Estimation of erosion rate on Anthemountas Basin

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Abstract. This paper describes the quantification process of erosion rate at the Anthemountas basin, district in South-Eastern Thessaloniki, Greece. The calculation is oriented in two directions: a) the calculation of erosion rate for sheet-rill erosion and b) the calculation of sediment discharge. In the first direction, RUSLE model is used and its parameters were estimated from literature tables or calculated from suitable functions. For the calculation of sediment discharge, the maximum water discharge of 50-year period is used, calculated with the method of unit hydrograph. Furthermore, the sediment transport is calculated with the function of Stiny – Herheulidze. Regarding the sheet-rill erosion, the spatial distribution of erosion rate at the Anthemountas Basin is produced. Finally, the calculated sediment discharge is characterized as medium magnitude. The results of this implementation are the first data level for the determination of priority action zones at the semi-mountainous areas of the Anthemountas River Basin.

Keywords: erosion, soil, sediments, sustainability, RUSLE, Anthemountas

1. Introduction

Anthemountas basin is located at the northern part of the peninsula of Chalkidiki in Northern Greece. it is situated/located at the borders of the Thessaloniki city, the second more populated city in Greece, where the last years it is characterized by increased urbanization. All the forms of human activities are hosted in the region, so that a mosaic of land uses is developed. The field observations and the contact with the local stakeholders have revealed an increased erosion problem in small and large sites and at the same time incorrect practices of land uses. By no doubt, the confrontation of the problem can be achieved only by the implementation of a complete soil management policy in the region.

Action 3, in the framework of the project *LIFE07/ENV/GR/000278 – Soil Sustainability*, is the first step of a coordinated and integrated effort to combat soil erosion and especially to manage and protect soil, by aiming at: a) the spatial-temporal distribution of sheet and rill erosion, b) the calculation of the maximum sediment discharge of 50-years period and c) the estimation and progress of degradation rate.

In detail, the purposes of this effort are: a) Proposal of an as simple as possible methodology-process of calculation of erosion rate based on easily accessed raw data, so that it can become an applied tool in other regions and b) The calculation of sheet-rill erosion rate in the Anthemountas basin.

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2. Methodology

The methodology that was applied during the implementation of this study consists of the following stages: a) comparison of soil erosion mathematical calculation models and selection of the final applied model, b) data collection and coefficients‟ production for erosion estimation, c) application of the selected model and d) sediment discharge calculation due to water runoff. The following chapters give a brief description of these stages.

2.1. Comparison of soil erosion mathematical calculation models and selection of the final implemented model

The first step of this stage is the literature review regarding erosion, estimation of soil degradation and calculation models for sheet-rill erosion. In the framework of this research, more than 21 sediment loss estimation models were found. Most of them had limited application and required data that were not available for the research area and are not widely used.

The second step was the determination of selection criteria for further investigation of the proper model for the case of the basin of Anthemountas. These criteria were: a) an acceptable wide use of the model, according to literature, b) the range of the use of the model should have been implemented in areas with similar climate, geological, land-use conditions and satisfactory results and c) the range of conditions should be wide, so that the model can be further applied in various environments.

Third step was the implementation of the above criteria on the group of models from the first step. The selected models, based on the above criteria, were the PESERA (Kirkby et al., 2004), WEPP [Foster and Lane (1987), Flanagan and Livingston (1995), Flanagan and Nearing (1995)] and RUSLE (Renard et al., 1991). To be more specific, PESERA has been implemented in countries of European Union, it was applied in areas with similar environment such as Mediterranean and the applied areas have a wide range of climatic geologic and land-use conditions. WEPP was mainly implemented in USA, on countries of Asia and on a wide range of conditions. The conditions of some of the implemented areas, in USA, approach the conditions of the research area. Finally, RUSLE is applied in an very large number of countries in all continents around the world with a wide range of conditions. It is applied in countries with similar conditions as in Greece, such as Italy and Spain.

Forth step was the determination of new criteria in order to select the final applicable model. These criteria were: a) as less as possible calculated or estimated coefficients for a more user-friendly use, b) the simplicity of the implementation and c) the implementation in European sites with similar condition as in the research area.

Fifth and last step was the selection of the model that was going to be implemented/applied in the research area. Considering the previous criteria, PESERA was not selected because it requires about 128 data layers (raw and produced) and this does not contribute to a user-friendly use. Besides having a wide implementation in member states of the European Union, it is quite difficult for Greek conditions. Also, WEPP was not selected because it has been implemented in countries outside

European Union (USA, Asia), even if it is relatively easy to use. Finally, RUSLE model was selected for the following reasons: a) requires the calculation-estimation just of six (6) coefficients-parameters, b) it is quite simple to implement without complex functions and c) it has been applied in Italy and Spain, countries with similar characteristics (climate, soil, geomorphology etc) as in Greece, with satisfactory results.

2.2. Data collection and coefficients' production for erosion estimation

On this stage, literature overview took place for seeking calculation or estimation methods for coefficients of the model that was selected [RUSLE (Renard et al., 1991), USLE (Wischmeier and Smith,1965,1978)]. In the framework of the search, for some of the coefficients, several methods were found for calculation or estimation. For this reason, it is appropriate to describe the methodology for each coefficient.

2.2.1. R coefficient

The first coefficient, for which a calculation method is sought is the rain erosivity coefficient (R). This factor is a function of the kinetic energy of rainfall, the maximum rate in period of 30min and the total amount of rainfall height. However, these elements are not usually available from most of the meteorological stations. The unavailability of data in many cases forced the development of a number of simplified mathematical approaches that were proposed for the estimation of this factor, some of which are mentioned below:

The annual value of R coefficient is set mathematically with the formula (Wischmeier and Smith, 1965, 1978) [1]:

$$R = \sum_{j=1}^{n} \left(60 \cdot E \cdot P \cdot I_{30}\right) \qquad [1]$$

where: P the total rainfall height of the storm (mm), I_{30} the maximum rainfall intensity in 30min period (mm/min), n the annual number of storms and E the kinetic energy (MJ/ha·mm) that is calculated with the formula:

$$E = 0,29 \cdot \left[1 - 0,72 \cdot e^{-3 \cdot i}\right] \qquad [1a]$$

where: i the mean rainfall intensity (mm/min).

Arnoldus (1977) ended up to the formula [2]: were p and P are the mean monthly rainfall of the month with the highest value and the mean annual rainfall in mm. This formula has been implemented in USA, Europe, Africa, Asia and in other parts of the world.

$$R = 0,264 \cdot \left(\frac{\sum_{k=1}^{12} p_k^2}{P} \right)^{1,5} \qquad [2]$$

Roose (1997) in West Africa came up with the formula [3] taking into account meteorological data of at least 10 years.

$$R = P \cdot a \qquad [3]$$

where: P the mean annual rainfall, α has a value of 0,5 ± 0,05 on most cases, 0,6 on seaside areas (< 40 km), 0,3 - 0,2 on tropical mountain areas, 0,1 on Mediterranean mountainous regions.

El-Swaify (1985) for Tailand has calculated R coefficient by using the formula:

$$R = \left(38,35 + 0,35 \cdot P\right) \qquad [4]$$

where: P the mean annual rainfall (also applied in [5], [6], [7], [8] and [9]).

Several researchers in USA have suggested various methods for the calculation of R coefficient without the need of long-term data for rainfall rate [Ateshian (1974), Cooley (1980), Simanton and Renard (1982)]. Renard and Freimund (1984) suggested for the calculation, the formula:

$$R = 0,04830 \cdot P^{1,61} \qquad \text{for P < 850mm} \qquad [5]$$

and

$$R = 587,8 - 1,219 \cdot P + 0,004105 \cdot P^{2} \qquad \text{for P > 850mm} \qquad [6]$$

Renard and Freimund (1984) also presented the formula:

$$R = \frac{\left(0,07397 \cdot \left(\frac{\sum_{k=1}^{12} p_k^2}{P}\right)^{1,847}\right)}{17,2} \qquad \text{for } \frac{\sum_{k=1}^{12} p_k^2}{P} < 55mm \qquad [7]$$

and

$$R = \frac{95,77 - 6,08 \cdot \frac{\sum_{k=1}^{12} p_k^2}{P} + 0,477 \cdot \left(\frac{\sum_{k=1}^{12} p_k^2}{P}\right)^{2}}{17,2} \qquad \text{for } \frac{\sum_{k=1}^{12} p_k^2}{P} \geq 55mm \qquad [8]$$

Lo and others (1985) used, in Hawaii, the formula:

$$R = 38,46 + 3,48 \cdot P \qquad [9]$$

In Europe, Rogler and Schwertmann (1981) have calculated the R coefficient by establishing the equation of Bavaria:

$$R = 10 \cdot \left(1,48 \cdot Ns - 1,48\right) \qquad [10]$$

where: Ns the mean summer (May-October) rainfall (mm)

For Italy D“ Asaro and Santoro (1983) formulate the relation:

$$R = 0,21 \cdot q^{-0,096} \cdot P^{2,3} \cdot NGP^{-2} \qquad [11]$$

where: q the elevation of the station (m), P the annual rainfall (mm) and NGP the annual number of days with rainfall.

Van der Knijff and others (1999) have implemented a simple formula (equation of Tuscany) based on data from 25 meteorological stations on the area of Tuscany in Central Italy.

$$R = P \cdot a \qquad [12]$$

where: P the mean annual rainfall (mm) and α is a coefficient between 1,1 and 1,5.

In Portugal, de Santos Louseiro and de Azevedo Couthino (2001) have developed the relation:

$$R = \frac{\sum_{k=1}^{12}\left(7,05r_{10} - 88,92d_{10}\right)}{N} \qquad [13]$$

where: r_{10} the monthly rainfall greater than 10mm, d_{10} the number of days of the month with daily rainfall height greater than 10mm, N the number of months that were used for the calculation.

Also, Van der Knijff and others (2002) used data from 47 meteorological stations from Italy and developed the relation [14], where it is a simpler form of formula [12], so that it can be applied around Italy:

$$R = 1,3 \cdot P \qquad [14]$$

From the above formulas, the most widely used ones are the equation of Bavaria [10] for northern and central Europe and the equation of Tuscany for Southern Europe, even though their discrimination is not completely defined. Considering the conditions and areas of implementation for each of the above formulas, the simplified equation of Tuscany [14] was selected to be used for the calculation of R coefficient.

2.2.2. K coefficient

The second coefficient (K) is the erodibility factor and it depends on the soil texture and the formula, that calculates it, is:

$$K = \frac{2,1\left[\left(\text{Silt} + \text{Very thin sand}\right)\cdot\left(100 - \text{Clay}\right)\right] + 3,25\cdot\left(b-2\right) + 2,5\cdot\left(c-3\right)}{100} \qquad [15]$$

where: *Silt*, *Very thin sand*, *Clay* are texture percentages, *b* is a coefficient of soil structure, and *c* the permeability rate.

However, considering that there are no texture data available for the research area the K coefficient was estimated approximately from the geology of the area by making logical assumptions for the produced soil types from the bedrock disaggregation and from similar estimation of literature (Table 1).

Table 1. K Coefficient for each geological formation

Geological Formation	K coefficient
Limestone	0,006
Schist	0,015
Gneiss	0,028
Gabbro	0,030
Alluvial deposits	0,100

Forthermore, the geological formations were digitized based on the maps of Institute of Geology and Mineral Exploration (IGME) and the values of the previous table were implemented.

2.2.3. L and S coefficients

The L and S coefficients give the formation of the relief in the model. Based on the revised edition of the USLE model, in order to implement these coefficients in GIS the following formula [16] was used to calculate the product LS (these two coefficients are managed as one):

$$LS = \left(m+1\right)\cdot\left(\frac{FlowAccumulation(FlowDirection([elev]))\cdot res}{22,13}\right)^{m}\cdot\left(\frac{\eta\mu(\frac{[slope]\cdot\pi}{180})}{0,0896}\right)^{n} \qquad [16]$$

where: *m* is a coefficient with values from 0,1 to 0,8, *FlowAccumulation* and *FlowDirection* are functions of GIS, *[elev]* the elevation in raster format, *res* the pixel size (in our case 10m), *[slope]* the slope in raster format and in degrees, π is 3,14, *n* a coefficient with values from 1,1 to 1,8. The Digital Elevation Model (DEM) was used on the previous formula to calculate the LS coefficients.

2.2.4. C coefficient

The fifth coefficient is the land-use parameter of the model. By estimating the factors that were found in literature per land use and considering the conditions of the regions they were estimated, the following Table 2 was created.

Table 2. C coefficient per land use.

Land use	C coefficient
Urbal zones	0,01
Airports-Swamps	0,00
Industrial zones	0,05
Mines	0,80
Non-irrigated rural areas	0,40
Irrigated rural areas	0,42
Forests-Tree crops	0,20
Pastures-Range lands	0,32
Complex cropping systems Tree and herbaceous vegetation	0,22
Grazing land	0,25
Scrub with sclerophyllous	0,35

Then, the CORINE data were used to produce the C coefficient. The CORINE data were updated with the use of Google Earth, an infrared satellite image by calculating the NDVI indicator and by on site observations. The consistence of the final landuse data were acceptable after the correction and revision.

2.2.5. P coefficient

The sixth and final parameter is the Coefficient of Systematic Erosion Protection Practice. This factor receives values from *0* to *1*. Value *0* means that, in the region, all the necessary measures were implemented to prevent erosion. The theoretic basis of this value should be mentioned because all the current practices and measures for erosion prevention are slowing down erosion and not completely stopping it. Value *1* means that, in the region, there are no systematic actions taking place and no prevention practices are implemented. It is important to mention that this coefficient is not affected by individual actions but only by a systematic effort in relatively, large areas, in comparison to the size of the basin. Consequently, considering that, on the research area, no systematic practices for soil protection are implemented the P coefficient takes the value of *1* for all the area of the basin.

2.3. Implementation of the selected model

The implementation of the selected model was accomplished with the use of GIS and especially with the tool Raster Calculator. Having determined the calculation method for each coefficient and having produced a data layer for each of them, the following formula was implemented (L and S coefficients were implemented as one layer):

$$A = R \cdot K \cdot (L \cdot S) \cdot C \cdot P \qquad [17]$$

in the environment of Raster Calculator tool, where the soil erosion rate layer was produced.

2.4. Calculation of sediment discharge due to water runoff

As already mentioned, the previous model calculates the sheet and rill erosion. Except these erosion types, they are also important the gully and bank erosion, which can be found along the hydrographic network of the basin. For the estimation of the magnitude of these types of erosion, sediment discharge of the basin of Anthemountas was calculated based on a 50-years period.

The calculation of sediment discharge was made based on the formula of Stiny-Herheulidze (Kotoulas, 1998):

$$G_{\max} = \frac{P_n \cdot m}{Y_n \cdot (100 - P_n)} \cdot Q_{\max} \qquad (m^3/\text{sec}) \qquad [18]$$

where: P_n the percentage weight of sediments for specific slope (Table 5), m the torrent behavior rate of the basin (Table 6), Y_n the density of transferred sediments (tons/m^3) and Q_{max} the maximum flood discharge (m^3/sec).

3. Results

The results and difficulties encountered in implementing the chosen model are presented in the following paragraphs.

3.1. Data collection and coefficient production for erosion rate estimation

The sheet-rill erosion rate calculation model *RUSLE* is the formula [17]. R coefficient was calculated based on formula [14]. For the implementation of this formula, it is necessary to calculate the mean annual rainfall height. For this task, meteorological data from five (5) stations that are in and around the research area were used. The elevation and the mean annual rainfall height for each of these stations (Table 3) were used to find the relation between the elevation and the mean annual rainfall height.

Table 3. Meteorological stations (M.S.) of the basin of Anthemountas.

ID	Name	Elevation	Mean annual rainfall height
1	M.S. “Macedonia” Airport	4m	356,84mm
2	M.S. Loutra Thermis	30m	418,84mm
3	M.S. Souroti	105m	449,60mm
4	M.S. Triadi	215m	469,49mm
5	M.S. Galatista	264m	473,26mm

The elements of the previous table 3 were used to produce a diagram that relates the elevation and the mean annual rainfall height. The trend line that was produced, gave an equation:

$$\text{Mean annual rainfall height} = 27,751 \cdot \ln(\text{Elevation}) + 320,45 \qquad [19]$$

with $R^2=0,9974$. This means that the previous equation is quite accurate and it can be implemented to all the region of the basin of Anthemountas. Based on this implementation and formula [17], the R coefficient distribution was produced. For the distribution of K coefficient the data layers of geological formations from IGME were used with the values of Table 1 and a new data layer was produced. As already mentioned, the L and S coefficients import in the model the form of the relief. An existed DEM of the area with 10m accuracy was used and the formula [16] to produce a new data layer with the distribution of the LS coefficients. C coefficient depends on each land use. For the recognition of land-uses on the basin of Anthemoutas, the updated and revised CORINE layer was used and the values of Table 2. A new data layer was produced with the distribution of the C coefficient. Finally, P coefficient received the value of 1 due to the fact that there is no systematic erosion management. The individual cases that were observed (right practices) are located scattered, fragmented and in small sites implemented.

3.2. Implementation of the selected model

In Raster Calculator, the data layers of the previous paragraph were imported and a new data layer was produced with the distribution of erosion rate. This distribution was classified based on similar classifications from literature [Karydas et al. (2008), Hyeon (2006), Feoli et al. (2008), Bartoloni et al. (2006), Miller et al. (2003)]:

1. Practically no erosion : less than 2 tons/ year / hectare
2. Low erosion : between 2 and 5 tons/ year / hectare
3. Medium erosion : between 5 and 15 tons/ year / hectare
4. High erosion : between 15 and 50 tons/ year / hectare
5. Very high erosion : more than 50 tons/ year / hectare

The statistical analysis of this classification concluded that the greater part of the area does not present any particular erosion problems (Table 4).

Table 4. Erosion rate distribution statistics.

Description	Erosion rate (tons/year/hectare)	Area (Km^2)	Percentage (%)
Very low	< 2	137,29	42,73
Low	2 – 5	87,63	27,27
Medium	5 – 15	78,88	24,55
High	15 – 50	16,86	5,25
Very high	> 50	0,64	0,20
Sum		321,30	100,00

The distribution of the values on the total region of the basin of Anthemountas based on the previous classification (Figure 1) results the finding that the high risk areas (high and very high erosion rate) are not more than *5,5%* of the total area of the basin, however they occur mainly on mountainous sites.

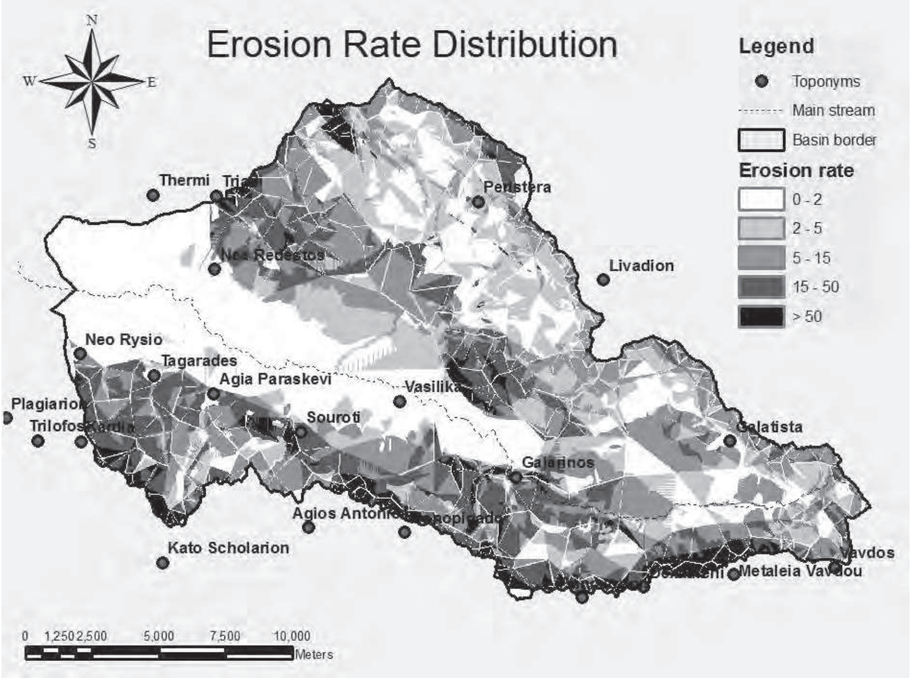

Figure 1. Erosion rate distribution

3.3. Calculation of sediment discharge due to water runoff

Besides the two types of erosion that are estimated with the use of RUSLE model, it is necessary to calculate the gully and bank erosion. The parameter that can be calculated, so that it can determine the volume of sediments and furthermore the erosion rate, along the hydrographical network is sediment discharge. Sediment discharge is calculated with the formula [18] of Stiny-Herheuidze (Kotoulas, 1998):

where: P_n : the % weight of sediments for specific slope (Table 5)
m : the torrential behavior rate of the basin (Table 6).
Y_n : the density of transported sediments (tons/m^3)
Q_{max} : the maximum water discharge (m^3/sec)

The mean slope of the basin is calculated from the formula:

$$J_{m_e} = \frac{\Delta H \cdot \sum l}{F} \qquad [19]$$

where: ΔH : contour interval (Km).
$\sum l$: the total length of all contours (Km).
F : the area of the basin (Km^2).

The contour interval ΔH is *20m*, according to the production specifications of the DEM. The total length of the contours is: *4.425,8Km*. The total area of the basin is: *321,30Km²*. The implementation of the formula [19] gives a value equal to: *27,55%*.

Table 5: P_n factor

Basin slope (%)	P_n(%)
5 – 15	20
16 – 25	25
26 – 35	30
36 – 45	35

Table 6: m factor

Basin category	Basin torrential behavior	Value of m		
		from	to	average
I	High	1,00	1,50	1,30
II	Medium	0,90	1,10	1,00
III	Low	0,70	0,90	0,80
IV	insignificant	0,50	0,70	0,60

According to the distribution of factor P_n (Table 5) and the result of formula [19]. P_n is equal to *30%*. Anthemountas is classified to category II (Kotoulas, 1998) based on its torrential behavior. Consequently, factor *m* (Table 6) is equal to *1 (average)*. The density (Y_n) of sediments was calculated from samples taken along the main channel of Anthemountas and is equal to: *2,175311tons/*m^3, the maximum water discharge with 50-years returned period is equal to *430,32*m^3*/sec*, based on the hydrological work of YETOS G.P, which is co-partner on the same project (LIFE07/ENV/GR/000278 - Soil Sustainability). The implementation of the above calculations on the formula [18] produced a value for sediment discharge equal to: *84,78* m^3*/sec*.

The classification of the sediment discharge requires the calculation of the ratio of sediments to the water discharge. This ratio is equal to: *19,70%* and according to Kotoulas (1998) classification (Table 7) the calculated sediment discharge is characterized as *medium*.

Table 7: Sediment discharge classification

Sediment discharge	Sediments‟ percentage (%)
Low	9
Medium	17 – 23
High	29 – 33
Debris flow	37 – 44,5

4. Conclusions

The conclusions from this research refer to the methodology and its implementation (results).

4.1. Methodology

The methodology for the evaluation of soil erosion that has been developed is simple in its implementation, as the parameters that consist the selected model can be calculated with relatively small amount of raw data and in discrete stages. The suggested methodology can be implemented on areas with similar climatic, relief and land-use conditions. This is a fact that fulfills the purpose of this research for pilot implementation and future expansion in broader regions. It is an important tool for the preliminary assessment of erosion events. The final assessment should be based on more factual and not bibliographic data but also taking into account other factors that affect each studied area.

4.2. Results-Conclusions

The products of this research can be used as reliable data layers on the implementation and integration process of the project LIFE07/ENV/GR/000278 – Soil Sustainability. These data layers are: a) the rainfall distribution and b) the updated land-uses. The distribution of K coefficient, as it has been estimated, gives satisfactory results for all the area of the basin of Anthemountas. However, the K coefficient will be updated and revised, after the completion of samples taken from rural areas of the basin, considering the texture of the samples. The NDVI indicator, used to update and revise the land-uses distribution and had an acceptable contribution on this process. It can also be mentioned that from the areas with natural vegetation, the mountain parts present greater vitality, health and relatively dense vegetation and the semi-mountainous areas have smaller indicator values due to sparse vegetation. The areas with high and very high erosion are less than 5,5% of the total area of the basin of Anthemountas. This area is relatively small (1.750 hectares), compared to the area of the basin (32.130 hectares). Also, the sites with very high erosion (> 50 tons/year/hectare) are not more than 2‰ of the total area, ie is less than 64 hectares. This percentage, even if it is small, is significant so that it should be considered to take measures to confront it. These, relatively small, areas affect directly or indirectly the lowlands of the basin on which there are widespread and extensive human activities. A similar conclusion comes from the magnitude of the calculated sediment discharge (84,78m^3/sec) and the percentage of sediments (19,70%). The characterization of the magnitude of the sediment discharge as medium, confirms the previous conclusion of influence of the areas of high and very high erosion to the areas of lower elevation. Furthermore, the revised CORINE data can be used in Anthemountas basin as its reliability and quality was significantly improved. This improvement consists on the recognition of the various land-uses on the basin and on the relatively small faults (few meters) on the borders of land-uses.

Finally, the recording of the current distribution of sheet and rill erosion will be the basic level of information, combined with the spatial distribution of human activities, for the identification of priority action zones and the final proposal for measures to prevent erosion on the sediment production sites and to protect infrastructure and urban planning. Also, comparing the results with on-site observations, it can be concluded that the implementation of the model has identified and determined, in a high rate (more that *80%*), the various erosion rate zones.

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