Erosion Model Sensitivity to Land Cover Inputs: Case Study of the Dubracina Catchment, Croatia

N. Dragičević[1], D. Whyatt[2], G. Davies[2], B. Karleuša[1], N. Ožanić[1]

[1]Faculty of Civil Engineering University of Rijeka, Croatia, Radmile Matejčić 3, 51000 Rijeka, Croatia
Telephone: (+385) 51 265 900
Fax: (+385) 51 265 998
Email: nevena.dragicevic@uniri.hr; barbara.karleusa@gradri.uniri.hr; nevenka.ozanic@uniri.hr
http://www.gradri.uniri.hr/hr/
[2]Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ, UK
Telephone: (+44) 01524 510239.
Fax: (+44) 01524 510269
Email: d.whyatt@lancaster.ac.uk; gemma.davies@lancaster.ac.uk;
http://www.lancaster.ac.uk/

1. Introduction

Land degradation, as a result of soil erosion and sediment transport, is one of the main challenges for land use management. The processes, caused by water erosion, vary in time and space, and as such are ideally suited to analysis using Geographic Information Systems (GIS).

This paper focusses upon uncertainties in the magnitude and spatial distribution of eroded material predicted by an established erosion model with alternative land cover/use inputs. According to Lenhart et al (2002) the level of model uncertainty is dictated by the variability and accessibility of its inputs. The sensitivity of a model can be measured as the difference in the predicted outputs as a consequence of using different inputs. It is common practice for sensitivity analysis to precede full model application, since this can often lead to a reduction in uncertainty in the final model (White and Chaubey, 2005).

Mendicino (1999) assessed how different GIS procedures for acquiring 2 and 3-dimensional hydrological and topographical parameters impacted upon estimates of soil erosion risk in the Revised Universal Soil Loss Equation (RUSLE). Similarly, Roo et al (1996) conducted sensitivity analysis upon the results obtained from a newly developed hydrological and soil erosion model, LISEM, comparing results with field observations. He found significant spatial and temporal differences in soil hydraulic conductivity across the catchment and initial pressure head. White and Chaubey (2005) conducted sensitivity analysis for the Soil and Water Assessment Tool (SWAT) in order to identify which parameters had the most impact on predicted flow, sediment yield and nutrient output. The most important parameters included the initial SCS runoff curve number for moisture condition, soil evaporation adjustment factor, USLE support practice factor and exponent parameter for calculating sediment re-entrained through channel sediment routing. Furthermore, Tucker (2004) noted that the predicted sediment amounts are highly sensitive to climate variation and vegetation cover. The aim of this paper is to analyse the sensitivity of outputs from an erosion potential method to different land cover/use inputs for the Dubračina Catchment area in Croatia.

2. Research area

The Dubračina Catchment (Figure 1a) is a small catchment (43 km^2) situated in the Vinodol Valley in the County of Primorsko-Goranska, Croatia. In addition to the main river Dubračina, the catchment includes many tributaries, all of which have torrential characteristics. The area is extremely valuable in terms of its natural and cultivated landscape, its biodiversity and its cultural and historical heritage. For this reason it carries the status of a Protected Area of Great Importance. The area is also known for landslides and erosion-affected areas, with processes triggered by a combination of steep topography, high annual rainfall and variable geology (Figure 1b). The upper catchment is characterized by steep slopes and active sediment movement on carbonate rocks (karstic terrain), while the lower catchment comprises less permeable Flysch deposits.

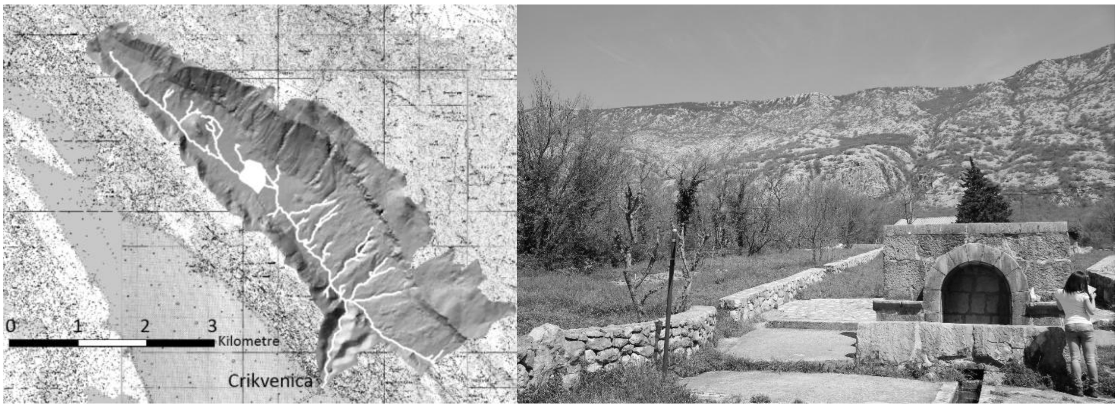

Figure 1. Dubračina Catchment: (a) The location of the catchment, variations in elevation and drainage patterns (b) Plate showing steep upper catchment (karst) and lower catchment (flysh).

The first written reports of erosion in the Dubračina Catchment, within the Slani Potok and Mala Dubračina sub-catchments, date from the late 19th century. These sub-catchments remain most affected by erosion processes to this day, containing the largest areas to be characterized as experiencing excessive erosion (Figure 2a).

Figure 2: Erosion processes: (a) Erosion affected area around the Slani Potok and Mala Dubračina sub-catchments (b) Sediment transported downstream from a site being excavated for mineral resources.

3. Applied Methodology and data selection

The Gavrilović method, also known as the Erosion Potential Method, is based on a Method for the Quantitative Classification of Erosion (MQCE) developed in the 1950s. It was developed for erosion mapping, sediment quantity estimation, and torrent classification, and as has been extensively applied for erosion and torrent-related problems in the Balkan countries since the late 1960s (Gavrilović, 2008). The Gavrilović method generates a number of outputs but the ones of most interest for this study (Equations 1-3) include (i) the total annual volume of detached soil (Wa, expressed in m^3/year) and (ii) the erosion coefficient (Z), an un-dimensional parameter that defines erosion severity or erosion intensity through both numerical and descriptive classification of its values.

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

$$T = \sqrt{\frac{T_0}{10} + 10} \quad (2)$$

$$Z = Y * X_a * \left(\phi + \sqrt{J_a}\right) \quad (3)$$

Where:

W_a - 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 [%]

This method can be characterised as semi-quantitative method as it gives final outputs based on combination of descriptive (Table 1.) and quantitative procedures.

Table 1: Descriptive evaluation of Gavrilović method parameters (de Vente, 2005)

Soil erodibility coefficient [Y]	
Hard rock, erosion resistant	0.2-0.6
Rock with moderate erosion resistance	0.6-1.0
Weak rock, schistose, stabilised	1.0-1.3
Sediments, moraines, clay and other rock with little resistance	1.3-1.8
Fine sediments and soils without erosion resistance	1.8-2.0
Soil protection coefficient [X_a]	
Mixed and dense forest	0.05-0.2
Thin forest with frove	0.05-0.2
Coniferous forest with little grove, scarce bushes, bushi prairie	0.2-0.4
Damaged forest and bushes, pasture	0.4-0.6
Damaged pasture and cultivated land	0.6-0.8
Areas without vegetal cover	0.8-1.0

Coefficient of type and extent of erosion [ϕ]	
Little erosion on watershed	0.1-0.2
Erosion in waterways on 20-50% of the catchment area	0.3-0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6-0.7
50-80% of catchment area affected by surface erosion and landslides	0.8-0.9
Whole watershed affected by erosion	1.0

An initial GIS database of the Dubračina catchment was constructed using data from various academic, government and non-government institutions. The parameters of the Gavrilović method were subdivided into spatially-variant and spatially-invariant categories based on the characteristics of the underlying data. As temperature data for the Dubračina catchment was available for only one meteorological station, this parameter was considered to be constant across the entire catchment area. All other data, including rainfall, soil erodibility and erosion characteristics were considered to vary across the catchment (Table 1).

Within this paper the authors wanted to explore the sensitivity of the erosion potential model to different land cover/use inputs. For that purpose, we did not modify any of the above mentioned parameters, we merely changed the land cover/use input layer in each scenario.
Two different land cover/use data sets were initially available; the 1:100,000 scale CORINE land cover map produced by the European Commission (EC) in 2006 (Figure 3a) and the 1:25,000 Spatial Plan of land use (Figure 3b) produced by the Croatian Government in 2004. The CORINE data were available at a spatial resolution of 100x100m whilst the Spatial Plan was converted to raster format at a spatial resolution of 25x25m. A third data set, based on supervised classification of a recent (2013) Landsat 8 scene was subsequently included in the study to provide a more up-to-date and higher resolution (15x15m) assessment of land cover (Figure 3c) than the CORINE data set.

Table 2 summarizes the differences between the three land cover/use data sources in percentage terms for the following categories: water, agricultural areas, bare rock, bare soil to rare vegetation, rare to medium vegetation, dense vegetation (forest), urban areas and exploitation of mineral resources (including cemeteries and construction sites).

In terms of attribution, the ‘agricultural areas’ land use category in the Spatial Plan is broadly equivalent to the ‘bare soil to rare vegetation’ land cover category in the CORINE and Landsat 8 data sets. The breakdown of land cover/use over the catchment is most similar between the Spatial Plan and Landsat 8 data sets for the categories ‘bare soil to rare vegetation’, ‘agricultural areas’ and ‘urban areas’. The breakdown of land cover/use is most similar between the CORINE data and the Spatial Plan for the ‘dense vegetation (forest)’ category. Such differences in spatial resolution and land cover/use attribution are likely to result in significant variance in modelled estimates of annual volumes of detached soil (Wa) and erosion intensity (Z) as predicted by the Gavrilović method.

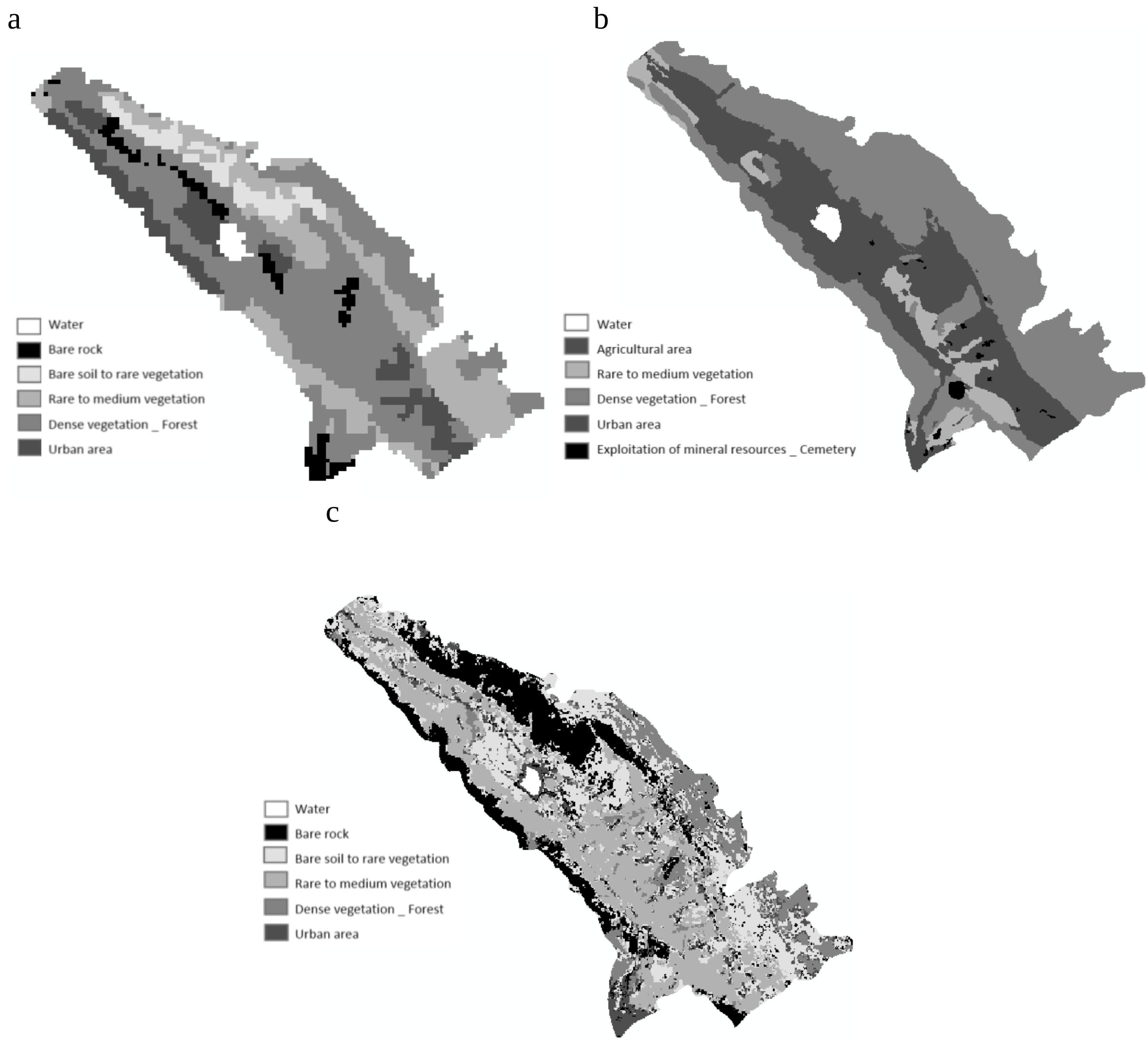

Figure 3: Land cover/use data for Dubračina catchment based on (a) CORINE (b) Spatial Plan and (c) unsupervised classification of Landsat 8 scene.

Table 2: Percentage breakdown of land cover/use for the Dubracina Catchment

Land Use/ Land Cover Category	**CORINE (100x100m)**	**Spatial Plan (25x25m)**	**Landsat 8 (15x15m)**
Water	1	1	1
Agricultural Areas		29	
Bare Rock	5		20
Bare Soil to Rare Vegetation	6		27
Rare to Medium Vegetation	24	8	31
Dense Vegetation (Forest)	52	54	13
Urban Areas	12	7	8
Exploitation of mineral resources (including cemeteries and construction sites)		1	
Summary	100	100	100

4. Results

In order to determine the impact of utilising different land cover/use inputs to model sediment erosion across the Dubračina Catchment the Gavrilović Erosion Potential Method was run three times in ArcGIS with different inputs (Figure 4).

As can be seen in Figure 4, CORINE, with the lowest spatial resolution, produces an estimate of annual volume of detached soil that is ~3 times smaller (250 m^3/km^2/year) than estimates based on the Landsat land cover input (682 m^3/km^2/year) and approximately half the size of the estimate based on the Spatial Plan land use input (426 m^3/km^2/year). Since the Spatial Plan represents an idealised account of how land should be used, as opposed to how it is currently being used, these data can be considered least reliable. If the spatial distribution of erosion intensity (Z) derived from the 3 inputs is compared with data obtained from field visual survey then the estimates derived from the Landsat land cover data are the most accurate, then those from the Spatial Plan, then those from CORINE (Figure 5).

The area characterised by excessive erosion on the erosion intensity map (Figure 5c) derived from the Landsat 8 data source, corresponds to an existing area in the field situated in the Slani Potok and Mala Dubračina sub-catchments (Figure 2a) which are most affected by erosion processes.

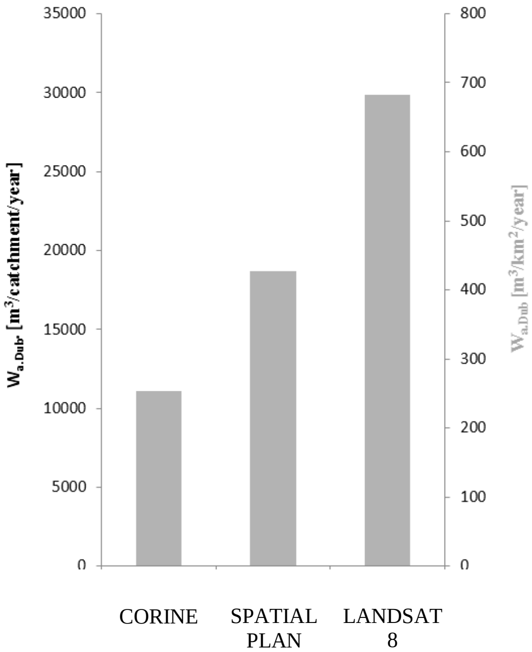

Figure 4: Predicted Total annual volume of detached soil for different land cover/use data

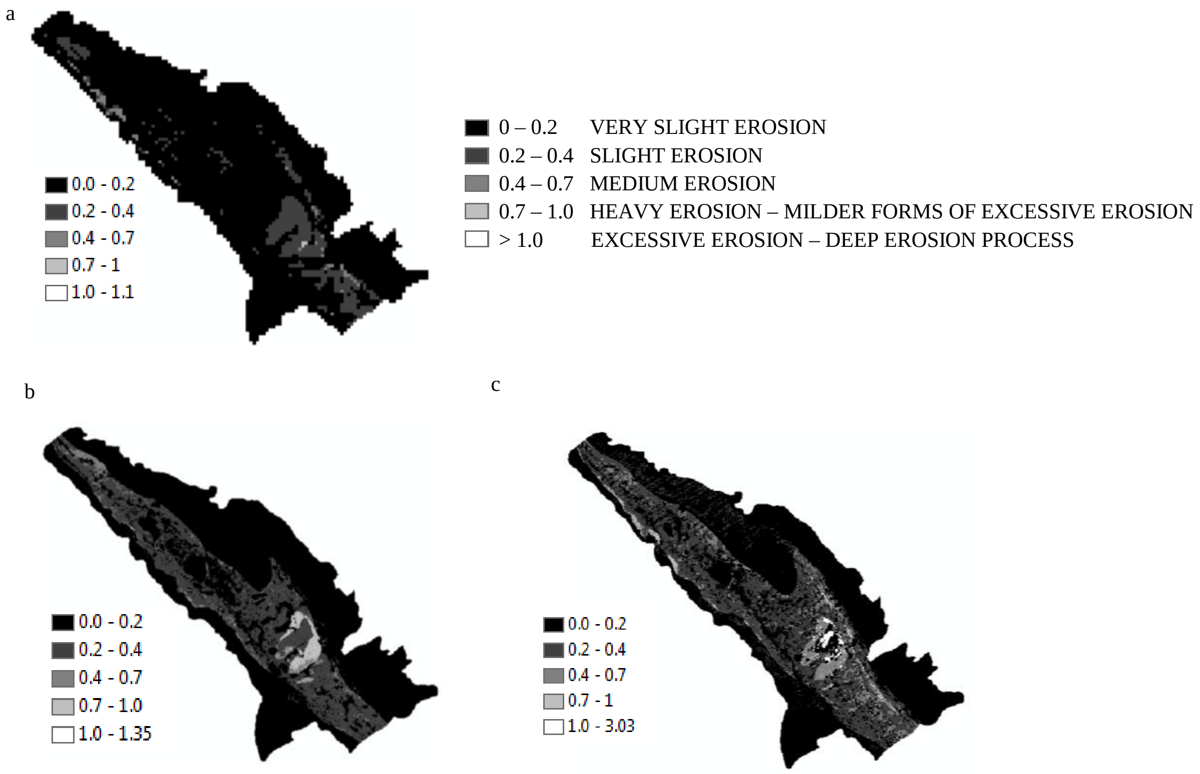

Figure 5: Spatial distribution of erosion intensity/severity within the Dubracina Catchment based on (a) CORINE land cover data (b) Spatial Plan (land use data) and (c) Landsat land cover data.

5 Discussion/Conclusion

In this study we have demonstrated that the Gavrilović Erosion Potential Method is sensitive to different assumptions about land cover and land use. Specifically, we have demonstrated that the highest rates of erosion (Z) and largest volumes of detached soil (Wa) are predicted when the model uses high resolution land cover classes derived from Landsat imagery. Furthermore, these estimates correspond spatially most closely to field visual observations, giving us confidence that the method may be used with confidence to evaluate erosion mitigation strategies across the catchment. In the next few months field equipment will be set up at various locations within the catchment to measure erosion rates and provide the necessary data for detailed model verification and calibration.

6. Acknowledgements

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Biography

Nevena Dragičević is a PhD student and teaching assistant at Faculty of Civil Engineering University of Rijeka, Croatia.

Duncan Whyatt is a Senior Lecturer in GIS within the Lancaster Environment Centre, Lancaster University.

Gemma Davies is the GIS Officer for Lancaster Environment Centre, Lancaster University, United Kingdom.

Barbara Karleuša is associate professor at Faculty of Civil Engineering University of Rijeka, Croatia.

Nevenka Ožanić is full professor at Faculty of Civil Engineering University of Rijeka, Croatia.