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Modelled impacts of policies and climate change on land use and water quality in Austria

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ABSTRACT

Climate change is a major driver of land use with implications for the quality and quantity of water resources. We apply a novel integrated impact modelling framework (IIMF) to analyze climate change impacts until 2040 and stakeholder driven scenarios on water protection policies for sustainable management of land and water resources in Austria. The IIMF mainly consists of the sequentially linked bio-physical process model EPIC, the regional land use optimization model PASMA[grid], the quantitative precipitation/runoff TUWmodel, and the nutrient emission model MONERIS. Three climate scenarios with identical temperature trends but diverging precipitation patterns shall represent uncertainty ranges from climate change, i.e. a dry and wet situation. Water protection policies are clustered to two policy portfolios WAP_I and WAP_II, which are targeted to regions (WAP_I) or applied at the national scale (WAP_II). Policies cover agri-environmental programs and legal standards and tackle management measures such as restrictions in fertilizer, soil and crop rotation management as well as establishment of buffer strips. Results show that average national agricultural gross margin varies by ± 2%, but regional impacts are more pronounced particularly under a climate scenario with decreasing precipitation sums. WAP_I can alleviate pressures compared to the business as usual scenario but does not lead to the achievement of environmental quality standards for P in all rivers. WAP_II further reduces total nutrient emissions but at higher total private land use costs. At the national average, total private land use costs for reducing nutrient emission loads in surface waters are 60–200 €/kg total N and 120–250 €/kg total P with precipitation and the degree of regional targeting as drivers. To conclude, the IIMF is able to capture the interfaces between climate change, land use, and water quality in a policy context. Despite efforts to improve model linkages and the robustness of model output, uncertainty propagations in integrated modelling frameworks need to be tackled in subsequent studies.

1. Introduction

1.1. Land use, water quality problems and policies

In Europe, agricultural nutrient management has a considerable influence on the quality of surface and coastal water bodies. Despite some reductions in nutrient loads, agriculture is the largest contributor to nitrogen (N) pollution in more than 40% of Europe's water bodies (EEA, 2012). In Austria, concerns regarding nutrient pollution of water bodies are threefold: First, nitrate leaching from agricultural land deteriorates groundwater quality. Second, about 15% of local surface water bodies are endangered of not achieving the good water quality status due to nutrient pollution today. They are mainly located in intensively used agricultural areas with phosphate-phosphorus exceeding Water Framework Directive (WFD) environmental water quality standards (EQS) (BMLFUW, 2015). Finally, 96% of the Austrian territory is located in the Danube Basin discharging towards the western shelf of the Black Sea, which is highly vulnerable to eutrophication with phosphorus (P; Danube plume) and N (towards central Black Sea) as limiting factors of algae growth (Kroiss et al., 2006). Thereby, agriculture is the main source for N pollution in the Danube Basin. In addition to N leaching from fertilization, ammonia volatilization from animal husbandry and its deposition plays a decisive role as well (Behrendt et al., 2005). In respect to P, wastewater management is the

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main source of water pollution in the Danube Basin, with agriculture being second. Water protection strategies for the near future are supposed to significantly reduce P pollution by enhanced wastewater treatment. However, agricultural sources are expected to be a longer lasting problem (ICPDR, 2015).

Insufficient environmental quality and high stakes for the society result in water protection policies at different governance levels. At global level, water protection is part of at least three Global Development Goals (SDGs), i.e. SDG 6 Clean Water and Sanitation, SDG 14 Life Below Water, and SDG 15 Life on Land. At the EU level, the WFD (2000/60/EC) including its influential Nitrates Directive (91/676/EEC) and Urban Waste Water Directive (UWWD, 91/271/EEC) results in national or regional policies that govern domestic, industrial, and agricultural processes to protect national and European water bodies. At the Danube Basin level, EU member states declared the basin as “sensitive area” according to the UWWD in respect to nutrient pollution. Regarding reduced N losses from agriculture at the national level, Austria implemented the Nitrates Directive with its “Aktionsprogramm Nitrat” (BMLFUW, 2012). Measures include restrictions of N-fertilizer applications in respect to timing, vulnerable locations, and amounts as well as specific requirements for manure storage and application. The main aim is to reduce nitrate pollution of groundwater. P releases from agricultural sources to surface waters are not in the focus of water protection policies in Austria so far.

1.2. Climate change and water systems

It is obvious that many countries in Europe have not achieved an area-wide socially accepted water quality status yet despite comprehensive policies and regional successes. Policies have been adapted to current socio-economic and bio-physical conditions but may become insufficient or inappropriate in the future. Growth in global population and per capita income, as well as climate change lead to direct and indirect impacts inducing land use changes (e.g. Wiebe et al., 2015). For example, climate change can increase or decrease the suitability for certain crops or land use types (e.g. Schönhart et al., 2016) or the marginal benefit of agro-chemicals. Results by Blanke et al. (2017) and Olesen et al. (2007) show large heterogeneity in N leaching changes among European regions from future wheat and maize production. Directions of change are uncertain in many regions including Austria among others due to climate model uncertainty. Rising temperatures increase biomass growth in water bodies (Zoboli et al., 2018) and changing precipitation patterns can alter nutrient emissions, soil erosion, dilution ratio, and flow regimes.

1.3. Integrated water system modelling

As pointed out in Zessner et al. (2017), the relationship between socio-economic conditions, climate change, agricultural production, water resources and diffuse water pollution are highly complex and require an integrated approach to assess the overall, sectoral and dissipated impacts (Dunn et al., 2012). Future policies to protect water bodies have to be adapted to direct and indirect climate change impacts. It requires scientific evidence on the combined and mutual effects of land use choices, water protection policies, and global change. Current research is biased towards water quantity, while water quality has been insufficiently studied so far (Cai et al., 2015).

In recent years, integrated models have been developed to tackle these complexities. However, only few cover the nexus of climate change and policy impacts, land use adaptation, and its consequences on surface water quality in a consistent way. Some studies apply exogenously given land use scenarios in integrated models to assess their environmental impacts and costs but do not consider climate change impacts (e.g. Dymond et al., 2010; Bohnet et al., 2011; Polasky et al., 2011; Kling et al., 2014). Others capture land use change − though not climate change − endogenously to either search for cost-efficient spatial allocations of management options to improve water quality (Xu et al., 2018) or to simulate land use decision processes in bottom-up land use models (Lehtonen et al., 2007). Honti et al. (2017) define management scenarios to take climate change adaptation into account and model the role of climate scenario uncertainty on runoff. Molina-Navarro et al. (2018) downscaled European level storylines to a Danish catchment level and analyzed land use and climate change impacts on water quality. Both examples, as well as those of Lautenbach et al. (2009), Mehdi et al. (2015a,b), consider changes in flow conditions endogenously but assume land use adaptation to climate change exogenously. Kraucunas et al. (2015) link climate change scenarios to bio-physical and partial-equilibrium models to analyze climate change impacts and adaptation. Regional land use maps are derived via top-down spatial disaggregation but water quality impacts are not considered. To conclude, most climate change studies on water quality either keep land use invariable over time (e.g. Sinha et al., 2017) or design land use scenarios − eventually stakeholder driven − prior to modelling (e.g. El-Khoury et al., 2015; Mehdi et al., 2015a). However, ignoring climate change adaptation of agricultural land use can create inconsistencies and may lead to wrong policy conclusions.

Rare examples of combining climate change, agricultural adaptation and its corresponding impacts on water quality − for nitrate and phosphate emissions or algal production − in a consistent quantitative manner is presented in Fezzi et al. (2015) and Bateman et al. (2016). They linked spatially explicit econometric land use models with statistical surface water quality models. Barthel et al. (2012) integrated climate change and socio-economic drivers into land use modelling and related N pollution of groundwater but did not consider P or surface water quality.

Stakeholder participation − achieved in some of the cited studies above − can be crucial for the quality and social acceptance of research outcomes in management and policy processes. Volk et al. (2010) highlight the lack of stakeholder integration in decision support systems for river basin management and Martin-Ortega et al. (2015) call for transdisciplinary studies to increase the robustness of solutions to wicked environmental problems such as water pollution. Iglesias et al. (2007) emphasize the importance of knowledge transfer to stakeholders in climate change research. They highlight among others the challenge of uncertainty management und the crucial role of science communication. These are strong arguments in favor of transdisciplinary research.

1.4. Added value and article concept

In this article, we tackle the identified methodological concerns and knowledge gaps, i.e. coarse spatial resolution and inconsistent representation of land use in water quality modelling under climate change, lacking knowledge on effective policies to govern climate change impacts and autonomous adaptation, and missing stakeholder engagement. Our major applied research objective is to assess the land use, farm economic, and environmental effects of stakeholder driven water protection policies to maintain water quality in Austrian rivers under climate change. From a methodological perspective, we test the applicability of a novel quantitative spatially explicit integrated impact modelling framework (IIMF) in a scenario context. The IIMF has been presented for the first time and applied on a reference scenario in Zessner et al. (2017). It combines among others a bio-physical process model to simulate crop yields, an economic land use optimization model to derive efficient land use choices, a precipitation/runoff model to compute flows, and a nutrient emission model to quantify environmental impacts. The IIMF provides consistent nutrient emission outcomes from socio-economic, climate change, and water protection policy scenarios. Climate change could improve or deteriorate the current status of Austrian water resources. The policies designed for water protection will be scrutinized for their effects on water quality, agricultural producer surplus, and private land use costs under

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