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Effect of land cover / use change on soil erosion assessment in Dubračina catchment (Croatia)

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Abstract: The assessment of erosion intensity and sediment production using Erosion Potential Method was made for the Dubračina catchment, Croatia. During the extensive research and data collection, several data sources for the land cover/use map were available: Spatial Plan, Corine database and Landsat images. Landsat data source was included in the study to provide a more up-to-date and higher resolution assessment and was available also for various time periods. Different information sources imposed the need to choose one data source as the most appropriate through the acknowledgement of their differences and the effect on the model outputs. The analysis presented in this paper also includes the change in erosion intensity and sediment production between the past and the present time. For this purpose, the land cover categories for Dubračina catchment were derived from the Landsat images. The most noticeable spatial change in erosion intensity between the two-time series is on sub-catchments Slani Potok and Mala Dubračina, where the area affected by excessive erosion was found to increase from the past to present time. The overall decrease in average values for the sediment production is noted from the past to present time but this change in values was not found to be significant, in contrast to the change in the spatial distribution visible on the maps.

Key words: Erosion Potential Method, soil erosion, erosion intensity, erosion sediment production, various data sources, changes in time, land cover/use

1. INTRODUCTION

Water erosion can occur in all types of soil at different rates and in different forms (Merritt et al., 2003). The most important elements (e.g. Morgan, 2005) that influence the rate of water erosion are climate, soil, topography, vegetation cover and anthropogenic factors.

The need for the information on soil erosion (Merritt, 2003), at temporal and spatial scales describing the sediment pattern throughout the catchment and its associated quantities, is increasing due to various demands from stakeholders and decision makers in spatial as well as soil and water conservation planning.

Within this paper, erosion assessment for the Dubračina catchment, Croatia, was made using the Erosion Potential Method for the past and present time. The emphasis is given on choosing the appropriate input data from various information sources for soil protection parameter that is based on land cover/use categories.

Applied erosion monitoring methods on the Dubračina catchment are presented and include the verification of the Landsat-derived land cover map for the present time and the erosion coefficient (intensity) map.

2. METHODODOLOGY AND INPUT DATA DESCRIPTION

2.1 Erosion Potential Method

The Erosion Potential Method - EPM (Gavrilović method) is based on erosion field research conducted in 1960`s in the Morava River Catchment area in Serbia (Gavrilović, 1972). The method was modified through the years by various authors (Dragičević et al., 2016). Today, the method encompasses erosion mapping, sediment quantity estimation, and torrent classification and has, since 1968, been extensively applied to erosion and torrent-related problems in the Balkan countries (Gavrilović et al., 2008).

Erosion model discussed within this paper is based on the EPM method and used to provide two main outputs (de Vente and Poesen, 2009) the total annual volume of detached soil W_a (Equation 1) and the erosion coefficient Z (Equation 3).

$$W_a=T*P_a*\pi*\mathrm{sqrt}(Z^3)*F \tag{1}$$

$$T=\mathrm{sqrt}(T_0/10+0.1) \tag{2}$$

$$Z=Y*X_a*(\varphi+\mathrm{sqrt}(J_a)) \tag{3}$$

where:
W_a - total annual volume of detached soil (m^3/year)
T - temperature coefficient (-)
P_a - average annual precipitation (mm)
Z - erosion coefficient (-)
F - study area (km^2)
T_0 - average annual temperature (^oC)
Y - soil erodibility coefficient (-)
X_a - soil protection coefficient (-)
φ - coefficient of type and extent of erosion (-)
J_a - average slope of the study area (%)

2.2 Case study: Dubračina catchment

The EPM was applied on Dubračina catchment, Croatia (Figure 1). The catchment has an area of 43 km^2 and is characterised by steep slopes in its lower and upper part, with an elevation difference of 920 m and a complex soil structure. High annual rainfall, steep topography and variable geology contribute to its land instability features such as landslides and excessive erosion processes. Although most of its tributaries tend to dry out during the summer period, during the rainy period, considerable flow oscillations are very common.

Figure 1. Distribution of the Dubračina catchment sub-catchments

The overall catchment can roughly be divided into an upper karstic part with steep slopes and active sediment movement, and a lower Flysch as a less permeable area. The complex geological structure, special valley cross section with distinct and steep slopes affected by erosion, local landslides and torrents are the reasons why this area has been known for many years as an area of potential erosion hazard.

2.3 Input data and data sources

Erosion intensity and sediment production for the Dubračina catchment using the EPM were assessed for two time periods: the past (1961-1990) and the present (1991-2020). The input data that differs for both time-series are as follows:

- Average annual precipitation,
- Average annual temperature,
- Soil protection coefficient.

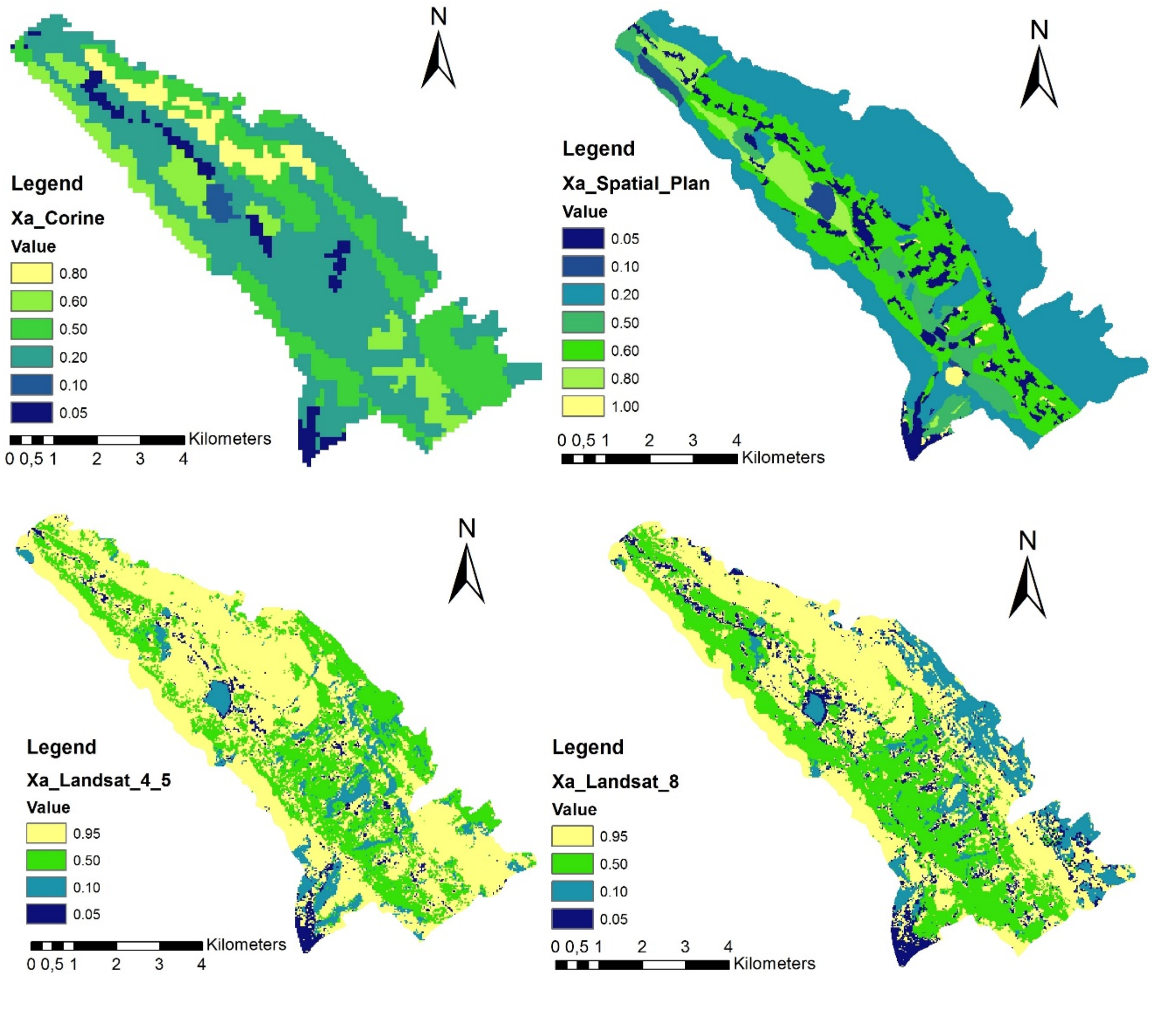

Figure 2. Soil protection coefficient based on different land cover/use maps

The spatial distributions of precipitation and temperature, with a resolution of 1000x1000 m, were obtained from the Croatian Meteorological and Hydrological Service for the time period of 1961 to 1990. Both the average annual temperature and the average annual precipitation for the town of Crikvenica were found to increase for the period from 1991 to today compared to the period of 1961 to 1990 (by 0.9°C and 55.9 mm) (Dragičević et al., 2017). Based on this changes and on the assumption that the spatial distribution pattern remains the same throughout the catchment, the spatial distribution maps for these parameters were derived also for the time period from 1991 to 2020. The soil erodibility coefficient is based on a pedological map of Primorsko-

Goranska County, with a scale of 1:100 000. The soil protection coefficient is based on land cover/use categories for the Dubračina catchment. Land cover/use maps were available from three different data sources:

- The Corine land cover map (1:100,000) developed by the European Commission (EC) in 2006,
- the Spatial Plan of land use (1:25,000) developed by the local government in 2004 and
- Landsat data.
- The Landsat data source provided two datasets, one for each time period:
- Landsat 4,5 with a cell size of 30x30 m from August 1984 representing the past time period 1961-1990 and
- Landsat 8 with a cell size of 15x15 m from August 2013 representing the present time period 1991-2020.

To facilitate Landsat data processing, based on supervised classification, the software ERDAS Imagine 2014 was used and six land cover classes were recognised: water, urban area, medium dense vegetation, bare rock, bare soil to rare vegetation and dense vegetation.

Furthermore, LIDAR data were used to generate a digital elevation model with a 2x2-m cell size spatial resolution. The coefficient of type and extent of erosion was based on the Spatial Plan map of known erosion-affected areas (scale 1:25,000).

3. RESULTS

3.1 Model output deviation due to land cover/use source change

In the case of Dubračina River catchment, where there was no previous existence of information database, during the extensive research and data collection, the authors have come across several data sources for the same parameter – soil protection coefficient. The need to choose one as the most appropriate has stressed the need to properly evaluate each data source and acknowledge the difference between them. That was made by the comparison of model outputs W_a and Z obtained using a different data source, each time, as a model input for soil protection parameter. The deviations in input datasets for soil protection parameter and derived model output values are shown in Table 1.

Table 1. Model uncertainty shown in percent change in the model output

Data source	Change in Soil protection coefficient dataset in comparison to Landsat 8 dataset [%]	Change in model output values in comparison to model outputs (Z_I and $W_{a.I}$) obtained using Landsat 8 dataset	
		[% Z_I]	[%Wa.I]
Spatial Plan	-45.5	-46.0	-46.9
Corine database	-45.0	-45.0	-44,7
Landsat 4,5	-2.5	+9.9	+9.8

As shown in Table 1, the comparison was made using Landsat 8 data source as the base input data in a model for X_a parameter. The similar difference in oscillation from basic model scenario using both Spatial plan and Corine database can be found in the similar approach used while creating these two datasets (both took into account topographic maps of the area). In contrast to them, the Landsat datasets are based on remote sensing technology obtained from the classification of earth satellite images. Below is a comparison of soil protection coefficient based on Landsat 8 scene (presenting basic scenario) with those obtained using different data sources for land cover/use input data. This parameter, when based on Corine dataset, deviates by 45% in relation to that based on Landsat 8 dataset. The 45% change in dataset causes 44.7% change in total annual volume of the soil model output and 45% change in erosion coefficient output. This parameter affects the model outputs greatly, and according to sensitivity analysis conducted by Dragičević et al. (2017) is classified as one with very high sensitivity to model.

In was noted that the Corine dataset was unchanged in the 10 year time difference for the area of Dubračina catchment, while the difference in land cover is obvious in Landsat satellite images. Thus, the Corine dataset in considered less reliable for this case study. Landsat dataset is chosen as most relevant for further model estimations also due to its highest resolution and detail in comparison to the other two data sources.

3.2 Past to present change in erosion assessment for the Dubračina catchment

The erosion coefficient, which indicates the erosion intensity in the catchment and the total annual volume of the detached soil, which indicates the overall erosion sediment production on an annual basis, were derived in a form of maps for the Dubračina catchment. For each output parameter (Z, W_a), two maps were generated (Figure 3), one representing the past (1961-1990) and the other representing the present (1991-2020). The maps showing the change between the time series for Z and W_a are also presented in Figure 3, which clearly indicates the areas of increase/decrease in the values.

The most noticeable spatial change in erosion coefficient was recorded around the Slani Potok and Mala Dubračina sub-catchments, where the area encompassed by excessive erosion ($Z \geq 1.0$) has increased from the past to the present. The change in the mean values between the past and the present is approximately 9%, showing an overall decrease in erosion intensity in the catchment over the years, with greater changes noted on the sub-catchments Kučina, Leskovnik, Slani Potok, Mala Dubračina and Ričina Tribaljska.

Similar changes are observed on the spatial distribution map representing the total annual volume of the detached soil, between the time periods. The average change in values throughout the catchment is found to decrease by 3% between the past and the present: in the past, the average value of the detached soil in the catchment was 15.64 m^3/cell/year, which is equivalent to 1564 m^3/km^2/year, and in the present time, the value is 15.12 m^3/cell/year or 1512 m^3/km^2/year. Based on these values, it can be concluded that this change is not significant; however, when the map showing the spatial distribution of its values (Figure 3) and the change in W_a per sub-sub-catchment is considered, sub-catchments of Leskovnik, Ričina Tribaljska, Slani Potok, Mala Dubračina and Kučina contribute the most to the overall change in W_a values; they all exhibit values that increase/decrease by up to several times the average values for the entire catchment.

The calculated value for the total annual volume of the detached soil for the present time is 64 810.75 m^3/catchment/year, and that for the past is 67 072.91 m^3/catchment/year, corresponding to an overall decrease in erosion production by 3.3. Overall, the average erosion coefficient for the Dubračina catchment in present time is 0.25, which classifies it as an area of slight erosion. Nevertheless, although the overall classification categorises the erosion processes in the catchment as slight, the maximum values reach 4.189, which is more than 4 times higher than the defined boundary value for the excessive erosion class.

4. MODEL VERIFICATION

The land cover maps derived from the Landsat images were verified using the visual land survey method and observing twenty on-site locations. The verification refers to the land cover map for the present time (1991-2020). For each location, GPS coordinates were noted, as were photographic documentation of the site. In addition to that, the descriptive observation notes of the onsite and close surrounding vegetation cover were noted as well. The observation was made in July 2016 to correspond to the same year period for which the land cover for the present time was made (August 2013). For each location, observation notes were compared in the ERDAS Imagine software to the land cover category derived from the Landsat data. The observed vegetation cover on the chosen location corresponded well to those obtained with the Landsat 8 image land cover classification.

For the same locations, visual signs of erosion processes, such as the presence of soil loss, gully formation, or sediment deposition on the site or in the river bed, are noted and compared with the erosion coefficient values that define the erosion intensity categorisation for each chosen location. Very good results were obtained from the comparison of the field survey and the erosion coefficient obtained using the EPM model for the present time series. Most of the observed points (eleven) correspond to very slight erosion, six points correspond to slight erosion, and one point corresponds to each of medium, severe and excessive erosion. In some points, the erosion coefficient was found to correspond to very slight to slight erosion, and some sediment yield was noted within the river beds. These sediments are the result of erosion processes in the upper part of the sub-catchments and not the location itself.

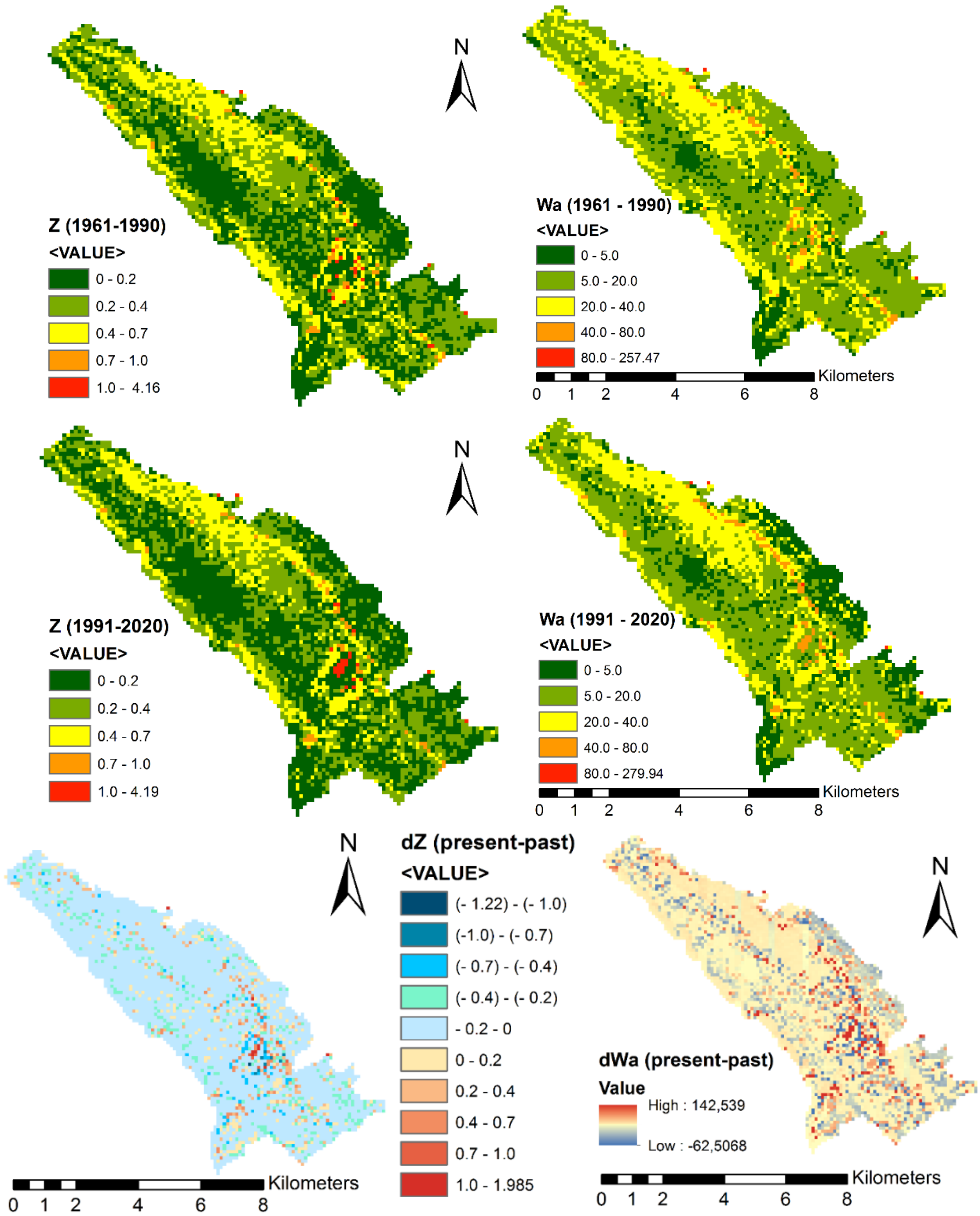

Figure 3. Model outputs: erosion coefficient and total annual volume of the detached soil [m^3/cell/year] for past and present time and the differences between time periods

5. CONCLUSION

The analysis indicates that when changing the data source, significant changes to the model outcome value (up to approximately 47% as shown on Dubračina River catchment study area) can occur. Such changes depend on detailed preliminary research and data gathering.

Landsat data was chosen as the most appropriate input data on which Soil protection coefficient is based due to its highest resolution and reliability.

The estimated values and maps derived by the EPM presented in this paper include outputs for the erosion coefficient (intensity) and the total annual volume of the detached soil for the past and present time. The most noticeable spatial change in the erosion coefficient between the time series is located near the Slani Potok and Mala Dubračina sub-catchments, where the area affected by excessive erosion was found to increase from the past to present. The overall decrease in the average values of the total annual volume of the detached soil is noted from the past (15.64 m^3/cell/year) to present (15.12 m^3/cell/year) time; however, this change in these values was not found to be significant, in contrast to the change observed in the spatial distribution visible on the maps.

The model output erosion intensity and land cover map for the present were verified using a visual survey monitoring method and a GPS device. All verifications revealed good results, and the high accuracy of the derived maps was confirmed.

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