Evaluating the OECD Gross Nitrogen Balance in Predicting Nitrate Contamination in Austrian Groundwater

Evaluierung der OECD Stickstoffbilanzierung hinsichtlich ihrer Vorhersagekraft der Nitratbelastung Österreichischer Grundwässer

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Summary

Nitrogen is an important input to agricultural production but also detrimentally affects the environment. Using data on more than 1000 Austrian municipalities, we provide a statistical analysis of (1) the determinants of nitrate concentration in groundwater, and (2) the predictive abilities of the OECD Nitrogen Balance as agri-environmental indicator. We find that the proportion of cropland exerts a positive effect on the nitrate content in groundwater. Also environmental factors are found to be important. Higher average temperature and precipitation lead to lower nitrate pollution of groundwater. We also show that the OECD Nitrogen Balance proves to be a good predictor for nitrate pollution, but its predictive power can be improved if average precipitation of a region is accounted for.

Keywords: Nitrate concentration, groundwater, OECD Nitrogen Balance, agriculture, regression analysis

Zusammenfassung

Stickstoff ist ein wichtiger Input in der landwirtschaftlichen Produktion, kann jedoch zu negativen Auswirkungen auf die Umwelt führen. Wir verwenden Daten von über 1000 Österreichischen Gemeinden und bestimmen anhand statistischer Analysen (1) die

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Faktoren, welche die Nitratkonzentration im Grundwasser beeinflussen, und (2) die Vorhersagekraft der OECD Stickstoffbilanz, um die Nitratkonzentration im Grundwasser zu bestimmen. Wir kommen zu dem Ergebnis, dass der Anteil von Ackerland an der Gemeindefläche einen positiven Effekt auf den Nitratgehalt im Grundwasser hat. Höhere jährliche Durchschnittstemperaturen und Durchschnittsniederschlagsmengen führen zu einer geringeren Nitratbelastung im Grundwasser. Wir zeigen, dass die OECD Stickstoffbilanz ein guter Schätzer für die Nitratbelastung von Grundwässern in Österreich ist. Die Vorhersagekraft kann allerdings verbessert werden, wenn jährliche Durchschnittsniederschlagsmengen einer Gemeinde in der Schätzung berücksichtigt werden.
Schlagworte: Nitratbelastung, Grundwasser, OECD Stickstoffbilanz, Landwirtschaft, Regressionsanalyse

1. Introduction

Excess supply of nitrate in agricultural production can lead to environmental pollution including contamination of the air, soil as well as (ground)water. Choosing appropriate policy measures to tackle the problem of nitrate contamination is challenging, since the determinants of nitrate pollution of groundwater are not obvious (Elmi et al., 2002; D'Haene et al., 2003; De Ruijter et al., 2007). We provide a systematic statistical analysis of the determinants of nitrate contamination in Austrian groundwater using a comprehensive data set. We firstly identify agricultural production practices and external factors such as weather conditions and soil characteristics. In the literature several determinants of nitrate leaching into groundwater have been identified, e.g. nitrogen fertilizer rates and soil organic matter (e.g. Korsaeth and Eltun, 2000), crop management practices (e.g. Lord et al., 2002), soil texture (e.g. de Ruijter et al., 2007), and precipitation surpluses (e.g. Elmi et al., 2002). Wick et al. (2010) provide an analysis of nitrate concentration in Austrian groundwater, but use different variables and different empirical models. To formulate and guide regulatory policies a meaningful indicator is needed to guide policies and compliance (De Ruijter et al., 2007, Watson and Atkinson, 1999). Secondly, we focus on the capability of the agri-environmental indicator – Nitrogen Balance – developed by the OECD to predict nitrate concentration in groundwater. As the Nitrogen Balance is a theoretical concept and as such captures the potential of nitrate pollution in a region, it is "not necessarily indicative of actual resource depletion or environmental damage" (OECD, 2008). Consequently, the question arises to which degree the indicator is capable of predicting nitrate pollution.

2. Data and Method

Our analysis is based on a similar data set as the analysis of WICK et al. (2010). In this analysis, we use additional explanatory variables. All available variables are aggregated to municipality level and, in contrast to WICK et al. (2010), to annual instead of quarterly level. The concentration of nitrate in groundwater in mg/l (*Nitrate*) is provided by the UMWELTBUNDESAMT (2009). This data is available on a quarterly basis from 01/1992 to 04/2008 on municipality level in Austria. The cross section dimension consists of 1238 municipalities, but nitrate concentration is not available for every time period in each of the municipalities.

We include data on annual average precipitation in mm (*Precip*) and the annual average maximum temperature in °C (*Temp*) for the years 1975 to 2007 provided by the ZAMG (Zentralanstalt für Meteorologie und Geodynamik) (STRAUSS et al., 2009). The Integrated Administration and Control System (IACS) database provides annual information on cropland (in hectares) for approximately 70 crops, and information on farming systems (conventional or organic) for the years 1999 to 2008 (BMLFUW, 2010). We aggregate these crops into four crop categories on municipality level: (i) oil seed and protein crops, (ii) cereal and maize crops, (iii) row crops and vegetables, and (iv) arable grassland. We use the proportional level of these crop categories at municipality level (*Landuse_j*). The sum of the proportion of permanent grassland and the proportion of cropland is referred to as agricultural land (*Prop_AL*). The indicator for farming practices (*Cult*) takes a value between 1 and 2, where 1 represents the organic and 2 the conventional farming system. Finally, we integrate two indicators of soil quality such as field water capacity (*fwc*) at 33 kPa in topsoil (cm3/cm3), and the volume of stones in topsoil (*vs*) (BALKOVIC et al., 2007). As the soil property data is only available for a reference period, we assume the values to be constant in our analysis. A higher field water capacity implies less leaching. The volume of stones in topsoil is an indicator for the permeability of the soil. The advantage of using these variables is that they describe soil characteristics directly instead of using a less transparent calculation such as the *Bodenklimazahl* (WICK et al., 2010). Summary statistics of the relevant variables are reported in Table 1.

Tab. 1: Summary statistics of relevant explanatory variables

Variables	Unit	Obs.	Period	Mean	Std	Min	Max
Nitrate	mg/l	15423	92-08	20.6	28.7	0.0	801.2
Precip	mm	14169	92-08	2.8	1.3	1.0	10.8
Temp	°C	14169	92-08	12.6	2.6	3.2	23.5
L._oilseed&pro	%	9974	92-08	0.03	0.0	0.0	0.3
L._arablegrass	%	7856	92-08	0.04	0.0	0.0	0.6
L._cereal&maize	%	7856	92-08	0.2	0.2	0.0	3.6
L._rowc.&veg	%	7856	92-08	0.02	0.1	0.0	0.8
Prop_AL	%	9974	92-08	0.5	0.3	0.0	5.2
Cult	1 - 2	9228	92-08	1.9	0.2	1.0	2.0
fwc	cm^3/cm^3	1087	cons.	0.4	0.0	0.3	0.5
vs	%	1087	cons.	8.6	4.1	1.0	15.0
Nbal	kg/ha	4870	03-07	40.0	24.1	-28	143.7
Fert	kg/ha	4870	03-07	99.2	43	0.1	181.9
Withd	kg/ha	4870	03-07	99.8	29.9	0.0	172.6

Source: own calculation

We have calculated the Nitrogen Balance (*NBal*) in kilogram nitrogen per hectare agricultural land for the years 2003 to 2007 on the municipality level (OECD, 2007). The indicator is computed as total nitrogen inputs minus total nitrogen outputs. Total inputs are the sum of (i) biological nitrogen fixation, (ii) atmospheric deposition of nitrogen compounds, (iii) livestock manure, and (iv) mineral fertilizer. Total nitrogen outputs include most importantly withdrawals of harvested crop- and grassland commodities (*Withd*). The total quantity of fertilizer is based on sales of inorganic fertilizer per province and the estimated quantity of nitrogen from livestock manure per province (*Fert*). The total fertilizer quantities are distributed proportionally among the municipalities within a province with respect to agricultural land. Balancing the computed nitrogen inputs and outputs can lead to both positive and negative values. We find that the magnitude of the Nitrogen Balance is positively correlated with the magnitude of nitrate concentration in groundwater. This is confirmed by a statistically significant positive Spearman rank correlation coefficient of 0.22 (Number of observations 5023). We perform regression analysis to identify the marginal effect of several potential explanatory variables separately. Since many of our explanatory variables are (almost) time constant, we apply a clustered pooled Ordinary Least Squares (OLS) estimator with White standard errors to account for possible heteroscedasticity in the data. In contrast to WICK et al. (2010), standard errors are then clustered by the cross-section dimension as observations of one particular municipality over a period of time are not independent (WOOLDRIDGE, 2001). To analyze the predictive power of the Nitrogen Balance in section 4, we use fixed effect estimation. In all regression analysis, we include year dummies to account for aggregate effects over time.

3. Determinants of nitrate concentration in groundwater

We investigate the degree to which particular land use and farming systems are related to nitrate concentration in groundwater.

$$\begin{aligned} Nitrate_{it} = {} & \beta_0 + \beta_1 Precip_{it} + \beta_2 Temp_{it} + \beta_3 Cult_{it} + \sum_j \beta_{4j} Landuse\_j_i \\ & + \beta_5 fwc_i + \beta_6 vs_i + \sum_k \beta_{7k} Year_{kt} + \varepsilon_{it} \end{aligned} \quad (1)$$

$$\text{where } j \in \{oilseed\ \&\ protein, arableland, cereal\ and\ maize, rowcrops\ \&\ veg, grassland\}$$
$$\text{and } k \in \{1999,\ldots,2008\}$$

The results are reported in Table 2. Equation 1 estimates the aggregated effect of the provided explanatory variables to explain the annual nitrate concentration in groundwater. Estimating equation (1), we find that all crop types exert a statistically significant positive effect on nitrate contamination of groundwater, except the proportion of arable grassland. We also find that those municipalities with more conventional farming systems, and thus more intense use of mineral fertilization, experience significantly higher levels of nitrate concentration in groundwater. Municipalities with higher annual average precipitation sums experience lower nitrate concentrations in groundwater. Increased rainfall fosters crop growth and in consequence nitrogen uptakes by crops as well as dilute nitrogen loads. High precipitation sums could also control for the geographical location of the municipality. Alpine municipalities (mostly located in the provinces of Salzburg, Tirol or Vorarlberg) have average annual precipitation sums higher than the Austrian average. As there is less agricultural activity at high altitudes, one would expect lower nitrate concentrations in these regions. The average maximum temperature exhibits a negative effect on nitrate concentration, which suggests that in municipalities with higher temperature leads to higher evapotranspiration rates and biomass production which in turn reduces leaching of nitrates into groundwater (SCHWEIGERT et al., 2004).

4. The nitrogen balance indicator and actual pollution

We consider a fixed effect panel estimation to investigate how well the Nitrogen Balance predicts nitrate concentration in groundwater. The following equations are estimated for the years 2003-2007:

$$Nitrate_{it} = \alpha_i + \beta_0 + \beta_1 Precip_{it} + \beta_2 Temp_{it} + \beta_3 NBal_{it} + \varepsilon_{it} \quad (2)$$

$$Nitrate_{it} = \alpha_i + \beta_0 + \beta_1 Precip_{it} + \beta_2 Temp_{it} + \beta_3 Fert_{it} + \beta_4 Withd_{it} + \varepsilon_{it} \quad (3)$$

The results in Table 2 indicate that the Nitrogen Balance is a suitable indicator to predict nitrate pollution in groundwater. Quantitatively, the Nitrogen Balance explains relatively little of observed nitrate concentration in groundwater. The estimated coefficient of β_3 implies that an increase of the Nitrogen Balance indicator by 10 kilograms per hectare nitrogen results in an increase of 0.35 mg/l nitrate concentrations in groundwater.

We also assess the effect of fertilization and withdrawal by harvested crops and forage (equation 3). As expected, we find a positive influence of nitrogen input and a negative one of nitrogen output on observed nitrate concentration. Also weather related factors are important in explaining nitrate concentration in groundwater, as already discussed in the previous section.

We account for the fixed effects of the previous regressions by considering site-specific characteristics such as proportion of agriculturally used land, soil quality and farming systems of the respective municipality. We assess whether the Nitrogen Balance performs better as a proxy for actual environmental pollution if these site specific characteristics are taken into account or not. We estimate equation 4 using a clustered pooled OLS Estimator:

$$Nitrate_{it} = \beta_0 + \beta_1 Precip_{it} + \beta_2 Temp_{it} + \beta_3 PropAL_{it} + \beta_4 Cult_{it} + \beta_5 fwc_i + \beta_6 vs_i + \beta_7 NBal_{it} + \sum_k \beta_{8k} Year_{kt} + \varepsilon_{it} \quad (4)$$
$$\text{where } k \in \{2003, \ldots, 2007\}$$

Tab. 2: Results of regression analysis for equation 1 to 5

Equation	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
parameter	**Nitrate**	**Nitrate**	**Nitrate**	**Nitrate**	**Nitrate**
Precip	-0.65**	-0.27***	-0.29***	-2.29***	-3.55***
Temp	-1.02***	-0.26***	-0.25***	-1.31***	-1.30***
Fwc	-104.5***			-203.3***	-202.7***
vs	0.12			0.164	0.175
Cult	2.95*			6.15***	5.71***
L._oil.&pro	65.60*				
L._arablegrass	24.21				
L._cereal&maize	24.61***				
L._grassland	56.63**				
NBal	-15.94***	0.035***		0.0654***	-0.0275
Fert			0.035***		
Withd			-0.026**		
Prop_AL				18.36***	18.28***
Precp* Nbal				95.52***	0.037**
Constant	60.39***	20.17***	20.59***	4423	98.94***
Observations	7036	4811	4811	0.24	4423
Adjusted R-squared	0.30	0.95	0.95		0.24
* p < 0.1, ** p < 0.05, *** p < 0.01					

Source: own calculation.

Again, the Nitrogen Balance exerts a statistically significant positive effect on nitrate concentration. But site specific variables might be important in determining the predictive power of the Nitrogen Balance. To test this hypothesis, we introduce interaction terms into the regression equation:

$$Nitrate_{it} = \beta_0 + \beta_1 Precip_{it} + \beta_2 Temp_{it} + \beta_3 PropAL_{it} + \beta_4 Cult_{it} + \beta_5 fwc_i + \beta_6 vs_i + \beta_7 NBal_{it} + \beta_8 NBal_{it} \cdot Feat_{it} + \sum_k \beta_{9k} Year_{kt} + \varepsilon_{it} \quad where\ k \in \{2003,...,2\,007\} \tag{5}$$

The variable *Feat* captures characteristics, such as precipitation, temperature, farming systems, volume of stones or field water capacity. The results demonstrate that of all exogenous factors only precipitation is crucial when determining the explanatory potential of the Nitrogen Balance (cp. Table 2). If high average precipitation is observed, the Nitrogen Balance does particularly well in predicting environmental problems, i.e. the marginal effect of the indicator is significantly influenced by the level of precipitation.

5. Conclusion

We have identified likely determinants of nitrate contamination of groundwater in Austria. We find that increased agricultural activity (especially if crops are conventionally cultivated) leads to higher nitrate concentration in groundwater on average. Higher average temperature and precipitation as well as a higher level of field water capacity lead to lower nitrate pollution of groundwater (also cp. ELMI et al., 2002; KORSAETH and ELTUN, 2000). We assess the explanatory power of the Nitrogen Balance, suggested by OECD as a priority agri-environmental indicator, when it comes to measuring actual nitrogen pollution. We find that the indicator exerts a positive influence on nitrate levels in Austrian groundwater, and conclude that it is a good predictor for environmental pollution. In addition, we find that the predictive power of the indicator can be improved when specific environmental conditions are taken into account (KORSAETH and ELTUN, 2000; OENEMA et al., 2003; SCHRÖDER et al., 2004). Particularly average precipitation seems to be important to increase the predictive power of the indicator. Our analysis suggests that the indicator should be expanded with these site characteristics if its purpose is to better predict environmental pollution.

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