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Groundwater quality in rural watersheds with environmental land use conflicts

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HIGHLIGHTS

- Conceive environmental land use conflicts (LUC) in rural watersheds
- Investigate groundwater quality in watersheds with LUC
- Investigate environmental implications of LUC

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ABSTRACT

The quality of groundwater was evaluated in a rural watershed of northern Portugal (River Sordo basin) where environmental land use conflicts have developed in the course of a progressive invasion of forest and pasture lands by agriculture, especially by vineyards. The selected groundwater quality parameters were the concentrations of sodium, calcium, bicarbonate, chloride and nitrates, derived from natural and anthropogenic sources. The environmental land use conflicts were revealed by the coupling of land use and land capability raster maps. The land capability evaluation allocated 70.3% of the basin to the practicing of agriculture, 20% to livestock pasturing and 9.7% to a mosaic of land uses including agriculture, livestock pasturing and forestry. The assessment of land use conflicts allocated 93.9% of the basin to no conflict areas. Minor conflict areas (4.1%) were found concentrated in the western region of the watershed. They correspond to an invasion of farmlands towards sectors of the catchment capable for the practicing of livestock pasturing. Moderate (1.6%) and major (0.4%) conflict areas were found limited to the eastern region, matching steep hillsides capable for the practicing of livestock pasturing or forestry but presently occupied with vineyards. The spatial distributions of ion concentrations were generally justified by common geochemical processes. The dominance of high concentration levels in moderate and major conflict areas was justified within the framework of nutrient dynamics in vineyard environment. Nitrate in groundwater was likewise produced via the nitrification of N-fertilizers. Apparently, this process promoted the weathering of plagioclase by the nitric acid reaction, in concurrence with the weathering by the carbonic acid reaction. The impact of nitrification was found more important in moderate and major conflict areas, relative to no conflict areas.

1. Introduction

Groundwater contamination in rural areas is controlled by numerous factors, including the use of the land. For example, in a county of China nitrate concentrations in groundwater were found to be higher in areas used for rotating irrigated cultures, in comparison with areas occupied by forests where a fast-growing tree system could act as buffer to retain the nitrate content (Chen et al., 2010). Another example is reported in Korea, where increasing nitrate concentrations were found to occur in cropping areas, cropping-livestock farming complex areas, and residential areas (Choi et al., 2007). The scenario of groundwater contamination changes as land use changes in space and time. An example supporting this statement comes from the Neal Smith National Wildlife Refuge, Iowa, USA, where the conversion of cropland to perennial land cover (prairie) resulted in a significant drop of nitrate and chloride concentrations in groundwater within a decade (Schilling and Jacobson, 2010). Another example comes from the region of Fife, Scotland, where the nitrate concentrations in public borehole water more than doubled in three decades, because the pumped sandstone aquifer is recharged by water draining from a land that is intensively

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cropped to green vegetables (Vinten and Dunn, 2001). Finally, in west Nottinghamshire, United Kingdom, predictive simulations of nitrate concentrations until the first quarter of the 21st century, using groundwater flow and mass transport modeling, indicate that a land use change from arable agriculture to woodland could help mitigate agricultural diffuse pollution within the Sherwood Sandstone aquifer (Zhang and Hiscock, 2010, 2011). These case studies, among many others, describe environmental implications of agricultural land use, namely the degradation of groundwater quality, and in some cases indicate specific land use changes as mitigation options. However, they do not fully explain the fundamental causes of groundwater contamination driven by agricultural activities, which in many cases are related to a conflict between the actual land use and the most adequate land use determined by a proper land capability evaluation. Attempts have been made to harmonize land use levels with natural terrain constraints, whereby intrinsic capability for general uses has been suggested (Agroconsultores and Coba, 1991; Collin, 1973, 1975; Collin and Melloul, 2001; Eldar, 1999; Lewy-Yanowitz, 1999; McHarg, 1969; among others). However, studies focused on the spatial quantification of conflict areas and their relevance for groundwater quality are lacking. The purpose of this paper is to delineate areas of land use conflict, using a geographic information system, and to compare spatial distributions of solutes in groundwater inside and outside these areas, to check whether or not contamination is specifically influenced by an improper use of the land. The studied region is the River Sordo basin, a rural area in northern Portugal essentially occupied by farmlands and forest spots, where specific and localized land use conflicts could be identified.

2. Study Area

The hydrographic basin of River Sordo is a rural watershed with an area of approximately 51.2 km^2 situated in the district of Vila Real, province of Trás-os-Montes and Alto Douro, north of Portugal, 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″. The main water course is 16.1 km long and drains to the right margin of the River Corgo. The relief is characterized by gentle slopes along the streams (<10%), especially in the wide open valley of Campeã, and steep slopes (>30%) in the adjacent hillsides and along the water divides of the NW, West and SW limits. A region of very steep hill slopes is also observed at the mouth of the river basin (Fig. 1). The drainage network is dendritic (tree like) and the basin has a radial shape where a number of sub-basins can be individualized. These sub-basins underwent variable geomorphic development, reaching an order 4 of Strahler (1957) in the western region where the basin widens. In the eastern region, where the basin shrinks, the sub-basins are mostly of order 1 (Fig. 2).

The basin of River Sordo is shaped on Hercynian granites and Cambrian (phyllites and greywackes) to Ordovician (mostly quartzites) metasediments of the Marão cordillera. In the central valley (Campeã), a swarm of aplitic dykes blocked the river flow promoting the accumulation of alluvial sediments on top of the metasediments (Fig. 3A). The mineralogical composition of the metasediments is characterized by an assemblage with quartz, albite, chlorite and muscovite. The granites are composed of quartz, K-feldspar, plagioclase (albite–oligoclase), biotite and muscovite (Pacheco and Alencoão, 2006). Altitudes in the basin vary between 185 and 1300 m above sea level. At these altitudes, the annual precipitation ranges from 1000 to 1750 mm·yr^{-1} and the mean annual temperature from 15.5 °C to 13 °C. Given the characteristic precipitation regime of SW European countries, with long dry periods followed by heavy rain bursts, erosion is intense. Pacheco and Van der Weijden (2014a) refers to an average soil loss of 4.59 t ha^{-1} yr^{-1} for continental Portugal. Resulting from an intensive hydric erosion, most soils in the River Sordo basin are skeletal, being mostly composed of leptosols with a thickness <25 cm. Exceptions are found in the central valley, where thick fluvissols were formed on top of alluvial sediments. Additionally, in the vineyards of the eastern limit, thick anthrosols were formed in association with the construction of terraces (Fig. 3B).

Land use in the River Sordo basin is related to altitude and relief. At the highest altitudes, average air temperatures are low and soils are very thin and poor. For this reason, land uses in these sectors are dominated by pine, eucalyptus or mixed forests and shrub land. In the central valley and along the margins of streams, where relief is gentle and soils are thick and fertile, land uses are characterized by annual

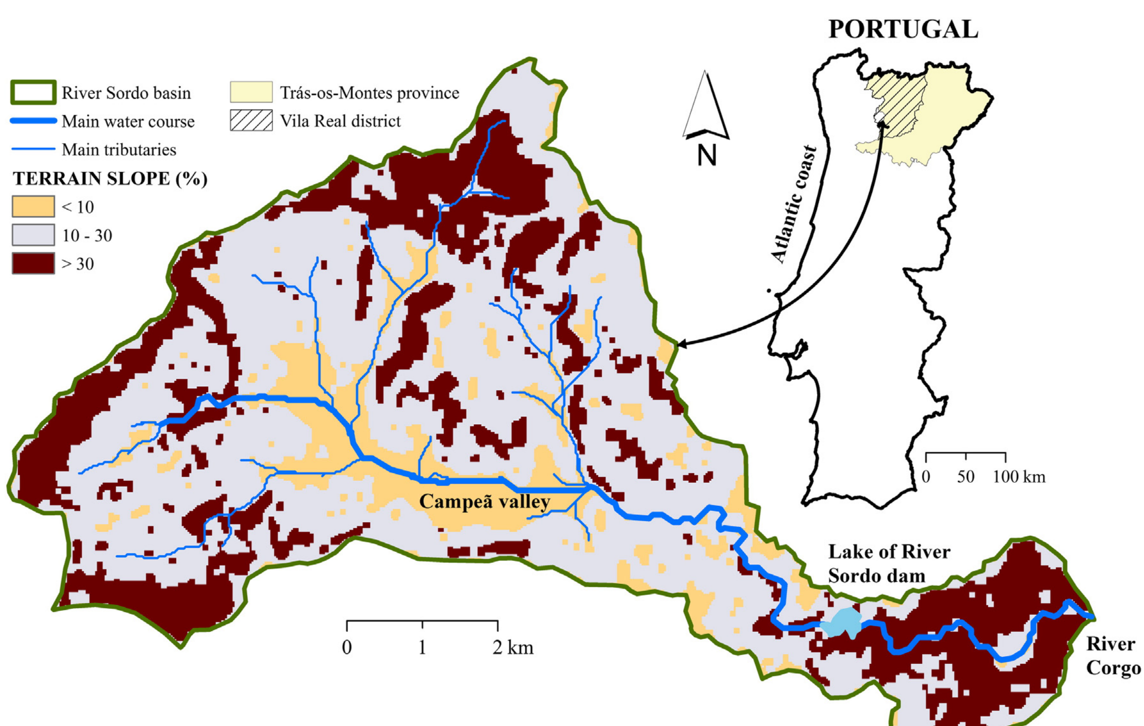

Fig. 1. Geographic location and slope map of the River Sordo hydrographic basin.