winds action that produce an effect of marine spray. This contribution of humidity allows the formation of persistent fog and high precipitation level in many points of the mountain. The humidity index in these points is over 1. The dominant vegetation is generally oak forest (*Quercus suber* and *Q. canariensis*) (Díez *et al.,* 1988). The understorey is dominated by species of leguminosae and heath. A broad-leaved forest grows near the streams, with species like *Alnus glutinosa* and *Frangula alnus*, or characteristic shrubby species as *Rhododendron ponticum* subsp*. baeticum.*

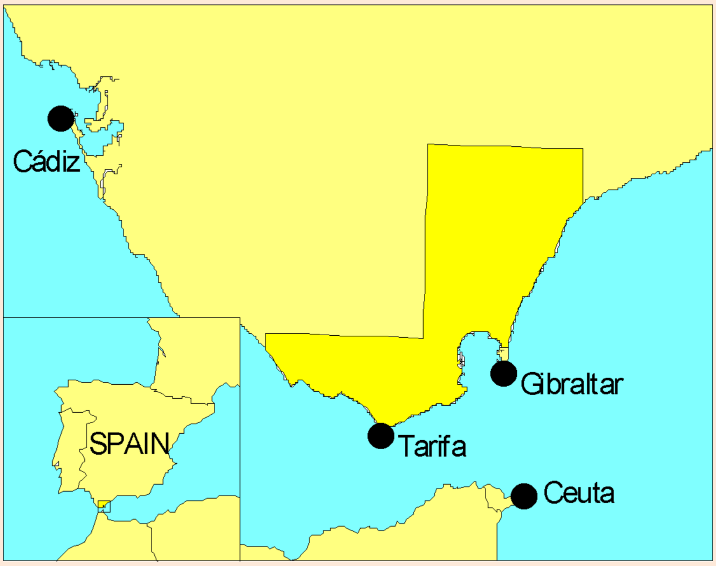

Figure 1. Location of Campo de Gibraltar.

3 METHODS

3.1 MAPPING OF EROSIVE STATUS

The erosive status map was carried out through several steps: land use map, soil map, vegetation cover map, soil protection map, slope map, lithofacies map and erodibility map.

The integration of these factors allowed us to divide the territory in stable units, not affected by erosion, and unstable units, affected by erosion. The mapping of erosive status was carried out by a method based on that used by PAP/RAC (1997) as shown in Figure 3.

The photointerpretation was carried out drawing the polygons on transparent undeformable material, placed on false color satellite images (Landsat-TM), georeferenced and geometrically corrected. The whole graphic information was rasterized by scannig, vectorized and processed by a GIS (ARC/INFO).

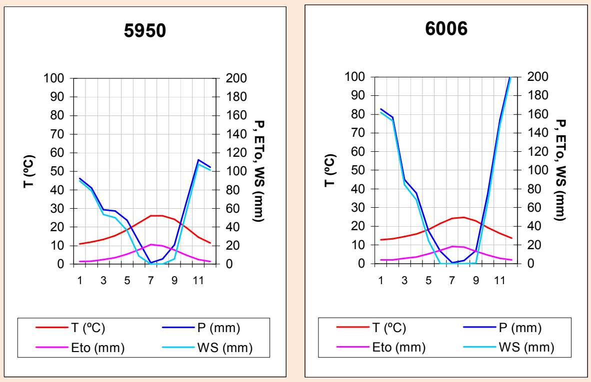

Figure 2. Climatic regimes in two stations from the study area. Guadalcacín Reservoir (5950) and Algeciras (6006).

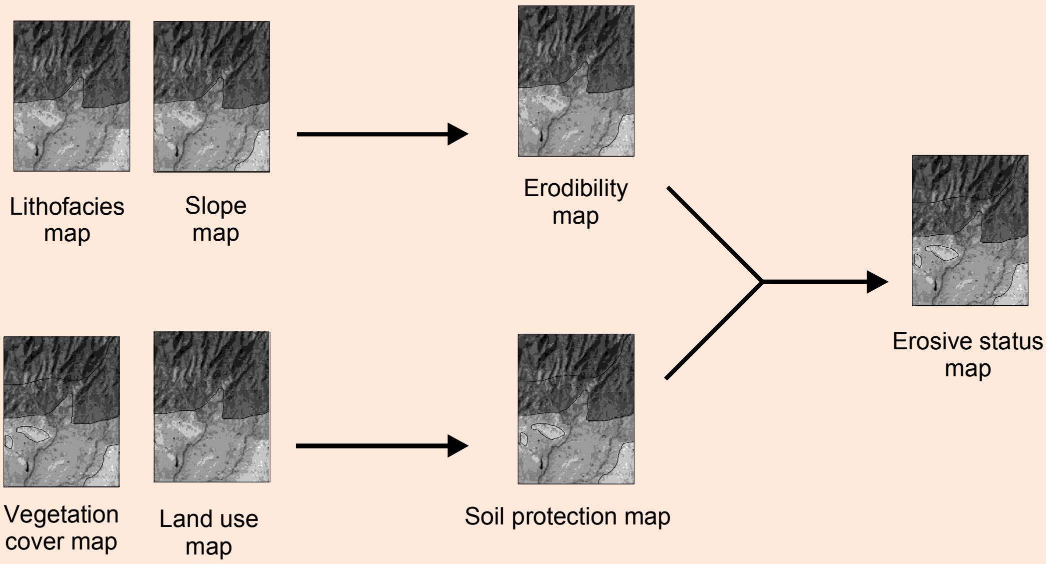

Figure 3. Scheme of the general methodology.

The slope map was carried out from the DTM. The lithofacies map was made using published geologic cartography and soil data. Eighty soil profiles were described and analyzed. The main morphological and chemical parameters used to supplement the lithological information were the following ones: soil depth, pH, organic carbon and organic matter, cationic exchange capacity, clay ratio and the hydraulic conductivity.

The erodibility map was obtained by overlapping the slope map and the lithofacies map. The land use and vegetation cover maps were made by photointerpretation of aerial photographs (S 1:20.000). The map soil protection map was obtained integrating these maps. Finally protection and soil erodibility maps were overlapped to obtain the erosive status map.

3.2 EROSION RISK

The erosion risk map was carried out from the erosive status map and the FMI. Pluviometric data from 109 representative meteorological stations were collected. In order to estimate the rainfall erosivity in the Campo de Gibraltar the FMI was calculated, since this index considers the precipitation of every month (Arnoldus, 1978). The Fournier index and other factors that consider only the rainiest month in the year are suitable for those types of climate where only exists one maximum of precipitation and where the rainy period is short. In the Campo de Gibraltar, however, there are at least two maximal precipitation picks (often in February and December), as well as rainfall is high in every month of the humid station. These months also have a strong incidence on the erosive processes, independently that they are a maximum or not (Jordan & Bellinfante, 2000). The FMI is calculated by the following equation:

$$FMI = \sum_{i=1}^{12} \frac{p_i^2}{P_t}$$

where: IMF is the Modified index of Fournier; p_i is the monthly half precipitation; P_t is the annual average rainfall.

In order to obtain information about the distribution of the climatic aggresivity in the Campo de Gibraltar, FMI data associated to each station were interpolated (Inverse Distance Weighted method; Watson and Phillip, 1985). So, a raster image was generated with a spatial resolution of 50x50 m^2. The FMI values were classified as proposed by CORINE-CEC (1992), as shown in Table 1

The erosion risk in the Field of Gibraltar was determined by overlapping the erosive status map and the FMI map. So a new subdivision of the polygons was made. The erosion risk was calculated according to the following equation:

$$R = ES \times FMIc$$

where: *R* is the erosion risk; *ES* is the erosive status class; *FMIc* is the FMI, classified according to the Table 1. The erosion risk values range from 1 to 20 (Table 2). Five erosion risk classes were determined, as shown in Table 3.

4 RESULTS

4.1 EROSIVE STATUS

4.1.1 PREDICTIVE PHASE

According to the methodology proposed by PAP/RAC, 5 lithofacies classes were determined (Table 4). The classification has been done on the basis of different previous works (ICONA, 1982; ICONA, 1986; Moreira, 1991; PAP/RAC, 1997). It has also been used soil parameters for lithological material clasification.

The slope classification was done using the DTM. The slope levels were classified as shown in Lowlands present low slope levels, while the relief in Algibe mountains is very sharp (in many points slope is higher than 76%). By overlapping of the lithofacies map and the slope map, we obtained the soil erodibility map.

The different land use types were defined by photointerpretation of aerial photographs and satellite images (Landsat-TM). Land use and vegetation published maps were used as a support. The determined land use classes and the vegetation cover values are shown in Table 6.

The map of erosive status was obtained by overlapping the soil protection and the erodibility map. The final map is shown in Figure 4. The erosive processes map (Figure 5), the mass earth movement map (Figure 6), the karstic processes map (Figure 7), the agradation map (Figure 8) are also shown.

Table 1. Classification of FMI values, as CORINE-CEC (1992).

Class	Range	Description
1	<60	Very low
2	60-90	Low
3	90-120	Moderate
4	120-160	High
5	>160	Very high

Table 2. Calculation of the erosion risk starting from the erosive status (ES) and the modified index of Fournier (FMI).

ES	FMI				
	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15

Table 3. Classification of the erosion risk (ER).

ER	Class	Descripción
1-4	1	Very low
5-9	2	Low
10-14	3	Moderate
15-19	4	High
20-25	5	Very high

Table 4. Lithofacies classes.

Class	Lithofacies	Description
A	Non-weathered compact rocks or soils.	Conglomerates or highly cemented soils. Sandstone outcrops and low erodible soils on sandstones. Massive limestones, with protected soils. Highly stony soils.
B	Moderately weathered rocks or soils.	Marly sandstones and limestones. Calcareous sandstones. Plutonic rocks.
C	Slightly to medium compacted rocks or soils.	Clayey sandstones. Soils on conglomerates. Metamorphic rocks (quartzites, phyllites and schists). Protected soils on flysch materials. Compacted marls.
D	Low resistant or deeply weathered rocks or soils.	Clays. Weathered soils on calcareous sandstones. Lowly cohesive marls.
E	Non cohesive sediments.	Sand and dunes. Highly erodible soils on flysch materials. Silt and marshes. Very lowly cohesive marls and sediments. Detritic materials.

4.1.2 DESCRIPTIVE PHASE

In the descriptive phase, stable areas (those where the erosive status is very low) and unstable areas were analyzed separately.

The stable areas are constituted by wide rocky outcrops and by protected forest or irrigated crop areas.

Erosive processes, mass movements and flooding processes were studied in unstable areas.

4.1.3 SYNTHETIC MAPS

Starting from the cartography of the different factors and processes, diverse thematic maps can be obtained using GIS.

Table 5. Slope classification.

Class	Slope (%)	Description
1	0-3	Smooth
2	3-16	Moderate
3	16-21	Deep
4	21-31	Very deep
5	>31	Strongly deep

Table 6. Soil protection classes.

Land use	Vegetation cover (%)			
	<25	25-50	50-75	>75
Dry farming	5	5	4	4
Irrigated crops	3	2	1	1
Ligneous crops (olive trees, fruit trees and vineyards)	5	5	4	3
Grasslands	5	5	4	4
Oak and cork oak forest with understorey formed by heath and leguminosae	4	3	2	1
Pine forest	4	3	2	1
Heathland and other shrubs	5	4	3	2
Uncovered soils	5	-	-	-

4.2 EROSION RISK

The erosion risk has been evaluated considering internal aspects of the land (the erosive status classes) and external (the erosive action of the rainfall, calculated as the FMI). The erosion risk map is shown in Figure 9.

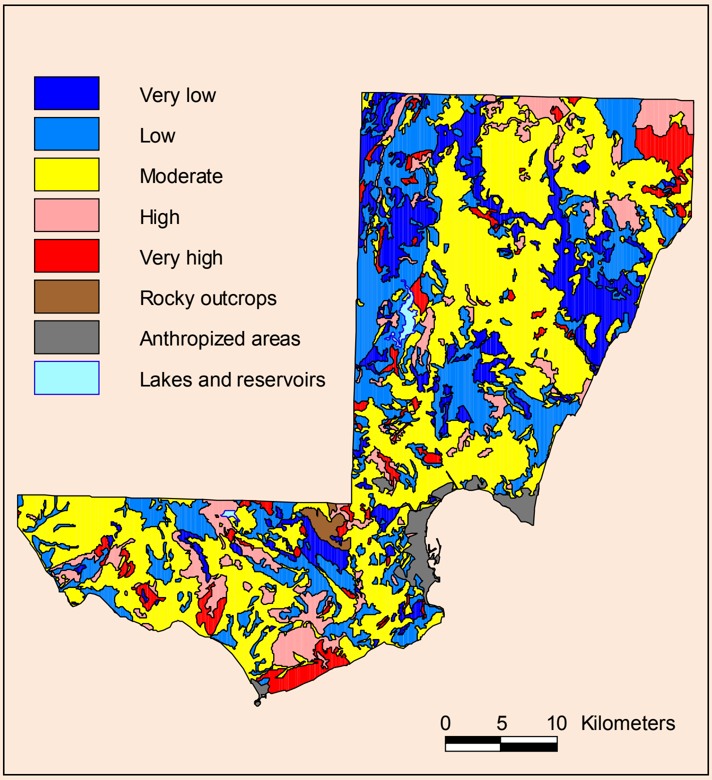

Figure 4. Erosive status map of Campo de Gibraltar.

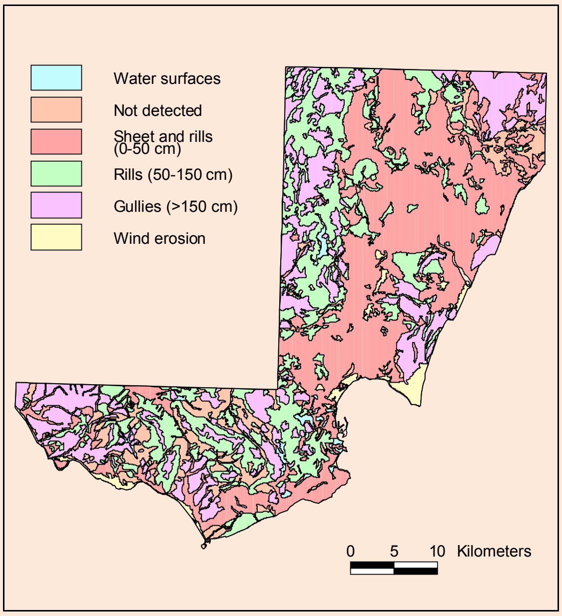

Figure 5. Erosive processes map.

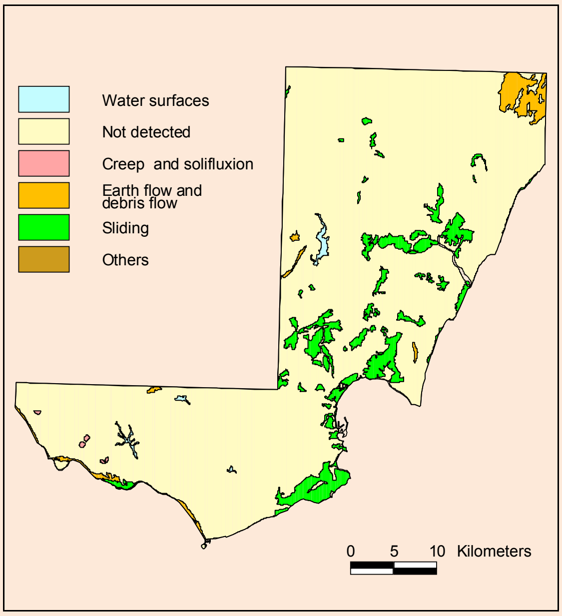

Figure 6. Mass earth movements map.

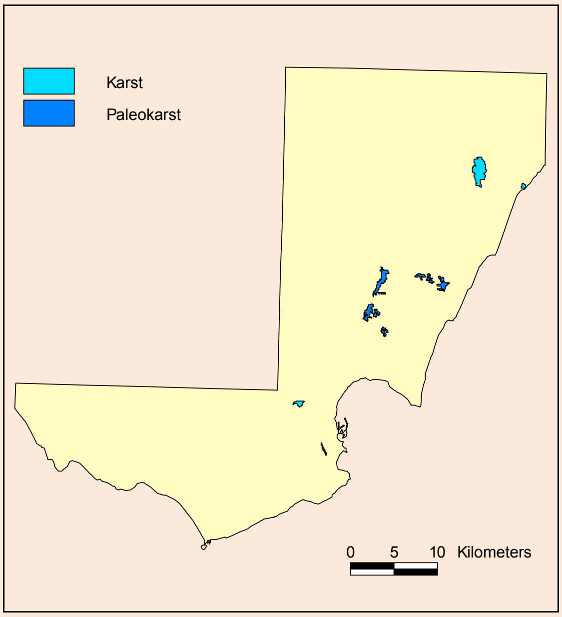

Figure 7. Karstic processes map.

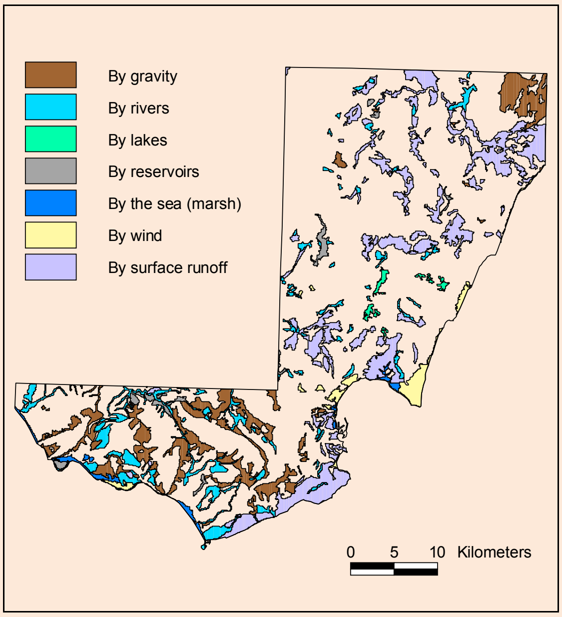

Figure 8. Agradational processes map.

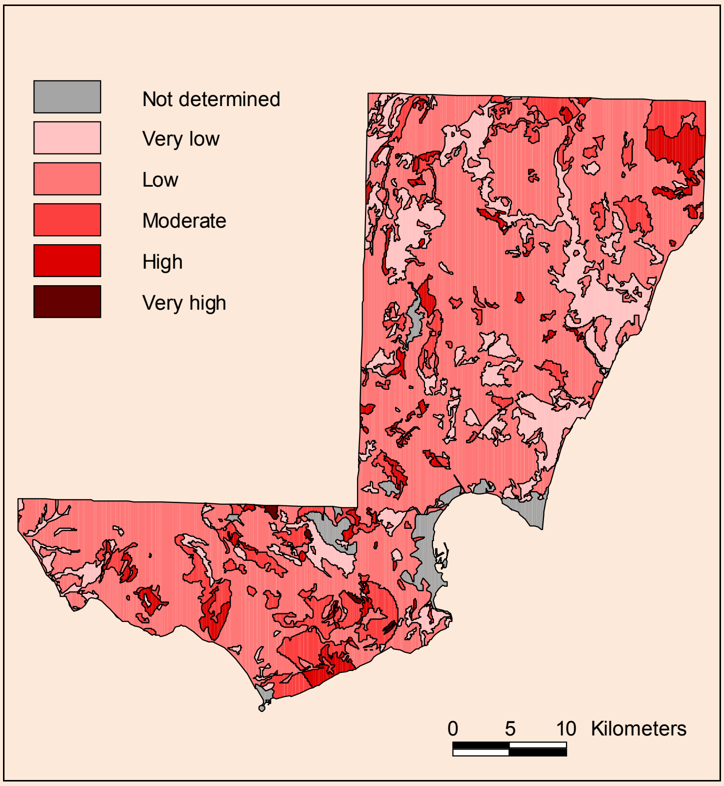

Figure 9. Erosion risk map of Campo de Gibraltar. The erosion risk was calculated by overlapping the erosive status map and the FMI.

5 CONCLUSIONS

5.1 EROSION LEVEL IN THE CAMPO DE GIBRALTAR

The erosive status in the sandstone mountains and the oak forest was qualified as low or very low. In spite of the high risk of water erosion, the deep slope of the hillsides and the influence of numerous folds and cracks on the morphogenesis, soil is greatly protected by a dense forest and shrub canopy.

In the southern low mountains, the erosion risk is highly increased, due to the strong erosivity of rainfall on hillsides exposed to S and SE.

The lands located below 200 m, and the depressions of La Janda and El Almarchal, are constituted by soft rocks. In front of the high erodibility of these materials, the smooth slope of the hillsides enhances the stability of the land. However, although the erosive status is low, the action of the erosive processes is important (even small gullies are present). Some lands located to the E of Tarifa show a high or very high erosive status. In these points the FMI shows moderate values, increasing the final erosion risk.

The most important river valleys (Hozgarganta, Guadiaro or Genal) and the streams of the SW portion of the study area, constitute sedimentation points, and have a very low erosion risk.

6 PROBLEMS ENCOUNTERED DURING MAPPING AND MODIFICATIONS OF THE ORIGINAL METHODOLOGY

The use of Geographic Information Systems constitute a very powerful tool for the spatial modelling of the erosion risk. In a GIS the information is constituted by a georeferenced database where we can assign quantitative or qualitative values to spatial elements of each layer of information. The photointerpretation of satellite images and aerial pictures, using auxiliary cartographic material, allows a better identification of the different elements that the automatic classification of images.

The identification of the different land use types is difficult, if it is carried out just using aerial photographs. The complementary use of false color satellite images (as those provided by Landsat-TM or IRS-PAN) allows us to define clearly the shape of the polygons at our work scale, and to discriminate between different vegetation types and cover classes non distinguishable in an aerial picture. The use of multi-temporal images also allows us to discriminate against annual cultivations and other land use types.

The activity of the erosive processes is very difficult to evaluate from aerial photographs, especially when a dense vegetation canopy can hide it. An intensive recognition in the field is needed.

In humid areas, where the erosive effect of the rainfall is very high at a local scale, we consider the necessity of using climatic aggresivity indexes. In the case of the Campo de Gibraltar, the use of the Fournier Modified Index allowed to map the erosion risk more accurately, if we take into account the intensity of the active water erosive processes. The pluviometric data are easily available and the GIS technology allows its integration in the assessment of erosion.

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