Nitrates Directive

A comparative study on Slovenia, Slovakia, and Czechia

Ebba Hult

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Abstract

This paper examines the nitrogen concentration in groundwater in Slovenia, Slovakia, and Czechia between 2000 and 2019 using panel data. The model consist of the dependent variable WaterQuality, the independent variable Nitrates Directive, five control variables and a Linear Time Trend. The study aims to assess whether or not an international directive from the European Union can help countries achieve lower nitrogen concentration in groundwater than those observed before its implementation. The following question is: *Has the nitrogen concentration in groundwater for Slovenia, Slovakia, and Czechia reduced after the countries implemented the Nitrates Directive when they joined the EU?* Results shows that the Nitrates Directive did not have the desired outcome and instead the concetrations increased after the implementation of the directive for all three countries. However, the Time Linear Trend in the model indicate that over time a downward trend in nitrogen concentration in groundwater occurs. The paper presents evidence suggesting that both economic- and environmental factors impact nitrogen pollution, along with the use of fertilizer and manure. However, many limitations in the paper exist such as valuable variables missing and to few observations is included in the model. It is clear through evidence that policymakers need to take on the issue regarding nitrogen pollution to improve water quality, and that the Nitrates Directive are important to ensure the safety of future generations.

Keywords: Nitrates Directive, Panel data, Water Quality, European Union

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EU	European Union

1. Introduction

Groundwater is the primary source of drinking water for approximately 50 percent of the world´s population. However, over the past decades, nitrogen concentration in both ground- and surface water has increased due to intensive agriculture production (Mahvi et al. 2005). According to Glavan et al. (2019), nitrogen is one of the primary polluters of water, resulting in serious consequences for the environment and human health. In response, the European Union has introduced several water directives throughout the years with the attempt of trying to mitigate the negative externalities of water pollution caused by the agriculture sector. This is an example of a market failure the EU tries to internalize in its policy (Oenema 2011). But at the same time, the need for higher crop yields continues, with an expected global population growth to reach 10 billion people by 2050, which will require a massive increase in food production (Waqas et al. 2023). This represents a difficult challenge for future policymakers to balance between food production and sustainable water management.

There is extensive literature on nitrative pollution from the agriculture sector and its environmental impact. Some of these also examine the effectiveness of the Nitrates directive in specific regions around the world (Borah et al. 2025). However, compared to previous research, this paper is interested in how countries after entering the EU, specifically subject to following the Nitrates Directives, affect the nitrogen concentration in groundwater. This is done using panel data on Slovenia, Slovakia, and Czechia between 2000 and 2019. These countries were selected as relevant case studies because they all joined the EU the same year, giving them the same starting point for the directive, along with having available data to collect for the model. The goal of the paper is to determine if the directive has helped lower the nitrogen concentration in groundwater after the countries joined the EU. By doing so, this study aims to assess whether or not an international directive from the EU can help countries to achieve a lower nitrogen concentration, than the result observed before its implementation. With that being said, the following question in this paper is:

Has the nitrogen concentration in groundwater for Slovenia, Slovakia, and Czechia reduced after the countries implemented the Nitrates Directive once they joined the EU?

This paper will present the historical background, alongside previous research, analysing the result of nitrogen concentration in groundwater. To investigate the research question, panel data was conducted to examine if implementing the Nitrates Directive, which is required once part of the EU, has helped the reduction of nitrogen concentration in groundwater for Slovenia, Slovakia, and Czechia. The remaining seven countries, Poland, Cyprus, Malta, Latvia, Lithuania, Estonia and Hungary that joined the EU the same year are left out of the model due to incomplete data. The results point out limitations in the directive´s effectiveness since none of the variables were significant, indicating high probability that either variables are missing in the model or the need for a better suited model. The paper also discuss what is necessary in the future regarding nitrogen use and environmental protection. This will be discussed in greater depth throughout the paper.

1.1 Background

In the twentieth and the beginning of the twenty-first centuries new technology was introduced, along with new production methods enabling farmers in the agriculture sector to increase food production significantly (Buckley et al. 2015). The nitrogen was transformed into fertilizer allowing greater plant growth, leading to a transformation in the agriculture production (FAO 2025). However, the increased usage of fertilizer in the agriculture sector to reach higher crop yields, whilst ignoring the environmental consequences from it, resulted in nitrogen becoming a global water polluter (Waqas et al 2023). Presented by FAO (2025), in many parts of the world, specifically in Western Europe, North America, and many places around Asia, more than 50 percent of nitrogen input is lost to the environment. The result demonstrates both problems for human health since it increases the risk for respiratory and heart disease, along with environmental issues such as degradation in water quality. Many researchers theorize that because nitrogen use has more than doubled since the pre-industrial times, along with climate change and a growing population, it is a high possibility that the amount of nitrogen in agriculture soil will increase (Dimkpa et al. 2020). But, many researchers across the world have also studied the EU´s position in the global climate and its unique seat they have regarding global environmental issues (Wang et al. 2024). According to the report of the Nitrates Directive between 2016 and 2019, it states that without the directive the European countries would in fact experience even higher levels of water pollution than without the directive, pointing out EU´s significant role in achieving a good environmental future (European Union 2021).

With that being said, the discussion surrounding environmental issues is not a new thing and has been the topic of question for some time. For instance, in late 1970, Denmark was one of the first countries to detect high nitrogen concentrations in groundwater (Kronvang et al. 2008). Despite the EU´s growing awareness and extensive work on decreasing nitrogen loss over the past decades, the amount of pollution on both ground- and surface water is still a big issue for many countries around the world. As mentioned by the study of Haene et al. (2014), the EU member states agriculture sector is responsible for around 80 percent of nitrogen concentration spillover into waters, specifically from applying fertilizers and livestock manure onto the soil. Initially, when the EU realized the connection between nitrogen pollution and water quality, the focus was on the concern of drinking water, especially regarding human health. This led to two new directives by the EU, "The Surface Water for Drinking Directive" in 1975 and "The Drinking Water Directive" in 1980. But in recent times the focus has shifted towards the environmental impact of nitrogen causes due to the agriculture sector. Therefore, in 1988 the European Commission suggested the "Nitrates Directive", to reduce nitrogen surplus in the agriculture sector and mitigate water pollution (Goodchild 1998).

The Nitrates Directive (91/676/EEC) was implemented in 1991 by the European Union, to protect ground- and surface water from pollution caused by the nitrates that originate from agriculture, and prevent further pollution from happening. In the directive it states that all member countries have to design "Nitrates-Vulnerable Zones", regions where nitrogen concentration in the grounwater is greater than 50 mg/l. Within these zones, the application of livestock manure is limited to 170 kg N per ha per year. Member countries are also required to set up action programs that include mandatory measures and detailed observance of nitrogen concentration. Farmers are also offered codes of "good agricultural practices". The codes are all voluntary and directed at helping farmers reduce nitrates pollution. Finally, the Nitrates Directive is reviewed every four years (European Union 91/676/EEC) and is closely linked with other EU policies concerning climate change, water, and agriculture (Council Directive 1991).

In 2004, Slovenia, Slovakia, and Czechia joined the EU, along with Cyprus, Estonia, Hungary, Lithuania, Latvia, Malta, and Poland (European Union 2024). Becoming a part of the EU market was the beginning for the countries of implementing EU regulations, including the Nitrates Directive into the country´s national laws. While the Nitrates Directive sets up specific goals, the countries are free to set up higher standards than those in the directive if the countries wish to do so (European Union 2021).

The formation of the Nitrates Directive by the EU, addressing nitrogen pollution in water, is particularly important in a world that is already facing other global challenges, including food insecurity, climate change, and human health (Borah et al. 2025). Given these findings, the choice of investigating Slovenia, Slovakia, and Czechia is because it provides unique information regarding whether or not the EU entrance helped the countries to lower their nitrogen concentration in groundwater after being subject to the Nitrates Directive, presenting material on EU´s role regarding environmental issues. Leaving out the remaining member states in EU is due to missing data, otherwise they would have been included. Therefore the following hypothesis is:

H_0 = After joining the EU, being subject to the Nitrates Directive, the amount of nitrogen concentration in groundwater decreased in the selected countries.

H_1 = after joining the EU, being subject to the Nitrates Directive, the amount of nitrogen concentration in groundwater did not change in the selected countries.

2. Previous Research

Previous studies have attempted to provide vital knowledge for governments on the relationship between nitrogen use and groundwater pollution, trying to understand the mechanisms causing the pollution in the worlds groundwater. A study by Buckley et al. (2016) on farm nitrogen balance post EU Nitrates Directive revealed that the introduction of the directive had a positive effect on lowering the gross nutrient balance in 150 Irish dairy farms. Because of the directives framework, the farmers began to use a new method that revealed the total amount of nutrient surplus the farmers were responsible for. This helped them get at better understanding of the excessive overuse of nitrogen and the environmental pressure they were causing due to it. As a result, the farmers were able to lower their levels of nitrogen loss. However, Hansen et al. (2017) argue the opposite, explaining that many studies in the Western world have instead pointed out that it is not enough with international regulation. Better groundwater quality requires stricter national regulations and specific regional mitigations. For example, countries like Denmark are moving further away from a one-size-fits-all national regulation and towards more specific regional regulations, since policies need to consider area variations. On the other hand, Martinez-Dalmau et al. (2021) argue that when policymakers generally construct an environmental policy, it is not for the environment per se, but more about correcting for the externalities that economic activities have given rise to.

The report of the Nitrates Directive between 2012 and 2015 reveals that some improvements in trying to balance the input of fertilization since the introduction of the directive in 1991 have occurred (European Commission 2018). However, Stredová et al. (2024) study claims that gaps exist in the EU´s Nitrates Directive, suggesting that some updates needs to be made. According to Velthof et al. (2014), who investigated the Nitrates Directive on nitrogen emission in the agriculture sector across all EU member states, found that nitrogen losses varied a lot between the member states. The main reason was that intensity of the livestock production in the country, revealing a difference of up to 250 kg N per hectare per year. Leuck et al. (1995) offer an explanation for this, arguing that livestock manure and fertilizer are not applied in the soil with the same objective. Fertilizer is typically regarded as a valuable nutrient source for crops and therefore needs to be used more attentively, while livestock manure is often viewed as a costly waste that the farmer needs to be disposed of. As a result, nitrate pollution tends to be higher in areas where livestock production occurs, and given that livestock production has increased since the 1950´s, along with the uncertainty of environmental changes (Musachhio et al. 2020), now more than ever, the importance of this matter can not be understated.

Other factors highlighted in previous papers impacting nitrogen pollution are weather conditions. Stredová et al. (2024) study found that Czechia has one of the EU´s largest inputs of nitrogen fertilizer, and in 2019 was ranked second in terms of positive gross nitrogen balance. The paper found that during colder months in Czechia when the nitrogen uptake is low by crops and the soil water is replenished, nitrogen loss by leaching[1] occurs more often. This is further supported by Velthof et al. (2014) and Leuch et al. (1995), who found similar findings, where nitrogen loss tended to be higher during periods of heavy rainfall, along with the specific characteristics of the soil.

Through a socioeconomic context, Hansen et al. (2017) investigated the connection between the annual nitrogen concentration in water and the economic growth in Denmark in the 20th century. The study revealed that between 1948 and 1983, GDP per capita and nitrogen leaching in groundwater increased, aligning with each other. However, in 1983, after reaching a certain economic stability, the amount of nitrogen concentration in groundwater started to slowly go down, while the economic growth continued to increase for the citizens. What Hansen and his coworkers believed to be the driving force was that the social dynamic had started to shift. Becoming more economically stable led people more environmental aware, presenting the Danish people with opportunities to demand for more groundwater protection laws. This resulted towards more sustainable agriculture in Denmark. According to Hansen results it is possible for countries to adjust towards more environmentally friendly methods while keeping production high, hence presenting the opportunity for farmers to accomplish both at the same time (Hansen et al. 2017).

Overall, components found that can influence the nitrogen concentration in groundwater include both economic- and environmental factors, as well as how fertilizer and manure is being used. This information is vital for the following section in this paper.

[1] The process where substances, such as nitrogen applied at the soil, come into contact with rain and move through the soil, contaminating the groundwater and causing environmental issues.

3. Data and Methods

3.1 Data

Data utilized in this paper were obtained from four different data sources, Eurostat (2025), OECD (2024), Our World in Data (2025) and the World Bank group (2025). The study consist of three European countries joining the EU in 2004 – Slovenia, Slovakia, and Czechia. The remaining seven countries that also joined EU the same year, Poland, Malta, Cyprus, Estonia, Hungary, Latvia and Lithuania, are left out of the model because of incomplete data. The data spans between 2000 and 2019, resulting in 60 observations.

The following variables were collected to examine nitrogen concentration – Water Quality, Nitrates Directive, GDP per capita, Precipitation, Fertilizer, Manure and Gross Nutrient Balance. Originally two additional variables were included in the model, Agricultural land, that would show the total amount of land used for agricultural purpose, since more agricultural land often correlate with more nitrogen usage. Including environment investment, would reflect the countries total spending towards the environment, giving indication on how much each country prioritize the conservation of the environment. However, due to high VIF value exceeding the permitted value of 10, indicating multicollinearity, the two were removed from the model. Fertilizer had a VIF value of 10.5, higher than the permissible amount, but because of the variable being essential in the model it was not removed.

3.2 Data Description

3.2.1 Water Quality

This dataset is used to estimate the dependent variable, called *WaterQuality*. The data is gathered from Eurostat and presents the concentrations of nitrates in groundwater measured in milligrams per liter (mg NO3/L), between the year 2000 and 2019. This indicator shows the countrys variation of nitrogen concentration in groundwater and illustrate how agricultural areas, amongst other industries, negatively impact the water quality. Also included is a summary statistics that provide information regrading water quality for Czechia, Slovenia, and Slovakia. Currently the drinking water standard in the EU limits NO3/L to 50 mg, as it is stated in the Nitrates Directive, revealing if the country go over or under the restraint (Eurostat 2025).

3.2.2 Nitrates Directive

Nitrates Directive, also called *NitratesD,* is the dependent variable that captures the effect of implementing the Nitrates Directive when a country becomes a member of the EU. The variable is converting into a dummy variable were 0 = 2000 to 2003, and 1 = 2004 to 2019.

3.2.3 GDP per capita

GDP per capita is an economic metric that examines Slovenia, Slovakia, and Czechia´s gross domestic productivity divided by midyear population. The data is collected through the World Bank group and is converted from the country´s national currency into current US dollars. It provides the total sum of the country´s gross value added by all the citizens producers in the economy and all taxes, minus subsidies (World Bank group 2025). Including GDP per capita it can control for economic differences between countries, since country´s with high GDP per capita tend to have more developed industries, meaning they are more likely to have prioritized environmentally friendly techniques.

3.2.4 Precipitation

Precipitation is gathered from Our World in Data and presents the total amount of the average depth of water falling down to earth surface, presented in millimeters. It includes both rain and snow, but not fog and dew (Our World in Data 2025). Including precipitation, it controls weather conditions and is relevant since high amounts of rainfall usually impact the amount of nitrogen leaching into groundwater.

3.2.5 Fertilizer and Manure

Both fertilizer and livestock manure is collected from OECD. It measures the nitrogen in livestock and fertilizer entering the agriculture system, expressed in tonnes (OECD 2024). Together, the two variables are vital in the model since it gives indication if the countries use the two in large quantities.

3.2.6 Gross Nutrient Balance

The Gross Nutrient Balance variable is gathered from Eurostat and measured in kilograms of nutrient, specifically nitrogen, per hectare. This dataset provides information regarding the linkage between the use of of agriculture nitrogen and the environmental impact. It calculates the balance between inputs of nitrogen and the output of nitrogen to the agriculture soil (Eurostat 2024). Including a variable that measure the excess of nitrogen reveals the inefficiency in the use of nutrients and the consequences the environment is receiving.

3.3 Descriptive Statistics

Table 1. Descriptive Statistics for Czechia

Variable	Obs	Mean	Std. Dev.	Min	Max
WaterQuality	20	19.41	1.33	17.68	23.34
GDP Per Capita	20	17005.23	5719.15	6062.92	24062.72
Fertilizer	20	340719.35	60804.46	244763	449319
Manure	20	113699.20	16868.06	89552.2	142506.2
Precipitation	20	792.3	93.1	588	964
Gross nutrientbala~e	20	78.62	12.242	56.5	102.4
NitratesD	20	.8	.41	0	1

Table 2. Descriptive Statistics for Slovakia

Variable	Obs	Mean	Std. Dev.	Min	Max
WaterQuality	20	18.37	2.68	14.24	24.7
GDP Per Capita	20	14646.9	4798.14	5421.65	19573.37
Fertilizer	20	113881.72	15141.35	84856.8	135553.3
Manure	20	62674.8	11030.48	38705.5	79113.3
Precipitation	20	850.65	116.37	612	1182
Gross nutrientbala~e	20	41.81	8.74	28.7	54.3
NitratesD	20	.8	.41	0	1

Table 3. Descriptive Statistics for Slovenia

Variable	Obs	Mean	Std. Dev.	Min	Max
WaterQuality	20	15.18	1.94	12.58	18.92
GDP Per Capita	20	20615.03	5295.35	10135.72	27461.98
Fertilizer	20	29346.13	2831.44	25139.4	34837.1
Manure	20	37687.97	1844.08	35037.3	42030.2
Precipitation	20	1324.95	191.93	909	1763
Gross nutrientbala~e	20	57.9	16.69	41.8	97.2
NitratesD	20	.8	.41	0	1

The following three tables include Czechia, Slovakia, and Slovenias descriptive statistics. First of, *WaterQuality* for each country indicate a mean value (19.405) for Czechia, (18.36) for Slovakia and (15.18) for Slovenia, in milligrams nitrate in the groundwater per litre. All are below the level of 50 mg/l to be considered "Nitrate-Vulnerable Zones".

The annual *GDP per capita* for Czechia range between 6 062 – 24 062 US dollars, Slovakia 5 421 – 19 673 US dollars, Slovenia 10 135 – 27 461 US dollars.

Indicating different economic circumstances between the countries, with lowest GDP per capita in Slovakia and highest in Slovenia.

The *Fertilizer* and *Manure* variable give the amount of tonnes that the agriculture sector in each country is using. Czechia is using the most amount tonnes of both fertilizer and manure out of the three countries. While Slovenia is using the least of both.

Precipitation indicate the amount of water Czechia, Slovakia, and Slovenia experience throughout one year. Slovenia have the highest amount of rainfall, during some years it rains 1763 mm, which is almost double amount of what it rained during the years with the lowest amount. Czechia and Slovakia precipitation is around the same amount. Including precipitation is relevant since it can impact nitrogen leaching in groundwater.

Gross nutrient balance reveal the surplus of nitrogen in the agriculture sector. All three countries experience high amount of overuse of nitrogen. Czechia has the highest level of gross nutrient balance and it is also the country with the most amount of fertilizer and manure, indicating a linkage between the two.

3.4 Method

To examine whether the dependent variable *WaterQuality,* specifically if the concentration of nitrogen in groundwater changed after the countries joined the EU, and becoming part of the Nitrates Directive a panel data model was conducted. Analyzing panel data, allows repeated observations of the same entity (Slovenia, Slovakia, and Czechia) over a longer period, increasing the statistical validity in policy analysis (Ho Eom et al. 2007). Given that the independent variable consists of a policy, and that the research question investigates the Nitrates Directive, fixed effect model seems appropriate in the paper. In order to measure the effect of the Nitrates Directive, a variable called *NitratesD* was constructed into a dummy variable, where 0 if = 2000-2003, or 1 if = 2004-2019.

$$\text{WaterQuality} = \beta_0 + \beta_1 \text{NitratesD}_{it} + ʈ\text{TimeTrend} + \upsilon X_{it} + \mu_i + \varepsilon_{it}$$

The model includes the dependent variable *WaterQuality* that measures the concentration of nitrate in groundwater for Slovenia, Slovakia, and Czechia between the years 2000 and 2019. β_0 is the intercept, holding everything else constant. *NitratesD* is the independent variable that control for before and after the directive was introduced, by converting into a dummy variable. X_{it} is a vector that consist of all the control variables – *Manure, Fertilizer, Gross Nutrient Balance,* *Precipitation* and *GDP per capita.* μ_i is country fixed effect and ʈ is the coefficient of the linear time trend. ε is the error term that captures all the factors that influence the dependent variable, that the model does not include. $_i$ represent the entities in the model and $_t$ the time period.

Country fixed effects are included to control for unobserved, time-invariant differences between countries. Instead of including year fixed effect in the model that may absorb all year-to-year variation, a linear time trend, called *TimeTrend*, is included in the model. The time trend will account for general trends over time that affects all countries and captures a gradual overall change.

4. Result

Table 4. Effect on Nitrogen in Groundwater

VARIABLES	(1) WaterQuality	(2) WaterQuality	(3) WaterQuality	(4) WaterQuality
NitratesD	-0.96	2.93	2.73	2.96
	(1.16)	(2.11)	(1.75)	(2.11)
GDP_Per_Capita		-0.0003*	-0.0003	-0.0002
		(0.0001)	(0.0001)	(0.00007)
Fertilizer		-0.000005	-0.000000	-0.000004
		(0.000005)	(0.000001)	(0.000006)
Manure			0.00002	-0.000002
			(0.00002)	(0.00002)
Precipitation			0.002	0.004
			(0.004)	(0.004)
Gross_nutrientbalance				0.04
				(0.03)
Linear Time Trend				-0.21*
				(0.05)
Constant	18.41***	22.06***	17.75*	14.81
	(0.93)	(0.59)	(5.89)	(6.70)
Observations	60	60	60	60
R-squared	0.04	0.28	0.30	0.42
Number of Countries	3	3	3	3
Country FE	YES	YES	YES	YES
Robust SE	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The result from Table 4 consists of panel data with four different model specifications, consisting of the connection between *WaterQuality* and *Nitrates Directive*. In Model 1 only *NitratesD* is included, capturing the effect of implementing the Nitrates Directive when a country becomes a member of the EU converted into a dummy variable were 0 = 2000 to 2003, and 1 = 2004 to 2019. For the following three models two control variables are included in each, except for model 4 where all control variables are included plus the Linear Time Trend. The model is to determine if *NitratesD* estimation changes throughout the model. Model 4 will be the model that is interpreted since it consists of all the variables plus the Linear Time Trend.

NitratesD is positive with no significant level, H_0 is not rejected. Interpreting the result, the policy had no significant impact on the dependent variable.

Both *Fertilizer* and *Manure* in model 4 have a negative value, suggesting that a one unit increase will decerase the nitrogen concentration in groundwater, holding all other constant. However, looking a *Gross Nutrient Balance,* the total nitrogen surplus in agriculture show a positive value, meaning that one unit increase the nitrogen concentration by 0.04 milligrams per liter. The *Precipitation* variable in the panel data shows no significance. In model 4 the precipitation is positive with one unit increase leading to a 0.004 milligrams increase of nitrogen concentration in groundwater per liter, holding everything else constant. Lastly, *GDP per capita* in model 4 is not significant and show that with one unit increase leads to a 0.0002 milligrams decrease of nitrogen concentration in groundwater per liter, holding everything else constant.

For all four models, Robust Standard Error and Country Fixed Effect are included to control for heteroscedasticity and unobserved, time-invariant differences between countries. The R-squared value in model 4 is 42 percent, representing the amount of variance in the dependent variable *WaterQuality* that is explained by the variables in the model.

In model 4 a *Linear Time Trend* is included and is significant at a 10 percent level with a negative value of 0.21. This suggest that over time there exists a general downward trend in nitrogen concentration in groundwater for the three countries.

5. Discussion

This paper investigates if entering the EU and thereby implementing the Nitrates Directive have impacted the nitrogen concentration in groundwater for Czechia, Slovenia, and Slovakia through a period 20 years using panel data. As mentioned at the beginning of this paper, when a new directive is introduced by the EU it is a action plan to try and mitigate the negative externalities that occur from the agriculture sector (Oenema 2011). Therefore the following section contains the results from the model along with previous research findings to investigate if the directive can help with lowering the nitrogen concentration in groundwater.

Firstly, fertilizer and manure, as mentioned in the result, had a negative value suggesting that nitrogen concentration decreased with more nitrogen use. This seems unlikely because more nitrogen should lead to a higher amount going to waste, impacting the water badly. However, looking at gross nutrient balance, the opposite is shown where the nitrogen concentration increases with more surplus, which is more likely in this case. This results is further supported by the findings of Velthof et al. (2014) study. Nevertheless, if we consider that it is the case that more nitrogen use leads to a decrease in water pollution, then alternative explanation is needed to explain it. One explanation could be that farms with more intensive production know how to use nitrogen more efficiently. Meaning that even though they use more nitrogen, they carry more knowledge and resources that can help the larger farms to decrease the nitrogen in groundwater, while smaller farms that use less nitrogen pollutes more. But this only speculation and needs more investigation to determine if any truth is in it.

GDP per capita result from model 4 showed that people in countries with a higher economic output also had lower levels of nitrogen concentration in groundwater. This leads to conclusion that people are more likely to be concerned about the environment when they can reach a certain point of economic stability, which is also discussed by Hansen et al. (2017) study. However, it is also important to consider that there is the high possibility that countries with economic stability also have a strong government, giving them a platform to establish policies that are built upon long-term environmental goals, rather than short once. This results suggests that it is important for policymakers to recognize that economic stability in a country offers advantages and should for that reason not be disregarded when constructing a policy at international level.

Regarding the precipitation variable, papers by Stredová et al. (2024), Velthof et al. (2014) and Leuck et al. (1995) all found similar findings to the results from this paper, implying that more rain leads to increase in nitrogen concentration in groundwater. However, the previous papers also presents the soil characteristics as an important factor which is not included in the model due to lack of data. Interpreting the result from descriptive statistics shows that Czechia had out of the three countries the highest mean value of nitrogen concentration in groundwater, but the lowest max value in precipitation, 964 mm. Meanwhile, Slovenia with the lowest mean value in nitrogen concentration in groundwater had the highest max value for precipitation, 1763 mm. This differs from the previous research. An alternative explanation for this is that due to lower levels of rainfall farmers may need to compensate by adding more nutrients in the soil to keep up with yield production, which the panel data show.

For the independent variable Nitrates Directive, *NitratesD*, it was not significant, H_0 can therefore not be rejected. The results further shows that the directive had the opposite effect on Czechia, Slovenia, and Slovakia after entering the EU where the directive seemed to increase the nitrogen concentration for the countries instead. But, it is most likely wrongful information and due to lack of significance, the result should be cautiously interpreted, reflecting limitations in the model. However, this does not mean that further investigations can not be made on potential reasons behind the result. First of all, only including three countries, giving 60 observations is most likely too small of a sample, and the model requires more countries that expand over a longer period, specifically earlier than 2000. Second, implementing a new directive in a country does require adjustment time for both the country and the farmers which can explain why the result is increasing and not decreasing. Third, even though the Nitrates Directive did not show a decrease, the Linear Time Trend did indicate that a decreasing trend of nitrogen concentration is happening in the countries over time.

Continuing, there was a lot of shortcomings in the panel data that need to be addressed. First, in the model, the Nitrates Directive is set to be implemented in Czechia, Slovenia, and Slovakia when they entered the union in 2004 by creating a dummy variable equal to 1 after 2004. However, since the directive has existed since 1991, it is important to consider that there is the possibility that the countries, earlier than 2004, started to change their national laws to mitigate the nitrogen in surface- and groundwater. However, this does not discourage the actual findings from the panel data, since the paper is still interested in the current changes once the country is a part of the EU. Therefore, while there may be gradual changes occurring earlier than 2004 for the countries, the actual effect of the nitrogen concentration in groundwater is interesting after 2004. This is because the countries are being held responsible for their progress by the EU once they are apart of the union. For future research, including a time lag in the model that account for the delay when the independent variable *NitratesD* impact the dependent variable

WaterQuality and when the effect is actually detected would have been a good idea. All in all, when investigating a directive it is important to consider this limitation since it may effect the results.

Second, it is important to consider that no significant result is shown probably because valuable variables are missing in the model that impact the dependent variable *WaterQuality*. As mentioned in the method, agricultural land and environmental investment were initially a part of the model, but due to multicollinearity, they were removed. Another variable that also was initially thought to be included but due to lack of data, was educational level since knowledge helps farmers to find alternative ways to decrease nitrogen pollution. Even additional variables not mentioned could have an impact on the dependent variable. For example, in the Nitrates Directive, there is a section about codes of good agriculture practices that are there to assist farmers and help them to use more environmentally friendly methods without harming their production. Therefore, it would have been a good idea to include a variable in the model that could account for farmers who have used any of these "codes". In Buckley et al. (2016) study the farms that required help saw a reduction in nitrogen in the groundwater, pointing to benefits of receiving guidance. However, this is highly dependent on the availability of data, which in this paper exhibited to be a bit of a challenge.

Third, looking back, it may have been a good idea to check if some of the variables exhibit a non-linear relation or that there is the possibility of measurement errors in the data such as human errors that made mistakes throughout the measurement process. These are all factors that needs to be considered influencing the results and explain why the model is unreliable.

Lastly, the fertilizer variable had a VIF value of 10.5 which is higher than the permissible amount of 10. This means that the model´s credibility is harmed since now there is the issue of multicollinearity between two or more variables. However, the value is not that much higher than the permitted amount. The decision to keep the variable in the model is due to the opportunity to investigate between fertilizer and manure since both are major contributors to nitrogen in groundwater. Regardless, the two did not differ much in the panel data and since none of them showed any significance, it is difficult to draw any specific difference.

With that being said, many countries continue to struggle with high levels of nitrogen in groundwater in Europe even though several regulations and directives have been introduced throughout the years. This suggests that the directive contains gaps that need to be investigated in order for countries to lower the nitrogen concentration in groundwater in a faster paste. As mentioned in the Stredová et al.

(2024) study, the regulations lack clarity and require updated action programs. There is also the issue with vague definitions of “nitrate-vulnerable zones”, specifically what area should be included. Countries that do not include the whole water area considered “vulnerable” are at risk of more nitrogen pollution, which means that the Nitrates Directive is less efficient.

Further, it is important to consider when investigation nitrogen concentration in groundwater how the research is constructed, showing the results in the most accurate way. This paper is looked at a country-level basis because of the available data. However, investigating the findings from the descriptive statistics from Slovenia, Slovakia, and Czechia *WaterQuality* max value shows a value below 50 mg/l. this implies that neither of the countries water is considered “nitrate-vulnerable zones”. However, the results can be misleading, since the value gives an annual level over the whole country instead of specific areas´ value. The consequence of this is that the places that do have high levels of nitrogen concentration, exceeding the 50 mg/l level get reduced by places with lower levels. This is because the value presented in the descriptive statistics shows the average nitrogen concentration by the countries. All in all, this is something that policymakers need to be aware of when constructing policies in attempt to protect water.

6. Conclusion

To sum up, the aim of this paper was to determine if an international directive, the Nitrates Directive, by the EU has helped lower the nitrogen concentration in groundwater by looking at three different countries over a period of 20 years.

Overall, the result from the model was limited, making it difficult to draw any specific conclusion since none of the variables were significant. However, still, we can speculate on the results along with previous research and reports. The results suggest that nitrogen concentration in groundwater is increased with the Nitrates Directive. While this is most likely due to an error in the model or misspecification, previous research has pointed out limitations in the directive´s effectiveness. It is clear that the EU´s Nitrates Directive has its gaps and that it requires changes to fulfil its goal of improving the water quality in countries, without harming future food production. Many previous research papers have pointed out the overuse of fertilizer and manure as a major cause to water pollution. While the results in this paper suggest the opposite, it is safe to say that the agriculture sector needs to improve its management of both. Further the economic situation of a country also seem to impact the amount of resources put into protecting the environment. However, this does not mean that not all countries in the EU do not have a responsibility to find ways to limit their nitrogen use.

In the end, the paper is important and shows that policymakers need to take on the issue regarding nitrogen pollution to improve water quality, not only for the environment but for human health as well. To do so, the EU needs to demand more from its member states, including stricter rules from the farmers on the use of nitrogen. But the EU has a responsibility to its member states as well. First, they need to make sure that the directive is clear and that it does not leave room for the countries to make their own interpretation. Second, the EU should help the farmers more, both financially and with new better methods that require less nitrogen in the agriculture. After all, the world´s population is increasing and while countries have started to recognize the global challenges of nitrogen pollution in water, the urgency for more drastic changes and implementations in EU´s directives is required to ensure the safety of future generations. But as presented by Brink et al. (2011), finding the balance between food security and the environment, while being a part of the world market is difficult. From a farmer´s perspective, it is not hard to understand that maximized production often exceeds environmental protection.

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