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Sensitivity analysis of a sediment dynamics model applied in a Mediterranean river basin: Global change and management implications

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HIGHLIGHT

- A sensitivity analysis was performed for a sediment model in a Mediterranean basin.
- For sediment retention benefits, the model was sensitive to erosivity and erodibility.
- For sediment export, it was also sensitive to land management factors.
- Management practices may mitigate the impact of climate change on sediment export.
- Sensitivity to physical or management factors varied with the forest cover proportion.

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ABSTRACT

Climate change and land-use change are major factors influencing sediment dynamics. Models can be used to better understand sediment production and retention by the landscape, although their interpretation is limited by large uncertainties, including model parameter uncertainties. The uncertainties related to parameter selection may be significant and need to be quantified to improve model interpretation for watershed management. In this study, we performed a sensitivity analysis of the InVEST (*Integrated Valuation of Environmental Services and Tradeoffs*) sediment retention model in order to determine which model parameters had the greatest influence on model outputs, and therefore require special attention during calibration. The estimation of the sediment loads in this model is based on the Universal Soil Loss Equation (USLE). The sensitivity analysis was performed in the Llobregat basin (NE Iberian Peninsula) for exported and retained sediment, which support two different ecosystem service benefits (avoided reservoir sedimentation and improved water quality). Our analysis identified the model parameters related to the natural environment as the most influential for sediment export and retention. Accordingly, small changes in variables such as the magnitude and frequency of extreme rainfall events could cause major changes in sediment dynamics, demonstrating the sensitivity of these dynamics to climate change in Mediterranean basins. Parameters directly related to human activities and decisions (such as cover management factor, C) were also influential, especially for sediment exported. The importance of these human-related parameters in the sediment export process suggests that mitigation measures have the potential to at least partially ameliorate climate-change driven changes in sediment exportation.

1. Introduction

Changes in rainfall and land-use patterns are severely influencing sediment dynamics (e.g., erosion and retention processes) in river basins (Walling, 2008). Recent studies suggest that this influence is particularly evident in scenarios of environmental land use conflicts, where actual land uses deviate from natural uses determined by soil characteristics (Pacheco et al., 2014; Valle Junior et al., 2014). Because of its sensitivity to global change and the environmental and economic relevance of sediment dynamics, erosion and its impacts receive increasing attention from local, national, European and global policy makers (e.g., European Commission, 2002; COST634, 2005; MA, Millennium Ecosystem Assessment, 2005). From drinking water to hydro-power or irrigation canals, there is a growing interest in assessing the sediment retention service provided by natural landscape, to adopt

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watershed management measures that enhance this service (Clark, 1985; MA, Millennium Ecosystem Assessment, 2005; CIRIA, 2013). Policy makers require reliable predictions of how global change will affect erosion and retention processes in order to design effective mitigation or adaptation measures. Therefore, it is crucial to evaluate and minimize uncertainty of the models to avoid bias in decision making (Chavas, 2000; National Research Council, 2005). Rusell (1949) has illuminated these circumstances with more optimism: 'When one admits that nothing is certain one must, I think, also admit that some things are much more nearly certain than others.' That is an encouraging statement especially for scientists whose basic vocation is to characterize and reduce uncertainty where possible.

Sediment production and transport in river basins is controlled by many factors, including rainfall patterns, soil characteristics, steepness of the hill-slope, and the type of vegetation cover. Different types of vegetation decrease soil loss and retain sediments from upslope areas to different degrees (Tallis et al., 2011). In Europe, in particular, the analysis of erosion rates under natural rainfall confirmed the dominant influence of land use and land cover. Generally, the erosion of a land with a permanent vegetation cover (shrubs, grassland and forest) is much lower than those on cultivated land (Cerdan et al., 2010). Soil loss may therefore be mitigated through agricultural best management practices (Bakker et al., 2008), but broader and more dramatic land-use changes such as a transition from vegetated to urban areas may have larger effects on the capacity of a landscape to retain sediments from upslope areas. The risks posed by altered sediment dynamics are particularly evident in Mediterranean and others semiarid regions, which are among the most vulnerable areas to global change (Schröter et al., 2005). Since the 1980s, a substantial body of work appeared about the erosion and transport of sediments in different parts of the Llobregat basin located in the northeast of the Iberian Peninsula (Cloret et al., 1983; Cloret, 1984; Cloret and Gallart, 1986; Llorens et al., 1998; Regüés et al., 2000; Regüés and Gallart, 2004; Farguell and Sala, 2005; Gallart et al., 2005; Catari, 2007) but none have targeted the basin in its entirety. Sediment dynamics models vary widely in complexity but typically involve a large number of parameters requiring calibration (Merritt et al., 2003). Irrespective of the model complexity, accurate characterization of all physical processes may not always be possible; input parameters are often difficult to measure and therefore need to be estimated. The uncertainties related to parameter selection may therefore be significant and need to be quantified to improve model interpretation for watershed management.

In this study we performed a sensitivity analysis of a simple sediment retention calibrated in a Mediterranean basin, in order to determine the parameters that had the greatest influence on the model outputs, and thus have particular importance for model calibration and interpretation. Such sensitivity analysis techniques have been widely used to reveal the relative importance of different factors in spatially distributed models (Confalonieri et al., 2010a, 2010b; Yang, 2011; Sánchez-Canales et al., 2012). The sensitivity analysis described here was performed for two separate components of the model, predicting exported and retained sediment, respectively, and reflecting two different ecosystem benefits (avoided reservoir sedimentation and higher water quality) (de Groot et al., 2010).

2. Material and methods

2.1. Study region

The Llobregat River basin is located in the NE of the Iberian Peninsula and drains an area of 4950 km^2. The river, which is 156 km long, arises in the Pyrenean Mountains and flows southward into the Mediterranean Sea near the city of Barcelona. This river is an important water source for Barcelona and its metropolitan area (over 3 million people). The basin is dominated by forest cover (38.2%) and by a mixture of grass and shrubland (31.6%, for more details, see Table 1). The climate is Mediterranean, with strong seasonal fluctuations in temperature and rainfall, and peak rainfall events in spring (March-June) and autumn (September-December). Annual rainfall ranges widely within the river basin, from 400 mm per year in the mid-section to 1000 mm in the upper segments (Mujeriego, 2006). There are three reservoirs located in the headwaters of the river basin: La Baells ($115 \cdot 10^6$ m^3), Sant Ponç ($24 \cdot 10^6$ m^3), and La Llosa del Cavall ($80 \cdot 10^6$ m^3). There are several drinking water treatments plants, the largest being located near the river mouth. In order to analyse spatial sensitivity, the river basin was divided into 7 sub-basins, three upstream of the three reservoirs (sub-basins numbers 2, 3 and 4, Fig. 1), and the other four covering the rest of the basin (sub-basins numbers 1, 5, 6 and 7, Fig. 1).

2.2. Modeling approach

Due to the fact that complex model with more parameters may have even greater uncertainty, we chosen for the sensitivity analysis a simple one as the InVEST sediment retention model.

The InVEST sediment retention model produces spatially explicit outputs at an annual average time scale, see Table 2 for details (Tallis et al., 2011; version 2.4). This model computes the total amount of sediment exported by estimating the average annual sediment generated by each parcel of land, employing a method based on the Universal Soil Loss Equation (USLE) (Tallis et al., 2011; Wischmeier and Smith, 1978) at the pixel scale. The USLE integrates information on land use/

Table 1
Characteristics of each sub-basin (from 1 to 7) and entire river basin (ALL).

		Sub-basin							
		1	2	3	4	5	6	7	ALL
Area	(km^2)	784.26	504.45	196.15	108.60	1105.01	818.88	1381.59	4898.94
River inside	(km)	157.03	86.32	32.53	17.20	241.53	156.80	329.42	1020.83
Km of river	per km^2 sub-basin	0.20	0.17	0.17	0.16	0.22	0.19	0.24	0.21
Slope	Max.	47.0	53.8	41.0	39.8	42.7	28.7	37.8	53.8
(degree)	Mean	6.4	16.1	16.8	8.3	7.1	5.4	6.4	7.9
% LULC	Urban land (0)	24.0	0.5	0.4	0.3	2.4	5.7	2.7	6.2
	Non irrigated land (1)	12.0	1.2	1.5	22.1	28.7	43.8	25.6	23.6
	Irrigated land (2)	1.5	0.0	0.1	0.0	0.3	0.1	0.3	0.4
	Shrub & grass land (3)	34.6	35.1	40.2	14.4	38.5	25.5	26.9	31.6
	Forest land (4)	27.9	63.2	57.8	63.3	30.2	25.0	44.5	38.2
Rainfall (mm)	Mean	669.32	992.24	948.63	728.36	650.52	599.36	708.81	715.65
Erosivity	Max	2682.91	2963.17	2955.18	2849.18	2774.33	2944.46	2679.48	2780.15
(MJ*mm/ha*h*y)	Mean	2604.55	2892.73	2929.34	2790.49	2718.22	2868.96	2608.93	2712.91
Erodibility	Max	0.0228	0.0250	0.0196	0.0194	0.0228	0.0256	0.0237	0.0234
(ha*MJ/mm)	Mean	0.0119	0.0157	0.0132	0.0164	0.0168	0.0154	0.0168	0.0154