

## SOIL EROSION RISK EVALUATION BASED ON EXPERT KNOWLEDGE AND GIS TECHNOLOGY – A CASE STUDY FROM THE SPANISH MOUNTAINOUS OLIVE PLANTATIONS (MONTORO, ANDALUSIA REGION)

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The soil erosion risk evaluation is one of the most important exercises in every agricultural territory. Currently a lot of models that deal with this kind of problem are known. However to run these models a great number of the information as an entrance data are required. The situation when there is no enough information is very common in real life. The new approach for territorial soil erosion risk evaluation is proposed in this work. Unlike the majority of previously elaborated models, the ANP based approach proposed here is able to evaluate the soil erosion risk with relatively small available data. As an example of the proposed approach the evaluation of soil erosion risk on olive groves in Montoro municipal territory is made. The final result shows the map with most vulnerable areas for soil erosion.

*Keywords: soil erosion risk, Analytic Network Process (ANP), GIS, olive plantations.*

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### ОЦІНКА РИЗИКУ ВИНИКНЕННЯ ЕРОЗІЇ ҐРУНТІВ ЗА ДОПОМОГОЮ ЕКСПЕРТНОЇ ОЦІНКИ ТА ГІЗ ТЕХНОЛОГІЇ НА ПРИКЛАДІ ГІРСЬКИХ ОЛИВКОВИХ САДІВ ІСПАНІЇ (МОНТОРО, РЕГІОН АНДАЛУЗІЇ)

Проведення оцінки ризику виникнення ерозії ґрунтів є одним з найважливіших завдань у дослідженні сільськогосподарської території. Для вирішення цього завдання існує широкий спектр математичних моделей. Але одним з головних недоліків існуючих моделей є їхня висока потреба в інформації. У даній роботі ми пропонуємо новий підхід до вирішення цього питання. На відміну від інших моделей, що оцінюють ризик виникнення ерозії ґрунтів, ми пропонуємо використання методу, заснованого на ANP, який дає можливість провести оцінку виникнення ерозії ґрунтів з допомогою відносно невеликої кількості інформації. Як приклад застосування цього методу була проведена оцінка ризику ерозії ґрунтів в оливкових садах муніципальної території Монторо (Південна Іспанія). У результаті застосування методу була отримана карта ризику ерозії ґрунтів на території, що вивчається.

*Ключові слова: ризик ерозії ґрунтів, АНП, ГІЗ, оливкові сади.*

The importance of the soil degradation phenomena is known worldwide (de Paz et al., 2006). The soil erosion is one of the greatest causes of soil degradation. In conditions of Spanish dry Mediterranean climate and steep slope landscapes the water erosion is claimed as one of the greatest environmental hazards both for agricultural activities and for the ecological diversity (Lal et al., 1989). Laguna (1989) comments that the volume of soil losses by water erosion in Spanish mountainous olive groves range between 60-105t per hectare/ year and at the same time the soil creation rate is about 1-2 t per hectare/ year. Other research carried out by López-Cuervo (1990) evaluates soil losses on a tree crops (olive and other fruits plantations) situated in Andalusia Region (South of Spain) as more than 80 t. per hectare/ year.

The magnitude of the soil erosion increases in the case of marginal olive plantations with a high risk of abandonment. Koulouri and Giourga (2006) claimed that uncontrolled abandonment of marginal olive plantations with a slope gradient superior to 25 % lead to a rise in water soil erosion. The study area is situated in mountainous region of Sierra Morena which could be classified as highly risky.

Our study represents a part of the three years project entitled «The social optimization of the agricultural territory. Mountainous olive plantations case (Montoro, Spain)». The main purpose of the work presented here is evaluation of the soil erosion risk on the study area.

Many models have been elaborated that try to quantify and model soil erosion process. For these purposes there are four main types of soil erosion have been distinguished: sheet, rill, gully and in-stream. The USLE model proposed by Meyer and Wischmeier (1969) was one of the first to recognize the existence of three stages of soil erosion process. This assumption has permitted the modeling of the erosion process via consideration of a limited number of processes that influence erosion. Subsequently Foster and Meyer (1975) have proposed a more elaborate model based on the same idea. Another interesting model was developed by Woolhiser et al. (1990) and known by the name KINEROS. This model is based on a breakdown of the main watershed on plans, channels and water reservoirs connected in a form of cascade where the water and sediments flow according to the transport equations. Nowadays up dates of this model exist with a name KINEROS 2. The disadvantage of the KINERO model is its great input information requirements. The EUROSEM model (Morgan et al., 1998) represents an adaptation of KINEROS that could be applied on the small watersheds and plot levels.

Although in this case being studied we only consider the part of sediment detachment in an erosion process, it's clear that the consideration of this part of the erosion process alone doesn't represent the whole reality. The central target of our study is the evaluation of the risk of erosion on the specific territory of mountainous olive plantations with an inclusion of the results in the posterior multi criteria analysis, which allows a decision to be made on the use of territory. Thus we focus our attention on the interactions between the factors that influence sediment detachment. As landscape elements related to soil erosion we chose the adaptation of the USLE/RUSLE (Wischmeier and Smith, 1978; Renard et al., 1991; Renard et al., 1997) components in accordance with the local conditions.

One of the main criticisms of the USLE based models is its non-consideration of the interdependence between factors. So, the consideration of the interactions between the factors was one of the main objectives of the study, and we decided to take advantage of use of the Analytic Network Process (ANP) Multicriteria Decision Making Technique. The ANP (Saaty, 1996; Saaty, 2005) is an improved generalization of the well known Analytic Hierarchy Process (Saaty, 1980) that provides the possibility to take interdependences between the decision factors into consideration. Both methods use expert opinions as inputs for decision factor weighing. But the advantage of the ANP consists in the possibility of network model structuring that reflects the interdependence between the things in the real world quite well. This is the case of the erosion influence factors. For this reason we have decided to apply the ANP on the territorial erosion risk evaluation.

Due to the fact that our study is applied on the mountainous olive groves landscape the use of the Geographical Information Systems (GIS) were indispensable. A number of studies have been carried out with the objective of simulating the soil erosion process, soil erosion hazard evaluation or hydrological process modeling on the landscape level, between them we can mention Carvajal Ramírez and Giráldez Cervera (2000), Millward and Mersey (2001), Şahin and Kurum (2002), Finlayson and Montgomery (2003), Cammeraat (2004), Cohen et al. (2005), Metternicht and Gonzalez (2005), de Paz et al. (2006), Ramos-Scharrón and MacDonald (2006). In spite of all the aforementioned studies having used different model types there is one similarity: all of them have been applied in the some area of the world.

In our study we have applied the ANP technique with a GIS to analyze the risk of erosion on the olive groves of Montoro. The theoretical backgrounds of the application of multi criteria evaluation methods on the solution of spatial problems have been well described elsewhere Malczewski (1999). Since then a large number of studies have adopted this approach.

In this work we don't consider the erosion by wind due to its relatively small impact on the study area landscape.

## CASE STUDY AREA

The study area is situated in the South of Spain in Cordoba province municipality Montoro, geographically bounded between longitudes  $-4^{\circ}33'$ ;  $-4^{\circ}9'$ ; and latitudes  $38^{\circ}16'$ ;  $37^{\circ}57'$  (Fig 1. Location and physical map of Montoro). The study area represented by olive plantations covers approximately 35 % of municipal territory and this type of land use is dominant on the Montoro's municipality. This area have a typical Mediterranean continental climate conditions with irregular precipitation distribution during the year (75,5 mm. middle precipitation of the winter; 8,7 mm. middle precipitation of the summer). The irregularity of this rainfalls is one of the main forces provokes the soil erosion in the area. The soils presented in this area are generally brown soils and rankers. In the South of the Montoro's municipal territory also could be found red soils and mixing type of red and brown soils.

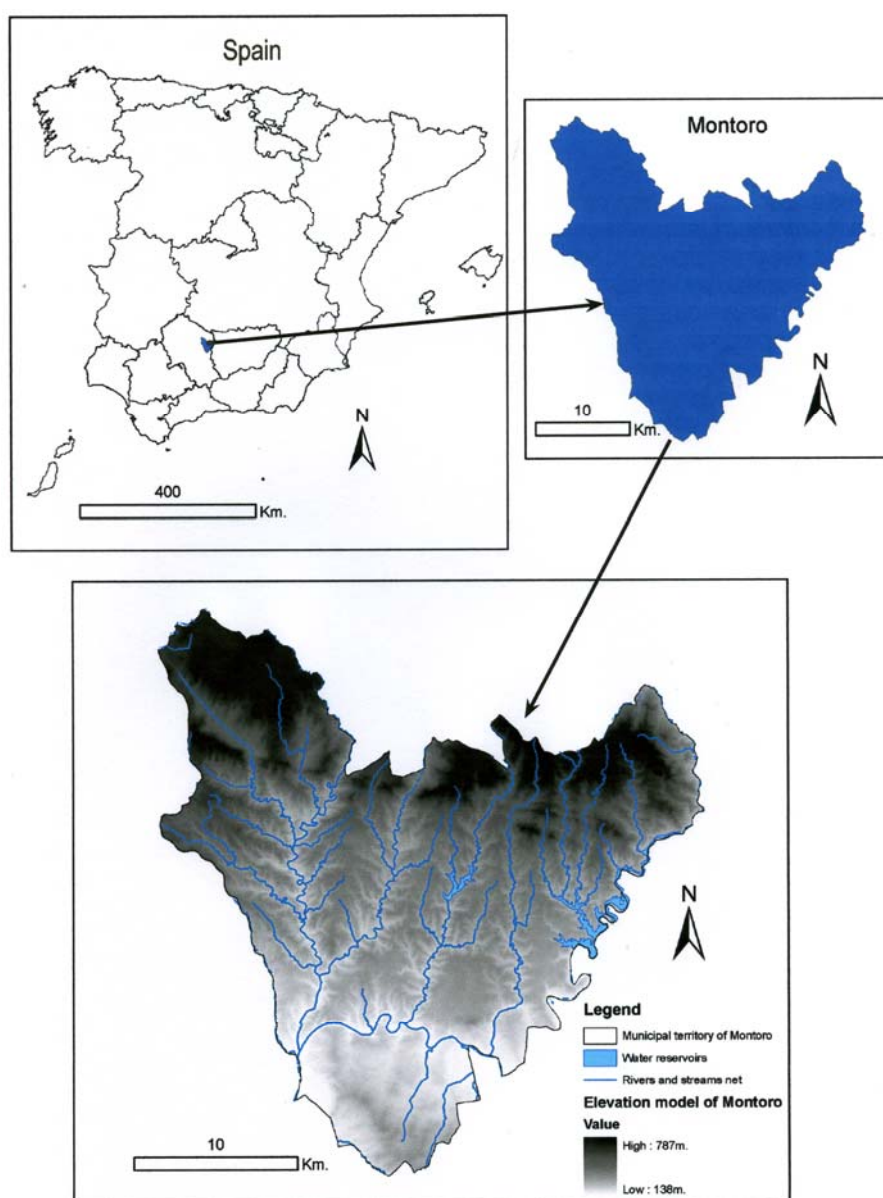


Fig. 1. Location and physical map of Montoro

The Central and Northern parts of the Montoro are mostly highlands with steep slopes that difficult enormously agricultural works, the slopes with a more than 15 % represents a 51 % of the territory. This explains that the agriculture in this region is mostly oriented to extensive olive plantation and dehesa (Fig. 2. Main land uses of Montoro). As a result of the steep slope relief the soil erosion risk on this area is very high. The elevations range from 140 m to 790 m above sea level (Fig 1.). The northern part of the municipality has highest elevations and the south part the lowest. The Guadalquivir river cross the southern part of Montoro from east to west and separate the municipality in two parts: the south part (approximately 20 % of the municipal territory) and the Central and Northern parts (around the 80 % of the municipal territory) The water flow direction is mainly from north to south (the Guadalquivir river direction) in the Central and Northern part and from south to north in the southern part of the municipality. The main water bodies ha concentrated in the Central and Northern parts of the area.

The Northern-East part of the Montoro's municipality is stated as a part of the Natural Park of Sierra Cardena and Montoro. That's way this area has high environmental values and all agricultural works there should be in agree with Natural Parks legislation requirements.

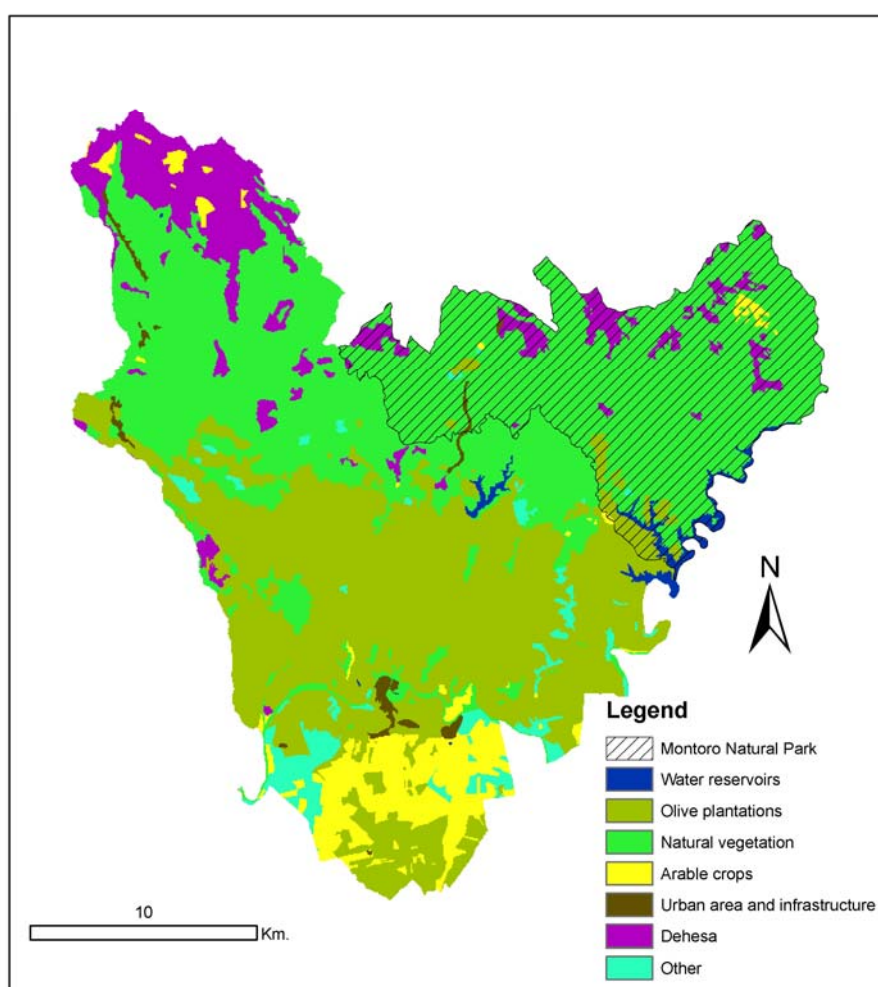


Fig. 2. Map with main land uses of Montoro

## METHODS

A schematic guideline of steps involved in the development of the soil erosion risk evaluation is shown in Fig. 3. As all study of this type our research begins with an identification of the most important soil erosion risk factors in the study area. Next step was factor's data collection. Following steps are related to the adaptations of the data to the necessity of the ANP model, ANP analysis realization, representation of results by the GIS technology and sensitivity analysis.

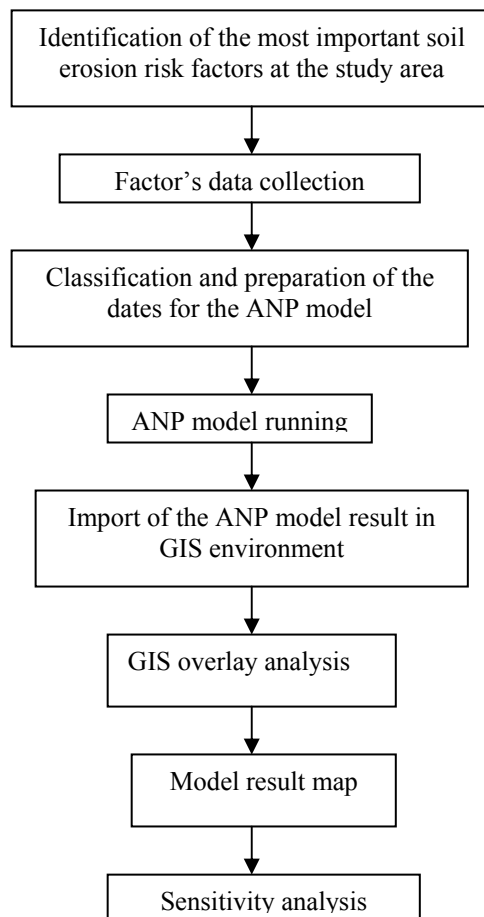


Fig. 3. Schematic guideline of steps involved in the development of the soil erosion risk evaluation

### *The erosion influences factors evaluation methods*

The soil erosion process by water is influenced by many factors. Nevertheless some efforts had been made to simplify those factors and as a result the USLE/RUSLE has been proposed. Widely used and known the equation  $A=R*K*L*S*C*P$  that multiply six erosion explained factors was proposed initially by Wischmeier and Smith (1978) and later some modifications were introduced by Renard et al. (1997), where  $A$ - is an accumulative soil loss (normally in one year);  $R$ - is a runoff erosivity factor;  $K$ - is a soil erodibility factor;  $L$ - is slope length factor;  $S$ - is a slope steepness factor;  $C$ - is a cover management factor; and  $P$ - is a support practice factor. However instead of the success of the initial applications this equation was an object of the severe criticism due to its limitations (Zhang et al., 1995; Larson et al., 1997). The major critics of USLE are that it was prepared for use on the USA conditions (Loch and Rosewell, 1992). That's why its use outside of the USA is very diffi-

cult by the absence of the parameters needs to run a model. The interdependence between the components is other part doesn't considered by USLE.

In a view of this we have decided the usage of the USLE/ RUSLE factors adapted to the local conditions of olive orchards of Montoro with addition of the rivers and streams proximity factor and the ANP evaluation model based on the expert knowledge as an alternative approach. In a difference of the classic USLE/ RUSLE models that offered the numerical soil loss calculation, the model proposed here only evaluate the relative importance of soil erosion risk measured in relative units. The scheme of the development and relationships of the submodels is allowed in the Fig 4.

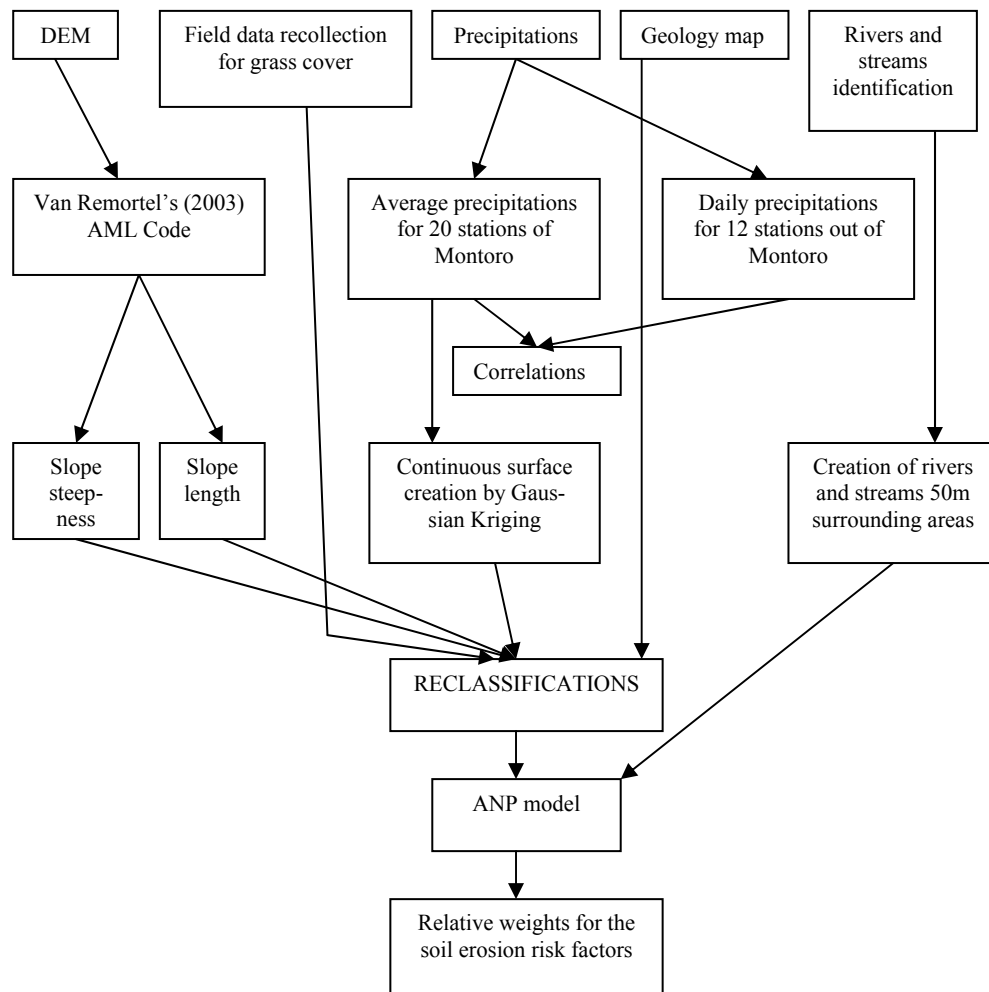


Fig. 4. Flowchart showing the submodel's development and relationships

#### *Analytic Network Process decision making technique*

The complete theoretical backgrounds of the ANP could be found on Saaty (1996) and Saaty (2005). In this paper we presents a brief explanations of this method following on Erdogmus et al. (2005), Cheng et al. (2005), Promentilla et al. (2006), and by commented earlier Neaupane and Piantanakulchai (2006).

The ancestor of the ANP was an Analytic Hierarchy Process (AHP) developed by Saaty with the aim of supporting arms-reduction negotiations between the USA and the Soviet Union in Geneva (Saaty, 1980). From that time and until now the method has be-

come quite popular and it was developed a numerous applications employed this technique. A detailed review of the AHP applications could be found in Vargas (1990), and overview of some resent applications in Vaidya and Kumar (2006). The hierarchy structuring of the decision problem and pairwise comparisons between the all elements of the same level is the distinctive points of the method. The 1-9 numerical scale was proposed for the pairwise comparison implementation, where 1 mean similar importance between the estimated criteria under estimation, while 9 indicates an extreme level of importance of one over the other. The AHP's main assumption is the independence between the elements of the same level and between different levels in the hierarchy. However it's rarely occurred in the real live. For this reson the AHP technique receives some criticism from many researchers (see for example Belton and Gear, 1983; Belton, 1986; Wang and Elhag, 2005). With the objective to improve the quality of the decision making Saaty proposed the generalization of AHP method called Analytic Network Process. This method is also known with a name of supermatrix approach and has been proposed to overcome the limitations of the linear hierarchic structures (Saaty and Takizawa, 1986; Saaty, 1996, 2005). The main innovation of the ANP is its network structure that permits the consideration of the interactions between the elements situated in different clusters and inner dependences between the elements in the same cluster. Another new concept is a supermatrix that consists in the weights previously derived from the pair-wise comparisons between the elements of the decision making network problem structure.

In the case of our study the simple network structure is used. However in a case of more complex problem Saaty (1996) and Saaty (2005) proposes the using of four sub-networks: Benefits, Costs; Opportunities and Risks. These sub-networks consideration permits to keep in mind all dimensions of the decision problem. In a case of the decision problem of election between any alternatives the sub-network with the alternatives should be included.

Actually a growing of the ANP application is observed. Between them we can comments works in: economic forecasting (Blair et al., 2002; Niemira and Saaty, 2004); product design and planning (Saaty and Takizawa, 1986; Chung et al., 2005); location selection o service provider selection (Cheng et al., 2005; Jharkharia and Shankar, 2007); evaluation of forest management strategies (Wolfslehner and Vasik, 2007); energy policy planning (Ulutas, 2005; Erdoğan et al., 2006); waste management (Promentilla et al., 2006); evaluation of transport projects (Shang et al., 2004); farmland appraisal (García-Melón et al., 2006), landslide hazard evaluation commented previously in introduction section (Neaupane and Piantanakulchai (2006)) and logistic strategy analysis (Meade and Sarkis, 1998).

However the scarce works can be found on the application of the ANP to the soil erosion risk evaluation. In our opinion the interdependence and feedback consideration in the structure and relatively little input information requirements makes this experts knowledge based decision support methodology as a quite suitable for erosion hazard evaluation on the landscape level.

#### *Geographical Information System implementation*

The analysis of the study area on a landscape level involves the use of GIS technology. The GIS technology permits the representation of the real landscape via the group of simple signs on the digital or paper map or plan. Another explanation of GIS could be found in Santiago (2005) and define a GIS as an information system for the management and analysis of geographical information, and the geographical information as an abstraction representation of the real world. As GIS Software it was used ArcGis 9.1 provided by ESRI. The input data were: land use map (1999; 1:50,000) corresponding to the study area (EGMASA, 2001); aerial monochrome photos (2001-2002; 1:5,000) and color photos (2005; 1:10,000); yield map of the olive plantations (2004; 1:25,000), and Digital Elevation Model with 10 m spatial resolution. These materials were provided by the Junta of Andalusia Cartography Service (Junta de Andalucía, 2004; 2005). Geological map of Spain (1:50 000; 2003-2006), part corresponding to the study area was provided by Spanish Geology and Miner Institute.

## RESULTS

The ANP analysis was carried out following the algorithm presented on the method section. The network structure of the problem and outer dependence between the clusters were simulated in Super Decisions 1.6.0 Software environment that automatically create a list of the pairwise comparisons needed to run a model (see Fig. 5. The Network structure of the erosion risk evaluation problem).

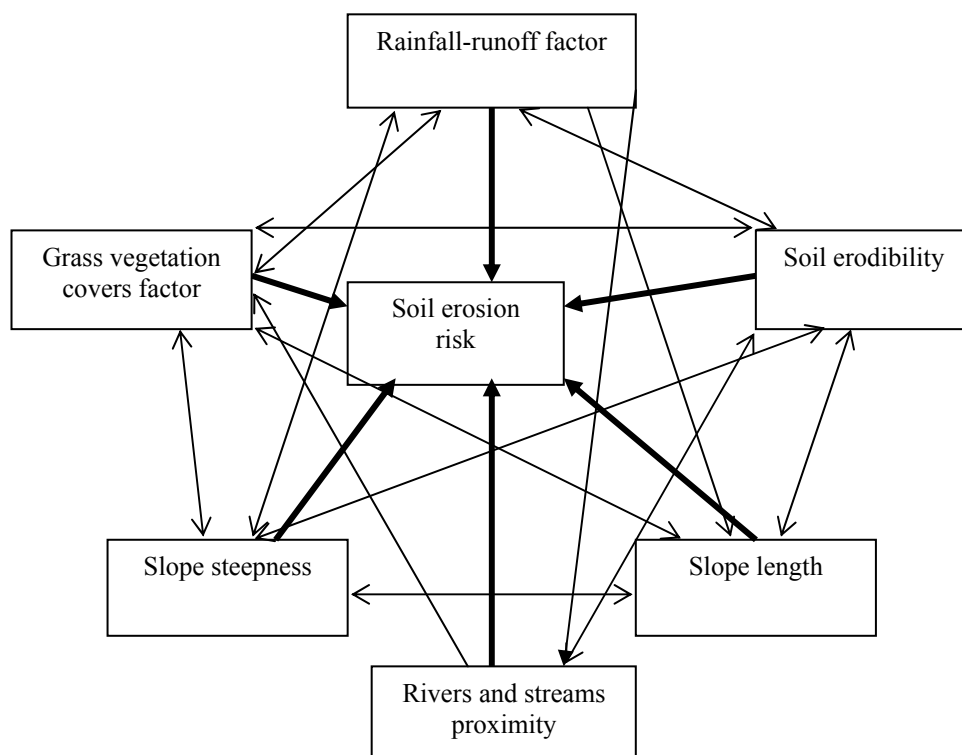


Fig. 5. The Network structure of the erosion risk evaluation problem

The direction of the arrows indicates the interdependence's relationships between the factors. Single direction arrow shows the dominance of one factor by other. Double direction arrow shows mutual influence between the factors. There are not inner dependences in our case, for this reason the inner dependence loops are absent. This is a simple structure with only one sublevel.

The pairwise comparison (PWC) between the nodes and the clusters was done by the research group involved in the project development in agree with the soil erosion expert's opinion and the consults with bibliography related to soil erosion process. That's why each PWC could be explained and justified. The relative values reached from the nodes PWC were introduced to the initial (unweighted) supermatrix. The cluster matrix was completed with results of clusters PWC.

Multiplying the initial supermatrix with a cluster weights matrix element by element was reached the weighted supermatrix. As we commented above the final phase of the ANP analysis consists in multiplication of weighted supermatrix times by it self until the limit matrix (*Table*) is reached. Due to the limitations of the Super Decisions Software that support only a simple cluster comparisons, this last operation was carried out using MATLAB Software. The example of the cluster comparison questioner could be found in Table 1. The similar approach was used for nodal comparison.

Table 1

The example of the cluster comparison questioner

Bearing in mind the soil erosion risk evaluation,  
Given that the “**presence/absence of grass vegetation cover**” is “**with grass vegetation cover**” which factor (cluster) is more important:

AP1	Rainfall-runoff potential (RRP)			X						
	Slope length (SL)									
	1	X	2	3	4	5	6	7	8	9

Bearing in mind the soil erosion risk evaluation,  
Given that the “**presence/absence of grass vegetation cover**” is “**with grass vegetation cover**” which factor (cluster) is more important:

AP2	Rainfall-runoff potential (RRP)								
	Slope steepness (SS)								
X	1	2	3	4	5	6	7	8	9

Bearing in mind the soil erosion risk evaluation,  
Given that the “**presence/absence of grass vegetation cover**” is “**with grass vegetation cover**” which factor (cluster) is more important:

AP3	Rainfall-runoff potential (RRP)			X						
	Soil erodibility (SE)									
	1	X	2	3	4	5	6	7	8	9

Bearing in mind the soil erosion risk evaluation,  
Given that the “**presence/absence of grass vegetation cover**” is “**with grass vegetation cover**” which factor (cluster) is more important:

AP4	Slope length (SL)			X						
	Slope steepness (SS)									
	1	X	2	3	4	5	6	7	8	9

Bearing in mind the soil erosion risk evaluation,  
Given that the “**presence/absence of grass vegetation cover**” is “**with grass vegetation cover**” which factor (cluster) is more important:

AP5	Slope length (SL)																
	Soil erodibility (SE)																
X	1		2		3		4		5		6		7		8		9

Bearing in mind the soil erosion risk evaluation,  
Given that the “**presence/absence of grass vegetation cover**” is “**with grass vegetation cover**” which factor (cluster) is more important:

AP6	Slope steepness (SS)																	
	Soil erodibility (SE)																	
	1		X	2		3		4		5		6		7		8		9

	RRP	SL	SS	SE	Weights
RRP	1	2	1	2	0.3333
SL	1/2	1	1/2	1	0.1667
SS	1	2	1	2	0.3333
SE	1/2	1	1/2	1	0.1667

$\lambda_{\max}=4.0000$   
 $CI=(\lambda_{\max}-n)/(n-1)=-1.4803e-016$   
 $CR=CI/RI=-1.6633e-016$  (less than 0.1)

Multiplying the initial supermatrix with a cluster weights matrix element by element was reached the weighted supermatrix. As we commented above the final phase of the ANP analysis consists in multiplication of weighted supermatrix times by it self until the limit matrix (Table 2) is reached. Due to the limitations of the Super Decisions Software that support only a simple cluster comparisons, this last operation was carried out using MATLAB Software .

The relative weights reached by ANP analysis were assigned to the factors raster layers previously created. Then following the recommendations of (Saaty, 2003, pp. 104-108) the additive function was applied via the Map algebra tool to get a total risk score for each cell. The final result map relative values range between 0.0902 and 0.6138. In order to compare scenarios in the sensitivity analysis and to make interpretation easier, the scale has been transformed into a commonly used 0 to 1 scale (Fig. 6. Result map). The normalization were carried out in the mode that worst possible relative value obtained the normalized value of 1, and the best possible scenario gained the normalized value of 0. The normalization process was carried out by following equation:

$$X_{\text{norm}} = \frac{X_{\text{raw}} - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}}$$

We didn't provide the clustering of the normalized map (Fig. 6. Result map). In general the clustering of the results depends of the subjective opinions of the researchers and particular necessity of the project.

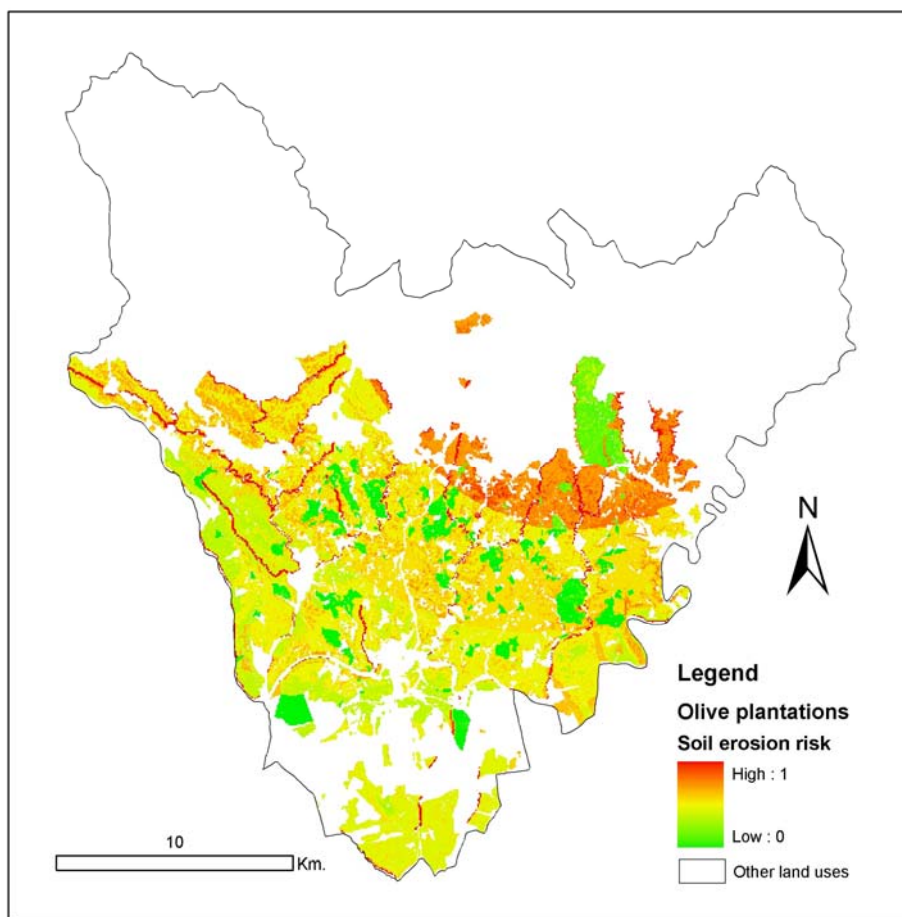


Fig. 6. Soil erosion risk evaluation result map



As Fig. 6 shows the olive plots that have a grass vegetation cover are less susceptible for the soil erosion risk. The areas enclosed to the rivers and streams have a quite high soil erosion risk that is in accordance with field observations. The northern-east zone of the study area outstands with high relative values of the soil erosion risk. This could be explained by the presence of steep and long slopes in this territory worsen by the high rainfall erosivity potential of the northern part of the municipality of Montoro.

## DISCUSSION AND CONCLUSIONS

The main contribution of our research is the evaluation of the soil erosion risk on the mountainous olive plantations of Montoro (Spain). The main novelty of our study consists in the application of the Analytic Network Process Multicriteria Decision Making Technique to the soil erosion risk evaluation that considers the interdependences and different importance of the factors. Our study is one of the first applications of the ANP in this area. The main advantage of this approach is relatively low necessity of the entrance empirical information. As a substitution of empirical data the expert's knowledge and opinions were used.

The consideration of erosion influence's factors relative weights for the soil erosion evaluation could be found in Cohen et al. (2005) that offer the use of graphical model to substitute the traditional USLE/RUSLE based model. The ANP model used in our study has some similarity with a graphical model of Cohen. The difference with a Cohen model consists in a source of the entrance information. Cohen et al. (2005) found the relative weights of the factors at the study area empirically. In the case of our study the factor's importance and interdependences between them was determined by the expert(s) knowledge, that is a good approach when the real data are absent (Boardman, 2006).

The result reached in the model shows that most vulnerable area is situated in a zones where joins two or more most powerful erosion promotion forces: high rainfall-runoff potential, steep and long slopes without grass vegetation cover under the olives. All areas near the rivers and streams could be considered as a highly vulnerable also. This kind of conclusion is obvious, however only the conjoin use of multi criteria analysis with GIS technology permits the exact geographical situation of the vulnerable areas. The core role of the ANP multi criteria decision making technique in our study consists in quantitative evaluation of the interactions between the factors and its posterior evaluation on relative scale. The supermatrix approach permits to transform the knowledge and intuition of the experts in numbers subsequently applied to landscape evaluation.

The zone situated on the north-east of the study area (Fig. 10) is outstands by his relatively high risk for soil erosion, that it was explained above. Although we didn't reclassify result map the «jumps» in the result values could be observed. This «jumps» are totally justified by the increase of the rainfall potential in the area and its appearance is due to previous reclassification of the continuous surface of the rainfall-runoff potential required by ANP model.

Between the limitations of the model proposed in our study we should mention various things. The no consideration of the transport and deposition of the detached soil particles is one of them. However this overlook could be justified by the assumption that the central purpose of the study is soil erosion risk evaluation only. Other limitation is too much of the PWC required in the ANP model. But this is a general problem of the ANP method, and as complex is the structure of the model as high the number of the PWC to answer.

Other possible source of the uncertainty of the model is a «human» factor. By the «human» factor we mean the experts opinion used for the factors evaluation. Indeed its possible that we obtain other evaluation if we ask other experts. Because it is related to the individual understanding of the problem by each expert.

The inclusion other factors such trees density, more sophisticated evaluation of soil erodibility and river and streams influence should improve the quality of the model, but in the same time can complicated it to much. The quality of entrance geographical information is other key factors to success soil erosion risk prediction.

Lastly we would like to outstand that the model offered here is totally opened to additions of any other factors and interdependences between them depending of the local conditions wherever the word. The joining of the empirical information with the expert's knowledge could help to better calibration of the model and is the important line for future research. Other interesting topic of future challenges is to intend the precise calibration of the ANP model weights with the object to quantify real soil losses on the area.

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