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Author(s)	O'Donoghue, Cathal; Howley, Peter; Hynes, Stephen; Fealy, Réamonn; Chyzheuskaya, Aksana; Green, Stuart; Meredith, David; Morrissey, Karyn
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The Spatial Relationship between Economic Activity and River Water Quality

Cathal O'Donoghue, Peter Howley, Stephen Hynes, Réamonn M. Fealy, Aksana Chyzheuskaya, Stuart Green, David Meredith, Karyn Morrissey

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Abstract

This paper, using Ireland as a case study, examines the relationship between economic activities and river water quality. The stipulation from the EU water framework directive (WFD) that all surface waters in the EU must be of 'good ecological status' by 2015 necessitate a quantitative understanding of the major determinants of water quality. Within this context, this paper combines a number of spatial datasets relating to agricultural, residential and industrial activities as well as the level of forest cover to examine the major economic influences on the ecological quality of water resources. It is hoped that providing a comprehensive understanding of the effect of a variety of economic activities that influence the ecological quality of water will be an important tool in the management of risk and will allow for more appropriate land use planning aimed at restoring and maintaining water quality as required by the WFD. Results indicate that the level of forestry, industrial activity, the intensity and type of agricultural activity and the type of wastewater treatment in an area are all critical factors affecting the quality of our water resources. Moreover, the results highlight the importance of a spatial dimension to any analysis as the principal factors affecting water quality often differ across river catchments.

Keywords: Water Framework Directive, river water quality, ordered logit

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Author Contact Details: Cathal O'Donoghue, SEMRU, National University of Ireland, Galway, Email: cathal.odonnoughue@nuigalway.ie

INTRODUCTION

The Water Framework Directive (WFD) adopted by the European Commission in 2000 requires the integrated management of water resources throughout the EU. The WFD can be considered as the first framework for EU action in the field of water policy management as it commits all Member States to ensure that all water bodies are of 'good ecological status' by 2015 (Elnaboulsi, 2009). For the first time, water quality targets are expressed not only in terms of chemical composition but also encompass wider aims relating to the aquatic *fauna* and *flora* (Fezzi et al., 2008). If this goal is to be achieved, however, then it will necessitate fundamental changes in the management of rivers and lakes across Europe (European Commission, 2000).

The Environmental Protection Agency (EPA, 2006) has indicated that water quality in Ireland is currently at a level below that required by the WFD. More specifically, the EPA found that 29 per cent of river channel length and 8 per cent of lake surface area examined were of unsatisfactory water quality. Nineteen per cent of the estuarine/coastal water bodies examined were eutrophic (over-enriched) while 3 per cent were potentially eutrophic. Finally, 57 per cent of the groundwater sampling locations were contaminated by faecal coliforms and approximately 25 per cent of the groundwater locations examined exceeded the national guideline value for nitrate concentration of drinking water.

While previous directives such as the nitrates directive focused on input based measures such as the threshold amount of fertiliser applied per hectare of agricultural land, the WFD is an outcome based approach, focusing on achieving good ecological status. As there are numerous potential causes of deterioration in water quality, there is a need for an integrated approach to water quality policy implementation by all sectors of society. As such, information on all the factors affecting the level of water quality in river systems is a key requirement for the development of policy that will ensure the WFD target of all water bodies achieving at least "good ecological status" by 2015.

To date, research examining the major influences on the ecological quality of water sources has largely been focused on the agricultural sector. This research includes Fezzi et al. (2008) who undertook an integrated cost-benefit analysis of different policies to fulfill the requirements under the WFD in relation to the agricultural sector in Britain. Cuttle et al. (2006) quantified the cost of an inventory of alternative mechanisms in the UK to control diffuse water pollution from agriculture. Lennox et al. (1998) compared the incidence of agricultural water pollution in Northern Ireland with those in England and Wales. There has also been a wide range of research in other EU member states concerned with examining the effects of agricultural activity on water quality and the costs of strategies aimed at abating the negative impacts of agriculture (e.g. Vatn et al., 1997, 1999, 2006; Brady, 2003; Brouwer et al., 2008, Pulido-Velázquez et al., 2008; Volk et al., 2008).

Findings from these studies generally suggest that to meet WFD goals, agricultural practices will have to be changed drastically. Some suggested changes have included a reduction by 50% of the application of fertilisers to crops and grass, sheep stocking rates to be halved and a reduction in cattle stocking rates by 25% (Haygarth et. al., 2003; Bateman et al., 2006). However, the linkages between agricultural activities and water pollution are far from being clearly understood. As reported by Withers and Haygarth (2007), in discussing research assessing the contribution of agriculture to eutrophication across Europe:

> " The precise role of agriculture in eutrophication still remains poorly understood and accurate source apportionment at different scales and relevance to impacts remains a crucial gap in our research portfolio that needs addressing" (2007, p. 3)

In water quality assessments, the principal focus has been on examining the impact of the agricultural sector. There is, however, a wide variety of economic activities that can have a significant negative impact on water quality. One recent study which did attempt to examine the effect of a broader variety of factors on river water quality was by Donoghue et al., (2005). In this Irish study, the effect of residential density as well as agricultural intensity on the ecological quality of water was examined. Linking catchment characteristics and water chemistry with the ecological status of 797 hydrologically independent rivers throughout Ireland, Donoghue et al. found that both human settlement (in terms of urban land use and by extension, population density) and agricultural activities (in terms of pasture/arable land use and animal stocking density) were related to water quality. Goldar and Banerjee (2004) also assessed the impact of a diverse range of factors on water quality in India. This study found that industrialization, irrigation intensity and fertilser use were all negatively associated with water quality.

Given the multiple potential sources of poor water quality, it is important to examine the effect of a diverse range of factors on the ecological quality of water resources. Previous studies have often been limited in scope often focusing on the impact of changes in one particular sector (generally agriculture) or being focused on one specific river catchment when evaluating the determinants of water quality. This paper adds to this literature by combining a number of spatial datasets relating to agricultural, residential and industrial activities to determine the major factors affecting water quality throughout Ireland. More specifically, data from the EPA water quality monitoring stations throughout the country are combined with the 2000 Irish census of agriculture which provides spatial information relating to agricultural activity, the 2002 Small Area Population Statistics (SAPS) which also provides spatially referenced information on septic tank and population density data and finally forestry cover data from the forest service in a Geographical Information System (GIS) framework.

Utilising these datasets, the main factors associated with water quality in Irish rivers are assessed using an ordered probit model. It is hoped that providing a comprehensive understanding of the variety of human economic activities that influence water quality will be an important tool in the management of risk and will allow for more appropriate land use planning aimed at restoring and maintaining water quality as required by the WFD. The paper continues as follows: Section two outlines the variety of datasets used in this analysis. Section three provides an overview of the ordered probit methodology used in the modelling process. Section four continues with a discussion of the results from the ordered probit model. Finally, this paper concludes with a discussion of its main findings and their implications for land use planning.

DATA

In this section the data used in this paper and the manner in which the different data sources were combined in a GIS framework is outlined. These datasets include the EPA water quality monitoring (Q-value) data, spatially referenced industrial activity and septic tank distribution data from the 2002 SAPS, levels of agricultural activity from the 2000 Irish Census of Agriculture, and forest land cover data from the Forest Service.

The EPA Water Quality Classification System

In Ireland, the Quality Rating System has been used to monitor the ecological quality of streams and rivers since 1971 (Flanagan and Toner, 1972; McGarrigle et al., 2002). Over 3000 sites on some 13,200km of main river channel are included in the current national survey and assessed using the Quality Rating System to characterise water quality (EPA, 2008). The Quality Rating System is a method whereby a Quality-index is assigned to a river or stream based on macroinvertebrate data, but also takes into consideration aquatic macrophytes and phytobenthos. The possible scores (Q-values) range from 1, indicative of extremely poor ecological quality to 5, indicative of minimally impacted conditions (i.e. pristine/unpolluted). Such a compression of biological information inevitably results in a loss of meaningful information; however such a classification is essential if this information is to be meaningfully represented within an economic framework.

The connection between Q-values and orthophosphate concentrations in rivers has previously been used as the basis of national legislation with a view to controlling eutrophication in Irish waters (DELG, 1998). One further advantage of the Quality Rating System by the EPA is that it has established links with a number of specified elements in Annex V of the Water Framework Directive (Donoghue et al., 2005). The Q-values from a set of 2548 river sites that were monitored by the Irish Environmental Protection Agency in 2005 were analysed in this study. Where a mid point was used in rating the Q values for certain monitoring points the lower value was applied in the model presented later, i.e. if for example the rating was given as 1-2 rather than 1 or 2 then a value of 1 was taken for that monitoring point for the purpose of this analysis.

The Irish Census of Agriculture

The second dataset used in this paper is the Irish Census of Agriculture. The objective of the census is to collect data relating to agricultural activities on all farms within Ireland (CSO, 2002). The census classifies farms by physical size, type and geographical location. A key requirement in determining a geographic assessment of the respective contribution to water pollution from a sectoral perspective is the availability and resolution of spatial data pertaining to these sectors. In Ireland, the lowest level of spatial disaggregation for publicly provided data is at the Electoral Division (ED)[1] level. Of the 3,440 Electoral Districts in the country, 2,850 contain farms; the average number of farms in each of these ED's is 53 (min 10, max 320).

[1] Formerly known as District Electoral Division (DED). The term Electoral Division was changed on 24 June 1996 (Section 23 of the Local Government Act, 1994).

The specific variables from the census of agriculture used in this analysis include the proportion of farmland in each ED under crops, the number of pigs per hectare in each ED and finally livestock density in each ED. The main source of diffuse pollution from grassland based sectors such as livestock rearing come from the release of large amounts of nitrous oxide. The main sources of nitrous oxide are: nitrogen fertilsers and manure and urea deposited by grazing animals (Monteny et al., 2006). The figures for livestock density were combined with Irish EPA conversion factors for different livestock types to produce an estimate of organic nitrogen produced per ED. Whereas livestock production in Ireland is extensive in nature, pig farming tends to be more localized and intensive. As such a separate variable representing the intensity of pig production was included in the analysis. The final agricultural related variable utilized in this analysis was the intensity of cereal production. In contrast to grassland based farm activities, cereal production requires much larger applications of chemical fertilizers with higher concentrations of phosphorous and potassium.

Forestry Cover Data

To provide information on the level of forest cover within each ED a land cover classification for Ireland developed by Teagasc under the Forest Inventory Planning System and Irish Forest Soils (FIPS–IFS) project was used. The FIPS–IFS land-cover data set was developed using GIS and remote sensing, along with ground-truthing provided by field sampling. The mapping unit employed in the FIPS–IFS land-cover data set was 1 hectare. The main class in the FIPS–IFS land-cover data set that we include in our analysis is a combined variable for mature forestry and immature forestry and scrub. This forest cover GIS data has been updated by Farelly, (2007) to reflect spatial changes in forestry cover in Ireland in recent years. The forest cover data used in this paper therefore is representative of forestry in Ireland in 2005. In terms of water quality one might expect the level of forest cover in a catchment to contribute to measured water quality either positively by acting as a filter or negatively if there is active forestry felling or ground preparation taking place, thus leading to sediment erosion and nutrient runoff.

Small Area Population Statistics (SAPS)

The Central Statistics Office (CSO) as part of the National Census of Population collect data pertaining to the structure and services to residential dwellings in Ireland including the number of rooms per house, toilet facilities, internet connections and sewerage facilities in each ED. In relation to sewerage facilites, the EPA (2006) found that the presence of septic tanks, which are the main method for wastewater treatment in rural households, have a significant negative impact on water quality and therefore a variable representing the proportion of households in each ED that have septic tanks was included in the analysis.

It was also thought useful to include a measure of economic activity within each ED. The SAPS dataset classifies all workers within each ED under eight industry types: Agriculture, Forestry and Fishing, Manufacturing, Construction, Commerce, Transport and Communications, Public Administration, Education, Health and Social work or Other Industry. This allows one to quantify the number of workers within each industrial category in each ED. A variable representing the proportion of all workers belonging to each of these industrial categories was included in the ordered probit model. By combining the agricultural, forestry and census data described above with the associated Q values for the EPA monitoring stations, it is possible to examine the major economic factors affecting river water quality. To this end, an ordered logit model is developed where the dependent variable is river water quality as measured by the Q-value index.

METHODOLOGY

The EPA Q-value system uses an index from 1 to 5 to assess the ecological quality of water resources at each monitoring point. This results in an ordinal dependent variable that takes on five discrete values (5 means higher water quality status than 4, which means a higher status than 3, and so on). However, it is unlikely the distance between each of the categories will be constant. In other words, it may take a bigger change in an independent variable to get over the "threshold" into one category than it takes to get into the next category. An ordered probit model estimates both the effects of the independent variables (through the systematic component) and the thresholds of the dependent variable (through the stochastic component) at the same time.

Characteristics such as physical land use, population densities and economic activity of the river catchments, denoted X_i, determine the level of water quality, denoted Y_i, at the monitoring points in each catchment. The subscript i indicates the i^{th} water quality monitoring point, i = {1, …, n}. Yi is a scalar that takes the values of 1, 2, 3, 4 and 5. Larger values indicate higher water quality. Y is an (n x 1) vector indicating the water quality level at each monitoring point. The i^{th} element of the vector indicates the i^{th} water quality monitoring point's level. X_i is a vector with k elements. The letter k indicates the k^{th} independent variable, $k = \{1, ..., K\}$. X is an (n x k) matrix summarizing each river catchments economic and land use characteristics. The nth row indicates the characteristics of the nth catchment. Therefore, we can state that:

$$Y_i = f(X_i) \quad \forall \quad i = 1, \cdots, n$$

Since the dependent variable is an ordered, qualitative variable, we estimate the relationship between *Y* and *X* with an ordinal response model. Assume that the level of water quality in a river catchment, denoted Y_i*, is a continuous function of catchment characteristics, denoted X_i, a vector of parameters of dimension *(k x 1)*, denoted β, and a disturbance term, ε, which is normally, identically, and independently distributed, $\varepsilon \sim N(0, \sigma^2)$. Increasing values of Y_i* indicate an increasing level of water quality associated with that river system.

$$Y_i^* = \beta' X_i + \varepsilon$$

However, the EPA water quality data only records the categorical level to which the monitoring point belongs. The probabilities of falling into ordered Q-value categories, 1 to 5 are given by the following:

$$\Pr(Y_i = 1) = \Phi(\mu_1 - \beta' X)$$

$$\Pr(Y_i = 2) = \Phi(\mu_2 - \beta' X) - \Phi(\mu_1 - \beta' X)$$

$$\Pr(Y_i = 3) = \Phi(\mu_3 - \beta' X) - \Phi(\mu_2 - \beta' X)$$

$$\Pr(Y_i = 4) = \Phi(\mu_4 - \beta' X) - \Phi(\mu_3 - \beta' X)$$

$$\Pr(Y_i = 5) = 1 - \Phi(\mu_4 - \beta' X)$$

where the μ's are unknown threshold parameters (cut-points) to be estimated with β, and the ranking depends on certain measurable factors *x* and certain unobservable factors Є. Since the disturbances are normally distributed, these probabilities are distributed according to the cumulative normal distribution, Φ. The ordered probit model is estimated using the method of maximum likelihood via the Newton-Raphson algorithm (Long, 1997).

RESULTS

A description of the dependent and independent variables used in the ordered probit model are presented in Table 1 along with summary statistics for each. The coefficient estimates and associated standard errors for the chosen model specification are then presented in Table 2. The explanatory variables represent the weighted average of the variable in the 5 complete ED's or proportion of area of the 5 ED's just upstream of the water quality monitoring point and in the water catchment area of the river. The ordered probit analysis was conducted to determine the major factors affecting the ecological quality of water sources measured at the EPA water quality monitoring points in each river catchment.

As the dependent variable, the Q-value, is categorically ordered, an ordered probit model was utilised. This takes the explanatory variables and estimates the probability of being in each category of water quality status (1 to 5). The functional specification of the ordered probit model is as follows:

> *Pr (Water Quality level$_i$) = f (Septic Tank Density per ED$_i$, organic nitrogen production per hectare per ED$_i$, intensity of pig production$_i$, proportion of farmland under crops in each ED$_i$, the proportion of all workers in an ED in each of the following industries: Agriculture Forestry and Fishing$_i$, Manufacturing$_i$, Construction$_i$, Commerce$_i$, Transport$_i$, Public Administration $_i$, Education, Health and Social Work$_i$, Other Industry$_i$, Forest Cover in each ED$_i$ and finally two regional dummy variables (Shannon and Eastern).*

The coefficients of the ordered probit model only indicate whether the explanatory variables are positively or negatively related to improved levels of water quality status (Long, 1997). Marginal effects on the other hand tell us how much the probability of being in each water quality category changes for a one unit change in a particular variable, or for a discrete jump in a dummy variable. Both the coefficients (column 1) and marginal effects (column 2-5) for each water quality category are reported in Table 2.

Insert table 1 here

Insert table 2 here

The density of septic tanks is statistically significant at the 1% level and works in the anticipated direction; the higher the density of septic tanks in the relevant ED's the lower the value of the Q-value index at the monitoring point in the river catchment. In Ireland, wastewater from a significant proportion of the population (generally in rural areas) is treated by small-scale on-site systems (septic tanks) where connection to a sewer is unfeasible. The results in Table 2 would suggest that this system is currently unsustainable if goals in relation to water quality are to be achieved.

Grassland based farm enterprises, namely beef, sheep and dairy production dominant Irish agriculture and account for approximately 80 percent of overall agricultural output value. Large amounts of nitrous oxide from animal manure as well as urea are deposited by grazing animals on the land in these farm enterprises (Monteny et al., 2006). The results in Table 2 would suggest that the quantity of organic nitrogen produced per hectare in the associated ED's is statistically significant (at the 1% level) and negatively associated with measured Q-values. In addition, the intensity of pig farming was also negatively associated with water quality (significant at the 10%

level). Therefore, in line with other research the results suggest that the more intensive the farm livestock rearing enterprise is, as measured by organic nitrogen production per hectare or the intensity of pig production, the lower the likelihood of achieving a higher Q value.

In Ireland, the area devoted to tillage is relatively small at about 10 percent and it also represents about 10 percent of agricultural output in value terms. Whereas grassland based farm enterprises would deposit large amounts of nitrous oxide, the tillage sector would require much larger applications of chemical fertilizers with higher concentrations of phosphorous and potassium. Similarly to the amount of organic nitrogen produced in each ED, the proportion of land dedicated to cereal production was also found to be negatively associated with water quality (significant at 5% level).

In relation to industrial activities, the proportion of public administration (5% significance level) and construction workers (10% significance level) were negatively associated with water quality. The number of construction workers in each ED can be a good proxy for the level of construction activity and it would be expected that this would have a negative effect on water quality. It is difficult to determine, however, why the proportion of public administration workers would have a negative effect on water quality. A negative relationship between population density and water quality has been widely reported (Donoghue et al., 2006) and it could be that as most public administration employment is in urban areas then this variable is capturing the effect of population density.

There is substantial evidence within the census and from other sources (Lafferty et al., 1999; Matthews, 2000 and Hynes et al, 2008) of significant regional variation in farm structures and farm output across Ireland. The North West and West of Ireland for example has a relatively high concentration of small extensively operated, dry-stock farms. Given the similarities in terms of agricultural activity, the Western, South Western and North Western river basin districts were grouped into one regional dummy (Western) and held as the base or reference category (see figure 1 for a map of all the river basin districts in Ireland). The Eastern part of the country can be regarded as generally having larger, more intensive dairy and tillage farm holdings. Two further regional dummies were created based on the river catchments in the Eastern part of the country. More specifically, given similarities in relation to agricultural activity and geographical location the Shannon and South Eastern river basin districts were combined into one regional dummy (Shannon) and the Eastern, Neagh Bann and North Eastern river basin districts were also combined (Eastern).

Insert figure 1 here

The results in table 2 would suggest that there is a marked regional variation in relation to water quality as both of the river basin district dummies were statistically significant at the 1 per cent significance level. As can be seen in Table 2, the Shannon region was negatively associated with water quality as compared with the Western region (significant at the 1% significance level) whereas the Eastern region was positively associated with water quality (significant at the 1% significance level). This would indicate that even after controlling for agricultural and industrial activities, forest cover and septic tank density there would still seem to be significant regional variation in water quality. This highlights the importance of a spatial dimension to any analysis as factors affecting water quality will often differ across river catchments.

The finding that the Eastern region has a much higher probability than the Western region of having a satisfactory water quality condition (Q-value of 4 or 5) is interesting in the light of a recent EPA report that specifies that the river basins within the Eastern region have a much higher risk of failing to achieve ‘good ecological status’ as defined in the water framework directive (EPA, 2008). The river basin districts within the Eastern region would generally have much higher levels of agricultural intensity than the river basin districts within the Western region. It could be that once the intensity of agricultural activity is controlled for, as in the ordered probit model specified here, then other factors not included in the model specification explain differences in water quality between the regions. For example, there are a greater proportion of water treatment plants[2] in the eastern part of the country and this may explain some of the regional differences observed by the model.

The level of forest cover in each ED was found to be positively related with water quality (significant at the 1 % significance level). The level of forestry in an area can have a negative impact on water quality where there is active felling or ground preparation as this can lead to sediment and nutrient erosion. It would appear, however, that in this instance forestry acts as a filter and reduces the amount of nutrient runoff into the river systems. This result is consistent with Novotny (2003) who suggests that undisturbed forests or woodland represent the best possible protection for land from sediment and pollutant losses. Woodlands and forests have

[2] Data in relation to the number of wastewater treatment facilities in each ED was not available to be included in the analysis

low hydrologic activity, due to high surface storage in leaves (interception), ground, mulch, and terrain roughness. Novotny (2003) also points out that even lowland forests with a high groundwater table (containing wooded wetlands) absorb large amounts of precipitation and actively retain water and contaminants.

Looking at the marginal effects displayed in Table 2 it would appear that septic tank density and organic nitrogen production per hectare are the two most important explanatory variables in terms of predicting the likelihood of a river monitoring point having an unsatisfactory water quality condition. For example, a 1 per cent increase in septic tank density reduces the probability of a river monitoring point having a satisfactory water quality condition (Q-value of 4 or 5) by approximately 13 percent. A 1 per cent increase in organic nitrogen production per hectare reduces the probability of a river monitoring point having a satisfactory water quality condition by approximately 6 percent. In contrast to these variables, the marginal effects in table 2 indicate that the level of forest cover in each ED significantly influences the probability of a river monitoring point having a satisfactory water quality condition. For example a 1 percent increase in the level of forestry increases the probability of a river monitoring point having a satisfactory water quality condition (Q-value of 4 or 5) by approximately 6.5 percent.

DISCUSSION

This paper undertook an exploratory data analysis concerned with determining the effect of both agricultural and non-agricultural economic activities on the ecological quality of water resources. To achieve this aim, a number of spatial datasets relating to agricultural, residential and industrial activities as well as the level of forest cover were combined within a GIS framework. Results indicate that septic tank density, and variables related to agricultural activity such as the level of organic nitrogen per hectare, the proportion of land used for the growing of cereals and intensity of pig farming were all negatively associated with water quality. In addition, the numbers of construction and public administration workers in each ED were also negatively associated with water quality. It could be hyothesised that these variables are capturing the effect of construction activity and population density on water quality. One final variable included in this analysis was the degree of forest cover which was found to be positively associated with water quality.

In relation to the agricultural sector, this analysis would suggest that the intensity of farming has a significant negative impact on water quality which is supportive of previous work discussed earlier (see Fezzi et al., 2008; Cuttle et al., 2006 and Haygarth et al., 2003). Given the strong association between agricultural activity and water quality it has been widely reported that the agricultural sector will need to undergo significant structural change if WFD requirements are to be met. Some of these suggested changes include reductions in the use of fertilizers and a reduction in sheep and cattle stocking rates.

Recent policy changes to the CAP could conceivably lead to a much lower level of agricultural activity (Oglethorpe, 2005; Osterburg and von Horn, 2006). More precisely, under the mid term review (MTR) of the Common Agricultural Policy (CAP) in 2003, member states within the EU agreed to implement a system of single farm payments (SFP) which were decoupled from production (Ackrill, 2008). Under this new system, farmers are paid a lump-sum cash payment based on historical payments, whereby actual production is not needed to receive support. The move towards decoupling of payments can be seen as significantly reducing the incentive for farmers to produce. This disincentive could, in turn, lead to a significant reduction in the intensity of farming practices (Howley et al., 2010a). For instance, it has been estimated that as a result of the move towards decoupling, the numbers of suckler cows and sheep will fall by 25 and 42 per cent respectively between 2005 and 2020 in Ireland (see Howley et al., 2010b). That said, while the agricultural sector is set to undergo significant structural changes as a result of recent changes to the CAP it is unlikely that these changes will be enough to fulfil requirements under the WFD.

In relation to the residential sector, it is also clear that the main option available for rural households when it comes to treating waste, namely septic tanks, is having a significant negative effect on the ecological quality of water resources. It is interesting to note that the effect of a 1 percent change in septic tank density on water quality was two times greater than a similar reduction in organic nitrogen associated with livestock density. The analysis presented here would suggest that appropriate forest management can have a beneficial impact on the ecological quality of water resources. Benefits such as open access recreation have often been put forward as a non-market benefit of forests and this analysis would suggest that benefits in relation to water quality could be one further advantage of good forest management.

To sum up, the analysis presented in this paper highlights the important relationship between land use and water quality. In particular, the level of forestry, construction activity, population density, the intensity and type of agricultural activity and the type of wastewater treatment in an area are all critical factors affecting the quality of our water sources. Moreover, the results highlight the importance of a spatial dimension to any analysis as the principal factors affecting water quality will often differ across river catchments. It is clear from this analysis that no one sector is responsible for adverse water quality and in turn the solution will depend on a multi-sectoral approach aimed at addressing the multitude of factors affecting water quality. In this regard, it is hoped that the analysis provided here will be an important tool in the management of risk and will allow for more appropriate land use planning aimed at restoring and maintaining water quality as required by the WFD.

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LIST OF TABLES

Table 1. Description and summary statistics of variables in Ordered Probit Model

Variable	Description	Mean	St. Dev.
Q-value	EPA Quality Classification score (1 to 5)	3.79	0.57
Septic Tank Density	Quantity of Septic tanks per ED	5.17	2.94
Organic nitrogen	Quantity of Organic nitrogen produced per hectare per ED (Kg)	107.49	38.55
Cereal production	Proportion of farmland in each ED under crops	0.07	0.11
Pig production	Number of pigs per hectare per ED	0.14	1.76
Agriculture, Forestry and Fishing	Proportion of all workers in ED working in Agriculture, Forestry and Fishing	0.19	0.09
Manufacturing	Proportion of all workers in ED working in Manufacturing	0.12	0.05
Construction	Proportion of all workers in ED working in Construction	0.17	0.06
Commerce	Proportion of all workers in ED working in Commerce	0.18	0.06
Transport	Proportion of all workers in ED working in Transport	0.04	0.02
Public Administration	Proportion of all workers in ED working in Public Administration.	0.05	0.03
Education, health and social work	Proportion of all workers in ED working in Education, health and social work	0.14	0.05
Other Industry	Proportion of all workers in ED working in other industry types	0.11	0.06
Forest cover	Proportion of the land cover in each ED provided by trees, shrubs or brambles.	0.12	0.12

Table 2. Base Ordered Probit: Coefficients and Marginal Effects

Dependent Variable: Water Quality	Base Version	$\frac{\delta 1}{\delta x}$	$\frac{\delta 2}{\delta x}$	$\frac{\delta 3}{\delta x}$	$\frac{\delta 4}{\delta x}$	$\frac{\delta 5}{\delta x}$
Septic Tank Density (-0.0590)	-0.360***	0.00245	0.02022	0.11431	0.12776	0.00245
Organic nitrogen (-0.0696)	-0.167**	0.00114	0.00938	0.05301	0.05925	0.00114
Cereal production (-0.0204)	-0.104***	0.00071	0.00583	0.03297	0.03685	0.00071
Pig production (0.00522)	0.00953*	0.00006	0.00054	0.00303	0.00338	0.00006
Agriculture, Forestry and Fishing (0.0178)	0.0202	0.00014	0.00113	0.00641	0.00717	0.00014
Manufacturing (0.0160)	0.0234	0.00016	0.00132	0.00744	0.00831	0.00016
Construction (0.0225)	-0.0430*	0.00029	0.00242	0.01366	0.01527	0.00029
Commerce (0.0279)	-0.0122	0.00008	0.00068	0.00386	0.00432	0.00008
Transport (0.0110)	0.000678	0.00000	0.00004	0.00022	0.00024	0.00000
Public Administration (-0.0229)	-0.0533**	0.00036	0.00299	0.01693	0.01892	0.00036
Education, Health and Social Work (0.0488)	0.0594	0.00040	0.00334	0.01886	0.02108	0.00040
Other (0.0330)	0.00310	0.00002	0.00017	0.00099	0.00110	0.00002
Forest cover in each ED (0.0286)	0.182***	0.00124	0.01024	0.05792	0.06473	0.00124
Shannon/South Eastern river catchments (0.0600)	-0.223***	0.00167	0.01325	0.07056	0.08009	0.00167
Eastern/Neagh Bann river catchments (0.0640)	0.209***	0.00124	0.01072	0.06609	0.07198	0.00124
Observations: 2424, Log likelihood -3387.8692,						
Standard error in brackets, * significant at 10%; ** significant at 5%, ***significant at 1%						

Figure 1: River Basin Districts