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Quantitative estimation of degradation in the Aliakmon River basin using GIS

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Abstract A new model was implemented for the quantitative estimation of degradation in the Aliakmon River basin. The empirical model developed by Gavrilović (1972) served as a starting point and was further extended by initiating appropriate adjustments through the use of a Geographic Information System (GIS). In the case of the Aliakmon River basin, the average annual degradation was estimated with remarkably high precision. Using this improved model, several maps were constructed, including a map of total potential erosion. To our knowledge, this is the first time that such a model has been applied on such a large basin. More importantly, based on our results we feel that this improved model of estimation may be applied to any basin, including high-relief regions and very large basins.

Key words Aliakmon River; Gavrilović method; GIS; Greece

INTRODUCTION

The study of the three-fold phenomenon of erosion–transportation–deposition of sediment in the basins of rivers and streams is a scientific issue that has been researched and analysed in a great number of papers. Such studies and analyses frequently focus on both qualitative and quantitative estimates, via empirical methods, or comparison models that can be locally or universally applied (Beasly & Huggins, 1991; Mitas *et al.*, 1996; Pintar, 1972; Rydgren, 1996; Terry, 1996).

This paper deals with estimating the annual potential degradation in the drainage basin of the Aliakmon River, the longest river in Greece. This degradation is the result of erosion that takes place in the sub-basins. The product of this degradation, sediment, is transferred through the drainage network. Some of this sediment reaches the rivers and exits onto the plains, while some remains in the mountain headwaters in the form of within-basin deposits.

The estimate is obtained through a general model of quantitative degradation in torrential basins. In this case, however, the model has been adjusted so as to, first, estimate the degradation of a drainage basin having an area much larger than that of a torrent (ephemeral stream) and, second, include information derived from a digital elevation model (DEM).

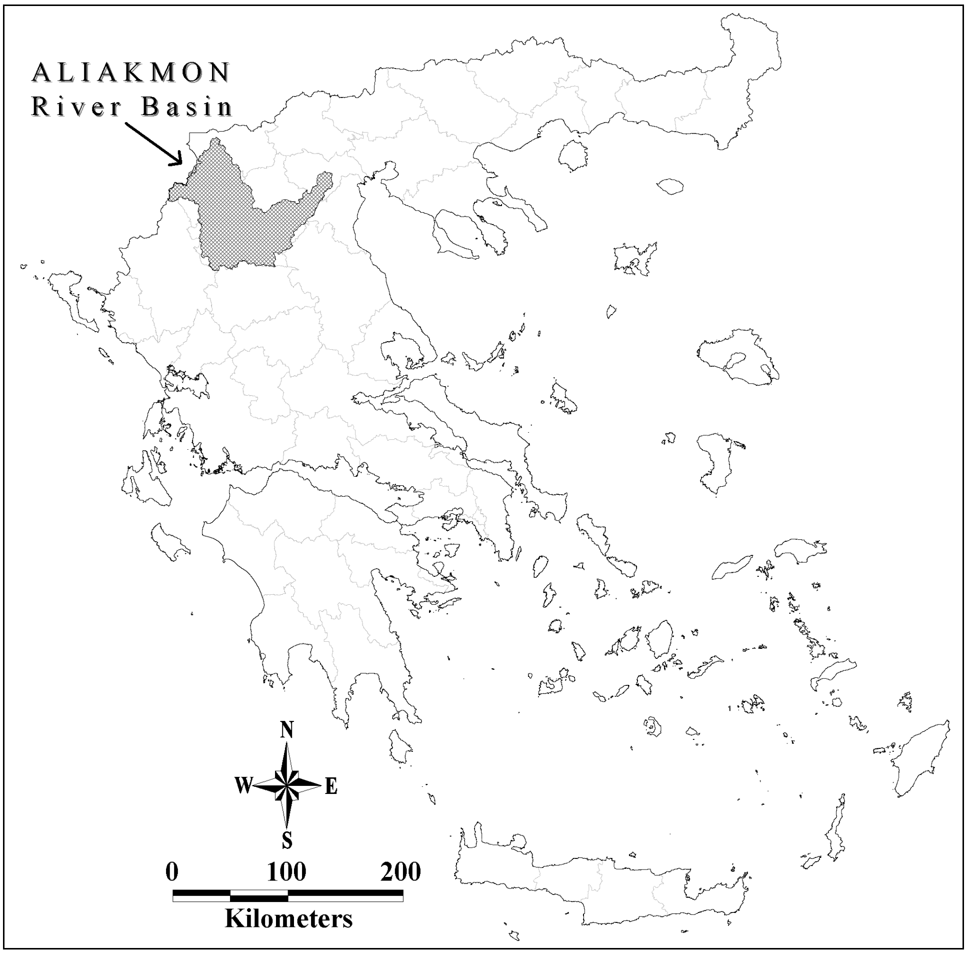

Fig. 1 Location of the research area.

RESEARCH METHOD AND RESULTS

The research area is the Aliakmon River basin, which has a drainage area of 7000 km^2. This basin extends from the border of Greece and Albania and makes up the largest portion of western Macedonia. The river flows past the city of Veria (Fig. 1), continues across the Thessaloniki plain, and discharges into the Gulf of Thermaikos. Sediment is transported in secondary and main stream channels, and in river channels. This sediment is the product of erosion in the sub-basins.

The method used in this study concerns the estimation of the potential annual degradation for the entire Aliakmon River basin. This is the estimate of the total mass of sediment that potentially can be detached from the beds of all the Aliakmon sub-basins, and by moving within the river channel, head towards the basin's exit area.

The empirical Gavrilović model has been used as the method's starting point (Gavrilović, 1972), with modifications as discussed by Emmanouloudis & Filippidis (1998, 1999). The general equation, which provides the average annual degradation in a basin (m^3), is calculated as:

$$W = T\,h\,\pi\sqrt{z^3}\,F \qquad (1)$$

where T is the temperature coefficient provided by:

$$T = \sqrt{\frac{t_o}{10}} + 0.1 \tag{2}$$

where t_o is average annual temperature in the basin (degree Celsius), h is average annual rainfall (mm), F is drainage area (km^2), and z is the erosion coefficient given by:

$$z = x\,y\,(\varphi + \sqrt{j}\,) \tag{3}$$

with x, y, φ as the coefficients dependent on vegetation, geology and the basin's erosive degree, respectively, and j as the slope in percent. In our earlier research, a GIS was used to provide values for the coefficients for cells that are usually a few tens of square metres in area. This was not anticipated in the original Gavrilović method, which uses gross values for these coefficients. In order to obtain the required coefficients, contours lines, triangulation points and summits were digitized from topographic maps of the region. These data were subsequently interpolated to generate a digital elevation model (DEM). On the DEM base, thematic maps have been constructed depicting slope, temperature, precipitation and other variables (Mapinfo Corporation, 1997; Neidig *et al.*, 1991; Northwood Geoscience Ltd, 1998; Shapiro & Westerveld, 1992). In addition to the above-mentioned maps, the geology of the Aliakmon River basin (based on the IGMR geological maps), the vegetation cover (based on CORINE classification and pseudo-colour satellite image of the area), and the drainage network, have been digitized. These geological and vegetation maps showed 27 different vegetation categories and 25 different geological formations in the basin area.

To simplify the estimation process and to cope with any difficulties in processing such a large area (1 700 000 computational cells), the following steps have been taken:

(a) Classification of the 27 different vegetation categories into four groups. Based on the relevant tables given by Gavrilović (1972), a different x value was given to each group. For example, vegetation categories that belonged to group A (dense forests and dense shrubs) were given values from 0.01 to 0.15, whereas those that belonged to group B (degraded, sparse forests, etc.) received values from 0.2 to 0.3.

(b) Classification of the 25 different geological formations into five groups was carried out based on the above-mentioned tables, and a specific y value was assigned to each of the five groups.

(c) Similarly, based on visual analysis of a false colour Landsat image, we categorized the erosion centres of the basin. This categorization resulted in four groups. Tables 1, 2 and 3 describe the vegetation, geological, and erosive divisions, and the estimates for the x, y, and φ coefficients, along with their respective values and the surface areas for each group.

Apart from the x, y, and φ coefficients, the estimations also require estimates of slope. It is possible to obtain the slope values by using the inclination table and the GIS for each of the 1 700 000 created cells. Finally, from x, y, φ, and j we can calculate all z_i values for the basin.

For further analysis, the 1 700 000 z values were re-sampled into 256 groups. Each group included z values over a range of 10 units (Gujarati, 1995; Norussis, 1994; Snedecor & Cochran, 1994) so that the first group included z values from 20 to 30 and

Table 1 *x* values.

Category	Description	Min	Max	Area (km^2)
A	forest and dense shrubs	0.01	0.15	2782.04
B	pine forest and thickets	0.2	0.3	310.588
C	sparse forest and bushes	0.4	0.6	1499.05
D	ranges and cultivation	0.6	0.8	1603.45
Total				6195.128

Table 2 *y* values.

Category	Description	Min	Max	Area (km^2)
A	hard rocks resistant against erosion	0.2	0.5	1489.03
B	rocks moderately resistant to erosion	0.7	0.8	738.419
C	fragmented rocks	1	1.1	205.014
D	deposits, moraines, clays, sandstones	1.3	1.6	2410.13
E	soils and soft rocks	1.8	1.8	1350.41
Total				6193.003

Table 3 φ values.

Category	Description	Min	Max	Area (km^2)
A	minimal erosion	0.1	0.2	968.865
B	moderate erosion	0.2	0.5	3860.95
C	landslides and local depositions	0.6	0.7	1198.13
D	accelerated erosion, gullies, rockfalls	0.8	0.8	165.059
Total				6193.004

Table 4 *z* values.

Group number	Value range from:	to:	No. of pixels	Area (m^2)	Percentage area	Cumulative % of area
1	20.72	29.75	5163	18 586 800	0.296	0.296
2	29.75	38.78	4553	16 390 800	0.261	0.557
...	...	...	...	...	...	...
...	...	...	...	...	...	...
255	2313.69	2322.72	102	367 200	0.006	99.998
256	2322.72	2322.72	34	122 400	0.002	100
Total					1.000	

consisted of 5163 cells; the second group included z values of 30 to 40 and consisted of 4553 cells, and so on. A number of these values are shown in Table 4. In order to determine the average annual degradation (W), we also need to estimate the average annual temperature t and the average annual rainfall h. The estimation procedure for these two variables should be analytical and based on the topographic characteristics of the basin. For this purpose, we chose to use the spatial distribution method, which is most suitable for temperature and precipitation. Following this, a series of calculations results in an estimate of W (annual degradation) for each cell of the basin.

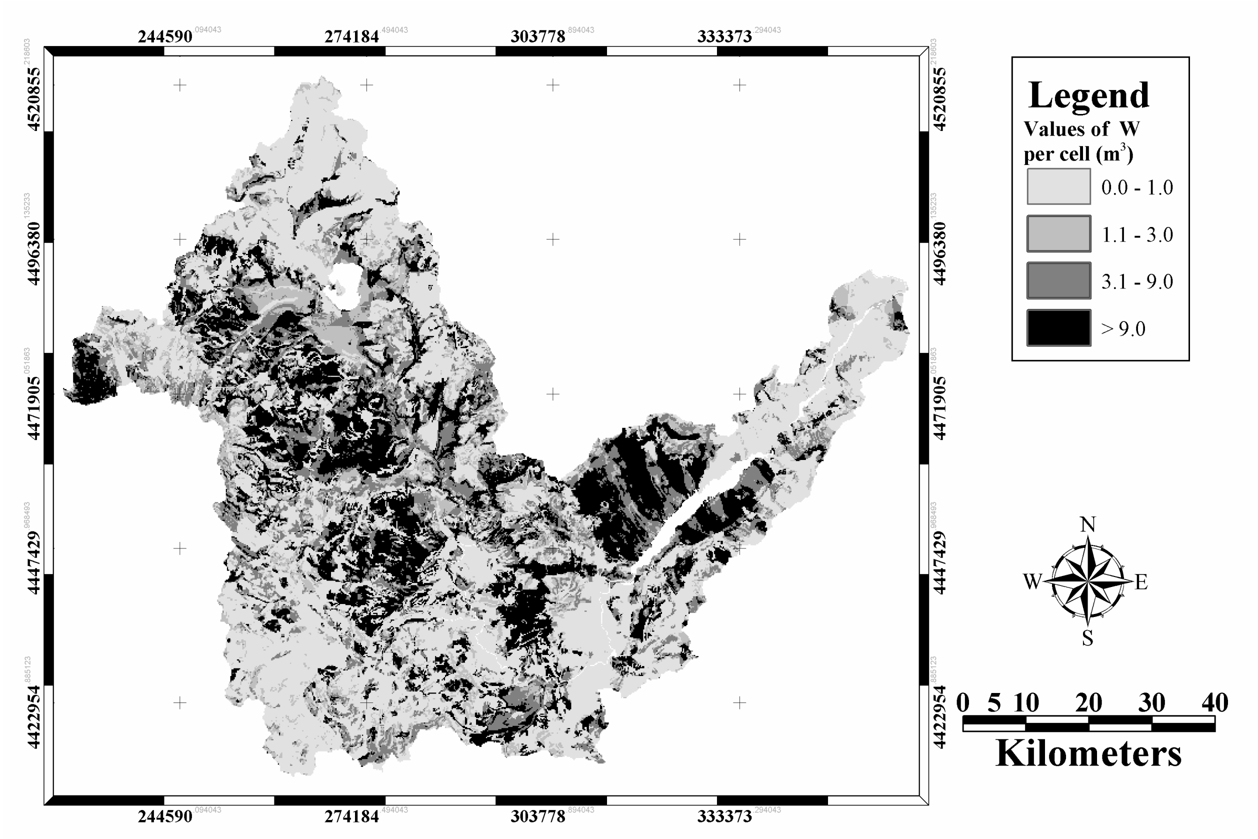

Fig. 2 Total degradation map of the Aliakmon River basin.

Table 5 Descriptive statistics of annual W values per cell (m^3).

Minimum	–0.000275218
Maximum	179.81500
Mean	7.35879
Median	2.55703
Number of cells	1 641 275
Range	179.81500
Coefficient of variation	1.54501
Standard deviation	11.36940
Pct null	1.27063
Node sum (W_{tot} of the Aliakmon basin)	12 077 800 (1 641 275 × 7.35)

To better understand the spatial distribution of the W values within the Aliakmon basin, we generated a map of W as shown in Fig. 2. Table 5 highlights W values along with other statistical attributes of the analysis. Interpretation of this Table 5 leads us to conclude that the annual degradation for the entire Aliakmon basin is estimated at 12 077 800 m^3, which corresponds to an average thickness of 1.9 mm. This number is quite high compared to the average values for Greece, but it must be taken into consideration that the Aliakmon basin is exposed to harsh climatic conditions and is composed of highly erodible bedrock (i.e. the molasse formations of the Central Greek trench). The estimated volume of leached material is very different from the volume of sediment, particularly the suspended material, which reaches the basin outlet. This occurs for the following reasons:

(a) In river basins, which consist of a high number of sub-basins, there is internal storage of large amounts of coarse materials. As a result, a significant portion of the eroded material never reaches the central riverbed (intra-basin deposition).

(b) Due to the extreme length of the central riverbed, even the fine suspended materials that eventually reach it are deposited locally along the entire length, in the form of alluvial terraces.

(c) In the Aliakmon River basin there are hydroelectric dams with corresponding reservoirs that are areas of bedload deposition, and sometimes of suspended load deposition.

(d) The broader Aliakmon River basin also contains the sub-basins that contribute water and sediment to Kastoria Lake. Because this lake effectively is a closed hydrological system, the whole area of the stream basins and, consequently, the corresponding degradation, relates (as far as the deposition process is concerned) to the area of the lake and not the Aliakmon central riverbed (Emmanouloudis, 1990).

It is therefore clear that further research and calculations are necessary to estimate the sediment yield of the Aliakmon basin.

CONCLUSIONS

A quantitative estimate of the erosion rate in the Aliakmon basin has been obtained with the aid of the modified Gavrilović model and a GIS. The Gavrilović model commonly has been used only for estimating erosion rates in basins of small ephemeral streams. By incorporating the method into a GIS system, this analysis was extended to the entire Aliakmon basin. Although the result of 1.9 mm is almost twice the average value given by Kotoulas for the broader Greek area, it is very close to the values given for the Sperhios basin of 1.55 mm and the Kastoria Lake basin (which is part of the Aliakmon basin) of 1.35 mm.

The most significant result of this study is that through the aid of GIS, the Gavrilović model can work in river basins, even in basins larger than that of the River Aliakmon, without any particular problems. Basin size, therefore, is no longer restrictive which it was in the classical application of the method; it was a limiting factor due to the difficulty of estimation and the sequence of coefficients. It should be added that during the classical application of the method to the estimation of degradation in river basins, it was necessary for estimation to take place in only the few parts of the basin that are highly erodible, and are known as erosion centres.

As a general conclusion, it can be stated that the precision, detail and speed of estimation provided by GIS allow methods such as that of Gavrilović, as well as other methods that come from the field of quantitative geomorphology, to extend and maximize their potential.

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