# Modified quantitative estimation model of erosion and degradation in four mountainous basins

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**Abstract** This paper presents a new version of a well-known stochastic model to quantitatively assess drainage basin degradation in order to determine erosion in four torrential mountainous basins. This new three-dimensional version, combined with using geographical information systems for data processing, can provide a quantitative assessment of the degradation of any torrential basin in a very short time. Although this system was originally designed for these four particular basins, its flexibility enables it to be adapted for any torrential basin.

## INTRODUCTION—DESCRIPTION OF THE PROBLEM

Drainage basin erosion and degradation is one of the most complex global environmental problems. Thus, it has for many decades been the subject of research in countries representing all of the primary climatic types. The problem is fairly severe in Mediterranean countries, due to climate and other factors, including irregularly distributed rainfall and insufficient plant cover.

The better known methods of analysis are USLE, WEPP, AGNPS, CREAMS, ANSWERS (Beasly & Huggins, 1991), EPIC (Rydgren, 1996; Terry, 1996), and Mitas *et al.* (1996), as well as the contemplative methods of Fournier, Corbel, and Gavrilovic (1972). The majority of them have been used primarily in the United States and to a lesser degree in Europe.

This paper aims at assessing the degradation of four torrential basins with the use of the stochastic Gavrilovic model in an enhanced form (supported by geographical information systems (GIS) software GRASS (Line & Foster, 1996, Shapiro & Westerveld, 1992)). This enables us to calculate the annual sediment and bed-load yield according to the Gavrilovic method in a much easier way, much faster and with much more precision, thanks to GRASS. Needless to say that loads can be calculated for any basin of any size. The advantage of our combined Gavrilovic–GRASS method when compared to the other widely-used methods is that it is the only one applicable to torrential mountainous basins covering a surface of up to 100 km$^2$ with mean surface slopes between 30% and 60% (Kotoulas, 1980). It is well known that such basins are the main suppliers of bed-load material to torrential stream.

It should also be pointed out that for the purposes of this paper, in order to assess degradation, the three-dimensional (3-D) basins area ($F_{3D}$) was used (Fig. 1) instead of the projected area ($F_{2D}$).

$F_{3D}$ is the basin area, not as measured from a map (this is $F_{2D}$), but the actual area of the basin in three-dimensions calculated after a 3-D construction of the basin using GRASS. The $F_{3D}$ is slightly greater than $F_{2D}$ and their deviation depends on the average surface slope of the basin (Emmanouloudis & Filippidis, 1998).

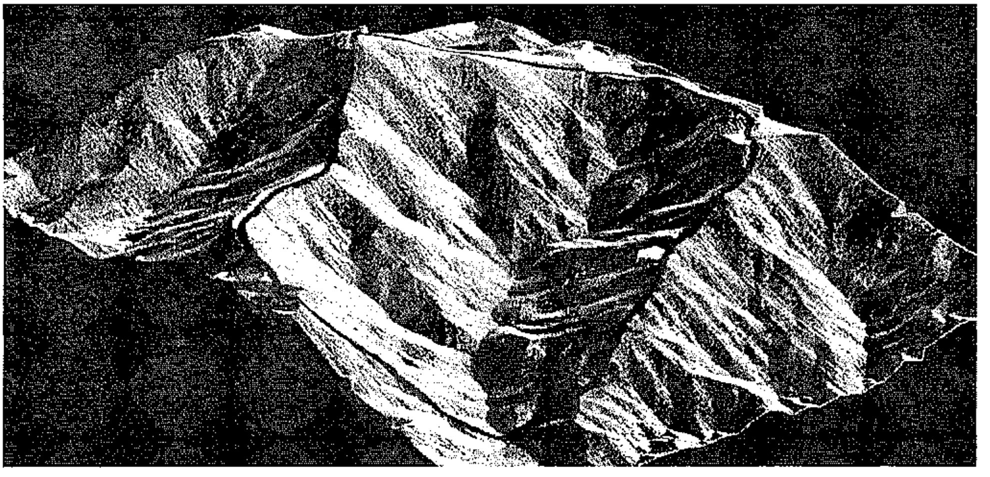

**Fig. 1** Three-dimensional view of Triantafillia basin.

## RESEARCH METHOD

The morphometric characteristics of the selected basins led to the selection of the Gavrilovic method, because its application is uniquely appropriate for estimating the degradation in small mountainous basins, such as those in our study.

In Table 1 the morphometric characteristics of the sample basins are given, which illustrate the mountainous character of the specific torrents.

According to the Gavrilovic method, the equation providing the average annual degradation in a basin is: $W = Th\pi\sqrt{z^3}\,F$ where $T$ is coefficient of temperature given by: $T = \sqrt{(t_0/10)+0.1}$ with: $t_0$, the average annual temperature in the basin; $h$, average annual rainfall (mm); $\pi$: 3.14; $F$: area of basin (km$^2$); and $z$: coefficient of erosion given by the ratio: $z = x\,y\,(\varphi + \sqrt{j})$ with $x$, $y$, $\varphi$ being the partial coefficients that

**Table 1** Morphometric characteristics of the sample basins.

| No. | Basin | $F$ (km$^2$): 2-D (projected) | 3-D | Maximum elevation (m) | Mean slope (%) |
|---|---|---|---|---|---|
| 1 | Riganorrema | 9.43 | 10.03 | 1420 | 30.90 |
| 2 | Fotini | 4.23 | 4.46 | 1190 | 29.41 |
| 3 | Mylos | 5.05 | 5.24 | 1080 | 23.00 |
| 4 | Triantafillia | 8.42 | 8.98 | 1580 | 33.32 |

depend on vegetation, geological base, and the degree of erosion of the basin respectively, whereas *j* is the average slope of the basin area expressed as the tangent of the angle of slope.

In this way, the model after use and adjustment shows an improvement in the following areas: (a) precision of calculations, (b) ease of entering unlimited parameters, (c) convenience in processing the variable values, and (d) appearance.

## RESEARCH RESULTS

The elaboration of the coefficients $x$, $y$, $\varphi$, and the other variables produces the erosion coefficients $z$ for each basin. The final coefficient $z$ of each basin was the weighed result of numerous partial coefficients $z_i$ in which each represents the erosion coefficient of a group of cells. It is evident that all cells of the same group have the same $z_i$ and the same slope. The groups for each basin ranged from tens to several hundreds. By this segmentation into cells the basin is completely divided into very small areas of 36–37 m$^2$ and for each one the erosion and slope coefficient are calculated—something that is not possible in the non GIS Gavrilovic model which uses the same slope for the whole basin.

Finally, in order to have an even more integrated picture of the distribution of $z$ upon all basins of the sample, we drew some maps showing the above-mentioned numerous values of $z_i$ classified into five categories. A different shade of grey was

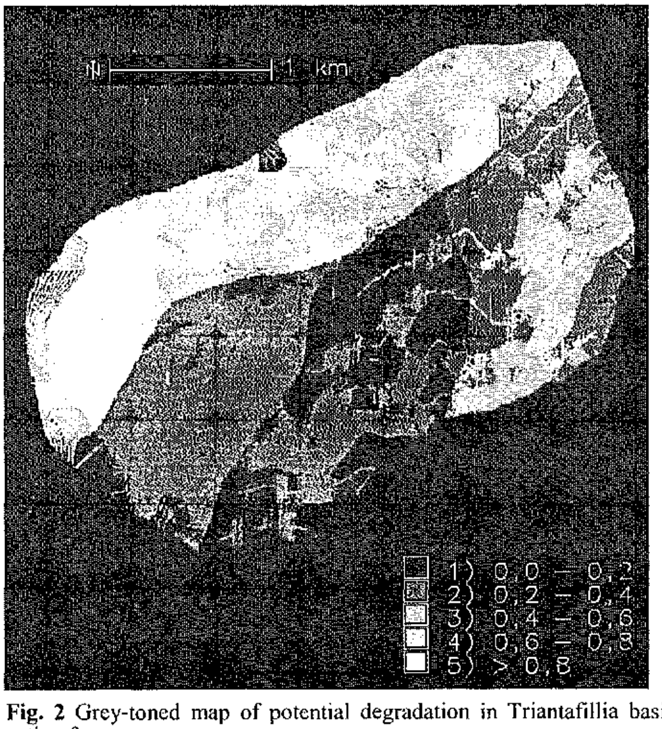


**Fig. 2** Grey-toned map of potential degradation in Triantafillia basin with classification for $z_i$.

applied for each category. In this way we had one much more synoptically and representative grouping of $z_i$. One such map is shown in Fig. 2.

Table 2 shows the values of the final $z$ estimation for all the basins of the sample and the total respective annual sediment and debris yield $W$. This table showed that the largest annual degradation is observed in the Mylos torrential stream and the smallest in the Triantafillia. The former is underlain by silt-mixed marls and sandstones; the latter by pure granites. Mylos is relatively sparsely vegetated with degraded coniferous forests and grasslands while Triantafillia has extensive forest stands and shrub in good condition. Thus, the larger average annual production of debris material from Mylos is clearly explained. Finally, the other two basins, Riganorrema and Fotini, because of their relative intermediate values for vegetation and geology coefficients, display correspondingly intermediate annual sediment and bed-load yields.

**Table 2** Final $z$ values and $W$ values.

| No. | Name | Coefficient $z$ | Average annual sediment and debris yield, $W$ ($m^3$ $year^{-1}$) | Average annual degradation (mm) |
|---|---|---|---|---|
| 1 | Riganorrema | 0.78 | 15 823 | 1.57 |
| 2 | Fotini | 0.66 | 5 484 | 1.22 |
| 3 | Mylos | 3.92 | 20 570 | 3.92 |
| 4 | Triantafillia | 0.75 | 6 823 | 0.75 |

## CONCLUSIONS

For the quantitative estimation of mountainous basin degradation, a new model was used. The contemplative model of Gavrilovic served as a starting point, which was further extended by initiating appropriate adjustments through the use of the GIS GRASS. In the case of the four torrential basins, the average annual degradation has been calculated with a remarkably high precision using this improved model.

Four maps of potential erosion were constructed after calculating degradation. The use of those maps, along with a standardized system of protection measures, can provide an integrated management plan. What is more important, however, is that this improved model of estimation may be applied to any basin, even extremely mountainous or very large basins. This advantage is lacking from all the other methods known so far.

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