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Finding options to improve catchment water quality—Lessons learned from historical land use situations in a Mediterranean catchment in Slovenia

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ABSTRACT

The main objective of this study is to investigate the impact of the historical land use situations on the river water quality under present climate and land management conditions and what can be lessons learned from it. The historical land use situations are based on digitised historical maps of existing past land use cover distribution of small Slovenian catchment (River Reka) from 1787, 1827, 1940 and 1984. Maps were compared between each other and baseline land use situation in 2009. The well-known river basin model SWAT was used to simulate the influences of land use situations on water quality, especially in terms of suspended sediments concentration. Results indicate that the historical land use situations would decrease water quality. Lessons learned from the study are as follows: (1) based on the more than 200-year-wide research time window, we can state that vineyards and orchards are preferred agricultural land use with undesired side effect on water quality; (2) climate, terrain characteristics and wine demand on the market are the driving factors for the land use pattern – share of vineyards remains fairly constant through the years, regardless of changes in authorities; (3) historical land use patterns would, in present times, cause an increased occurrence of erosion and deterioration of environmental conditions for organisms in surface waters; and (4) the present land use pattern with regard to the observed sediment concentration is still not an optimal solution. Further land use adjustments or agri-environmental measures are required to achieve water quality improvements. Historical examples can serve as lessons learned for the future with the purpose of minimising the influences of planned land use changes on water resource quality and quantity.

1. Introduction

The distribution and intensity of cultivation of agricultural land has changed rapidly throughout history, viz. abandonment, reclamation and urban development (Howden et al., 2010). Land use conversion usually leads to changes in water cycle (blue and green water) and water quality (sediment, nutrients). Due to constant economic development and urbanisation, further reductions in the farmland area are expected causing intensification of remaining for agriculture adequate lands (Naylor and Falcon, 2010; Simelton, 2011; Francis et al., 2012). The most suitable areas for agricultural production usually coincide with areas of natural importance and drinking water resources, resulting in a permanent conflict of interest (Gordon et al., 2010; Zupanc et al., 2011). Another European trend present in the study area is intensification vs. extensification of agricultural land (Temme and Verburg, 2011; Bindi and Olesen, 2011; Otero et al., 2011; Navarro and Pereira, 2012). Agricultural land in less favourable areas is becoming extensified due to deficiencies in soil, climate, slope, geology and water resource properties and intensified in areas where certain agricultural practices have optimal natural conditions for growing and low production costs. Both processes are base for constant conflicts arising between land owners or farmers, land and water managers and policy makers (Mottet et al., 2006). Regarding to surface water quality are high priority topics in EU: soil loss due to erosion and leaching of nutrients from intensified agriculture lands.

A soil loss rate that exceeds more than 1 t ha^{-1} year is regarded as irreversible within a time span of 50–100 years (Verheijen et al., 2009). Erosion can cause a significant reduction of the soil fertility (depth, nutrients) and deposition of fine sediments in rivers (Ramos and Martinez-Casasnovas, 2006). It affects growth, reproduction and mortality rates of the zooplankton, benthic invertebrates and ultimately fish communities (Lohse et al., 2008; Kemp et al., 2011). Depending on the geology and soil type, a majority of the nitrogen (N) loss is associated with leaching to groundwater and, to a

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lesser extent, with surface runoff transport. Leaching of N occurs during wet periods of the year and in periods after crops are harvested. In that periods are fertilisers and mineralised crop biomass residues exposed to leaching as N is not actively absorbed by plants when precipitation exceeds evapotranspiration (Rusjan et al., 2008; Glavan and Pintar, 2010). Phosphorus (P) is a macronutrient required for the life of all living cells that plants absorb directly in the form of orthophosphate (PO_4^{3-}). Excessive use of P fertilisers may lead to P soil saturation, causing excess P transport with runoff bound to soil particles or through drainage (Bowatte et al., 2006). Most P in inland waters is contributed by point sources (wastewater treatment plants). Due to advances in wastewater P stripping, the emphasis is now put on diffuse P sources from agriculture. Mediterranean areas such as the River Reka catchments with a relatively high annual precipitation rate, high convective storm intensity, geology (flysch) and soil types susceptible to erosion are inclined to water quality problems related to erosion of soil particles (sediment transport) and adsorbed nutrients (Garcia-Ruiz et al., 2011; Maetens et al., 2012; Duran Zuazo et al., 2012).

The European Commission has funded the EUROHARP project with the purposes of ensuring adequate water quality tools and models for estimating nutrient losses from diffuse sources (Kronvang et al., 2009). Models can facilitate the enforcement of the Water Framework Directive (2000/60/EC), Nitrate Directive (91/676/EEC) and Fish Directive (2006/44/EC) (Volk et al., 2009; Moriasi et al., 2012). Catchment models like Soil and Water Assessment Tool (SWAT) can provide fast, effective and affordable insight into the effects of land use change and agricultural land management on the environment.

Historical maps are commonly the most important databases for various spatial analyses of historical land use and for defining future landscapes (Guan et al., 2011; Kaplan et al., 2012). By using historical land use situations, we would like to confirm or exclude past patterns as potential future land use situations or as reference land use situations for improving surface water quality conditions. In the previous water quality studies, land use changes were observed using a series of remotely sensed images such as aerial ortho-photographs and satellite images dating back to the 1950s (Miller et al., 2002; Sriwongsitanon and Taesombat, 2011; Fox et al., 2012). Unavailability or nonexistence of historic land use maps as well as efforts required for processing and digital transformation hinders the use of historic land use maps for investigating the impacts such land use patterns might have on water quality. Usually, most of the modelling studies address hypothetical future land use scenarios, oriented to crop rotations or best management practices (Fohrer et al., 2005; Lorz et al., 2007; Bormann et al., 2007; Volk et al., 2009; Glavan et al., 2011; Mango et al., 2011; Wolf et al., 2012; Warburton et al., 2012). This study on land use change impacts on riverine water quality is unique because it covers a period of over 200 years. Land use maps used in the study are snapshots of land use situation at certain time and not a continuous record.

The study is based on a previous SWAT case study carried out for blue water flow and green water flow and storage, where it was shown that using historical land use situation maps can lead to better understanding of water cycle components (Glavan et al., 2012a). The main objective of this study is to investigate the impact of the historical land use situations on the river water quality under present climate and land management conditions. Further, we investigate methodological efforts required to use historical land use maps as input for water quality modelling. Thus, we want to find out what lessons can be learned from such historical situations for land use patterns of today or the future as instruments of water quality improvement.

2. Materials and methods

2.1. Study area

The River Reka catchment (30 km^2) in the Goriška Brda region (72 km^2) is situated at the Slovenian-Italian border close to the Adriatic Sea (Fig. 1). The most visible topographical characteristics are the hill ridges with steep slopes (on average 16°), oriented from northeast to southwest to the Friulian lowlands. Southwestern exposure gives a warm and sunny sub-Mediterranean climate, favourable for agriculture. The average annual (1994–2008) observed precipitation is 1485 mm, average annual blue water flow (river flow) is 607 mm, average annual green water flow (evapotranspiration) is 772 mm and average annual green water storage (soil water) is 107 mm (Glavan et al., 2012a).

The upper parts of the valleys are steep, while the lower parts are wide and suitable for intensive agricultural practices other than vine-growing or fruit-growing. Land owners have consequently constructed terraces covering 29% of the total area for easier cultivation and erosion prevention. Almost 70% of these terraces are used for vineyards (Zorn and Komac, 2009). According to the land use database, economically unfavourable forest (56%) covers mostly steep and shadowy (S, NW, NE) areas and higher altitudes unsuitable for viticulture. The forests are used mainly as wood biomass and as end pillars in the vineyards. Vineyards cover more than 23% of the area, followed by permanent grassland (8%), urban (4%), extensive (3%) and intensive (2%) orchards. Share of vineyard land use has remained relatively constant for over 200 years. Due to technological advancements (tractors), the number of domestic animals decreased, resulting in overgrown grassland and planting of vineyards in the flatlands (lower cost of production).

Soils in the study area are generally classified as brown soil on Eocene flysch (Euthric Cambisol). Typical flysch geology of the study area consists of repeated sedimentary layers of sandstones, marl, slate and limestone, which can crumble quickly under the influence of precipitation and temperature change. Highly erodible bedrock material geology also accelerates surface runoff. Due to inappropriate agricultural practices and land management (terracing of slopes that are too steep, ungrassed vineyards), very strong erosion processes are observed and are expected to occur on a greater scale in the future as climate studies predict higher annual precipitation and more intensive storm events (Bergant and Kajfež-Bogataj, 2005; Ceglar et al., 2008). These erosion processes have already resulted in gully erosion and landslides on terraced vineyards (Hrvatin et al., 2006; Zorn and Komac, 2009). This erosion causes high sediment loads and concentrations above guidance levels (25 mg L^{-1}) in the surface waterways. The river network is extensive because of impermeable flysch bedrock (Fig. 1). Groundwater is practically nonexistent. Rivers have torrential and Mediterranean character with fast surface runoff, which quickly fills the river channel in case of large rainfalls with dry riverbeds in the dry summer season.

Because of the absence of regular state monitoring (Bende-Michl et al., 2011; Ullrich and Volk, 2010), water quality measurements in the Reka catchment were carried out for the period between 1.7.2008 and 30.6.2009 at the official state discharge measuring point of the Reka tributary Kožbanjšček at Neblo (Fig. 1). We carried out 365 daily measurements of suspended sediment (SS), total phosphorus (TP) and nitrate-nitrogen (NO_3-N) and 19 three-week measurements of orthophosphate (PO_4^{3-}). The average annual concentrations of SS, NO_3-N, TP and PO_4^{3-} in the research period were 32.6 mg L^{-1}, 0.61 mg L^{-1}, 0.12 mg L^{-1} and 0.01 mg L^{-1}, respectively. The highest SS concentration of 661 mg L^{-1} was measured in August 2007. The average annual sediment concentration is above guidance level and causes problems to the flora and fauna in the rivers. Nitrate-nitrogen and phosphorus concentrations are