Agriculture and nitrate contamination in Austrian groundwater aquifers: An empirical analysis

Landwirtschaft und der Nitratgehalt in österreichischen Grundwässern: Eine empirische Analyse

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Zusammenfassung

Obwohl der durchschnittliche Nitratgehalt im österreichischen Grundwasser in den letzten zwei Jahrzehnten gesunken ist, existiert eine beträchtliche Variation des Nitratgehalts über Bundesländer, Gemeinden und über die Zeit, die bisher noch nicht ausreichend erklärt werden konnte. In folgender Analyse erörtern wir anhand unterschiedlicher Regressionsmodelle den funktionalen Zusammenhang zwischen standortspezifischen Faktoren wie Niederschlag und Bodenqualität, landwirtschaftlichen Produktionsaktivitäten wie Getreidebau und Viehhaltung sowie der durchschnittlichen Nitratkonzentration im Grundwasser pro Gemeinde. Die Ergebnisse zeigen, dass Niederschlag einen nicht-monotonen Zusammenhang mit dem Nitratgehalt im Grundwasser aufweist. Die Bodenqualität, gemessen an der Bodenklimazahl, als auch der Anteil von Ackerland am gesamten Gemeindegebiet und eine hohe Konzentration von Viehhaltung weisen ebenfalls einen positiven Zusammenhang mit der Nitratkonzentration auf. Grünland hingegen weist einen negativen Zusammenhang auf.

Schlagwörter: Nitratkonzentration, Grundwasser, Landwirtschaft, Regressionsanalyse

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Summary

Even though nitrate concentration in Austrian groundwater has been decreasing over the last two decades, a satisfactory explanation for the variation over municipalities as well as time is still missing. In the course of this study we investigate site characteristics and agricultural production factors influencing nitrate content in groundwater by means of regression analysis. Accounting for a time dimension, our explanatory variables include precipitation, soil characteristics as well as land cover and crop cultivation choices. Results show that precipitation exerts a non-monotonous effect on nitrate concentration. In addition, higher soil quality, among others indicated by the *Bodenklimazahl*, is positively related to the dependent variable of interest. Finally, cropland cultivation as well as a high concentration of livestock impact positively on nitrate concentration in ground waters, whereas grassland has a negative effect.

Keywords: nitrate concentration, groundwater, agriculture, regression analysis.

1. Introduction

Nitrogen is one of the major nutrients applied in agriculture to increase crop production. However, excess supply of nitrate might lead to environmental damage, causing contamination of the air, soil as well as water. Since nitrogen is highly soluble, excess easily leaches into groundwater aquifers, where it might contaminate drinking water, or cause eutrophication of aquatic ecosystems. The EU directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources sets a nitrate concentration threshold of 50 mg/l in groundwater, which is still not met in many European regions (EEA, 2009).

This critical threshold is also exceeded in some Austrian municipalities. Nevertheless, the average nitrate concentration in the entire country has decreased over the past 18 years from 26 mg/l in 1992 to 21 mg/l in 2008. However, monitoring of groundwater aquifers shows a high variation of nitrate levels over time, as well as over municipalities (UMWELTBUNDESAMT, 2009; cp. Figure 1).

Nitrate concentration is traditionally low in Salzburg, Tirol and Vorarlberg, whereas in the regions of Wien, Niederösterreich and

Burgenland the concentration is high. A general downward sloping trend is observed in all nine provinces of the country though.

Since bio-physical and chemical aspects which influence the nitrate conversion are very complex, research into the proximate causes for this variation is still scarce. The tool of regression analysis is capable to estimate functional relationships between likely causes and effects.

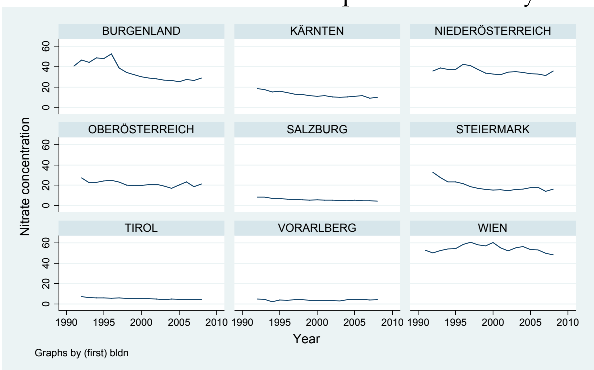

Figure 1: Average nitrate concentration in the nine Austrian provinces between 1991 and 2008, in mg/l

Source: UMWELTBUNDESAMT, 2009

Having access to detailed data from various sources, we attempt to identify factors influencing nitrate concentration in groundwater aquifers. In particular we investigate the following research question:

What is the role of precipitation, different land covers, soil characteristics, land uses and livestock in explaining the concentration of nitrate in groundwater?

There is some research investigating similar issues. SCHWEIGERT (2004), for instance, focuses on the role of precipitation and temperature to explain nitrate concentration in the soil. HOFREITHER and PARDELLER (1996) investigate the impact of agricultural activities on the nitrate content in groundwater. Finally, SINABELL (2009) deals with the effects of agricultural policy support on nitrate contamination in groundwater aquifers.

2. Data

To shed light on the research question at hand we use the following variables in our models: The dependent variable is concentration of nitrate in groundwater in mg/l (*Nitrate*), provided by

UMWELTBUNDESAMT (2009). This data is available on a quarterly basis from 04/1991 to 04/2008 on municipality level in Austria. The cross section dimension consists of 1238 municipalities. We are presented with an unbalanced panel data set, i.e. nitrate concentration is not available for every time period in each of the municipalities. We further include data on precipitation (*Precip*) in mm taken from selected weather stations provided by ZAMG on a daily basis (cp. STRAUSS et al., 2009), which are assigned to the respective municipalities. The daily measurements are aggregated to average daily precipitation in the respective quarter. As depicted in Figure 2, average daily precipitation in the country as a whole shows an upward trend, - an observation, which is of importance in the following analysis.

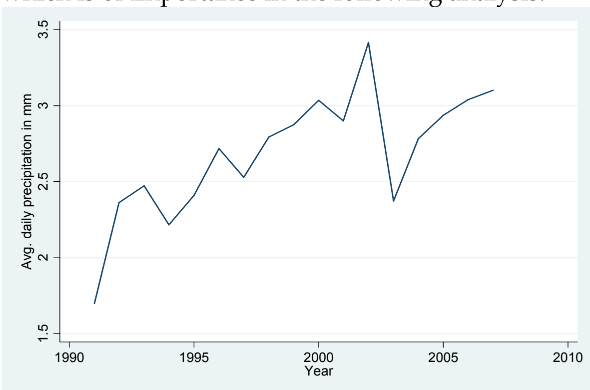

Figure 2: Average daily precipitation in mm.
Source: STRAUSS et al., 2009

Data on the land categories in Austria are taken from the CORINE Land Cover database 2006. Land cover categories, such as buildings, cropland, meadows, heterogeneous agricultural land, forests, wetland and water have been computed as proportion of total size of the municipality. We only include the land cover categorization of the year 2006 into our analysis and therefore treat these categories as time constant. Currently, we integrate two measures of soil quality in our analysis. We focus on the *Bodenklimazahl (BKLZ),* a soil/site quality index used by the financial administration (BODENSCHÄTZUNGSGESETZ, 1970) as well as on information on the field water capacity (*FWC*), which is taken from the European digital soil map (BALKOVIC et al., 2007). The data on soil quality is available for all municipalities and assumed to be time constant. Agricultural information on cultivated crops and livestock is provided by the IACS database. We have data available for the years 1999 and 2002 to 2006. The data are available on farm level on an annual basis. For our analysis these values are aggregated on municipality level (Vienna is not included until now). The cultivated crops have been aggregated into four crop groups: (i) oil seed and protein crops, (ii) cereal and maize crops, (iii) row crops and vegetables, and (iv) arable grassland, and are included into our regression models as proportion of total municipality territory. Information on livestock is also provided by the IACS database on farm level. We have aggregated the livestock information to municipality level and calculated animal units (*Großvieheinheiten, GV)* per municipality. To make data on crop cultivation and livestock comparable to our dependent variable measurements they have been aggregated on a quarterly basis.

3. Empirical analysis and results

As described we are presented with a panel data set. Since most of the explanatory variables, such as land cover, land use (crop cultivation and livestock) and soil quality are either time-constant or exhibit very little variation over time, we focus on pooled Ordinary Least Squares (OLS) regressions (as opposed to a fixed effects panel analysis) to explain the variation of nitrate concentration.

To allow for non-linear and in particular non-monotonous or exponential effects of the explanatory variable, we often include squared terms into our regression equation (GREENE, 2008).

3.1 Site specific characteristics

As a first step we investigate the relationship between various site specific characteristics, such as land cover, precipitation, and soil quality, and nitrate concentration in groundwater ($Nitrate_{it}$) (cp. equation 1). The time dimension (t) in this setting is given by quarters, whereas the cross-sectional dimension (i) represents municipalities.

The explanatory variables include precipitation of the previous quarter ($Precip_{it-1}$), assuming that the effect of precipitation on nitrate leaching in groundwater is not immediate but takes time[1]; the proportion of land cover given as % of total municipality ($Prop\_j_i$), whereby j

[1] However, the duration of precipitation to leach into the groundwater may vary according to the geological conditions.

describes land cover types: buildings, cropland, meadow and forest; soil qualities are described by the field water capacity (FWC_i) and the Bodenklimazahl ($BKLZ_i$); as well as year dummies ($Year\_k_t$), where k denotes the respective years 1992 to 2008.

$$Nitrate_{it} = \beta_0 + \beta_1 \Pr ecip_{it-1} + \beta_2 \Pr ecip^2_{it-1} + \sum_j \beta_{3j} \Pr op\_j_i + \sum_j \beta_{4j} \Pr op\_j_i^2 + \beta_5 FWC_i + \beta_6 BKLZ_i + \sum_k \beta_{7k} Year\_k_t + \varepsilon_{it} \quad (1)$$
$$where\ j \in \{buildings, cropland, meadow, forest\} \quad and\ k \in \{1992,...,2008\}$$

Precipitation is conjectured to play an important role in explaining the variation in nitrate contents. High levels of precipitation can either accelerate the leaching of nitrate excesses into groundwater, or support the dilution of nitrates (PARDELLER, 1996) such that the coefficient of precipitation could have a negative or a positive sign, that is β_1 >< *0*, β_2 >< *0.*

We expect a clear positive effect of the proportion of cropland cover on nitrate, β_{3crop} >0, since higher fertilizer rates may lead to excesses, which leach into the groundwater. Conversely, we expect meadow land cover and forest land cover to have a negative impact on nitrate concentration, $\beta_{3meadow} < 0$, $\beta_{3forest} < 0$. Concerning the proportion of buildings in a municipality we expect a non-monotonous effect, that is at least after a certain threshold the relation to nitrate concentration in the groundwater should turn positive, $\beta_{4buildings}$ >0.

With respect to soil characteristics we expect the field water capacity to be negative, because a higher field water capacity implies less leaching, $\beta_5 > 0$. Contrarily, the expectations about the coefficient of the *Bodenklimazahl* is a priori ambivalent, β_6 >< 0. High soil quality reflected in a high *Bodenklimazahl* could lead to more intensive cultivation and could therefore be positively correlated to nitrate concentration. On the other hand, high soil quality could counteract leaching and could therefore have a negative effect on the nitrate concentration (PARDELLER, 1996). The results of regression 1 are depicted in Table 1.

The results show that precipitation has a statistically significant non-monotonous effect on nitrate concentration. Initially, precipitation has a negative effect, but after a specific threshold, the amount of precipitation has a positive effect on nitrate concentration. This is in particular interesting, as this effect can capture the changing volume of precipitation over quarters, but equally the increase of the average amount of precipitation over the last 30 years. A non-monotonous effect is also confirmed for the proportion of buildings as well as

meadows. For which initially a negative effect on nitrate concentration is found, which seems to weaken with increased coverage.
Cropland has a positive effect on nitrate concentration, as expected. Since the squared term on cropland is positive as well, we expect the marginal positive impact of cropland to be increasing. Finally, high forest coverage has a negative effect on nitrate concentration. The effect of the field water capacity on the nitrate content is, as expected, negative, whereas the *Bodenklimazahl* has a positive effect which would confirm the hypothesis that better soil quality fosters more intensive agriculture.

Table 1: Coefficients explaining nitrate concentration in groundwater

	Nitrate concentration		**Nitrate concentration**
Precipitation	-0.502***	Cropland	14.85***
Precipitation^2	0.0471***	Cropland^2	32.89***
Meadow	-22.75***	Forest	42.10***
Meadow^2	23.48***	Forest^2	-46.38***
Buildings	-31.08***	FWC	-78.76***
Buildings^2	56.15***	BKLZ	0.0293***
		Constant	26.21***
Observations 49407		*** p<0.01, ** p<0.05, * p<0.1	
Adjusted R-squared 0.273		Control for Year dummies	

3.2 Land use - crop cultivation and livestock

Observing that cropland does have a positive effect on nitrate concentration we investigate the degree to which particular crops are related to nitrate concentration in the groundwater. This analysis includes IACS data and therefore only covers the years 1999 and 2002 to 2006. Previous results have shown that increasing volume of precipitation has a positive effect on nitrate concentration. As demonstrated in Figure 2, the period 1999 and 2002-2006 exhibits a higher average precipitation so that we omit the squared term for precipitation.
Before estimating the effects of particular crops and livestock, we validate the effects of cropland and meadows for the IACS data. Then we separately investigate the effects of on the one hand crop cultivation (regression 2, Table 2), and on the other livestock on nitrate concentration (regression 3, Table 2).
Regression 2 estimates a model of the form

$$Nitrate_{it} = \beta_0 + \beta_1 \Pr ecip_{it-1} + \sum_j \beta_{2j} \Pr op\_j_{ik} + \beta_3 \Pr op\_meadow_{ik} + \beta_4 \Pr op\_meadow_{ik}{}^2 + \beta_5 FWC_i + \beta_6 BKLZ_i + \sum_k \beta_{7k} Year\_k_t + \varepsilon_{it} \quad (2)$$

$$where\ j \in \{oil\,seed\ \&\ protein, arable\ grass, cereal\ \&\ maize, rowcrops\ \&\ vegetable\}$$
$$and\ k \in \{1999, 2002, ..., 2006\}$$

Again we focus on the precipitation of the previous quarter and expect the coefficient of precipitation to be positive, $\beta_1 > 0$. The coefficients of the various crops are expected to be positive, $\beta_2 > 0$. Our expectation for the coefficients of soil quality remains the same as in regression 1.

Regression 3 includes controls for the effect of livestock on the nitrate concentration.

$$Nitrate_{it} = \beta_0 + \beta_1 \Pr ecip_{it-1} + \beta_2 GV_{ik} + \beta_3 GV_{ik}{}^2 + \sum_j \beta_4 \Pr op\_j_{ik} + \sum_j \beta_5 \Pr op\_j_{ik}{}^2 + \beta_6 FWC_i + \beta_7 BKLZ_i + \sum_k \beta_{10k} Year\_k_t + \varepsilon_{it} \quad (3)$$

$$where\ j \in \{cropland, meadow\} \quad and\ k \in \{1999, 2002, ..., 2006\}$$

Table 2: Regression 2 and regression 3 based control effect of IACS data – crop cultivation and livestock on nitrate concentration in the groundwater

Regression 2	**Nitrate concentration**	**Regression 3**	**Nitrate concentration**
Precipitation	0.133*	Precipitation	0.219***
Oil seed & protein	65.94***	Meadow	-45.06***
Row crops & vegetable	43.75***	Meadow²	59.15***
Arable grassland	36.59***	Cropland	53.22***
Cereal & maize	26.32***	Cropland²	-19.30***
Meadow	-47.40***	GV	-4.762***
Meadow²	55.57***	GV²	1.743**
BKLZ	0.0349***	BKLZ	0.0312***
FWC	-56.18***	FWC	-52.74***
Constant	21.06***	Constant	20.10***
Observations	18936	Observations	18782
Adjusted R-squared	0.306	Adjusted R-squared	0.310
*** p<0.01, ** p<0.05, * p<0.1		Control for Year dummies	

With respect to livestock, which is measured in animal units *(GV)* we expect it to have a positive impact on nitrate concentration due to organic fertilizer production. This effect should in particular become apparent when there is a certain amount of livestock present, such that

we expect $\beta_3 > 0$. The other variables are the same controls we discussed before and the expectation of the sign remains unchanged.
In regression 2, we find that all crops exert a statistically significant positive effect on nitrate contamination in the groundwater. The strongest adverse effect comes from oil seed and protein crops, followed by row crops and vegetables. The weakest positive effect among the crops stems from cereals and maize.
In regression 3, livestock exhibits a negative correlation with nitrate concentration. The squared term, however, proves our hypothesis that a high concentration of livestock units impacts positively on nitrate concentration.

4. Conclusion and outlook

Crop cultivation, in particular oil seed and proteins, row crops and vegetables, and a high number of livestock units exert a positive effect on nitrate concentrations in Austria, whereas meadows, forests and small number of buildings tend to affect them negatively. Precipitation exhibits a non-monotonous effect which can be explained by the existence of two counteracting (namely dilution and leaching) processes. High quality soil has a positive effect on nitrate concentration, suggesting that more intensive cultivation outweighs the effect of less leaching in such soils. For future research we plan to expand the described analysis in several ways. For one we will integrate measures for fertilization, nitrate withdrawal, nitrate fixation and atmospheric deposition (all of which are components of the gross nitrogen balance) in the empirical models. We also plan to investigate the effect of different cultivation techniques (biological vs. conventional cultivation) as well as irrigation. Finally, we will concentrate on the effect of differing soil characteristics and analyze spatial patterns using spatial econometrics/cluster analysis techniques.

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