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Characterization of a Typical Mediterranean Watershed Using Remote Sensing Techniques and GIS Tools

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Abstract

Geographic Information Systems (GIS) were used to establish an information data base to characterize a watershed in Northern Greece, analyze the distribution of the drainage network according to the different characteristics of the watershed using a drainage density index based on GIS. The drainage network was delineated from ASTER GDEM and Landsat-8 OLI data. Digital image processing was based on enhancement techniques. GIS characterized the watershed easily and efficiently. The drainage density index, based on the number of pixels, was appropriate for analyzing the distribution of the drainage network in relation to other characteristics of the watershed. The possibility of using GIS to generate buffer zones around linear and area features helped to quantify sensitive areas close to streams. The problem of cell resolution was overcome by reference to the mapping scale and other factors. Landsat-8 OLI data gave promising results, closely accurate to those from a 1:50,000 topographic maps. The number of streams and total stream lengths of all orders from ASTER GDEM data were higher than from the other sources. Geometric characteristics of the watershed derived from ASTER GDEM data were almost the same as from the 1:50,000 topographic maps. Best results were from a new band index based on Bands 2 and 5. Both techniques, GIS and Remote Sensing, are suitable for application to watershed management in the Mediterranean region.

Keywords: ASTER GDEM; Digital image processing; GIS; Mediterranean; Remote sensing; Watershed management

Introduction

A watershed is a land unit which drains into a stream system and includes a major part of the natural resources. From these resources, water is of vital importance; the development of a nation is intimately connected with its water resources. In the Mediterranean area, all natural resources are in strong relationship to each other's. However, their state is man-induced, not only because of the long history of this area but also because of the vital link between man and land in a sociodynamic context, which in turn has led to the degradation and erosion of soils and watersheds, as shown in studies in Egypt, Greece, Italy and Spain [1-5].

In particular, accelerated land or soil erosion, in contrast to physical erosion, especially in semiarid areas of the Mediterranean, is mainly due to the action of man on his natural environment [5]. In Greece, this problem has increased through the pressure of man on the natural resources that are located in the watershed. Over four million hectares have been either completely or partially eroded, and it is estimated that around 1,000 cubic meters per square kilometer of material is eroded by streams each year [6].

Sound management of degraded watersheds requires not only the study of their characteristics, but also the investigation of their interrelationships. The study of this balances, whether influenced or not, requires such dealing, because in non-induced conditions a watershed forms an ecologically balanced system. Watershed management deals with all land resources, such as forest lands, range lands, areas destroyed by erosion, or others that can serve as protection areas [7]. Like other kinds of management, watershed management needs the sophisticated tools which have been developed in recent decades, Remote Sensing and Geographic Information Systems (GIS) have an important contribution to make.

A water shed is suitable for applications of GIS and Remote Sensing not only because it represents a natural hydrologic and topographic unit [8,9], but also because watershed management is a broad field that includes a multitude of subjects in the biophysical domain [10]. These two techniques are the most suitable for natural resources management in general [11] and for watershed management specifically.

Superficial deposits and the solum overlying the solid rock are often described in terms of the percentage of several soil types extending over the area of the watershed [12]. The soil is important in watershed management, as it consists of mineral particles, organic material and moisture. It is distinguished from the parent material or rock below, in that it supports the roots of vegetation and the un decomposed organic material above. The depth, texture, structure and porosity are hydrologically important.

A watershed has not been regarded as an integrated system: characterization, analysis of the characteristics and their interrelationships, and emphasis on the problems threatening it. In a GIS, answers about how, why and what to characterize, analyze and emphasize in a watershed are needed. In particular, the drainage network, as a skeleton of the watershed, has to be studied and analyzed. Erosion is a main problem in the watershed, but, most studies have concentrated on the use of empirical formulae [13], such as the

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universal loss equation (USLE), which is not always the appropriate tool for erosion studies. Further, new developments in data collection systems such as the Landsat-8 OLI system may answer the need for drainage network delineation and update. As in the case of soil types, vegetation character needs to be specified precisely and this can often be achieved by distinguishing major land use types such as broad leaf, conifer, agricultural and urban. Vegetation is an essential component as through plants, land becomes productive. Vegetation protects soil against erosion, is one of the factors by which a watershed can be manipulated and regulates runoff and infiltration. In some cases, one particular form of land use may be of paramount significance. In this case, the percentage of this single type within a basin may be used as an index of land use character. The objective of this study was to investigate the watershed as an integrated system using Remote Sensing and GIS, taking the drainage network as the skeleton of the watershed.

Materials and Methods

Study area

The study area was the Olynthos watershed, located in the Halkidhiki peninsula, near Polygyros south east of Thessaloniki in Northern Macedonia, Greece (Figure 1). It lies approximately between 23°17' to 23°E and 40°15' to 40°30'N. The main river is called the Olynthos and the watershed area is approximately 244 km^2, with an altitude ranging from sea level to 1100 m. The area is of particular interest because of its typical Mediterranean bioclimate, characterised by hot and dry summers and cold humid winters, and because Halkidhiki is of particular interest to many natural resource managers because of manmade problems [4,14-19]. The area is also of interest for dam construction on the upper part of Olynthos River which carries large load of debris after heavy rains, the result of soil erosion, a serious problem in the area. Water supply can be also, at least in part, solved. The climate ranges from semiarid to temperate and humid Mediterranean [20]. Data from the Taxiarchis meteorological station, located in the northern part of the watershed at an altitude of approximately 1000 m (outside the watershed) shows that the mean annual rainfall is 759.5 mm and the mean annual air temperature is 10.7°C. South of the area, the rainfall decreases and the temperature increases. The major part of the area is characterized by moderate humidity and temperature, a mild and wet winter and a warm and dry summer. The geology of the area varies from south to north. The southern part of the area is dominated by tertiary calcareous deposits; the northern part is mainly composed of phyllites, quartzites and epigneisses. Close to the sea, there are mainly alluvial deposits [21]. The geological structure and the numerous lithological types, combined with the effects of human activities on the land, are the primary factors in determining soil variability and productivity. Climatic and edaphic factors and human activities are important factors affecting vegetation in most parts of the study area. In particular, during the dry summer, only plants adapted to the unfavorable conditions are able to survive. Fire, wood cutting and heavy stock grazing are the factors contributing to the degradation of the vegetation stands, accounting for the dominant maquis vegetation which is mainly composed of sclerophyllous evergreen shrubs adapted to the Mediterranean ecosystem.

Data collection

Two field visits to the area were necessary to acquire general information on the Land Use Land Cover (LULC) characteristics of the area, and to become familiar with the aerial photographs in the field. Development of LULC classification categories and accuracies were based on the field trips. The determination of the various classification categories was based on the hydrological importance and the frequency of occurrence. The classification system included twelve categories; the methodology followed was that of Karteris and Pyrovesti [22] with some modifications (Figure 2). Delineation of the watershed boundary on the orthophotomaps, after enlargement of the topographic maps

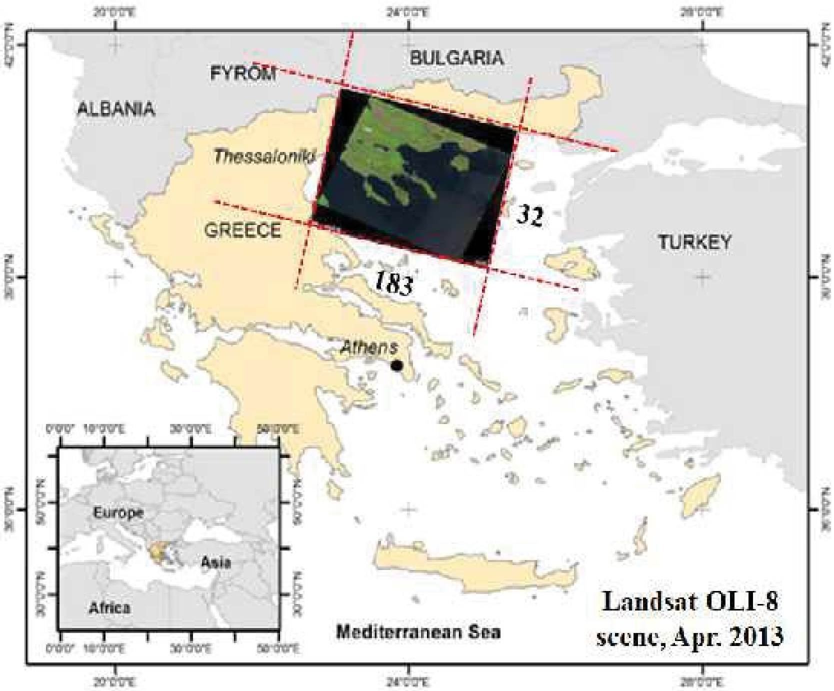

Figure 1: Location of the study area.

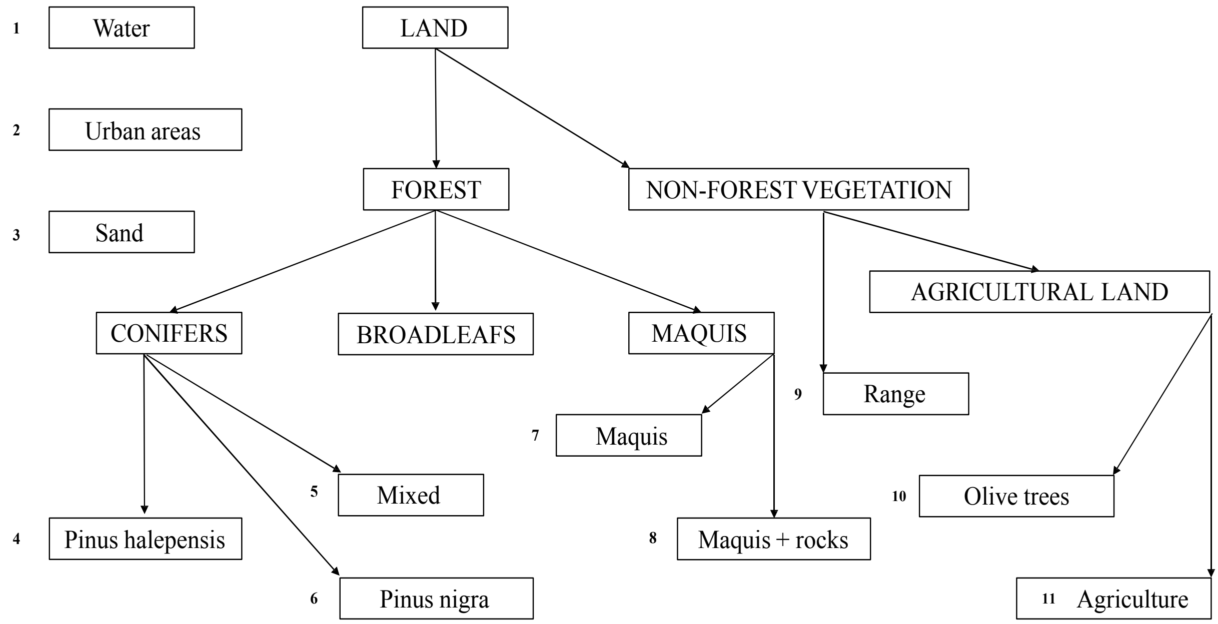

Figure 2: The classification scheme.

at 1:20,000 was carried out to cross check the outcomes of remote sensing data analysis. The orthophotomaps gave a preliminary LULC distribution. The preliminary map from the orthophotomaps was modified by the use of aerial photographs and adjusted to the new classification system.

Watershed characterization

This was based on the independent analysis of ASTER GDEM data. Under ArcGIS environment, Arc Hydro tools were specifically used. The Arc Hydro tools were used to derive several data sets that collectively describe the drainage patterns of a catchment. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation [23]. These data are then used to develop a vector representation of catchments and drainage lines. Using this information, a geometric network is constructed.

Topographic characteristics

Area (A): the total watershed surface, generally expressed in square kilometers; Order (u): in a drainage network, there is a need to apply ordering procedures for further statistical analysis; many ordering systems have been developed. Strahler's [24] method was adopted for this study as it is the most objective and straight forward system [12,25]. Assuming that the channel-network map includes all intermittent and permanent flow lines located in clearly defined valleys, the smallest finger-tip tributaries are designed Order

1. Where two Order 1 channels join together, a channel segment of Order 2 is formed; where two of Order 2 joins together, a segment of Order 3 is formed and so forth [26]. Number of streams of order u (Nu) is the total number of streams of any order u. Stream length (Lu) is the length (in kilometers) of any stream of order u. Density of the stream network (Dd) is the sum of length of all streams per unit of drainage area: Dd=LLu/A. Drainage density is independent of order.

Digital image processing

Multiband enhancement band combination, principal component analysis (PCA) and band rationing were the main techniques applied to different bands. PCA was used to reduce image dimensionality and improve the appearance of the image on many bands together. Rationing consisted of dividing the digital number (DN) of each pixel in one band by the corresponding DN in another band. Normalized Difference Vegetation Index (NDVI) was created to enhance the drainage network, using the Algebra algorithm available in the ENVIS system (Band 4-Band 3/Band 4+Band 3). The ratio and index images were subjected to spectral and spatial enhancement to delineate the drainage network.

Results and Discussion

Supervised classification using different classification algorithms were performed. Both statistical and graphical analyses of feature selection were conducted. All visible and infrared bands (except for the thermal infrared band) were included in the analysis. SVM showed better classification results than the other classification algorithms [27]. Figure 3 shows that only 6 classification categories were performed following the adopted classification scheme. The absence of the other different categories is explained by limited surface heterogeneity found in the study area [27].

The overall accuracy assessments ranged from 78.25% to 98.51% and were considered reasonable for forestry purposes by Congalton [28] and Congalton and Green [29]. When Mahanaholbis distance was used the overall accuracy was the lowest (78.25%). The category of conifers was classified with an accuracy of 83.54% (*Pinus halepensis*). Also there were misclassification errors between the categories of *Pinus halepensis* and mixed conifers, Olive cultivation and agriculture according to the statistical separability index.

Support Vector Machine gave the highest overall accuracy (98.51%). The categories of *Pinus halepensis*, mixed conifers, olive trees,

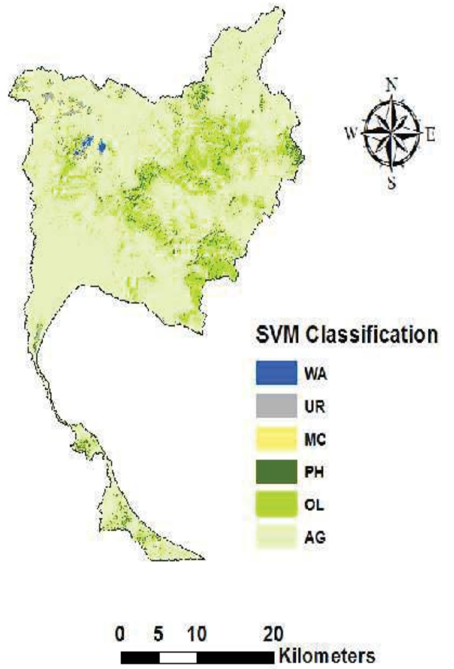

Figure 3: Support Vector Machine classification. (Where: WA: water, UA: urban area, MC: mixed conifers, PH: Pinus halepensis, OL: olive trees and AG: agriculture).

agriculture and Urban gave the highest producer's accuracy amongst the various channels combinations.

The NDVI composes a measurement for the photosynthetic activity and is strongly in correlation with density and vitality of the vegetation. The normalizing reduces topographically and atmospheric effects and enables the simultaneous examination of a wide area. Red and Near Infra-Red reflectance measurements are used to compute a vegetation index such as NDVI [30]. Figure 4 demonstrated that the NDVI values decreased gradually from the upstream toward downstream.

Fills sinks in a surface raster to remove small imperfections in the data. A sink is a cell with an undefined drainage direction; no pixels surrounding it are lower. The pour point is the boundary cell with the lowest elevation for the contributing area of a sink. If the sink were filled with water, this is the point where water would pour out. Digital Elevation Model shown in Figure 5, was undergone fill sinks for better watershed characterization results [31,32].

The concept is to create a raster of flow direction from each cell to its steepest downslope neighbor as it illustrated in Figure 6. If a cell has the same change in z-value in multiple directions and is not part of a sink, the flow direction is assigned according to the most likely direction.

The tool is to create a raster of accumulated flow into each cell. A weight factor can optionally be applied. Pixels of undefined flow direction will only receive flow; they will not contribute to any downstream flow. A cell is considered to have an undefined flow direction if its value in the flow direction raster is anything other than E, SE, S, SW, W, NW, N, or NE. Figure 7 shows that there are two main accumulated flows located within the study area. From the digital elevation model (DEM), both slope and aspect were automatically obtained from Arc Hydro Tool. Slope categories were obtained from slope category report and tabulated in degrees (Table 1) then converted to percentage and reclassified (Table 2). The slope categories scheme deviates from that of Nakos [33], in which: 0 to 40%: gentle, 41 to 75%: middle, 76% and higher: severe.

Total number of pixels in each altitude category is given in the last column of Table 3, and the drainage density (Ddc) calculated for each altitude category (Table 4), computed as the total number of pixels in all drainage network tributaries divided by the area of each altitude category. The variation of the drainage density index in relation to altitude is explained as following: at the highest elevation, this index is low because of the presence of dense forest cover in these parts of

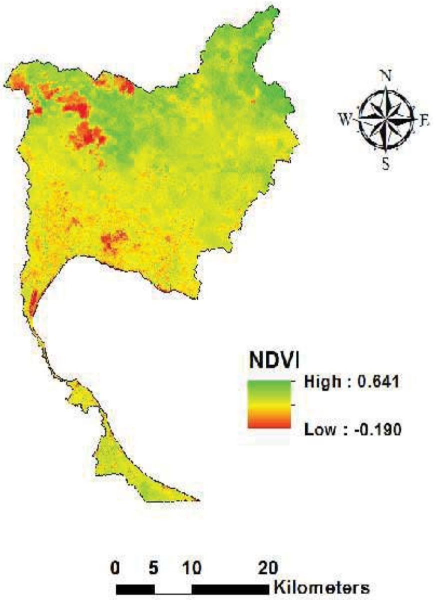

Figure 4: Mapping of Normalized Difference Vegetation index with the study area.

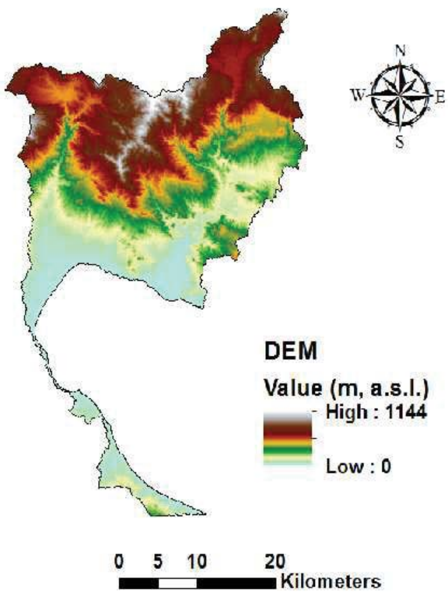

Figure 5: Digital Elevation model of Olynthos area.

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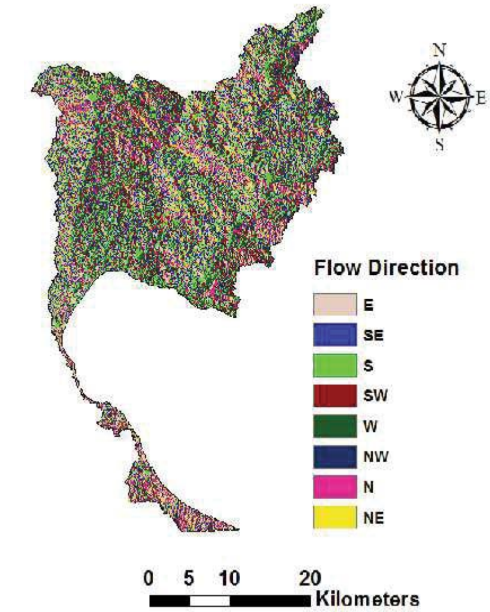

Figure 6: Flow Direction of Olynthos area.

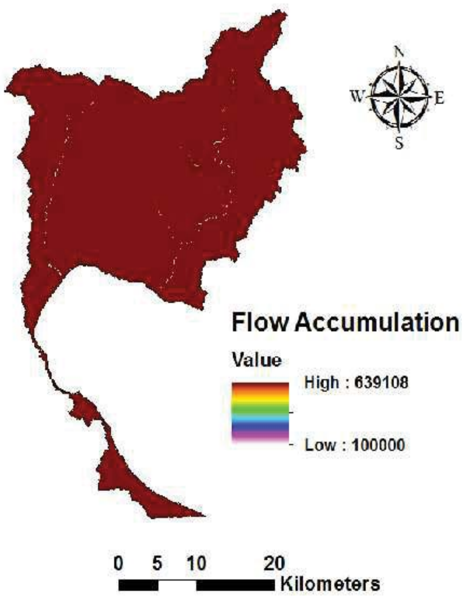

Figure 7: Flow Accumulation of Olynthos area.

the watershed. At middle elevations, the value reaches a maximum and then decreases, due the increase of the area of altitude categories.

The tool is to calculate the upstream or downstream distance, or weighted distance, along the flow path for each cell. A primary use of the Flow Length tool is to calculate the length of the longest flow path within a given basin. This measure is often used to calculate the time of concentration of a basin. In Figure 8, downstream distance in (m) of the designated study area of Oylnthos is demonstrated.

The output of Stream Order will be of higher quality if the input stream raster and input flow direction raster are derived from the same surface. If the streamraster is derived from a rasterized streams dataset, the output may not be usable because, on a cell-by-cell basis, the direction will not correspond with the location of stream pixels. The results of the Flow Accumulation tool can be used to create a raster stream network by applying a threshold value to select pixels

Slope category	Percentage	km^2	Number of 30 × 30 m pixels
0-15%	50.20	122.39	48957
16-40%	2.47	6.01	2406
41-65%	1.13	2.76	1103
66-85%	2.38	5.81	2324
86% and higher	43.82	106.82	42729
Total	100.00	243.80	97519

Table 1: Slope categories of the watershed: percentages of total, km^2 and number of 30 × 30 m pixels.

Aspect category Aspect category	Percentage Percentage	Km^2	Number of 30 × 30 m pixels Number of 30 × 30 m pixels
No aspect	50.20	122.39	48957
Southeast facing	1.55	3.77	1508
East facing	9.95	24.26	9704
Northeast facing	6.83	16.65	6660
North facing	6.37	15.54	6215
Northwest facing	5.52	13.47	5387
West facing	6.05	14.75	5900
Southwest facing	7.00	17.08	6831
South facing	6.52	15.89	6357
Total	100.00	243.80	97519

Table 2: Aspect categories of the watershed: percentages of total, km^2 and number of 30 × 30 m pixels.

Altitude category	1st	2nd	3rd	4th	5th	Total
1	4	0	0	0	0	4
2	52	0	0	0	0	52
3	269	40	0	0	0	309
4	642	213	45	0	0	900
5	1216	575	178	66	0	2035
6	1659	981	320	189	11	3193
7	803	534	369	222	16	1944
8	391	171	130	92	87	871
9	409	140	119	74	86	828
10	632	337	140	89	282	1480
11	274	299	311	30	154	1068
Total	6351	3290	1612	762	471	12739

Table 3: Distribution of the drainage network tributaries according to altitude.

Category	Ratio values	Ddc value
1	4/224	0.018
2	52/692	0.075
3	309/4242	0.073
4	900/8816	0.102
5	2035/16442	0.124
6	3160/22644	0.139
7	2082/13438	0.155
8	871/5861	0.149
9	846/5051	0.167
10	1284/8348	0.154
11	1196/1176	0.102

Table 4: Drainage density index computed for the altitude categories of the watershed.

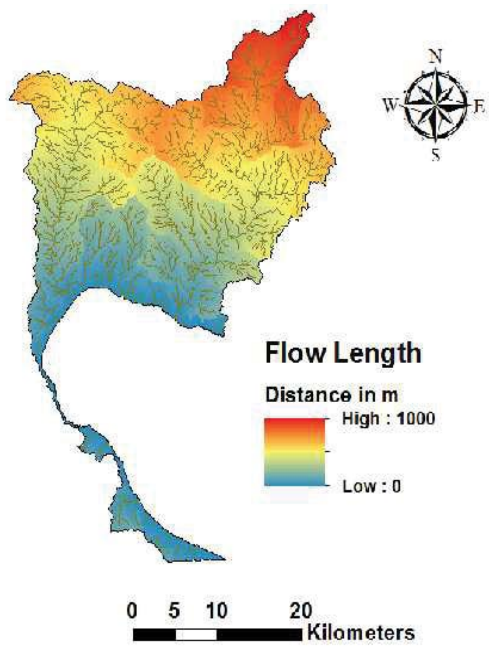

Figure 8: Downstream flow length of Olynthos area in meter.

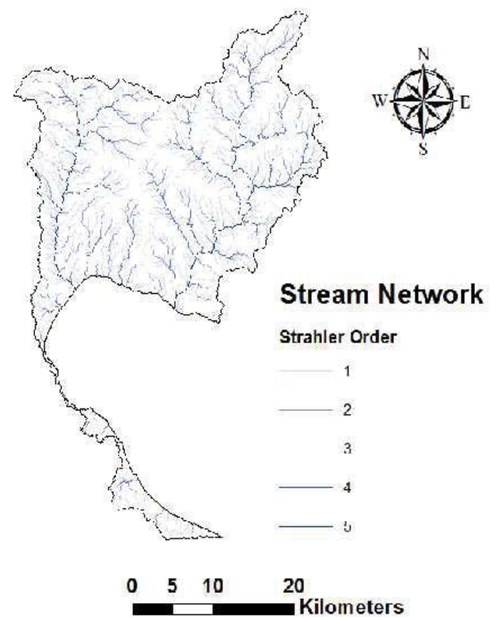

Figure 9: Stream Network of Olynthos area.

with a high accumulated flow. An analytical method for determining an appropriate threshold value for stream network delineation is presented in Tarboton [34]. Stream order only increases when streams of the same order intersect. Therefore, the intersection of a first-order and second-order link will remain a second-order link, rather than creating a third- order link as it shown in Figure 9.

The bifurcation ratio, is the total number of streams in any order (u) divided by the total number of streams of the next order (u+1) (Rb=Nu/Nu+1), showed that there was no great difference between the three sources. The lowest value was obtained from the Landsat OLI-8 data, which may have been due to the few streams all orders. The highest bifurcation ratio (Rb=6), which was obtained in the fourth order of the Landsat OLI-8 image, can be explained by the low number of fourth order streams. Bifurcation ratios (Rb) from the topographic maps (1:50,000 and 1:100,000) and Landsat OLI-8 image.

Conclusions and Prospects

Watershed degradation; which lead to reduced productivity, even on marginal lands, needs information which should be supplied in an accurate and timely effective manner. GIS and Remote Sensing are the best answer to this problem. The application of GIS using ArcMap in this study shows that characterization of a watershed can be simple and efficient. The drainage index, based on the number of pixels, was a good indicator of the distribution of the drainage network tributaries in relation to the characteristics of the watershed. It substituted the former drainage index based on measurement of total stream length which is a time consuming method. The ability of ArcMap to generate buffer zones around streams permitted the quantification and the assessment of the impact of land use activities. Better results may be obtained if a complex model for erosion potential assessment is used. This model integrated several outputs to locate precisely water stream networks and sink areas, most of which were located on agricultural land and Olive cultivation, indicating their sensitivity and the need for erosion protection. The drainage network was delineated from ASTER GDEM data using the ENVI image processing system. Solid results were obtained; moreover, the number of streams and total stream length in all orders obtained from the ASTER GDEM were closely equaled to those from the 1:50,000 topographic maps. A common Normalized Difference Vegetation Index for image enhancement gave satisfactory results, mainly at high altitudes with dense vegetative cover. Both GIS and Remote Sensing techniques can be used separated or in combination in watershed analysis. Future research must study the possibility of mapping and monitoring soil erosion from satellite imagery and GIS techniques in such a typical Mediterranean environment.

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