Science of the Total Environment 485–486 (2014) 110–120

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Soil losses in rural watersheds with environmental land use conflicts

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HIGHLIGHTS

- Conceive environmental land use conflicts (LUC) in rural watersheds.
- Investigate soil erosion in watersheds with LUC.
- Predict soil erosion in the absence of LUC.

ARTICLE INFO

Article history:
Received 1 January 2014
Received in revised form 10 March 2014
Accepted 16 March 2014
Available online 3 April 2014

Editor: Simon Pollard

Keywords:
Soil loss
Hydric erosion
Environmental land use conflict
USLE
GIS

ABSTRACT

Soil losses were calculated in a rural watershed where environmental land use conflicts developed in the course of a progressive invasion of forest and pasture/forest lands by agriculture, especially vineyards. The hydrographic basin is located in the Douro region where the famous Port wine is produced (northern Portugal) and the soil losses were estimated by the Universal Soil Loss Equation (USLE) in combination with a Geographic Information System (GIS). Environmental land use conflicts were set up on the basis of land use and land capability maps, coded as follows: 1—agriculture, 2—pasture, 3—pasture/forest, and 4—forest. The difference between the codes of capability and use defines a conflict class, where a negative or nil value means no conflict and a positive i value means class i conflict. The reliability of soil loss estimates was tested by a check of these values against the frequency of stone wall instabilities in vineyard terraces, with good results. Using the USLE, the average soil loss (A) was estimated in $A = 12.2\ \text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ and potential erosion risk areas were found to occupy 28.3% of the basin, defined where soil losses are larger than soil loss tolerances. Soil losses in no conflict regions ($11.2\ \text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) were significantly different from those in class 2 ($6.8\ \text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) and class 3 regions ($21.3\ \text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) that in total occupy 2.62 km^2 (14.3% of the basin). When simulating a scenario of no conflict across the entire basin, whereby land use in class 2 conflict regions is set up to permanent pastures and in class 3 conflict regions to pine forests, it was concluded that $A = 0.95\ \text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ (class 2) or $A = 9.8\ \text{t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ (class 3), which correspond to drops of 86% and 54% in soil loss relative to the actual values.

1. Introduction

Among the factors explaining the intensity of soil erosion, plant cover and land uses are considered the most important, exceeding the influence of rainfall intensity and slope gradient (García-Ruiz, 2010; Kosmas et al., 1997; Thornes, 1990; Wainwright and Thornes, 2004). Estimates of soil losses under various plant cover and land use settings are reported in quite a number of studies (Cerdan et al., 2010; Durán-Zuazo et al., 2013; López-Vicente et al., 2013; Nunes et al., 2011; Tefera and Sterk, 2010; Vacca et al., 2000). Given the disparity of erosion rates among the different settings, it becomes evident that a change in the plant cover or land use of a region will inevitably lead to a soil loss increment or decrement in that region.

Cases of soil loss increment are frequently related to deforestation and substitution of forests by crops, meadows or permanent cultures such as orchards or vineyards. Usually, these land use changes result in gully development and shallow landslides that can increase the sediment load in rivers and ultimately contribute to the formation of new sedimentary structures including fluvial terraces, alluvial fans and deltas (Beguería et al., 2006; García-Ruiz and Valero-Garcés, 1998; Martínez-Casasnovas and Sánchez-Bosch, 2000). Cases of soil loss decrement are often related to farmland abandonment (Bellin et al., 2011; Ruiz-Flaño, 1993; Ruiz-Flaño et al., 1992), although abandoned farms have often been associated with important erosion processes shortly after desertion (Bellin et al., 2009; Lesschen et al., 2007). The decrement occurs in the long term and is associated with the recovery of the vegetation cover (dense forest or shrub) and the improvement of the chemical, physical and hydrological properties of soils (Bonet, 2004; García-Ruiz and Lana-Renault, 2011). Other cases

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http://dx.doi.org/10.1016/j.scitotenv.2014.03.069
0048-9697/

of soil loss decrement are related to reforestation of croplands (Wang et al., 2012).

In rural watersheds, land uses are usually characterized by farmlands in the lowland valleys, where soils are thicker and more fertile; pastures for livestock production, vineyards and orchards in the mid-altitude valleys, with small forest spots in the adjacent hillsides; and continuous forests in the highlands. In traditional agrarian systems, these land uses are conforming to the land capability determined by an evaluation of soil characteristics such as depth or fertility and local environmental conditions such as topographic slope or water availability (Agroconsultores, Ltd., Coba, Ltd., 1991). But there are rural watersheds where the actual land use deviates from the most capable use, in which case an environmental land use conflict is generated with consequences on soil erosion intensity (Mello Filho, 1992; Valle Junior, 2008; Valle Junior et al., 2013, 2014).

Notwithstanding the literature about the impact of land use changes on soil erosion is vast (Alkharabsheh et al., 2013; Ciampalini et al., 2012; Cotler and Ortega-Larrocea, 2006; Heckmann, 2014; Szilassi et al., 2006; Wijitkosum, 2012; Zokaib and Naser, 2011), only a few papers were specifically dedicated to the analysis of soil losses in places where environmental land use conflicts were developed (Haygarth and Ritz, 2009; Olarieta et al., 2008; Zucca et al., 2010). The purpose of this paper is to contribute with some new insights about this topic. Firstly, land use conflicts are investigated in a rural watershed, by comparing the maps of land use and land capability using the approach of Valle Junior (2008). Secondly, soil losses determined by the Universal Soil Loss Equation (Wischmeier and Smith, 1978) are compared among places that are inside or outside the conflict areas.

2. Study area

The Meia Légua stream is a right margin tributary of the Douro River located in the southern limit of the Vila Real district, Trás-os-Montes and Alto Douro province, north of Portugal (Fig. 1). The stream is a 6.5 km long 9.2% inclined water course following NW–SE and NNE–SSW directions determined by the local fracture network. The hydrographic basin covers an area of approximately 18.3 km^2, being asymmetrical to a NNE–SSW longitudinal axis with the wider hillsides located at the right margin.

Altitudes in the basin of Meia Légua stream range from 50 to 650 m and annual precipitation from 1240 to 1540 mm. As is typical for the SW European countries, precipitation regime in the area is characterized by long dry periods followed by heavy rain bursts. According to Brandão et al. (2001), the maximum precipitation (P_{max}, in mm) in a period comprehended between 10 min and 24 h (D, in minutes) is described by the relationship $P_{max} = a \times \ln(D) - b$, with $a = 21.484$ and $b = -6.997$ around the study area. This relationship provides an estimate of 163.2 mm for the local maximum precipitation in 24 h.

The watershed is entirely shaped on Cambrian schists and graywackes, the alteration of which produced leptosols along the western boundary of the catchment and the NW–SE branch of the main valley, fluvisols along the NNE–SSW branch of the main valley, and anthrosols elsewhere (Fig. 2). Using a method by Smith and Stamey (1964), Catalão (2009) estimated the following erosion tolerances for these soil types (values in $t \cdot ha^{-1} \cdot yr^{-1}$): 3.83 for leptosols, 12.93 for the fluvisols and 14.81 for the anthrosols. Based on soil characteristics such as depth or fertility as well as on environmental conditions such as topographic slope or water availability, land capability outside the main urban areas was assessed and defined by the codes $A_iP_jF_k$, where A, P and F mean agriculture, pasturing and forestry, respectively, and the subscripts mean not adapted (0), well adapted (1), moderately adapted (2), poorly adapted (3) or conditionally adapted (4). According to this nomenclature, a parcel coded as $A_0P_3F_1$ is not adapted to agriculture, is poorly adapted to pasturing and is well adapted to forestry. The most capable use has the code closer to 1. In the basin of Meia Légua stream, because specific soil types developed under specific environmental conditions—leptosols in the hilly regions, fluvisols along the valleys and anthrosols in the vineyards, the most capable uses (Fig. 2) reflect the soil characteristics, as follows: agriculture in the anthrosols, forestry in the leptosols and pasturing for livestock production mixed with forestry in the fluvisols (Agroconsultores, Ltd., Coba, Ltd., 1991).

Land is mostly (75%) occupied by vineyards, the reminder being used for orchards, oliveyards, cropland, small spots of pine, eucalyptus and various deciduous forests; or taken by urban areas, roads and

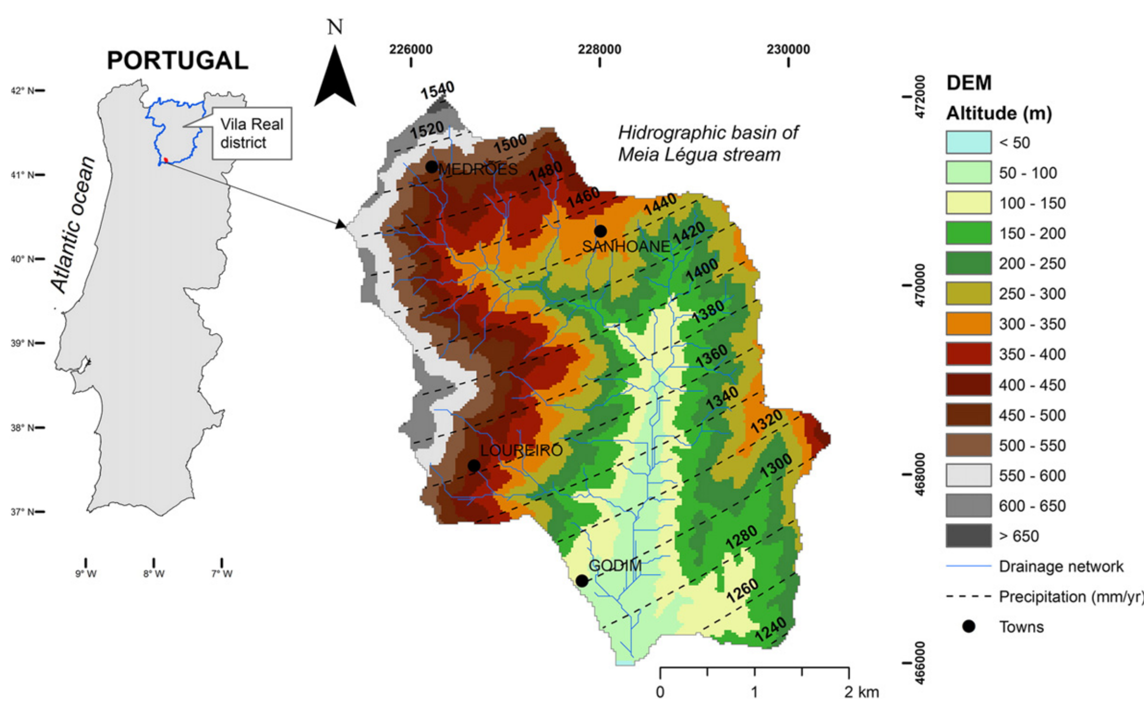

Fig. 1. Geographic location, digital elevation model and precipitation contours in the hydrographic basin of Meia Légua stream.