Land Use Policy 41 (2014) 172–185

Contents lists available at ScienceDirect

Land Use Policy

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

Environmental land use conflicts: A threat to soil conservation

R.F. Valle Junior[a], S.G.P. Varandas[a], L.F. Sanches Fernandes[a], F.A.L. Pacheco[b,*]

[a] *Centre for Research and Technology of Agro-Environment and Biological Sciences, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal*
[b] *Chemistry Research Centre, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal*

A R T I C L E I N F O

Article history:
Received 18 July 2013
Received in revised form 19 March 2014
Accepted 25 May 2014

Keywords:
Soil vulnerability
Environmental land use conflict
Multi criteria analysis
Weighted linear combination
Land use policy

A B S T R A C T

Soil vulnerability and environmental land use conflicts were quantified and cross tabulated in the Sordo River basin (Trás-os-Montes Province, NE Portugal) to provide insights about the risk of soil degradation within that basin. Soil vulnerability was assessed by algorithms of multi criteria analysis and weighted linear combination, whereas environmental land use conflicts were described by an original approach. Three vulnerability scenarios were considered, enhancing the importance of topographic slope, soil class and use and occupation of soils, respectively, as vulnerability factors. Regardless the scenario, approximately two-thirds to the basin was defined as areas with high vulnerability. Fortunately, only 10.9% of the basin is in environmental conflict, where actual land uses deviate from natural uses determined by soil characteristics. The cross tabulation of high vulnerability areas with conflict areas, which defines the areas at risk of soil degradation, reveal that risk areas account for approximately 3.2–8.4% of the basin, depending on the scenario, being concentrated in steep slope hillsides suited for forest or mixed forest and pasture occupations but actually used for irrigated crop lands, vineyards and olive yards. Some conservation practices are implemented in the vineyard and olive yard areas, namely through the construction of terraces. These structures minimize soil erosion but are potentially unstable beyond given intervals of terrain slope. On the other hand, the maintenance of terraces is costly and for that reason eventually unaffordable for many farmers, and they also entail a mischaracterization of the historical and architectural heritage of the Douro Wine Region (UNESCO World Heritage). In this context, it was suggested the approval of legislation as regards the design, construction and maintenance of terraces, while in a broader perspective it was recommended the appreciation of a European Directive for soil protection and its subsequent transposition to the national legislation.

Introduction

The use of the land with disregard for the soil characteristics combined with a lack of strategies for the conservation of soil, have accelerated soil erosion around the globe compromising social development. In the Trás-os-Montes province (NE Portugal), the anthropogenic causes of soil degradation were predominantly related to a poor management of forested areas. The most fragile soils could have been protected by a forest cover preferably composed of climacic vegetation such as oak or cork oak, but owing to a lack of regulation they were occupied by foreign species such as pine or eucalyptus. Providentially, the plan for forest management of Trás-os-Montes (Regulate Decree n° 2/2007, published officially in 17 January 2007), which defines critical areas as regards risk of forest fire, sensitivity of soils to erosion, ecological relevance, etc., established a set of species to be planted in those areas and is now being used as regulatory tool in acts of expansion or conversion of the local forest heritage. In compliment to the improper management of forests, soil degradation in Portugal was related to environmental land use conflicts. For example, the areas suited for the practicing of agriculture represent solely 10% of the territory but the areas occupied by farms are much larger than this threshold, reaching 30%. Besides, there is a persistent use of steep slope landscapes for agriculture, especially for vineyards and olive yards, sometimes not accompanied by the proper soil conservation practices. Due to this overexploitation, around 70% of Portuguese soils are threatened by erosion and 30% observe an accelerated process of degradation.

With the advent of Geographic Information Systems (GIS), prevention of soil degradation could be handled by spatial models of land suitability and land use change. These models have the capacity to integrate changes in soil cover with their natural, social, political and economical drivers, and in the sequel project environmentally correct pathways of land occupation into the future

* Corresponding author. Tel.: +351 259 350280; fax: +351 259 350480.
E-mail address: fpacheco@utad.pt (F.A.L. Pacheco).

http://dx.doi.org/10.1016/j.landusepol.2014.05.012

(Bottero et al., 2013; Pinto, 2010; Veldkamp and Lambin, 2001). A critical review on GIS-based land suitability analysis was written by Malczewski (2004). A common application of GIS-based land suitability models is in the setting of a particular land use based on the definition and combination of multi criteria. This has been operated in several nature conservation (Geneletti, 2004), agriculture (Hayashi, 2000; Manos et al., 2010; Mendas and Delali, 2012; Walke et al., 2012), forestry (Hutha et al., 2005; Phua and Minowa, 2005), irrigation (Anane et al., 2012; Darouicha et al., 2012) and water management (Al-Adamat et al., 2010) projects. The multi criteria approach combined with GIS is also known as multi criteria spatial decision support system (Malczewski, 1999, 2006) and usually includes the definition, standardization and spatial delineation of environmental factors and constraints relevant for the problem, succeeded by their weighted linear combination (Banai, 1993; Camara et al., 2001; Eastman, 1998; Jiang and Eastman, 2000; Malczewski, 2000; Pinto, 2010; Samizava et al., 2008; Weber and Hasenack, 2001; Zadeh, 1965). In compliment to land use setting, multi criteria spatial decision support systems have been used as tools in the design of human development strategies, with the main purpose of reducing poverty (Garfi et al., 2011). In this context, several consensus building models were developed to handle the conflicts among different stakeholders with competing interests in the process of land use allocation (Koontz, 2005; Feick and Hall, 2001; Zhanga et al., 2012). But, to date, little attention has been given to the analysis of land use conflicts resulting from a misuse of soil relative to its suitability, i.e. to the so-called environmental land use conflicts (Valle Junior et al., 2013). The purpose of this paper is to fill in this gap by investigating environmental land use conflicts in the Sordo River basin (Trás-os-Montes Province, NE Portugal). In a first stage, a soil vulnerability map is produced for the study area based on the application of a multi criteria analysis, and subsequently this map is cross tabulated with an environmental land use conflict map. In the areas where conflicts exist and soil vulnerability is high, the environment is considered at risk and hence concomitant management strategies are proposed to minimize soil degradation.

Study area

The hydrographic basin of Sordo River, which is integrated in the large Douro River basin where the famous Port wine is produced, is located in the region of Trás-os-Montes, north of Portugal. It is an experimental watershed where a number of environmental studies has been conducted, namely as regards the modeling rock weathering (Pacheco and Alencoão, 2006), groundwater vulnerability (Pacheco and Sanches Fernandes, 2013), groundwater flow systems and bimodal landscapes (Pacheco and Van der Weijden, 2014a), and environmental land use conflicts (this study). With an area of approximately 51.2 km^2, the Sordo River basin is situated between the northern latitudes of 41° 16′05.57″–41° 20′12.81″ and western longitudes of 7° 55′21.82″–7° 45′42.45″, covering a large portion the Vila Real and Santa Marta de Penaguião municipalities (Fig. 1). It is a mountainous watershed of the Marão cordillera where the altitudes vary between 300 and 1100 meters above sea level, the annual precipitation exceeds 1000 mm yr^{-1}, and the mean annual temperature approaches 14 °C. The main water course is approximately 16.1 km long and, in combination with its tributaries, forms a tree like (dendritic) drainage network. Slopes are gentle along streams (<10%), especially in the central area where the landscape is characterized by a wide open valley (<5%), being steep (>30%) in the adjacent hillsides and along the water divides of the NW, West and SW limits. A region of very steep slopes is also observed at the mouth of the river basin (Fig. 1). The basin has a radial form where a group of 53 micro basins can be individualized (Fig. 2).

The geologic setting is characterized by crystalline rocks made of Paleozoic metassediments intruded by Hercynian granites, covered in the central area by alluvial deposits. The most representative soil types are the leptosols, but in association with the main streams, especially in the central area, some spots of fluvisols were also formed. In the eastern limit of the basin, some anthrosols were developed in connection with the expansion of vineyards and olive yards (Fig. 3). Land suitability was defined on the basis of a comparison between the soil characteristics/environmental conditions (e.g. fertility, erosion risk) and the requisites or limitations of a particular use. The most suited land uses, also called natural land uses, are illustrated in Fig. 4. The soil characterization as well as the land suitability analysis was the result of a project conducted by Agroconsultores and Coba (1991) in a partnership with the Trás-os-Montes and Alto Douro University.

The use and occupation of land are essentially conditioned by the basin morphology. In the areas where relief is gentle, especially in the margins of stream valleys, land uses are characterized by annual crop agriculture or natural pastures, whereas in the steep hillsides of the western side and at the most elevated altitudes, where the soils are poorer, occupation of space is mostly characterized by pine, eucalyptus or mixed forests and shrub land. Finally, in a small area of the eastern side of the basin, land is occupied by vineyards and olive yards. Fig. 5a and b illustrates how land uses were allocated in 1990 and 2007, respectively. Within this period, landscape changed mostly because many shrub land areas were converted into forests, permanent cultures were transformed into pastures, and urban areas expanded considerably. The conversion of agriculture areas into pasture land reflects the well known decline of agriculture as a subsistence activity of many families, which followed the adherence of Portugal to the EU and the implementation of a common agriculture policy.

Materials and methods

Multi criteria analysis of soil vulnerability

According to Malczewski (1999), the general framework for a GIS-based (or spatial) multi criteria analysis, also known as multi criteria spatial decision support system, consists of a sequence of elements, including problem definition, evaluation criteria (objectives and/or attributes (factors and constraints)), alternatives, constraint maps, decision-maker preferences, decision rules, sensitivity analysis and recommendation. This general framework has been used by several authors (e.g. Garfi et al., 2011; Geneletti, 2004; Shee and Wang, 2008) and is elegantly portrayed in a study about soil erosion carried out by Dragan et al. (2003).

The development of a spatial multi criteria analysis of soil vulnerability (Fig. 6) involves the following steps (Ferretti, 2011): (a) *Raw data acquisition*. A thematic map has to be constructed for each identified attribute (factor or constraint); (b) *Standardization*. The scores of factors and constraints are made dimensionless and mutually comparable; (c) *Weighting*. The relative and overall importance of each factor is evaluated as regards the achievement of the proposed objective; (d) *Aggregation*. An overall soil vulnerability index for each site of the study area is calculated using an adequate aggregation rule; (e) *Sensitivity analysis*. This final step has the aim to test the robustness of the results and the role played by uncertainty factors. The next sections provide details about the steps outlined above.

Evaluation attributes (factors and constraints)

The general rule for selecting evaluation attributes is that each attribute must be comprehensible and measurable and a