PREDICTION OF DESERTIFICATION RISK USING RECOMMENDED EUROPEAN METHODOLOGY AND GIS TECHNIQUES. STUDY CASE: THE PREFECTURE OF KILKIS IN NORTHERN GREECE

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ABSTRACT. - Prediction of Desertification Risk Using Recommended European Methodology and Gis Techniques. Study Case: The Prefecture of Kilkis in Northern Greece. Several areas in Balkans and Danube Basin countries are threatened by the widespread occurrence of desertification that could lead to severe degradations of the natural resources such as the impoverishment of soils, the deterioration of the biomass or even the reduction of the biodiversity. Some areas in Greece are already or likely to be affected by desertification and the present work aims at developing a model for the assessment of the desertification risk, using the prefecture of Kilkis as study case. The assessment methodology consists in combining various desertification indicators relative to the climate, vegetation, soils and management into a unique final index. The prior knowledge of the dominant processes acting in the region is integrated to the model by performing a multi-criteria analysis. The use of the GIS technique allowed an efficient processing of the collected data and the generation of relevant intermediate thematic maps and a final desertification risk map.

1. Introduction

The definition of desertification has evolved along time. For instance, the UNEP regularly upgraded its understanding of the desertification phenomenon. In 1977, desertification was considered as "the reduction or destruction of the biological potential of land that can lead to desert-like situations and an aspect of ecosystem degradation following a consistent reduction in their biological potential." In 1984, the UNEP agreed with the FAO to define desertification as "All encompassing expression to indicate socio-economic, natural and anthropic processes causing a modification in the soil, vegetation, atmospheric and water balance of regions characterized by aridity induced by edaphic and climatic factors". Later in 1991, a third revision of the definition led to the identification of desertification as being the "Land degradation in arid, semi-arid and dry/sub-humid areas, due principally to negative human impacts", where the term "land" refers to soil and local water resources, land surface areas and natural vegetation. In 1994, the former definition was widened to include the climatic variations as one more cause together with human impact.

Due to the increasing concern by the international community about desertification risks and its probable ecological and socio-economic effects, several projects were dedicated to the study of desertification phenomenon. The main objectives were to understand the mechanisms, identify the causes and evaluate the consequences of desertification DISMED [1], MEDALUS [2], DeMon [3], DESERTLINKS [4], LADAMER [5], DeSurvey [6]. Detailed reviews of EU research on desertification processes, desertification monitoring, modelling and mitigation are respectively presented in [8], [9], [10] and [11].

Following the latest definition proposed by the UNEP, the present work aims at developing an integrated system for the assessment of desertification risks and providing the decision makers with a risk map that allow them to launch specific remediation actions in the affected zones and promote management policies to avoid the activation of the desertification process in non affect areas.

In the present paper, first is described the MEDALUS methodology for the identification of Environmentally Sensitive Areas to desertification. Based on the latter a new methodology for desertification risk assessment is proposed in the third section. The fourth section is dedicated to the Multi-criteria analysis used within the developed model. Finally, the output maps generated for the prefecture of Kilkis are presented and the results are interpreted.

2. Description of the MEDALUS index for the identification of Environmentally Sensitive Areas (ESAs)

Some particular conditions that can cause desertification in northern Mediterranean regions were mentioned in the UNCCD in its Annex IV [7]:

(a) Semi-arid climatic conditions affecting large areas, seasonal droughts, very high rainfall variability and sudden and high-intensity rainfall.

(b) Poor and highly erodible soils, prone to develop surface crusts.

(c) Uneven relief with steep slopes and very diversified landscapes.

(d) Extensive forest coverage losses due to frequent wildfires.

(e) Crisis conditions in traditional agriculture with associated land abandonment and deterioration of soil and water conservation structures.

(f) Unsustainable exploitation of water resources leading to serious environmental damage, including chemical pollution, salinization and exhaustion of aquifers.

(g) Concentration of economic activity in coastal areas as a result of urban growth, industrial activities, tourism and irrigated agriculture.

In order to identify the Environmentally Sensitive Areas (ESAs) to desertification and considering the various possible causes of desertification in

European Mediterranean regions, the MEDALUS project [2] introduced the index (ESAI) that is based on a multi-factor approach. The generation of the ESAI is in fact related to a set of indicators that are grouped into four categories: climate quality, soil quality, vegetation quality and management quality (Table 1). The GIS analysis of these quality data and their classification provide four quality indices: Climate Quality Index (CQI), Soil Quality Index (SQI), Vegetation Quality Index (VQI) and Management Quality Index (MQI). The merging of these quality indices leads to the generation of the final ESAI.

Table 1. Structure of the ESAI

	Climate quality	*Soil quality*	*Vegetation quality*	*Management quality*
Indicators	- Rainfall - Aridity - Aspect	- Texture - Parent Material - Rock fragment - Depth - Slope - Drainage	- Fire risk - Erosion protection - Drought resistance - Vegetation cover	- Land use intensity - Policy enforcement

Application of the proposed methodology in the study area of Kilkis

In order to assess the desertification risk in the inland prefecture of Kilkis, located in Northern Greece in the Central Macedonia region (Fig.1), the MOONRISES* project undertook to follow a similar approach to the one described in the previous section. Unless specified, the indices and classes were similar to those chosen for the calculation of the ESAI. Some improvements were nevertheless introduced in order to include a prior knowledge of the climate conditions, vegetation and soil characteristics as well as the management practices in the region.

The ESAI is easy to implement when all the data can be collected. In the case of the prefecture of Kilkis, some data were not available. Therefore, one of the challenging issues was to find alternative ways to provide the required information.

The size of the territory of the Kilkis prefecture (nomos) is 2,519 sq km and its population is 91,828 inhabitants (2001). The capital of the prefecture is the City of Kilkis with 17,430 inhabitants (total Kilkis municipality /dímos/ population is 24,812 inhabitants). The prefecture population density is only 36 inhabitants per sq km. The prefecture comprises two provinces (eparchia).

* INTERREG III B ARCHIMED

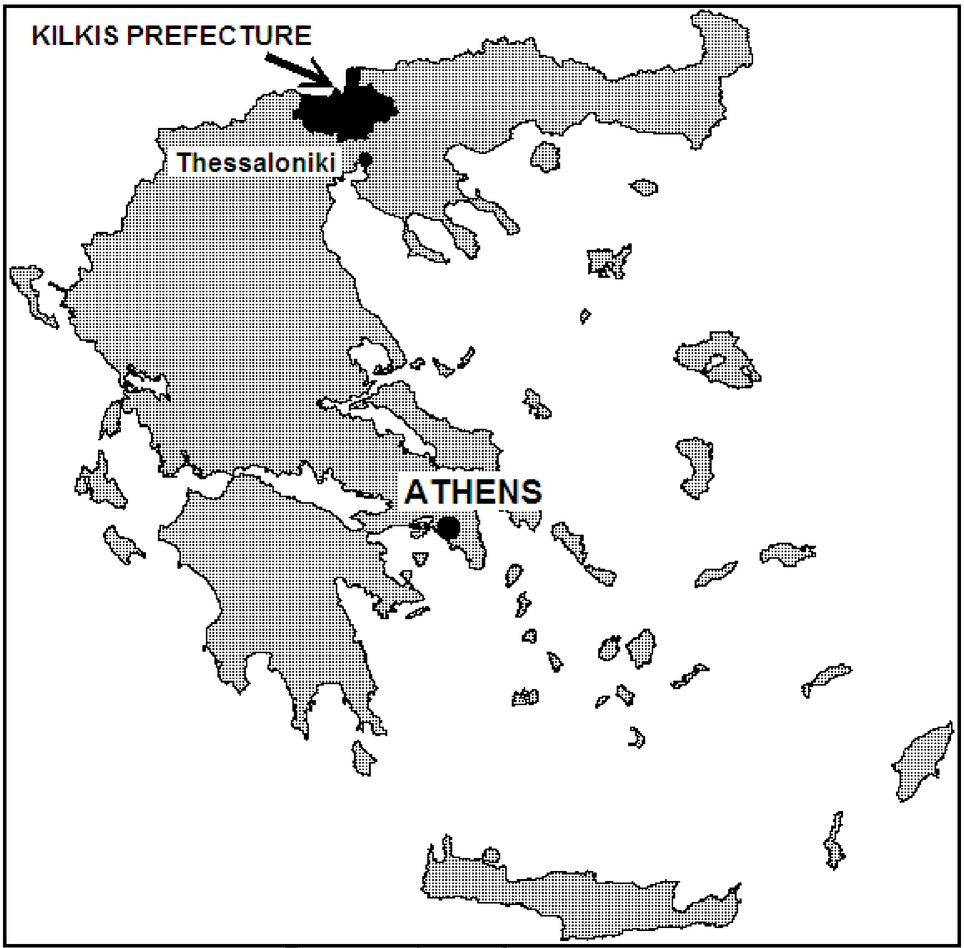

Fig. 1. Location of Kilkis prefecture study territory in Greece

From the geology viewpoint, the East of the territory of the Kilkis prefecture is a part of the Thracian-Macedonian Massive – built by old (Hercynian and Precambrian) crystalline (both metamorphic and intrusive) rocks disturbed by dense network of faults and fractures. Individual blocks of rocks were lifted up during the Alpine orogenic period (folding) and later created the system of mountains and basins between them. These massifs border the Balcanides folded zone in the North. The Western part of the Kilkis prefecture belongs to the so called Vardar-zone. It consists of old rock massifs bordering the Hellenides folded zone in the West. The Axios (Vardar) River valley represents the border between these main geological units. The territory is tectonically active and thus sensitive to earthquakes.

The terrain of the Kilkis prefecture study territory presents a transitional composition due to its opening to the North and South. The Eastern border wing to the neighbouring Serres prefecture is represented with the Mavrouni Mts. (max. 1177 m) joining in the North-Eastern corner the Kerkini Mts. (Bjelasica Mts.) on the border with Republic of Macedonia (max. 2030 m, outside the study area). The Western margin of the Kilkis prefecture follows the ridges and valleys of the Paiko Mts. (max. 1647 m). The central part of the prefecture is filled by a hilly land separating the wide and flat Axios (Vardar) River valley in the West from the local Gallikos River basin draining the Eastern half of the prefecture inland. Both rivers courses follow the semi-meridional tectonic lines. Irregular network of basins (grabens) and horsts (hilly lands and mountains) locks also two non-drained tectonic basins with the bigger Doirani Lake (Dojransko jezero) at the Greek-Macedonian border in the North and the much smaller Lake Pikrolimni in South at the border to the Thessaloniki prefecture.

The climate of the Kilkis prefecture is mostly moderately warm and continental. The only lowest areas along the Axios River course and lower Gallikos belong to the Mediterranean climate zone. Vertical climate zones are typical for the mountain regions from Mediterranean in the Southern lowland through dominating continental climate to cold (snowy) alpine mountain climate in the ridge and summit zone (Kerkini Mts.).

The fertile alluvial plains of Axios, Gallikos and their tributaries are covered with fluvizems followed by semiarid chernozems and cambisols into neighbouring lower plateaux and hilly lands on loamy Tertiary and Quaternary deposits, while clayic Neogene sediments and heavy flysch weathering products carry vertisol cover. The most common soil class – Cambisols – cover also slopes of the most surrounding mountains, substituted by rendzinas in limestone areas.

The original vegetation respecting climatic, soil, geological and terrain condition (from evergreen Mediterranean (*Quercus Ilex* and other Oak sp.) forests through broad leaved deciduous (Oak sp., Beech sp., Ash, Mapple, etc.) and mixed forests (with Pine sp.), to Alpine meadows were removed, changed and/or reduced during the more than 5000 years of human cultivation, especially since the Copper and Iron Ages (since the end of the 2nd millennium B.C.). While the lowland and hilly land areas were completely deforested and turned into an intensive agrarian land with dominating arable land and some orchards and vineyards, foots of mountains still have some pastures and grassland. Wooden land continues to exist in more dissected and elevated mountainous areas usually at a distance from permanently settled locations. Forest openings are typical for wider ridges, gentle slopes and plateaux and are used for sheep grazing what is broadly accepted as the main factor of lowering the upper natural forest line in local mountains.

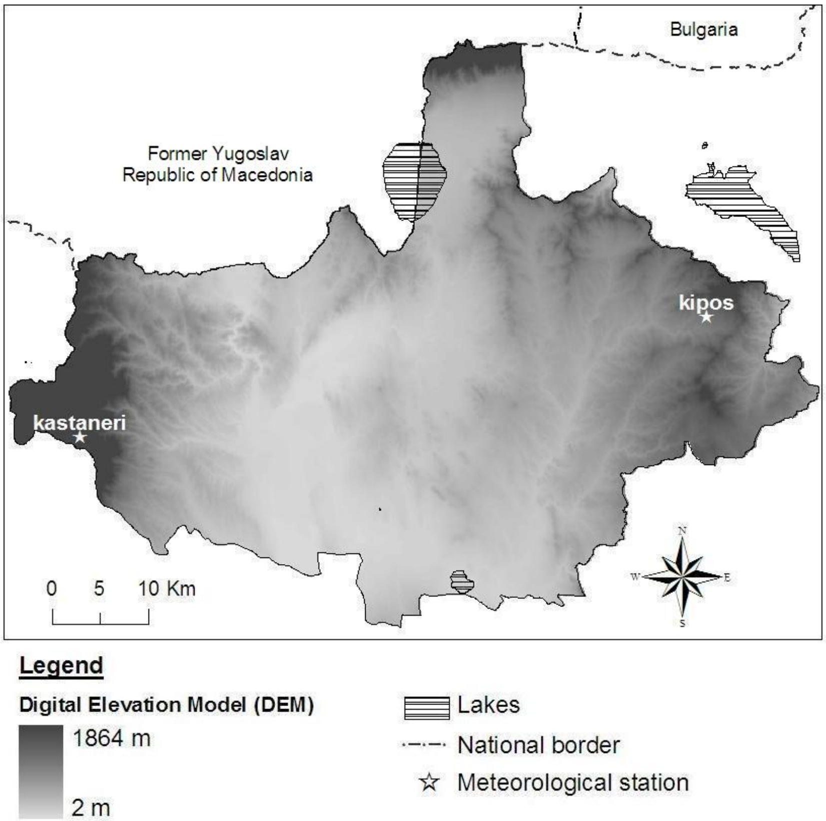

Fig. 2. Digital Elevation Model of the Kilkis prefecture study territory

a) Climate layers

Prediction of the meteorological variables

For the implementation of the Climate Quality Index (CQI) only precipitation and temperature are required. In the prefecture of Kilkis, the data were collected from two meteorological stations: Kastaneri and Kipos (Table 2 and Fig.2). Once the discrete temperature and precipitation annual values available, an interpolation was required to cover the whole prefecture. In previous studies, numerous variables were used to estimate the precipitation and temperature distributions: the longitude and latitude, the land to sea ratio, the elevation, the mean/maximum elevation within a radius of 1, 5 or 10 km, the slope, the aspect and the distance/direction to the nearest coast [12][13]. Composite variables obtained, for example by the multiplication of simple variables [14][15], were also used for interpolation. Nevertheless these variables do not equally affect the meteorological conditions and their relevance depends on the characteristics of the area (area extent, location, topography).

Considering the extent of the area of Kilkis (approx. 2500 km^2), its location at more than 100 km from the sea and the terrain specificities (mountainous area with elevations varying between less than 5 m a. s. l. in the Axios valley to a maximum elevation of about 1864 m a. s. l.), the elevation was used as the decisive variable to perform a basic linear regression. Two rasters were then obtained representing the precipitation and temperature values for the whole prefecture of Kilkis.

It can be noticed that the precipitation regression line presents a positive slope, meaning that the rainfall increases with the elevation, while the temperature behavior is opposite, decreasing with the elevation. This approximation is valid for inland areas, while the temperature-elevation relation can be different in costal zones due to the sea effect.

Table 2. Meteorological data for the Kilkis area

Variables	*Kastaneri*	*Kipos*
Elevation (m)	1360.05	583.92
Precipitation (mm)	893	587
Temperature (°C)	9.48	13.6

The rainfall layer

Having the precipitation distribution in a raster format, three classes were created according to the rain water amount. To each class, an index is then assigned and a new raster layer was generated with three unique values reflecting the annual rainfall.

The aridity layer

The aridity variable evaluates the degree of dryness in an area. Several indices such as the Bagnouls-Gaussen Index (BGI), the Index of Emberger, the index of de Martonne (1923) or the classification of Thornwaite (1931) allow the estimation of the aridity by using exclusively basic meteorological data. Later in 1997, the UNEP proposed an index based on the evapotranspiration which is another important factor of the hydrologic budget. The index is expressed by the ratio between the annual precipitation and the annual reference evapotranspiration (ET_0).

While in MEDALUS the BGI bioclimatic index was used for the mapping of the aridity, in the present study, data were missing for the estimation of one term in the formula. The UNEP index also proved to be a good estimator of the aridity, but the estimation of ET_0 is rather complex. Therefore, the equation of de Martonne was used instead. The aridity index of de Martonne, is based on easily retrievable data and is calculated using the following formula:

$$I_M = \frac{P}{T + 10} \qquad \text{(Eq.1)}$$

where, *P* is the annual average rainfall in mm and *T* is the annual average temperature in °C.

Based on the range of the aridity index, seven climatic classes were identified and to each class an index between 1 and 2 was assigned (Table 3).

Table 3. Aridity classes

Aridity index	*Climate type*	*Index*
0 - 10	Arid	2
10 - 20	Semi-arid	1.8
20 - 24	Mediterranean	1.6
24 - 28	Semi-Humid	1.4
28 - 35	Humid	1.2
35 - 55	Very Humid	1.1
>55	Extremely Humid	1

The aspect layer

The aspect factor was also required for the creation of the climate quality index. In fact, the solar warm distribution varies with the aspect variable and therefore affects the water availability in the area. Two major classes were identified: one corresponding to the South, South-West and South-East orientations and a second class including the remaining orientations.

b) Soil layers

The Soil Quality Index (SQI) combines 6 layers: soil depth, slope, soil texture, parent material, rock fragment and drainage. Data relative to the rock fragment cover percentage were not available therefore only 5 layers were computed.

The soil depth layer

The depth layer available for the prefecture of Kilkis presented 9 classes of soil depths. The number of classes was then limited to 4 classes: deep, moderate, shallow and very shallow. The reclassified raster map was then used to create the soil depth layer, where a depth index was assigned to each pixel according to the depth class it belonged to.

The slope layer

The slope is a relevant factor of desertification since steep sloped terrains usually are characterized by an important runoff activity. The Digital Elevation Model (DEM) of Kilkis was used to generate a raster map with the slope percentages. The layer was then classified into 4 categories and the appropriate index was then assigned to each category.

The soil texture layer

Soil texture was used as indicator of the water retention capacity of the soil. A sandy soil is for example less capable of retaining water than a clay textured-soil and is therefore more prone to drought. The data about soil texture not being available, the necessary data were extracted from the soil thematic map. For this purpose, each category of the initial map was assigned a class of texture (Table

4). Once this step performed, the soil texture layer was generated by the assignment of the appropriate index to each class.

The soil parent material layer

A procedure similar with the one described above helped to classify the soil parent material layer, since the appropriate soil data was not available for the target area of Kilkis.Table 4 illustrates the parent material class corresponding to each soil class (Fig. 3).

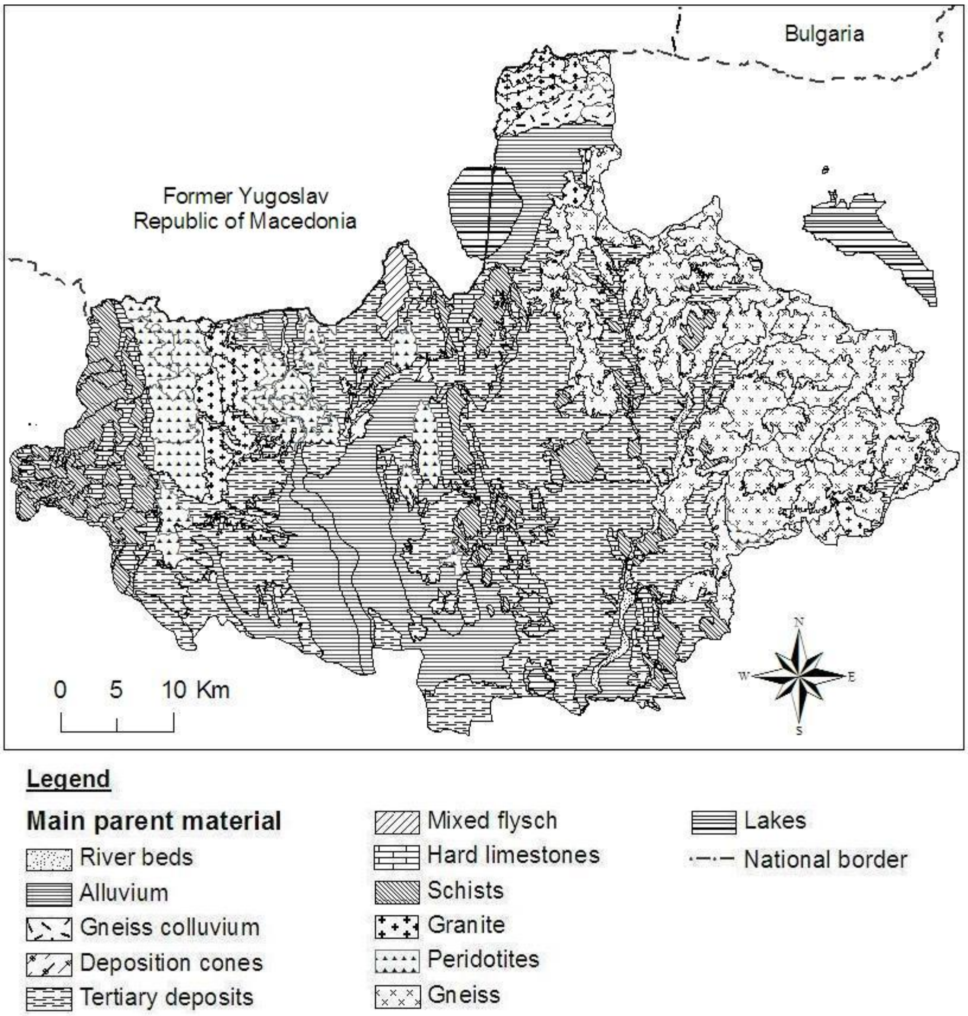

Fig. 3. Soil parent material map of the Kilkis prefecture study territory

Table 4. Remap table of the soil map

Soil parent material map classes	*Parent Material impact*	*Soil texture*	*Soil Drainage*
A-Alluvium	Good	Good	Well drained
B-River beds	Good	Good	Imperfectly drained
C-Hard limestones	Moderate	Poor	Poorly drained
F-Mixed flysch	Moderate	Moderate	Imperfectly drained
N-Granite	Moderate	Good	Well drained
P-Peridotites	Moderate	Good	Poorly drained
S-Deposition cones	Poor	Good	Imperfectly drained
T-Tertiary deposits	Poor	Good	Well drained
W-Gneiss colluvium	Moderate	Good	Imperfectly drained
X-Schists	Good	Good	Imperfectly drained
Z-Gneiss	Moderate	Good	Well drained

The drainage layer

Similarly the drainage layer was created using Table 4 and assigning to each category of drainage the adequate index afterwards.

c) Vegetation layers

The vegetation plays an important role in the desertification process by affecting the run-off, the evapotranspiration, the soil composition, etc. The vegetation quality index is based on 4 layers: fire risk, plant cover, erosion protection and drought resistance. Having no such data directly available, the field expertise was essential for the interpretation of the CORINE map and the extraction of the necessary data (Table 5).

The Erosion protection layer

Using the erosion risk map, available for the prefecture of Kilkis, the 9 existing classes were reduced to 4 classes considering the dominant erosion risk category. Once this task performed, the attribution of the appropriate indices was straightforward.

The other vegetation layers

The three vegetation layers (Plant cover, drought resistance and fire risk) were, as previously mentioned, extracted from the CORINE map (Fig. 4), according to the remap table between the CORINE nomenclature and the three vegetation descriptors (Table 5).

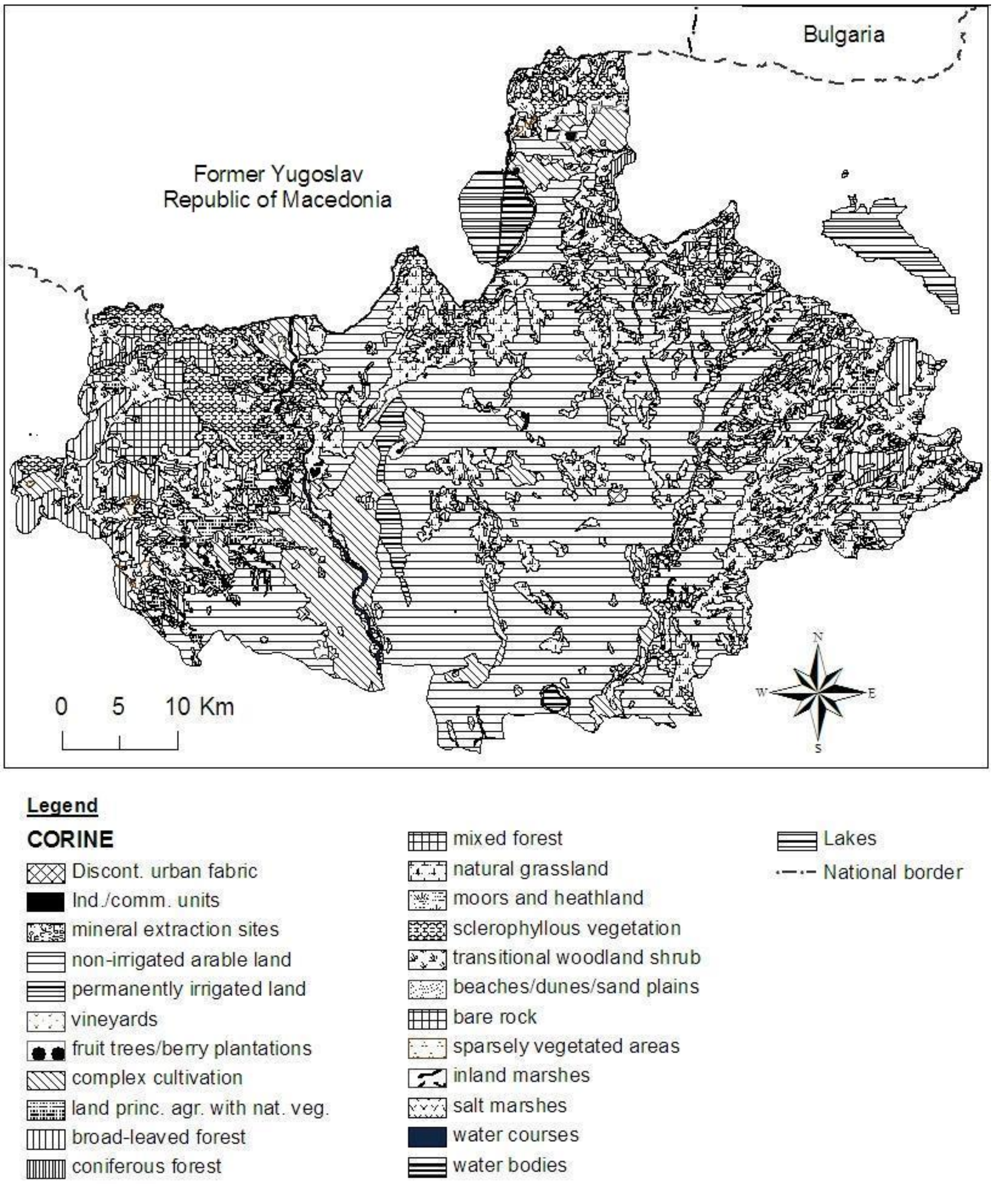

Fig. 4. CORINE land use map of the Kilkis prefecture study territory

Table 5. Interpretation of the CORINE nomenclature

CORINE code	*Category description*	*Vegetation quality*		
		Plant cover	*Drought resistance*	*Fire risk*
112	Discont. urban fabric	Very Low	Very Low	Low
121	Ind./comm. units	Very Low	Very Low	Low
131	mineral extraction sites	Very Low	Very Low	Low
211	non-irrigated arable land	Low	Moderate	Low
212	permanently irrigated land	Low	Low	Low
221	vineyards	Low	Moderate	Low
222	fruit trees/berry plantations	Moderate	Moderate	Low
242	complex cultivation	Low	Moderate	Low
243	land princ. agr. with nat. veg.	Moderate	Moderate	Low
311	broad-leaved forest	High	Very High	Moderate
312	coniferous forest	High	High	Very high
313	mixed forest	High	Very High	Moderate
321	natural grassland	Moderate	Low	Moderate
322	moors and heathland	Low	Moderate	Moderate
323	Sclerophyllous vegetation	Moderate	High	High
324	transitional woodland shrub	High	Moderate	Moderate
331	beaches/dunes/sand plains	Very Low	Very Low	Low
332	bare rock	Very Low	Very Low	Low
333	sparsely vegetated areas	Low	Moderate	Low
411	inland marshes	High	High	Low
421	salt marshes	High	High	Low
511	water courses	Moderate	High	Low
512	water bodies	Moderate	High	Low

d) The management layer

It is undeniable that social, economic and policy factors play a role in accelerating or slowing down the desertification phenomenon in a particular area. Trying to take those parameters into consideration, the management quality layer was produced by assigning an index depending on the land use: crop land, pasture land, natural area, mining area or recreation area. Therefore, to each category of the CORINE nomenclature an index of management quality (high, moderate and low) was assigned, assuming that the management conditions within the same prefecture are similar for parcels having the same land use. According to the land use, a specific assessment criterion was used. The list of criteria is presented in Table 6.

Table 6. Management Assessment criteria

Land use	*Assessment criterion*
Cropland	Land Use Intensity (LUI)
Pasture	Stocking rate
Natural area	General Management characteristics
Mining area	Erosions control measurements
Recreation area	Visitors ratio

Multi-criteria analysis

To compute the quality indices and the final ESAI, the approach adopted by MEDALUS was to assign equal weights to the layers, ensuring this way the easy and straightforward application of the methodology to any region, once the necessary layers were computed. In the present work, it was admitted that climate, soil, vegetation and management do not have the same effect on the desertification process and the contribution of each layer was either emphasized or diminished by the selection of adequate weights.

The advantage of this approach is that the weights can be tuned according to the area studied, therefore favoring one indicator rather than another depending on the characteristics of the region.

The drawback of the approach is that this assignment requires a prior knowledge of the physiological, meteorological and management characteristics of the region. The help of an expert would therefore be needed to determine the appropriate weights for each layer.

The problem that had to be solved was how to decide about the desertification risk existing in a specific area taking into account various parameters (physical and socio-economic) that do not have the same priority. The Analytic Hierarchy Process (AHP) proposed by Saaty [16][17] is widely used to perform such a multi-criteria analysis. The approach consists in assigning priorities to conflicting criteria, by using pair wise comparisons based on forming judgments between two particular variables rather than attempting to prioritize an entire list of elements [18].

In order to perform the multi-criteria analysis a Multi-Criteria Decision Support System (MCDSS) has been developed by the Laboratory of Remote Sensing and GIS of the School of Agriculture, Aristotle University of Thessaloniki. The MCDSS was implemented within Visual Basic for Applications (VBA) and works as an extension to ArcGIS. The application takes as input a set of rasters and provides a Graphical User Interface (GUI) in order to set the preference values for each pair of rasters (Fig. 5). The Analytic Hierarchy Process is then performed and a new raster is generated according to the preference/pair comparison matrix.

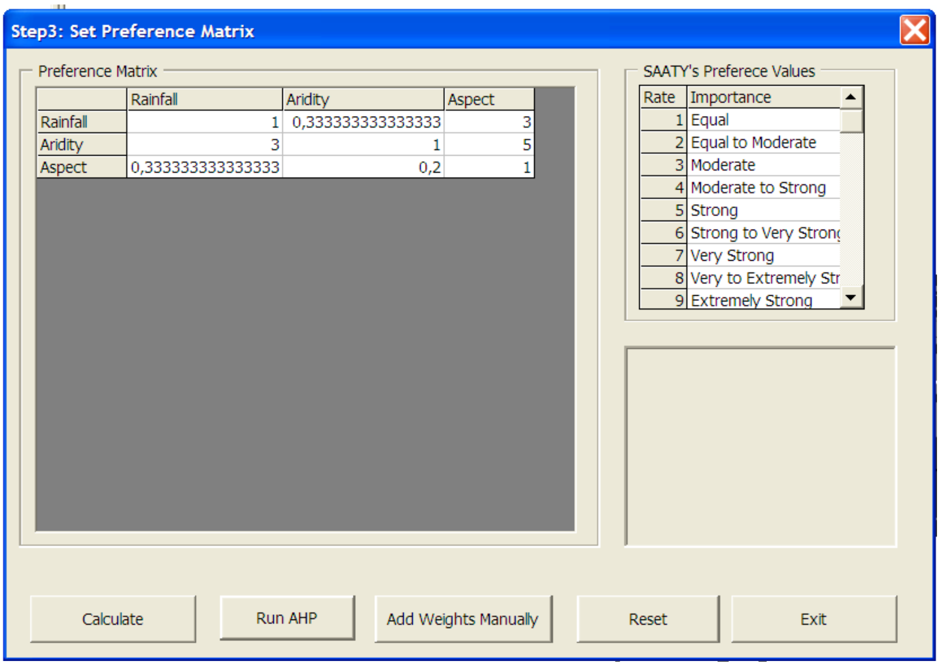

Fig. 5. The Multi-Criteria Decision Support System GUI

The preference matrices used to combine the layers corresponding to the area of Kilkis are presented in Table 7, Table 8, Table 9 and Table 10.

Table 7. Pair comparison matrix for the climate layers

Climate quality	*Rainfall*	*Aridity*	*Aspect*
Rainfall	1	1/3	3
Aridity	3	1	5
Aspect	1/3	1/5	1

Table 8. Pair comparison matrix for the soil layers

Soil quality	*Soil texture*	*Parent material*	*Drainage*	*Depth*	*Slope*
Soil texture	1	3	1	1/3	1/3
Parent material	1/3	1	1/5	1/5	1/3
Drainage	1	5	1	1/3	1/3
Depth	3	5	3	1	1
Slope	3	3	3	1	1

Table 9. Pair comparison matrix for the vegetation layers

Vegetation quality	*Fire risk*	*Drought resistance*	*Vegetation cover*	*Erosion protection*
Fire risk	1	1/5	1/3	1
Drought resistance	5	1	3	3
Vegetation cover	3	1/3	1	3
Erosion protection	1	1/3	1/3	1

Table 10. Pair comparison matrix for the adapted quality index layers

Desertification risk index	*Climate quality*	*Vegetation quality*	*Soil quality*	*Management quality*
Climate quality	1	5	3	5
Vegetation quality	1/5	1	1/3	3
Soil quality	1/3	3	1	3
Management quality	1/5	1/3	1/3	1

3. Results and interpretation

The four quality maps obtained for the region of Kilkis are presented in Figure 6, Figure 7, Figure 8 and Figure 9, while Figure 10 corresponds to the desertification risk map. All the maps were processed with ArcMap. The projection system used was the Greek grid and the spatial resolution is 20 m×20 m.

As Figure 1 shows, the prefecture of Kilkis is dominated by a moderate quality climate. The small proportion of high quality climate coincide with the mountainous areas where the precipitation is higher and the aridity index rather low. It can also be noticed that the area presents a small percentage of poor quality soils and is more or less equally covered by high and moderate quality soils. As for the vegetation quality it is low on almost half of the territory. This is mainly due to the low plant cover and the moderate drought resistance. The management quality is from low to moderate for almost the whole prefecture.

Table 11. Distribution of the risk categories

Risk category	*Area percentage*
Non affected	3.5 %
Potential	1.2 %
Fragile 1	2.6 %
Fragile2	32.3 %
Fragile 3	13.7 %
Critical 1	7.9 %
Critical 2	27 %
Critical 3	11.8 %

Table 11 points out that around 46 % of the prefecture of Kilkis is critical to desertification mainly due to a low vegetation and management quality. About 48 % of the area was classified as fragile. These areas are very sensitive to degradation under any change to the delicate balance of climate, and land use. A slight change is likely to enhance reduction in biological potential and thus lead to the reduction of the vegetation cover and the increase of the erosion rate. For 1.2% of the Kilkis prefecture there is a potential risk of desertification. These areas are sensitive to degradation under significant changes of the climate and of human activity. Only 3.5 % of the study area is not affected by desertification.

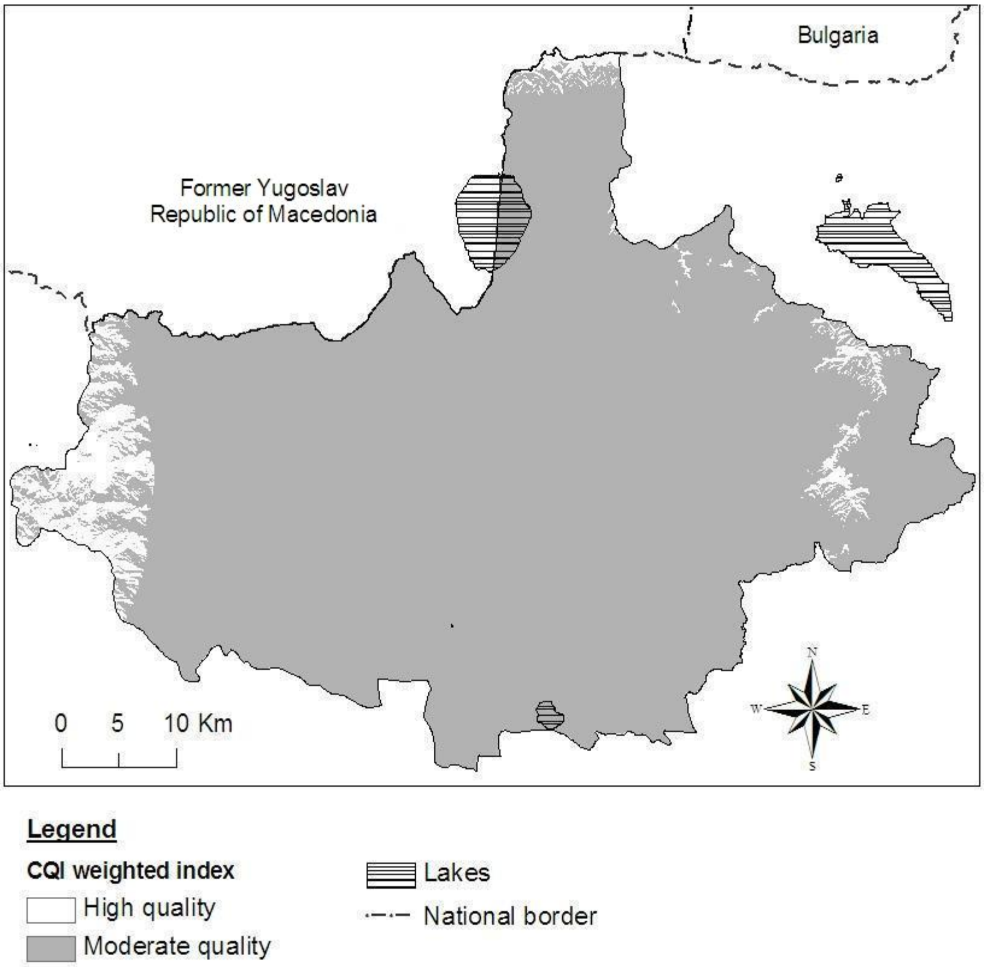

Fig. 6. Weighted Climate Quality map of the Kilkis prefecture study territory

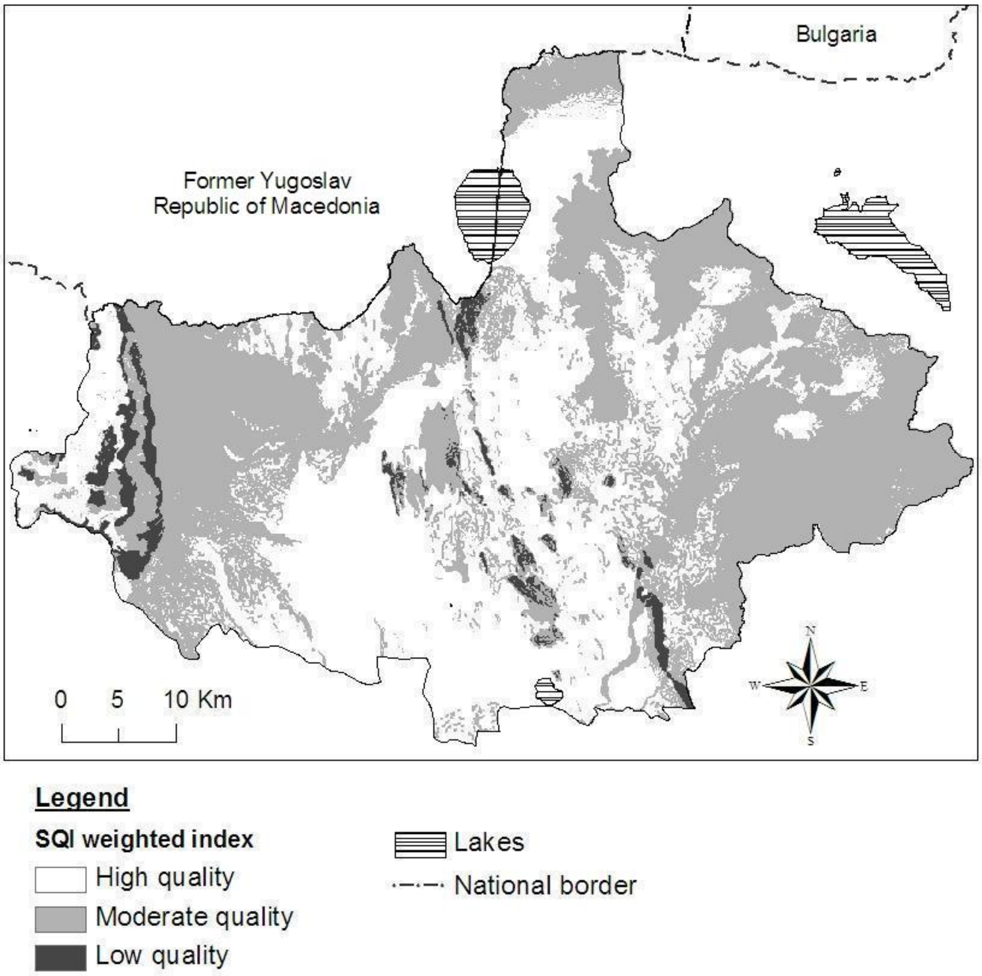

Fig. 7. Weighted Soil Quality map of the Kilkis prefecture study territory

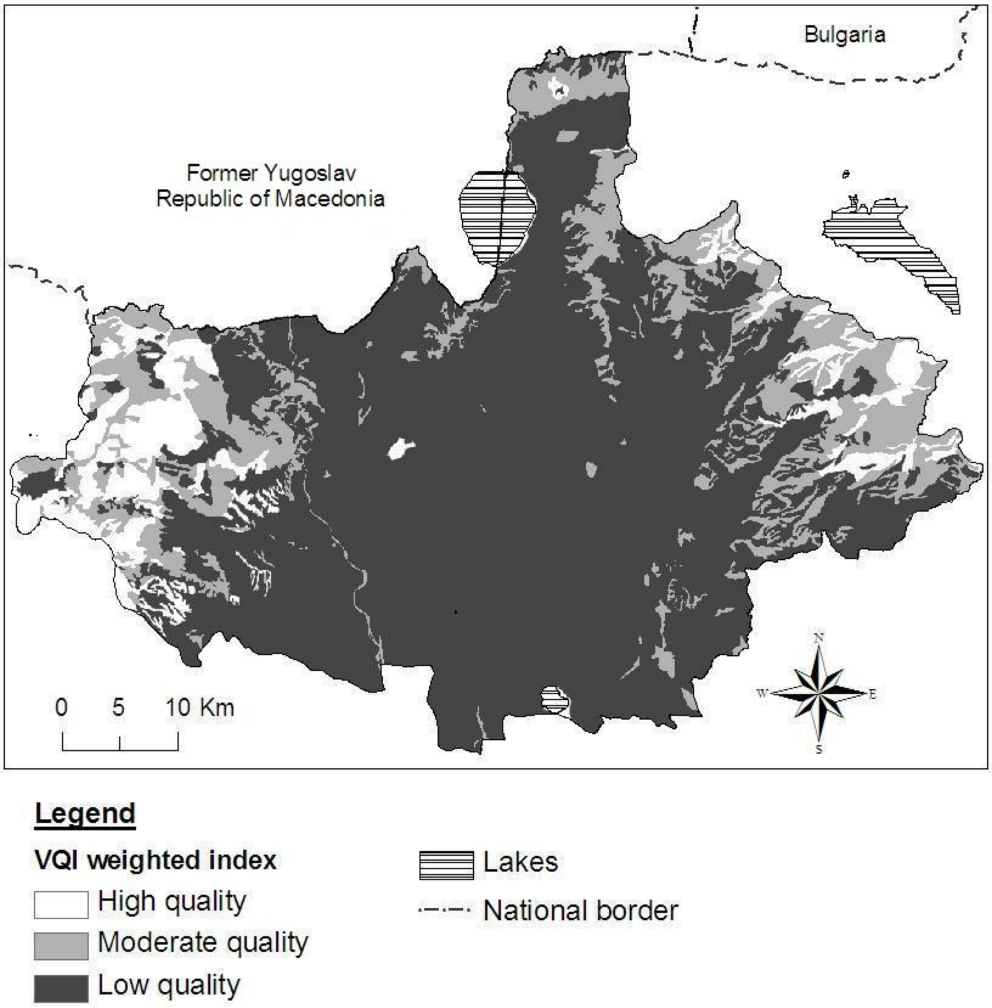

Fig. 8. Weighted Vegetation Quality map of the Kilkis prefecture study territory

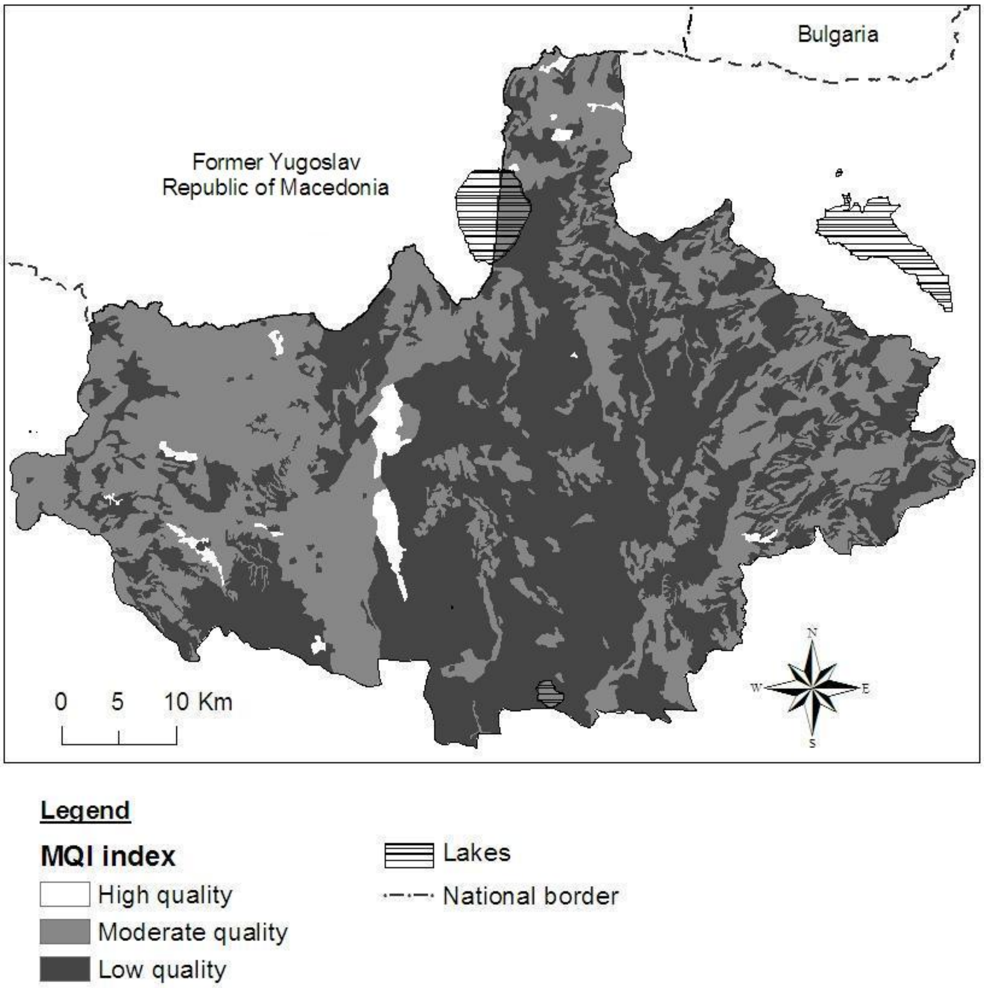

Fig. 9. Management Quality map of the Kilkis prefecture study territory

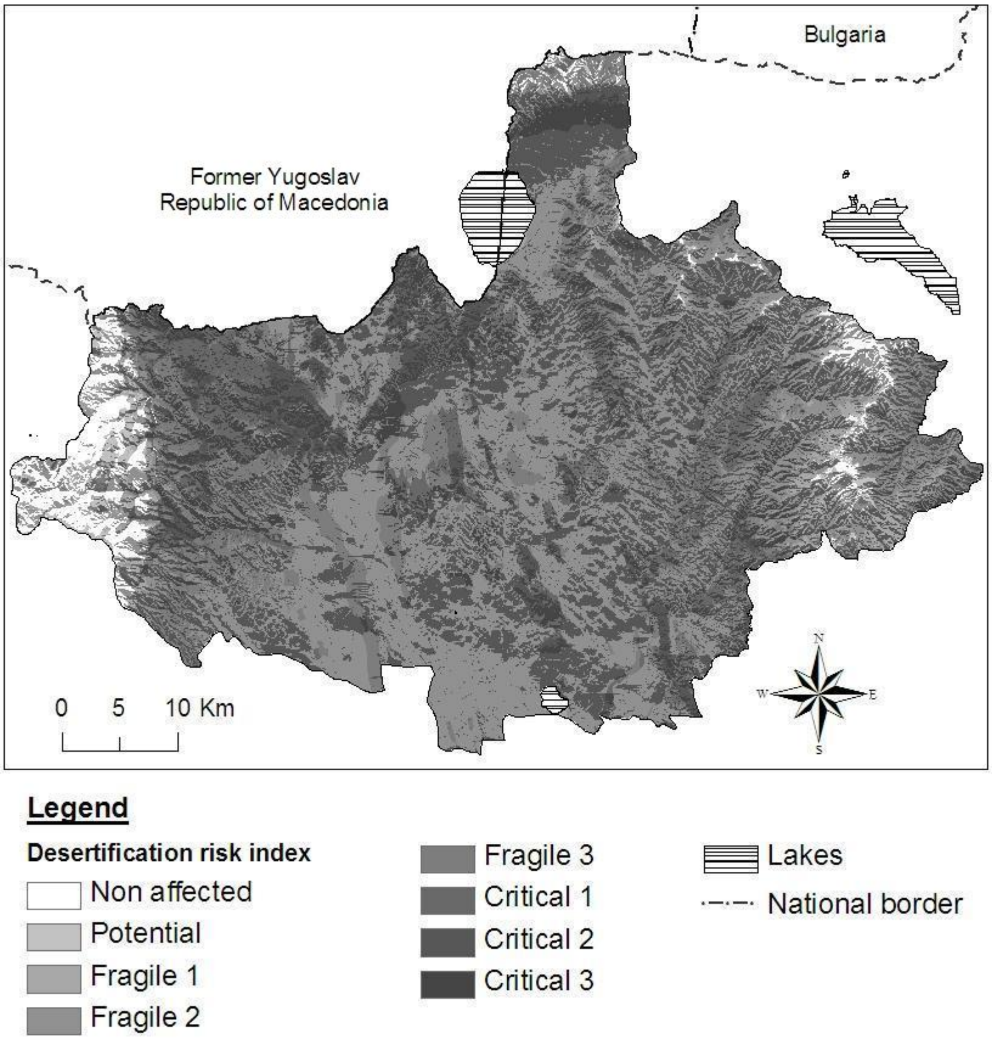

Fig. 10. Desertification Risk map of the Kilkis prefecture study territory

Conclusion

A desertification risk assessment model was designed and applied to the prefecture of Kilkis in Central Macedonia. As expected, the experiment revealed that a significant percentage of the area is sensitive to desertification with a lower extent presenting a critical risk of desertification; this means that the fragile balance between natural and human activity must be preserved and serious protection actions have to be rapidly undertaken in the concerned areas before the process reaches a point where the damage on soil and vegetation is irreversible.

Acknowledgments

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