Science of the Total Environment 548–549 (2016) 173–188

Contents lists available at ScienceDirect

Science of the Total Environment

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

Environmental land use conflicts in catchments: A major cause of amplified nitrate in river water

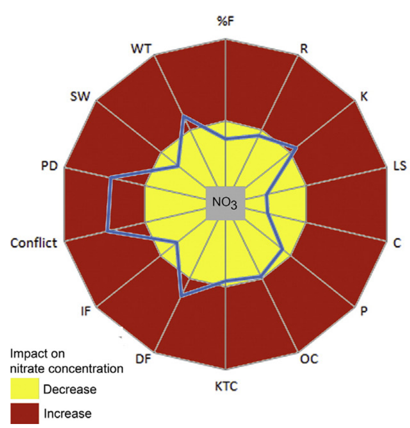
F.A.L. Pacheco [a,c,*], L.F. Sanches Fernandes [b,d]

[a] *Chemistry Research Centre, Vila Real, Portugal*
[b] *Centre for the Research and Technology of Agro-Environment and Biological Sciences, Vila Real, Portugal*
[c] *Department of Geology, University of Trás-os-Montes and Alto Douro (UTAD), Ap. 1013, 5001-801 Vila Real, Portugal*
[d] *Department of Engineering, UTAD, Portugal*

HIGHLIGHTS

- Environmental Land Use Conflicts (ELUC) are uses that ignore soil capability.
- In mainland Portugal, ELUC occur preferably where vineyards invaded forested areas.
- Nitrate concentrations in agricultural watersheds are amplified by ELUC.
- Elimination of ELUC favors compliance with the Water Framework Directive.

GRAPHICAL ABSTRACT



Predictor	Description
%F	Percentage of forested area in the watershed
R	Rainfall-runoff factor
K	Soil erodibility factor
LS	Combined slope length factor and slope steepness factor
C	Cover-management factor
P	Support practice factor
OC	Content of organic carbon in the topsoil
k_{TC}	Average transport capacity coefficient
DF	Area occupied by dry farming
IF	Area occupied by irrigated cultures
Conflict	Average conflict within the watershed
PD	Average population density
SW	Average coverage by sewage systems
WT	Average coverage by wastewater treatment plants

ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form 30 December 2015
Accepted 30 December 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Watershed
Agriculture
Nitrate
Environmental land use conflict
Human health
Partial Least Squares (PLS) regression

ABSTRACT

Environmental land use conflicts are uses of the land that ignore soil capability. In this study, environmental land use conflicts were investigated in mainland Portugal, using Partial Least Squares (PLS) regression combined with GIS modeling and a group of 85 agricultural watersheds (with >50% occupation by agriculture) as work sample. The results indicate a dominance of conflicts in a region where vineyards systematically invaded steep hillsides (the River Douro basin), where forests would be the most appropriate use. As a consequence of the conflicts, nitrate concentrations in rivers and lakes from these areas have increased, sometimes beyond the legal limit of 50 mg/L imposed by the European and Portuguese laws. Excessive nitrate concentrations were also observed along the Atlantic coast of continental Portugal, but associated to a combination of other factors: large population densities, and incomplete coverage by sewage systems and inadequate functioning of wastewater treatment plants. Before this study, environmental land use conflicts were never recognized as possible boost of nitrate concentrations in surface water. Bearing in mind the consequences of drinking water nitrate for human health, a number of land use change scenarios were investigated to forecast their impact on freshwater nitrate concentrations. It was seen that an aggravation of the conflicts would duplicate the number of watersheds with maximum nitrate concentrations above 50 mg/L (from 11 to 20 watersheds), while the elimination of the conflicts would greatly reduce that number (to 3 watersheds).

* Corresponding author.
E-mail address: fpacheco@utad.pt (F.A.L. Pacheco).

http://dx.doi.org/10.1016/j.scitotenv.2015.12.155
0048-9697/

1. Introduction

Land use is a site of perpetual disagreement (Sze and Sovacool, 2013). The sources of land use conflict are many and may include divergence among stakeholders over fundamental values, resource scarcity, power imbalances, and a lack of clear institutional arrangements including property rights (Brown and Raymond, 2013). The conflicts may be alarming when the usage of the land is proposed for high-risk ventures (Hilson, 2002; Wester-Herber, 2004), or in regions experiencing urbanization and progressive relocation of farms from the urban fringe to remoter rural areas (Darlya and Torre, 2013; Henderson, 2005; Hui and Bao, 2013). At the extreme, conflict over land may become intractable (Asah et al., 2012) or even be a reason for the outburst of violence (Dazzi et al., 2013). The resolution or anticipation of land use conflicts is often accomplished by a collaborative and participatory process that engages different stakeholders and concerned groups (Barnaud et al., 2013; Zhang et al., 2012), being technologically assisted by Geographic Information Systems (GIS) and land use change models (Von der Dunk et al., 2011; Ioja et al., 2014) and sometimes mediated by neutral parties (Andrew, 2003; Van Leeuwen, 2010). Usually, the outcome of participatory planning is the development of sustainable, multi-functional landscapes (De Groot, 2006).

In rural areas, land use conflicts are frequently related to the expansion of croplands towards areas occupied by natural vegetation or forests. Apart from any societal tension derived therefrom, these conflicts represent an important threat to biodiversity because the invaded natural or forested areas usually provide the last safe havens for many species (Wessels et al., 2003). Besides, the expansion of agriculture towards marginal areas usually neglects land capability the reason why farmlands in these areas tend to occupy poor erosion-prone soils, where productivity objectives are accomplished by enhanced, sometimes excessive, application of commercial easily leachable fertilizers. In the sequel, sediment exports from these areas tend to increase (Pacheco et al., 2014; Valle Junior et al., 2014a), while nutrients suspended or dissolved in runoff are likely to infiltrate contaminating groundwater (Valle Junior et al., 2014b) or accumulate in rivers and lakes endangering the aquatic ecosystems through eutrophication (Valle Junior et al., 2015). In cases where land uses do not comply with land capabilities set up by soil properties (e.g. texture, percentage of organic matter) and environmental conditions (e.g. slope gradient, drainage), an environmental land use conflict is said to exist (Mello Filho and Rocha, 1992; Valle Junior, 2008).

A common nutrient leached from agricultural areas, including those in environmental land use conflict, is nitrate (Pacheco and Van der Weijden, 1996; Pacheco et al., 1999). This compound has become an increasingly human health problem, as by the end of the 19th century the rate of creation of reactive nitrogen in the world has increased about tenfold due to anthropogenic activities and it is estimated that human interference with the nitrogen cycle has already exceeded the safe operating boundary of the Earth by a factor of 3.5 (Gao et al., 2014). Although still controversial, the ingestion of drinking water nitrate, especially in concentrations above the regulatory limit of 50 mg/L in the European Union (Nitrates Directive, 91/676/CEE), seems to favor endogenous formation of N-nitroso compounds (Shephard and Lutz, 1989) which in turn increases the risk of cancer in adults (Khademikia et al., 2013), methemoglobinemia in children (Ward et al., 2005), and adverse reproductive outcomes. These evidences concern public health organizations because the population exposed to nitrate levels in drinking water above 50 mg/L is very large worldwide, reaching 10 million people in 15 European countries (WHO, 2011). Nitrate can reach both surface and ground water as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater treatment and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. Although dressings of fertilizers are among the major sources of nitrate in surface and ground water, it is barely recognized that land use conflicts in rural areas can play a major role in amplifying the nutrient exports from the crop fields towards the aquatic media. The Net Anthropogenic Nitrogen Input (NANI) algorithm, introduced by Howarth et al. (1996), updated to a toolbox by Hong et al. (2012) and recently applied elsewhere (Hong et al., 2012, 2013a,b), is a simple quasi mass balance approach that estimates the human-induced nitrogen inputs to a watershed and that has been shown to be a good predictor of riverine nitrogen export. However, it does not explicitly deals with the conflict problem.

The main purpose of this study is therefore to document the aforementioned relationship between increased nitrate concentrations in surface water and environmental land use conflicts, using 85 agricultural watersheds (>50% occupation by agriculture) as work sample. The conceptual model of nitrate transport across the hydrographic basins adheres to the "pressure-pathway-receptor" method proposed by the European Union (EU, 2003), whereby the information on pollution sources is coupled with soil erosion, sediment transport and biogeochemical models to explain nutrient concentrations in a receptor (river or lake). In this study, this model has been mathematically handled by Partial Least Squares (PLS) regression combined with GIS modeling. As secondary purpose this work aims at predicting the impact to nitrate concentrations of rising, reducing or eliminating environmental land use conflicts throughout the studied area.

2. Materials and methods

2.1. Study area

The study area comprises a number of agricultural watersheds distributed within mainland Portugal. The Portuguese territory is laid on the westernmost promontory of Europe between the latitudes 36°36′––42°12'N and longitudes 6°12′–9°36'W, limited to the north and east by the Spanish border and to the south and west by the Atlantic coast. Irrespective of being a small country (total area: 92,080 km^2), it spans a wide range of landforms, climatic conditions and soils (Fig. 1a–c). The topography is markedly contrasting between the mountainous regions of the north and centre and the great rolling plains of the south, which are separated from each other by the River Tejo. The reflexes of topography on climate are noteworthy, because the mountainous regions are considerably colder and wetter than the plains. The weather along the northern coast and in central Portugal is mild. The ocean moderates coastal temperatures, but the inlands, especially in the south, can be quite hot with temperatures sometimes above 40 °C during the summer months. Because of its Mediterranean climate, most of rainfall occurs in the winter season. The soil systems of Portugal are usually sandy, arid, acidic and usually rocky in the north. The main soil types are cambisols, luvisols, leptosols and podzols. Organic matter is not abundant in any of these soils, but is more profuse in the cambisols than in the other types. In 2006, the Corine Land Cover survey (Fig. 1d) classified 38.4% of mainland Portugal as covered by forest land, mainly maritime pine, deciduous oak and scrubs, the rest being used for agriculture (33.3%), occupied by transitional areas (13.8%) and urban centers (3.5%), or preserved as natural or semi-natural (11%). In those days, coniferous and mixed forests were dominant in the northern and central mountains while deciduous forests were prevailing in the southern plains. Population is concentrated along the Atlantic coast (Fig. 1e). In these areas, population densities sometimes exceed 500 hab/km^2 (Porto and Lisboa towns) while in the inlands large portions of the territory are populated with less than 25 hab/km^2. Paradoxically, the coverage by sewage systems and wastewater treatment plants is larger in the inlands than along the coast (Fig. 1f). The combination of large population densities with a limited coverage by sewer systems and wastewater treatment plants make coastal areas prone to contamination of water masses. The public supply of freshwater in Portugal is sourced by groundwater and surface water (Fig. 2a). To the north, the sources of surface water prevail because precipitation in this region is abundant. To the south, given the scarcity of