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Environmental characteristics, agricultural land use, and vulnerability to degradation in Malopolska Province (Poland)

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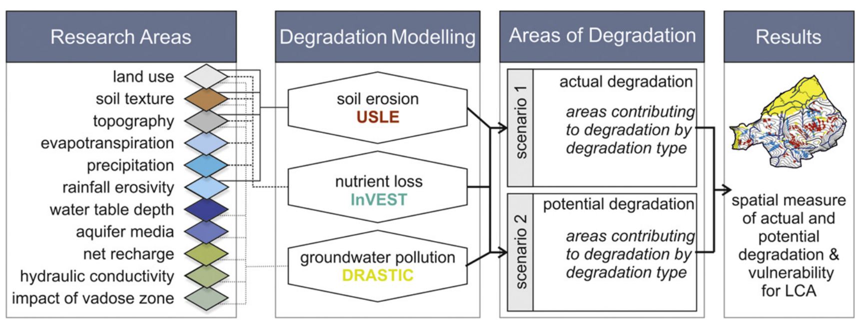
HIGHLIGHTS

- The impact of agriculture on environmental degradation varies in different areas.
- Soil erosion, nutrient loss and groundwater pollution are modeled in the study.
- All three types of degradation rarely occur simultaneously.
- Soil erosion is the most influential factor in decision-making on land management.

GRAPHICAL ABSTRACT



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ABSTRACT

Environmental degradation encompasses multiple processes that are rarely combined in analyses. This study refers to three types of environmental degradation resulting from agricultural activity: soil erosion, nutrient loss, and groundwater pollution. The research was conducted in seven distinct study areas in the Malopolska Province, Poland, each characterized by different environmental properties. Calculations were made on the basis of common models, i.e., USLE (soil erosion), InVEST (nutrient loss), and DRASTIC (groundwater pollution).

Two scenarios were calculated to identify the areas contributing to potential and actual degradation. For the potential degradation scenario all study areas were treated as arable land. To identify the areas actually contributing to all three types of degradation, the de facto land use pattern was used for a second scenario.

The results show that the areas most endangered by agricultural activity are located in the mountainous region, whereas most of the degraded zones were located in valley bottoms and areas with intensive agriculture. The different hazards rarely overlap spatially in the given study areas – meaning that different areas require different management approaches.

The distribution of arable land was negatively correlated with soil erosion hazard, whereas no linkage was found between nutrient loss or groundwater pollution hazards and the proportion of arable land. This indicates that the soil erosion hazard is the most influential factor in the distribution of arable land, whereas nutrient loss and groundwater pollution is widely ignored during land use decision-making. Slope largely and most frequently influences all hazard types, whereas land use also played an important role in the case of soil and nutrient losses. In this study we presented a consistent methodology to capture complex degradation processes and provide robust indicators which can be included in existing impact assessment approaches like Life Cycle Assessments and Grey Water Footprint analyses.

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1. Introduction

This study focuses on the impacts of agricultural land use on soils, ground, and surface waters. Agriculture impacts the natural environment in many different ways. However, the scope of this impact depends on natural conditions and the effects may vary in terms of hazard type and intensity (Stoate et al., 2001; Bärring et al., 2003; Gomes et al., 2003; Bai et al., 2008; Borrelli et al., 2014). Thus, natural conditions such as topography, soils, climate, and geology significantly shape the vulnerability of agricultural landscapes towards different types of environmental degradation like soil erosion and water pollution. Modern agriculture severely affects the environment due to the use of fertilizers, pesticides and irrigation in the pursuit of maximum yields (Stoate et al., 2001; Van der Werf and Petit, 2002; Louwagie et al., 2011). The main consequences of these activities include soil erosion (Holmes et al., 2012; Borrelli et al., 2014; Šarapatka and Bednář, 2015), nutrient loss (Arheimer and Lidén, 2000; Bechmann and Våje, 2002), water pollution (Van der Werf and Petit, 2002), and biodiversity loss (Stoate et al., 2001; Pacini et al., 2003). They also result in eutrophication and in the extinction of flora and fauna (Arheimer and Lidén, 2000; Stoate et al., 2009). Furthermore, habitat fragmentation is another negative effect of agricultural land use (e.g., Stoate et al., 2001; Stoate et al., 2009; Waswa et al., 2013). All of these processes lead to environmental degradation. The vulnerability to degradation, i.e., the degree to which a specific system is likely to experience harm (Adger, 2006; Slootweg and Jones, 2011) due to agricultural activity, depends on the environmental characteristics of an area, as the effects on the environment may vary despite similarities in land use (Van der Werf and Petit, 2002; Darradi et al., 2012).

The assessment of environmental degradation provides the information necessary for sustainable land management. This is particularly the case in agrarian landscapes that combine production and ecological functions. However, many studies focus on a single type of degradation, e.g., groundwater pollution (Secunda et al., 1998; Saha and Alam, 2014), nutrient loss (Bechmann and Våje, 2002), or soil erosion (Dunjó et al., 2004; Nunes et al., 2011).

In contrast, multi-criteria analyses concerning different types of environmental degradation resulting from agricultural use are still uncommon, despite their importance for sustainable land management. There are some examples of multi-criteria analyses that have been proposed for the assessment of different environmental functions for spatial planning purposes (e.g., Graubaum and Meyer, 1998; Marks et al., 1989; Otahel and Polacik, 1987). In Poland, such analyses have been conducted by Kistowski (1996), Pietrzak (1998), Przewoźniak (1991), and Tracz (2004). However, multi-criteria analyses strictly focused on an agricultural impact assessment on the local-regional level are missing.

Recently, in additions to degradation analyses in landscape ecology and sustainable development, Life Cycle Assessment and indicators such as the Carbon Footprint, the Water Footprint, and the Ecological Footprint have become widely used to quantify environmental impacts (e.g., Lovarelli et al., 2016; Pellicer-Martínez and Martínez-Paz, 2016; Jefferies et al., 2012). Though initially developed for industrial production, these assessment frameworks are increasingly used to calculate the impact of agricultural production (Caffrey and Veal, 2013; Milà i Canals et al., 2007; Mattsson et al., 2000).

Still, there are some substantial limitations to overcome. Caffrey and Veal (2013) concluded that there is a lack of consistent Life Cycle Impact Assessment methodology to measure impacts that are of major concern to agriculture, that are, for example linked to land use and soil erosion. Also Lovarelli et al. (2016) point out the necessity to include important agronomic features such as soil texture and nutrient content into Water Footprint Analyses.

With reference to the processes of soil erosion, nutrient loss and groundwater pollution, Grey Water Footprint analyses are of special concern. This indicator refers to water pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing water quality standards (Jefferies et al., 2012). Furthermore, Lovarelli et al. (2016) state an increasing deficit in Grey Water Footprint assessments and a possible underestimation of the problem by assessments that do not include impacts on water quality.

Our study provides an approach that can feed quantitative and qualitative information about the impact of land use pattern on soil and water bodies into the different impact assessment frameworks. The study might especially contribute to the assessment of Grey Water Footprints by providing spatially specified results about ground water pollution by pesticides as well as potential eutrophication of surface water bodies caused by soil erosion and accumulation processes. At the same time the approach of this study is able to produce site specific results while using important agronomic soil and landscape features.

Therefore, the aim of this research is to analyze potential and actual environmental degradation resulting from agricultural activity in Malopolska and to determine the influencing factors. The analyzed types of degradation included three of the most common regional degradation processes, i.e., soil erosion, nutrient loss and groundwater pollution. Specifically, the following questions were considered:

(1) What is the spatial distribution of potential and actual environmental degradation and where are the most affected areas?
(2) What is the relationship between environmental degradation, land use and the specific characteristics of each geographical area studied?
(3) How can the results be applied to assess agriculture sustainability in the context of vulnerability to degradation?

2. Materials and methods

2.1. Study area

Malopolska is a province in the southern part of Poland. It is characterized by a relatively high percentage of arable land, but a low intensity of agriculture. In 2012, 38% of the province was identified as agricultural land (Dmochowska, 2014). The average farm size in Malopolska is 3.9 ha, compared to an average of 10.5 ha on a national level (Agency for Restructuring and Modernization of Agriculture, 2015). Mineral fertilizer inputs are comparatively low. In 2010, the average amount of mineral nitrogen fertilizers used in Malopolska was 47 kg ha^{-1} yr^{-1} per utilized agricultural area. On a national level the average was 81 kg ha^{-1} yr^{-1} (Central Statistical Office of Poland, 2010). Although, the use of plant protection products in Malopolska is also relatively low, there is a strong increasing trend (Jankowiak et al., 2012). The average amount of active ingredients for potato crop protection in Malopolska in 2003 was 1–3 kg per ha of utilized agricultural area per year, whereas in Poland it was 4–7 kg (Jankowiak et al., 2012). On a national level herbicides, hormones and insecticides has drastically increased over the last decade (Jarecki and Bobrecka-Jamro, 2013). In addition, levels of fungicides, seed treatments, and plant growth regulators use have also increased.

Malopolska is one of the Polish provinces most endangered by soil erosion from water (Wawer, 2007). Around 27% of its total area is categorized as having a medium to high soil erosion rate, and over 11% has a high soil erosion rate (Wawer and Nowocień, 2007; Wawer and Nowocień, 2008). The main causes are: unfavorable topographic conditions (Wawer and Nowocień, 2007; Wawer and Nowocień, 2008) and high rainfall erosivity (Licznar, 2006). Another threat to the environment in this region is nutrient loss (Kopiński and Tujaka, 2009), which is caused by similar factors. As a consequence of soil erosion and nutrient loss, but also due to the utilization of pesticides, water pollution is a significant threat in Malopolska.

The province is heterogeneous in terms of natural conditions as well as the type and intensity of land use. As a consequence of geological diversity and climatic variability, eleven physicogeographical