EPM for Soil Loss Estimation in Different Geomorphologic Conditions and Data Conversion by Using GIS

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Abstract. Techniques like remote sensing and GIS are nowadays applied to evaluate erosion risk. The real use of GIS comes from the ability to integrate spatial information as well as statistical and analytical processes to derive spatial patterns not readily apparent to the observer. Various methods/models have been developed to assess erosion intensity, soil loss, production of erosive material, sediment transport etc. The Erosion Potential Method (EPM) is the most used method for erosion risk assessment and development of erosion maps for Western and Central Balkan countries. The main aim of this project is to construct a GIS overlay model with the use of some basic GIS analytical functions according to the EPM. The study area covers two regions with different geomorphologic conditions. Significant erosion processes as well as sedimentation processes are visible on the field, especially intense erosion, as gullies, landslides, rock falls and talus cones which are not taken into consideration with other more commonly used methods in Europe. EPM will be employed in the GIS environment for soil loss estimation in m³/km²/yr as initially imposed by this method, and later data will be converted in t/ha/yr as imposed by the more commonly used methods in Europe, which will consequently give an idea about the applicability of the EPM model in different geomorphologic conditions to obtain compatible and comparable results with the results obtained from other methods.

1. Introduction

The EPM is factor-based, which means that a series of factors, each quantifying one or more processes and their interactions, are combined to yield an overall estimation of soil loss. EPM gives a quantitative estimation of erosion intensity as well as the estimation of sediment production and transportation [1]. While most of the models are aimed to estimate long-term annual amounts of soil loss that results from sheet or rill erosion and/or sediment transport or erosion and deposition over the land surface by rill and inter-rill processes on agricultural fields, the EPM model does not only predict the amount of erosion production that results from sheet or rill erosion, but it also considers additional soil loss that might occur from gully, wind or tillage erosion [2]. EPM, which recognizes various erosion processes as sheet, rill, gully and mass movement, is dominantly used but annual erosion rates are expressed in m³/km², while erosion rates obtained by other methodologies in EU countries are expressed in t/ha annually [3]. Besides this, there is a terminological difference.
According to Blinkov [4] the difference between soil loss and sediment production (erosive material production) is the crucial thing. For agronomists the most important thing is soil loss that in fact means losses of consolidated undisturbed material that could be expressed in cm of topsoil annually or t/ha annually. USLE and similar methods/models refer to soil loss, i.e. loss of consolidated material [5].

On the other hand, water management’s main interest is in the quantity of erosive material (soil particles, rock particles, etc) in the streams and reservoirs. This material is unconsolidated material. EPM was developed primarily for water management needs and sediment production means unconsolidated material. Blinkov [4] cited that sediment is defined as fragmented material formed by physical and chemical weathering of rocks. Sediment transport study includes movement of huge boulders down mountain sides, to diffusion of colloid-sized material in groundwater systems. Transport is driven by gravity and drag forces between the sediment and surrounding liquid transport of sediment is usually divided into three types: bedload, saltation, and suspension. Sediment transport depends on sediment properties, characteristics of the sediment bed, and properties of the liquid flow [6].

Researchers have shown that the causes of gully erosion initiation vary according to different soil types. They show that this type of water erosion can be created differently in different soil conditions [7]. Soil properties, rainfall and runoff intensity, wind action, geological, hydro-geochemical and geotechnical characteristics and anthropogenic activities are factors generating soil and gully erosion processes. Many researchers have shown that gully erosion is an important soil degradation process and produced sediment from these processes cannot be omitted in the process of erosion sediment estimation. Since, in the case of deep gullies, rocks and landslides generate too much sediment, land cover and visible erosion processes must be more accurately determined and taken in consideration especially in erosion sediment estimation [1, 8].

In this case, application of this approach on a smaller scale basin faces some difficulties in the attempt to derive these areas in one category. Those are at first sight negligibly small areas, but in terms of sediment quantity are of great importance because they significantly increase the total amount of sediment production. Consequently, standardization of the methods and approaches cannot be carried out since standardization focuses on prescribing the assessment itself, thereby if prescribed assessment will automatically result in comparable results [9]. However, common and specific aspects can be explored for each individual situation if different methods express resulting values in the same measurement units.

The objective of the current research is to apply the EPM model to estimate soil loss by under GIS environments expressed in m$^3$/km$^2$ and consequently converted in t/ha/year. Thus, the obtained results will be compatible and comparable, hence consistent, thereby minimizing the differences between standards or measures with similar scope.

2. Materials and Methods

2.1. Study area.

The study was carried out in two different areas where the focus is on the analysis of the impact of different slopes and geomorphologic conditions on erosion processes and erosion rate quantity. Study Area – 1 (SA-1) – Upper part of Bregalnica River watershed - in the area of the combined valley-hilly mountain region that belongs to old Balkan relief structures where agricultural land is significant, and Study Area – 2 (SA-2) – National Park “Mavrovo” – in an area of young alpine mountain configuration where all types of erosion are present and there are many landslides, landfalls, rock falls and talus cones, where dominant land cover types are forest and grasslands [10].

Bregalnica watershed is in the east part, draining surface waters from an area of. The upper part of the Bregalnica watershed is extending upstream of Kalimanci Dam, from 22°27’44” to 23°02’03” East longitude, and from 41°35’09” to 42°09’16” North latitude. It has an area of 1124.7 km$^2$. The climate in the watershed is conditioned by the geographical location of the area and its topographic features. Although Males and Pijanec are two adjacent areas, they differ significantly. Berovo Valley which is higher has a climate that is formed under the influence of the eastern continental and mountain climate of the neighboring mountains, and the climate is determined as moderate-cold-continental [11].
Figure 1. Location of both study areas in FYR of Macedonia. Upper part of Bregalnica River Watershed on the right (SA-1 colored with pink) and National Park of Mavrovo on the left (SA-2 colored with blue).

2.2. Erosion Potential Model for erosion rate estimation.

The method has been tested in some catchment areas in Iran, and it is found that output results are compatible with field observation. EPM is factor-based, which means that a series of factors, each quantifying one or more processes and their interactions, are combined to yield an overall estimation of soil loss. The EPM Gavrilovic [12] Method is a parametric distributed model for qualifying the erosion severity and estimating the total annual sediment yield of a catchment.

The EPM method gives a quantitative estimation of erosion intensity as well as the estimation of sediment production and transportation. This method in general considers four factors that depend on surface geology and soils, topographic features, climatic factors (including mean annual rainfall, and mean annual temperature), and land use. To agree with other models for erosion rate estimation, a preliminary estimation of specific annual sediment production E is required [13]. According to this method, specific annual sediment production E will be calculated by the equation:

$$E = M \times Z^{1.5} \, (m^3/km^2/year)$$  \hspace{1cm} (1)

Where:

- $M$ - Climatic erosion potential of the watershed.
- $M = T \times H_{year} \times \pi$
- $T$ - Temperature coefficient which is calculated by the expression:
  $$T = \sqrt{\frac{t_0}{10}} + 0.1$$
  
t - Annual average air temperature ($^\circ$C)
- $H_{year}$ - Average annual precipitation (mm)
- $Z$ - Average coefficient of erosion of the watershed ($0.05<Z<1.5$) by Gavrilovic [12].
In order to apply equation (1) in our model and obtain values for \( Z \), one more step needs to be fulfilled. According to the equation by Gavrilovic [12], the average erosion coefficient of the watershed is calculated as follows:

\[
Z = \gamma \times Xa \times (\phi + \frac{J_{sr}}{2})
\]

\( \gamma \) - Reciprocal value of the coefficient of resistance of the soil to erosion (0.25<\( \gamma \)<2.00).

\( Xa \) - Coefficient of regulation of the basin taking into consideration the level of protection of the land from erosive forces in natural conditions (X) and artificial conditions (a) (0.01<\( Xa \)<1.00).

\( \phi \) - Numerical equivalent of visible and clearly articulated process of erosion in the watershed (0.10<\( \phi \)<1.00)

\( J_{sr} \) - Average slope of the watershed expressed in decimals.

Even though EPM was firstly developed as an empirical model whose reliability was based on observation or experimental evidence, GIS applications and Remote Sensing in erosion and sediment yield assessment and erosion processes evaluation can be assisted by Remote Sensing techniques. The integration of such data layers with the generation of erosion-severity and sediment yield maps can readily be performed by the use of the analytical tools of a GIS which gives an opportunity to computerize the process of calculation and creation of outputs with already set parameters as consistent input.

2.3. Conversion of erosion rate data acquired by EPM in weight units [t/ha].

Using the existing national datasets with standardized quality and their implementation in already developed EPM methodology by Gavrilovic [12] and application in the GIS environment for estimation of erosion and soil rate values, since this model is the most applicable in the case of gullies, rocky areas, and landslides, which are an important input in erosion rate estimation and therefore erosion processes [14].

Consequently, applying a specific approach for conversion of already estimated erosion rates from produced erosion maps according to the EPM method expressed in t/ha by using all specifics working in the GIS environment. Thus, obtained results will be compatible or comparable, hence consistent, and thereby will minimize the differences between standards or measures with similar scope.

2.4. Collection of indicator values for the soil threat and risk perception.

In order to calculate \( E \) values by applying equation by Gavrilovic [12], due to the lack of a digital database available for every parameter needed, most of the data necessary to develop and validate this model were derived from a combination of pre-existing analog maps where each thematic map was scanned and digitized into GIS (Figure 2).
3. Results and discussions

The aim of this work was to develop and apply a model based on expert knowledge and available data for the sediment and soil rate estimation at the watershed scale. Factors influencing erosion have been graded for the diverse geomorphologic situations and erosion mechanisms have been expressed with the help of expert-defined empirical rules.

Depending on the area conditions concerning the erosive processes and land cover conditions, appropriate values for φ and Xa values were assigned according to the readymade tables by Gavrilovic [12]. For the areas with intense erosion processes and land cover conditions more prone to erosion, higher values were assigned for φ and Xa accordingly. Further processing in the calculation of Z values was obtained by multiplying these coefficients according to the formula (X). By simply overlaying all layers of γ, φ and Xa and Z values, it was easy to identify that cells with the highest value of Z at the same time hold high values for γ, φ and Xa (Table 1).

| Destructiveness category | Subcategories          | Erosion Coefficient | Study Areas | φ Value |
|--------------------------|------------------------|---------------------|-------------|---------|
| 1. Excessive erosion     | 1.1. Deep erosion      | 1.25                | SA-1        | 1.00    |
|                          | 1.2. Mixed erosion     | 1.05                | SA-1        | 1.00    |
| 2. Strong erosion        | 2.1. Deep erosion      | 0.95                | SA-1        | 0.90    |
|                          | 2.2. Mixed erosion     | 0.85                | SA-1        | 0.80    |
|                          | 2.3. Surface erosion   | 0.75                | SA-1        | 0.70    |
| 3. Moderate erosion      | 3.1. Deep Erosion      | 0.65                | SA-1        | 0.60    |
|                          | 3.2. Mixed erosion     | 0.55                | SA-1        | 0.50    |
|                          | 3.3. Surface erosion   | 0.45                | SA-1        | 0.40    |
| 4. Low erosion           | 4.1. Deep erosion      | 0.35                | SA-1        | 0.30    |
|                          | 4.2. Mixed erosion     | 0.25                | SA-1        | 0.25    |
| 5. Very low erosion      | 5.1. Erosion in traces | 0.15                | SA-1        | 0.15    |
|                          | 5.2. Very low erosion  | 0.05                | SA-1        | 0.10    |
| Water bodies             | Water bodies           | 0.00                | SA-1        | 0.00    |
The results showed that the value of Z is significantly higher in areas where intense erosive processes are present as rills and gullies. On the other hand, on estimating the erosive potential by Gavrilovic [12] it was found that the highest erosion sediment amounts have the same cells which hold values of Z. Consequently, the cells with the higher Z values significantly increase the E value and by all means directly affect overall E estimates (Figure 3).

Figure 3. Dataset for Z value calculation for SA-1
This indicates that under conditions of intense erosive processes and poor land cover protection, total production of erosion sediment is significantly increased in contrast to the case in which these conditions would not have been taken into consideration, and therefore the accuracy of the final results of the whole area would be directly affected [15]. This case justifies the use of this model to calculate the erosion potential in the presence of intense erosive processes, which are not taken into account with the most commonly, used methods which significantly increase the total quantity of sediment production of the whole area [16].

The model was applied on SA-2, but the difficulty occurred in defining $\gamma$. Here is the essential cause of this research work that is highlighting the difference in applying the same approach in geomorphologic different areas. The differentiation that occurs is in the process of determining the $\gamma$ factor. In this case, apart from the soil map for this SA the geology map was also considered in order to determine the rock characteristics and their susceptibility to erosion according to the Gavrilovic [12] tables, only in areas where they come to the surface and topsoil is absent. Therefore, one more factor was explored and as a result, a more precise estimation for erosion rates was obtained. As stated in the SA-2 description there are small areas where topsoil is lost in total and the substrate comes to the surface. Since EPM gives different values for those areas, according to the tables by Gavrilovic [12] these areas were taken into account for calculating overall sediment production. $\gamma$, $\phi$ and $X_a$ values were assigned to the previously modified layers in the same way as for the SA-1 except for the coefficient $\gamma$.

Given that in the description of the EPM model there is no restriction in slope values, it has been successfully applied in the SA-2, which is a mountainous region. These results were similar to the results in SA-1 that showed familiarity for Z and E meaning that cells with high Z values at the same time hold high values for E, but here the difference is that there are extreme values for Z [17]. The final calculation of Z values showed that high values of $\gamma$, $\phi$ and $X_a$ according to the existing conditions on the field combined with high elevation result in higher values for Z over 3.5 and therefore higher values in the overall sediment production rate E. According to Kale et al. [18], this stems precisely from the fact that it is a mountainous area especially with alpine configuration where the slope of the land reaches extreme values, combined with high values for $\gamma$ which further increase the value of Z and thus the final results of E as shown in Figure 4 [19].
Consequently, as mentioned in the SA description for NP Mavrovo, small BR areas on the mountain hills are a source of large amounts of sediment production which significantly increase the weight unit of the overall erosion sediment amount (Figure 5).

Sediment production assessment was the main objective of the study as a relative approximation of the threat in order to delineate areas of high risk with detailed amounts of soil loss as well [20]. Estimation of soil loss rates for each study area and data conversion in t/ha/yr, in order to be comparable and compatible with the most commonly used models for soil loss estimation in Europe, was the second objective of this study. Since EPM in this research is repeatedly compared with other methods and as
the main purpose is to calculate soil loss in order to obtain comparable and comparative results with the
results obtained by other afore-mentioned and described methods, BR areas were not taken into
consideration and only soil loss rates were considered in data conversion [21]. Bulk density was used as
a fundamental soil property density.

![Figure 5. Erosion Potential values (m³/km²/yr) for SA-1(left) and SA-2(right)]](image)

This approach allows integration of lateral variability in the soil without the consequence of
averaging properties over a large depth range. The following points can be noted for both study areas
accordingly:

Study Area-1 – Overall erosion rate estimates were fully converted from volume to weight unit by
multiplying the E (m³/km²/yr) value with the bulk density (cm³/g) value of every soil type present in this
area (Table 2).

| Soil loss (t/ha/yr) | Min | Max  | Range      | Mean  | Std. Dev. |
|--------------------|-----|------|------------|-------|-----------|
| SA-1               | 0   | 49.3268 | 49.3268   | 3.20729 | 4.00108   |

Study Area -2 – Erosion rates for this area were converted by multiplying the E (m³/km²/yr) values
with the bulk density (g/cm³) value of every soil type present as well. The difference is in omitting BR
areas in the final calculation for soil loss rates. Areas with bare rocks were excluded from this calculation
(Table 3).

| Soil loss (t/ha/yr) | Min | Max  | Range      | Mean  | Std. Dev. |
|--------------------|-----|------|------------|-------|-----------|
| SA-2               | 0   | 81.2694 | 81.2694   | 2.88902 | 4.86397   |

The final calculation resulted in the final map creation for soil loss estimates expressed in (t/ha/yr)
as illustrated in Figure 6.
4. Conclusions
Surface erosion and mass movements within a catchment area produce sediment which becomes available for transport. Surface erosion is definitely the most important source of sediment production wherever vegetation does not provide a sufficient cover of the soil from the rainfall impact, and morphological conditions are such that they foster the removal of particles by overland flow. Changes in land use due to development strategies exposing erosion-sensitive geological formations and poor vegetation cover are the main factors in increasing annual sediment amount available for erosion and transport. Soil erosion mapping is one of the most important and basic methods in erosion and sediment yield studies to determine suitable soil conservation programs. In the past few years a number of projects have attempted to assess the risk of soil erosion at national, European and international level. Even though a wide variety of models are available for assessing soil erosion risk, most of them simply require so much input data that applying them at small scales becomes problematic. At the same time, the most commonly used methods for estimating sediment yield were first developed for the analysis of the effects of agricultural practices given that only soil loss is considered which is a limiting factor for their use in other sectors. For this research a model-based approach was used to assess soil erosion risk. The well-known Erosion Potential Model was used because it is one of the least data demanding erosion models since the availability of input data as a critical selection criterion when assessing soil erosion risk at the regional, national or continental scale. On the other hand, this model demonstrates that it can be equally used for overall erosion rates and at the same time for soil loss estimates as well. Besides, this method has been previously developed for western Balkan countries and it has been applied widely at different scales; therefore, it was expected to be successfully used for the SAs explored in this research.

Based on the results obtained by the EPM/GIS model and taking into account that they can provide reliable data for both overall erosion rates and soil loss, fully comparable with other models obtained in the framework of EU projects, targeting at soil conservation and planning renewable natural resource projects.
As a final conclusion, the contribution of this thesis may be considered as a further step towards a coordinated soil erosion map of all countries in Europe. Nevertheless, some major improvements could be achieved by using more detailed thematic maps as a better representation of climatic factors, land cover, digital elevation models as well as the use of satellite data that have better spectral and geometric characteristics than the aerial photos that were used. Finally, more detailed soil data is needed (especially soil depth, stone volume and surface texture) and its classification according to EU standards.

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