Water Quality under Land Use Pressure: Economic and Institutional Perspectives

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Abstract

Recent drought episodes have underscored growing tensions in water resource management. These supply pressures coincide with mounting concerns over water quality, as both climate change and land use practices contribute to the degradation of surface and groundwater. Agriculture, in particular, has been singled out for its role in nitrate and pesticide contamination. This article investigates the economic and institutional determinants of raw water quality in France, with a specific focus on agricultural land use. Using spatial econometric models and a panel dataset covering the Rhin-Meuse basin from 2008 to 2023, we assess the extent to which agricultural activity influences nitrate and pesticide concentrations in water catchments. We also examine how social, geographic, and governance factors interact with land use patterns to shape pollution outcomes. Spatial spillover effects are explicitly accounted for, highlighting the role of neighborhood externalities in the degradation or protection of water resources. Our findings reveal that...

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1 Introduction

The sustainable management of drinking water is an increasingly urgent challenge, particularly in the face of intensifying climate change. Rising temperatures and prolonged droughts are placing unprecedented pressure on freshwater resources, raising critical concerns about the organization and governance of water supply services. In France, the summer of 2023 provided a stark illustration of these vulnerabilities: 343 municipalities required emergency water deliveries, and 90% of the country was subjected to water restrictions. Meanwhile, the French Ministry for the Ecological Transition reports that roughly one billion cubic meters of drinking water are lost annually through leaks in public distribution networks—equivalent to the yearly consumption of 20 million people.

Before being treated for human consumption, drinking water is extracted from surface water or groundwater sources. Yet the quality of these raw water sources raises growing concern: in 2024, 2,700 French catchment areas were classified as priority sites due to chronic contamination by phytosanitary products and nitrates, highlighting widespread diffuse pollution and increasing pressure on water treatment systems. Local governments, as key actors in water service provision, are directly involved in managing these challenges and ensuring safe and sustainable supply.

Municipalities are the primary authorities responsible for drinking water provision in France. In accordance with the principle of local public service autonomy, they may choose to manage the service directly or delegate it to private operators via contractual arrangements. However, the extreme fragmentation of the French municipal landscape—comprising over 34,000 municipalities—raises significant challenges in terms of economies of scale, technical expertise, and regulatory compliance. From a neo-institutionalist perspective, such fragmentation increases transaction costs, limits institutional capacity, and exacerbates coordination failures across jurisdictions (Oliver, 1991; North, 1990). In particular, small-scale service provision can result in inefficiencies due to bounded rationality and information asymmetries, especially when environmental externalities are spatially diffuse.

To address these limitations, intermunicipal cooperation (IMC) has become a cen-

tral mechanism of institutional adaptation. They allow municipalities to pool resources, reduce duplication, and internalize externalities through collective action. In line with theories of polycentric governance and institutional complementarity (Ostrom, 1990), IMCs are expected to improve the alignment between ecological scales (e.g., catchment areas) and administrative competencies. They provide a framework for transaction cost minimization (Williamson, 1985), enhance mutual monitoring, and foster learning among local actors. As such, understanding how IMC interacts with land use dynamics is crucial for explaining territorial variations in water quality outcomes and the effectiveness of local environmental governance.

Beyond governance, land use constitutes a critical determinant of raw water quality. The spatial organization of landscapes surrounding water catchments influences the mobility of pollutants and the vulnerability of surface and groundwater resources. Among land cover types, agriculture is the most significant contributor to diffuse pollution, due to the widespread use of nitrogen-based fertilizers and phytosanitary products (Tong and Chen, 2002; Lerner and Harris, 2009). These chemical inputs often leach into aquifers or are carried by surface runoff during rainfall events, especially when combined with soil compaction and inadequate vegetative buffers (Veron, 2024; Feuillet and Michon, 2016).

From a policy standpoint, nitrates and pesticides are among the most frequently monitored pollutants in Europe, owing to their persistence and health risks. Under the EU Drinking Water Directive and Nitrates Directive, maximum concentration thresholds have been established (e.g., 50 mg/L for nitrates), prompting stricter monitoring and remediation in affected zones. Elevated levels of these contaminants in raw water increase treatment costs and can threaten compliance with regulatory standards (Abildtrup et al., 2013; Honey-Rosés et al., 2014). Consequently, land use patterns are not merely background variables but central elements in understanding the ecological and economic dimensions of drinking water governance.

This paper examines how agricultural land use and governance structures jointly influence the quality and costs of raw water. Using an original dataset for the Rhin-Meuse basin in France (2008–2023), we implement a two-step empirical strategy. In the first step, we model the impact of land use, climate, and socioeconomic factors on

water quality, using nitrate and pesticide concentrations as indicators. In the second step, we assess how predicted water quality affects drinking water prices, incorporating governance variables and spatial spillover effects.

We aim to answer the following research questions: (i) How does agricultural land use patterns affect the concentration of pollutants in raw water sources? (ii) What is the economic impact of degraded water quality on drinking water prices? (iii) How do institutional configurations—notably the interaction between IMC and private management—shape these outcomes?

Our findings indicate that ... (to be completed). We also find strong evidence of spatial dependencies in both water quality and pricing, highlighting the importance of coordinated policies across neighboring jurisdictions.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on land use, water quality, and water governance. Section 3 outlines the institutional context in France. Section 4 and 5 detail the data and empirical methodology. Section 6 presents the results and their policy implications. Section 7 concludes.

2 Literature review

A growing literature has investigated the determinants of water quality, highlighting its dependence on a combination of economic, spatial, and institutional factors. The provision of water services, as a local public good, involves both technical efficiency considerations and complex externalities related to resource quality and environmental protection. In this context, the quality of raw and treated water has emerged as a key outcome variable in the analysis of public utility performance and regulatory effectiveness.

While water services in France operate within a relatively robust institutional and regulatory framework - defined at both national and European levels - empirical evidence points to persistent disparities in water quality across territories. These variations reflect the differentiated capacity of local actors to address pollution pressures, implement protection measures, and manage infrastructural constraints. They also raise important questions about the alignment between ecological challenges and governance

structures. A growing body of empirical and theoretical work seeks to understand how local institutions, land use patterns, and interjurisdictional coordination jointly shape environmental outcomes and the cost of public service provision.

2.1 Technical and institutional factors

Drinking water services supply drinking water to the population by extracting raw water from the ground. During this process, the water flows through pipelines and undergoes treatment. To maintain water quality, the distance it travels through the distribution network should be minimized as much as possible. Therefore, in most countries, municipalities are tasked with overseeing the management and regulation of water quality. Ensuring efficient production and distribution requires them to possess adequate technical capabilities.

First, network length is a key determinant of water quality, as resource quality deteriorates with the distance traveled. Destandau and Garcia (2014) highlights the critical issue of heterogeneity among water utilities. Water quality can vary significantly depending on the specific characteristics of each utility, as network length and infrastructure renewal differ across local governments. Beyond the distance traveled by the resource, interconnections between services matter too. Interconnections involve the reciprocal linking of distinct distribution units to ensure supply continuity and to enhance both the qualitative and quantitative security of drinking water provision for each interconnected unit. Kiliç (2021) empirically shows that they are negatively correlated with water quality.

The treatment processes applied to raw water to make it drinkable are, unsurprisingly, key determinants of water quality. However, the volume of water circulated through the distribution network also plays a significant role. Research on water utilities showed that maintaining high water quality depends on an optimal network design and appropriate water turnover rates. A study by Carabeț et al. (2011) indicates that factors such as flow dynamics and volumes introduced in the network play a significant role in contamination risks, disinfection effectiveness, and the overall quality of drinking water. Finally, the age and deterioration of the drinking water distribution network are crucial factors influencing drinking water quality: the older the distribution network,

the more likely the quality of drinking water is to deteriorate (Denis and Florentin, 2024).

The management model (public or private) is a key variable in previous studies assessing both drinking water quality and the technical efficiency of the sector. The findings consistently indicate a significant impact of private management on water quality. While Fu et al. (2020) show that publicly managed water services tend to be less compliant with microbiological quality thresholds, Le Lannier and Porcher (2014) and Maziotis and Molinos-Senante (2024) highlight that publicly managed services demonstrate greater environmental responsibility and adopt more sustainable water management practices in accordance with quality standards. However, these results must be interpreted in light of population density, as noted by Benito et al. (2019), who finds that higher population density positively influences both environmental efficiency of the sector and the quality of the resource. More specifically, higher population density tends to degrade water resource quality, as it necessitates more extensive and complex water treatment facilities. Consequently, services may face challenges in maintaining consistent quality standards under high demand.

2.2 Climate change and soil management influence

Land uses and water quality are closely related since nitrate levels are low under forest cover. Nitrates are among the most closely monitored pollutants in drinking water, and the European Directive of November 3, 1998, on the quality of water intended for human consumption set the maximum allowable nitrate concentration at 50 mg/L. In an empirical study, Fiquepron et al. (2013) assess a positive relationship between land use, forest presence, and water quality. Their analysis goes further, showing that afforestation can lead to a reduction in the average household drinking water bill by €22 per year.

These findings align with the conclusions of Hascic and Wu (2006); Langpap et al. (2008); Phiri et al. (2020), who identify a significant relationship between raw/drinking water quality and land use. According to Feuillet and Michon (2016), between 1997 and 2013, a total of 7,716 water catchments were decommissioned in France, primarily due to pollution. In these affected catchments, pollutant concentrations exceeded the

drinking water standards established by the French Ministry of Health. Lerner and Harris (2009) found that inappropriate land use and particularly poor land management lead to chronic groundwater quality problems.

Tong and Chen (2002) build on this by arguing that runoff, which is closely linked to land use patterns, is a major source of nonpoint source pollution. The agricultural sector, in particular, is considered the largest contributor to water pollution through runoff and the leakage of nutrients, sediments, pesticides, and other contaminants. Hascic and Wu (2006) support this finding, observing that runoff from agricultural land is the primary cause of water pollution. Moreover, Abildtrup and Strange (2000) showed that forest land use is generally associated with the protection of water resources from contamination and with lower drinking water supply costs. Similar conclusions were reached by Ernst et al. (2004), who highlighted the crucial role of forests in maintaining raw water quality.

Binkley and Brown (1993) argue that cultivated lands release more than five times as much sediment into waterways as forested areas, which, in turn, tend to occupy the most integral parts of the watershed. More recently, Veron (2024) showed that French public policies regarding the protection of water catchment areas lack coherence, which may have negative consequences for resource quality. Consequently, estimating drinking water quality without accounting for land uses and catchment areas may lead to biased results.

More broadly, the impact of climate change is becoming a central factor in the analysis of drinking water quality. An extensive literature review by Delpla et al. (2009) highlights that climate change can directly affect water quality through various mechanisms. First, rising temperatures lead to an increased frequency of drought events. Van Vliet and Zwolsman (2008); Van Vliet et al. (2023) establish a significant relationship between temperature rise and the physico-chemical quality of drinking water, showing that higher temperatures contribute to quality deterioration. The same pattern is observed for nutrient levels (Wilhelm and Adrian, 2008) and microbiological quality (Charron et al., 2004). Finally, Hamid et al. (2020) expand on this analysis by identifying local determinants of drinking water quality. According to their findings, temperature and land use must be incorporated into water quality assessments, as they

play a crucial role in driving its spatio-temporal variations.

3 The French institutional context

3.1 Overview of the French water sector

The management of raw and drinking water is governed by a strict institutional and regulatory framework operating at multiple scales. In Europe, key directives have been adopted to standardize and systematize water quality monitoring. The Water Framework Directive[1] established a comprehensive framework for water policy across the European Union, aiming to protect and enhance the status of aquatic ecosystems while promoting the sustainable use of water resources. It introduced a paradigm shift from a purely sectoral or administrative management of water toward an integrated, river basin–based approach. One of its core innovations is the requirement to achieve "good status" for all surface and groundwater bodies, both in terms of ecological and chemical quality, by explicitly linking environmental objectives with economic instruments such as cost recovery and the "polluter pays" principle (Kaika, 2003).

In France, municipalities are administratively responsible for the provision of drinking water. In other words, water supply and sanitation services (including wastewater collection and treatment) are public services managed at the municipal level, under the authority of the mayor.

In France, the Water and Aquatic Environments Act[2] (LEMA) was enacted to align domestic water policy with the EU Water Framework Directive and strengthen integrated basin-scale governance. Notably, LEMA introduced the concept of Organismes Uniques de Gestion Collective (OUGC) for irrigation in aquifers under structural water deficits—especially in areas dominated by agriculture—to regulate water allocations among users more effectively (Figureau et al., 2014). It mandated the creation of protection perimeters around drinking water catchments and enabled the sequencing of land-use regulations—such as compulsory buffer strips, nutrient management plans, and phytosanitary product tracking—to curb nitrate and pesticide leaching. Despite such provisions, challenges persist due to fragmented land ownership, varying enforcement

[1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000.
[2] Law No. 2006-1772 of 30 December 2006.

levels, and the political sensitivity of regulating agricultural practices, as observed by national water agencies (Figureau et al., 2014).

In practice, some local authorities delegate the development and operation of these public services to private companies. Public service delegation involves the transfer of operational responsibility to a private operator, who assumes the financial risk and retains the revenue generated by the service. This arrangement typically entails a comprehensive transfer of service management or infrastructure operations, while core public authority responsibilities remain with the municipality. A municipality's decision to delegate its water service is rarely random and can be influenced by several factors. Financial considerations are often decisive: when facing high levels of debt and lacking the means to maintain the water system, a municipality may opt for delegated management. In addition, increasingly strict regulations governing equipment standards, personnel management, safety, and legal liability may encourage local authorities to outsource the service in order to navigate complex legal requirements.

Moreover, the technical complexity of water service provision and the expertise required—both of which can entail substantial costs—may lead municipalities to delegate the service to benefit from the efficiency, infrastructure quality, and technical competence offered by private operators. However, delegation also involves various risks, including commercial risk and uncertainties related to construction and operational performance, which must be factored into the decision.

Because drinking water is sourced from natural resources, it is essential to protect these resources to prevent pollution and to avoid the need for complex and costly water treatment processes. In this context, public authorities have established procedures for declaring water catchments to be of public interest, which includes the creation of legally protected zones around water abstraction points. These procedures are now mandatory for all public water sources intended for human consumption.

Each catchment area has a specific "recharge zone," referring to the territory from which infiltrated or runoff water feeds the source. This zone is the priority area for protecting the water resource from diffuse pollution. Protected zones are a key tool for preventing and reducing contamination that could compromise the quality of water extracted. Responsibility for establishing and managing these protected areas lies with

the local authorities that own the water abstraction points.

In France, drinking water is managed through water supply services. To ensure effective management, municipalities can form inter-municipal associations or joint bodies, such as water syndicates or municipal communities. These groupings may manage the service directly with their own staff—this is referred to as direct public management. Alternatively, they may enter into delegation contracts with specialized private companies. Although France has relatively abundant water resources, delivering potable water to every household remains a complex and costly undertaking. Drinking water treatment increasingly relies on advanced technologies. The water bill paid by French consumers covers not only the treatment and distribution of drinking water but also wastewater treatment and environmental protection efforts.

3.2 Needs and limitations of the French agricultural sector

Freshwater consumption in France—defined as the share of water withdrawn but not returned to aquatic ecosystems—is unevenly distributed across economic sectors. According to national water accounting data, agriculture is by far the largest consumer, accounting for 58% of total freshwater use between 2010 and 2019. This is followed by domestic water production (26%), energy generation—primarily for cooling in thermal power plants (12%)—and industrial uses, including tourism and agri-food processing (4%) (ONEMA, 2016; Eaufrance, 2023).

The agricultural sector's dominance in water use is consistent with its macroeconomic weight in France. A 2024 report from the French National Institute of Statistics and Economic Studies (INSEE) confirmed that France remains the leading agricultural producer in the European Union. In 2022, French farms generated €88.2 billion in agricultural output, with €56.9 billion from crop production and €31.4 billion from animal production. France alone accounted for 17.9% of the EU's total agricultural value. Since 1980, the structure of French agricultural production has shifted markedly, with crop production increasing from 54% to 61% of total output, while the share of livestock has declined from 42% to 33%. Meanwhile, agricultural services—such as landscape management and on-farm processing—have doubled, albeit from a low base (from 3% to 6%).

This structural evolution raises pressing environmental concerns, particularly in the context of increasingly frequent droughts and mounting water scarcity. Intensive agricultural practices are among the primary sources of nonpoint pollution in surface and groundwater bodies (Tong and Chen, 2002; Lerner and Harris, 2009). The widespread use of pesticides and synthetic fertilizers contributes to elevated levels of nitrates and phytosanitary residues, which often infiltrate water catchments and necessitate more advanced and costly treatment processes by drinking water utilities (Fiquepron et al., 2013; Honey-Rosés et al., 2014). These additional treatment costs may ultimately be passed on to consumers through higher water tariffs, creating a spatially and socially uneven burden of environmental degradation.

In recent years, a growing number of farmers have adopted more environmentally friendly practices. As of January 2023, more than 36,000 farms in France were certified under the High Environmental Value (HVE) label, and over 60,000 were engaged in certified organic farming—a number that has increased 2.5-fold in the last decade (Veron, 2024). While these trends are promising, they do not eliminate environmental externalities entirely. Even under organic or HVE-certified systems, nutrient runoff and pesticide residues may persist depending on crop type, soil conditions, and climatic variability. As such, the actual effectiveness of these certification schemes in protecting water quality remains an open empirical question.

4 Data and sample

4.1 Dependant variables

Price. The variable representing the price of drinking water paid by consumers was derived from the SISPEA database (Information System on Public Water and Sanitation Services). This dataset covers the period 2008–2023 and compiles information annually reported by local water utilities. In accordance with the French General Code of Local Authorities, all water services are legally required to produce and disclose an annual report on the quality and price of drinking water, thereby ensuring transparency for consumers.

The unit price per cubic meter is calculated based on an annual consumption of 120

m^3. Set by local public authorities, the price reflects multiple determinants, including the nature and quality of the water resource, geographical conditions, population density, the chosen level of service, infrastructure renewal policies, and the scale and financing of investments. This price encompasses all components of the water service — production, transmission, and distribution — together with the fees levied by the Water Agencies for resource preservation and pollution control. Where applicable, it also includes the charges collected by Voies Navigables de France for surface water abstraction, as well as the value-added tax (VAT). The water price variable used in this study refers to the portion of the household bill attributable solely to drinking water services, excluding the component related to wastewater treatment.

The price, set by local authorities and public agencies, represents a descriptive indicator of the drinking water service. It results from multiple factors, some of which are context-specific, such as the quality of the raw water resource. Land-use patterns within the catchment area may exert an indirect influence on this price by affecting water quality and, consequently, the treatment costs required to ensure drinkable standards.

Quality. The data on raw water quality used in this study were obtained from the Naïades database, the national repository for surface and groundwater monitoring in France. Naïades compiles measurements produced by a wide range of public and private entities for regulatory, research, or operational purposes. Each record distinguishes between the data producer—the institution commissioning the monitoring activity—and the operators responsible for field sampling and laboratory analysis. In most cases, water agencies, regional environmental directorates (DREALs), or accredited laboratories act as producers, while sampling and analytical work may be performed either in-house or by external contractors. All measurements follow standardized national protocols for physico-chemical and hydrobiological parameters, ensuring the comparability and reliability of the dataset across sites and over time.

The Naïades database provides several types of water quality measurements, including physico-chemical, hydrobiological, and hydromorphological indicators. Among these, the physico-chemical data are the most systematically reported and cover the longest continuous time series, particularly for the Rhine-Meuse river basin. For this

reason, our analysis focuses on raw water measurements of nitrates and pesticides, which are key indicators of agricultural and land-use pressures on water resources. In Naïades, pesticide contamination is recorded as the sum of quantified pesticide concentrations, expressed in micrograms per liter (µg/L). This aggregate measure corresponds to the cumulative concentration of all individual pesticide substances detected in a given sample, following national monitoring protocols established by the French Water Agencies and the Ministry for Ecological Transition. These measurements are obtained through laboratory analyses of water samples collected at defined monitoring points within the catchment area, and they are subject to standardized procedures ensuring comparability across years and locations. Nitrate levels are measured in milligrams per liter (mg/L) using similar protocols.

Based on these continuous indicators, we construct binary variables identifying whether a given water sample exceeds the official quality thresholds defined by the European Drinking Water Directive (EU Directive 2020/2184) and transposed into French environmental regulation. For nitrates, the quality standard is set at 50 mg/L, above which water is considered non-compliant for human consumption. For pesticides, the limit is defined as 0.1 µg/L per individual substance and 0.5 µg/L for the sum of all detected pesticides. Each observation is therefore assigned a value of 1 if the concentration exceeds the corresponding regulatory threshold, and 0 otherwise. These binary indicators allow us to capture episodes of water quality deterioration and to link them empirically to local governance structures, land-uses and characteristics of water services.

4.2 Explanatory variables

Land uses. The Corine Land Cover (CLC) dataset provides a harmonized biophysical inventory of land use and land cover across Europe. It is produced through visual interpretation of satellite imagery with a spatial resolution of approximately 20 meters, following a 44-class nomenclature established at the European level. The dataset maps homogeneous land-cover units with a minimum mapping area of 25 hectares (5 hectares for detected land-cover changes). Initiated in 1985 under the Copernicus Earth Observation Programme, CLC supports the consistent monitoring of land-use changes across

Member States and the development of European environmental policies.

In this study, we use CLC data to characterize the land-use composition of each catchment area. We focus on four aggregated land-use categories: (1) forests and semi-natural areas, (2) agricultural land, (3) artificial surfaces (mainly urban and industrial zones), and (4) other land uses, including wetlands and water bodies. These categories capture the dominant land-use patterns likely to influence raw water quality, particularly through their indirect effects on nutrient runoff, pesticide diffusion, and hydrological dynamics. Furthermore, by comparing CLC layers over successive years, we are able to analyze land-use transitions within catchment areas—most notably, the conversion of agricultural land into forested areas or into urban and industrial zones. These transitions are particularly relevant for understanding the evolving pressures on water resources and the long-term environmental impacts of land-use change.

The Registre Parcellaire Graphique (RPG) is a detailed geographical database that serves as the national reference for administering the Common Agricultural Policy (CAP) subsidies in France. It provides geospatial information on agricultural plots, including their location, crop type, and the characteristics of the farms that declare them. These data make it possible to construct indicators describing the structure and intensity of agricultural activity within each catchment area. In particular, the RPG allows us to distinguish between conventional and organic farming practices, the latter being generally associated with lower pesticide use and thus considered less harmful to raw water quality. Based on these data, we also derive a variable representing the number of agricultural holdings within each area, which serves as a proxy for the density and fragmentation of farming activity. The combination of these indicators provides a more refined understanding of how agricultural practices and structures interact with land-use patterns and environmental pressures on water resources.

5 Empirical strategy

We implement a two-step empirical strategy to assess how land use and institutional arrangements affect both water quality and pricing, while accounting for spatial dependencies.

In the first step, we estimate panel models that explain variations in water quality—measured by nitrate and pesticide concentrations—as a function of land use, climate, and socioeconomic characteristics. We use the following econometric specifications:

$$\text{Nitrates}_{it} = \alpha_i + \beta \text{LU}_{it} + \gamma \text{Climate}_{it} + \delta \text{Socio}_{it} + \rho W X_{it} + u_{it}$$

$$\text{Pesticides}_{it} = \alpha_i' + \beta' \text{LU}_{it} + \gamma' \text{Climate}_{it} + \delta' \text{Socio}_{it} + \rho' W X_{it} + v_{it}$$

where LU_{it} represents land use variables (agricultural, forest, urban, others), $Climate_{it}$ includes meteorological variables (e.g., temperature, precipitation), and $Socio_{it}$ captures demographic and economic characteristics. WX_{it} denotes spatially lagged variables to capture neighborhood spillover effects.

In the second step, we estimate the economic impact of water quality by modeling drinking water prices as a function of predicted nitrate and pesticide levels, land use, control variables (e.g., population, volume of water distributed), and governance configurations:

$$\text{Price}_{it} = \mu_i + \theta \widehat{\text{Quality}}_{it} + \lambda LU_{it} + \beta X_{it}^k + \rho W X_{it} + \varepsilon_{it}$$

To test governance effects, we include interaction terms between inter-municipal cooperation structures (EPCI) and private management indicators:

$$\text{Price}_{it} = \cdots + \phi(EPCI_{it} \times PrivateMgmt_{it}) + \cdots$$

This allows us to identify whether private management embedded within inter-municipal frameworks moderates the impact of water quality on pricing.

6 Discussion

Preliminary results suggest a strong and significant association between land use and water quality indicators. Agricultural land is positively associated with nitrate and pesticide concentrations, consistent with the runoff hypothesis. In contrast, forest cover

appears to mitigate pollution levels, confirming its protective role for water sources.

We also find that degraded water quality—especially due to pesticides—translates into higher drinking water prices. This reflects the increased treatment costs required to meet quality standards. Spatial spillover effects are significant, indicating that water quality in one municipality is influenced by conditions in neighboring areas. This spatial interdependence justifies coordinated land-use and water protection policies.

The interaction between governance structures and water pricing provides further insights. In municipalities where private operators manage the service within inter-municipal structures, price increases associated with poor water quality tend to be more pronounced. This may be attributed to cost-driven pricing by private firms and weaker incentives to implement preventative environmental measures compared to publicly managed entities.

7 Conclusion

This study highlights the complex relationships between land use, water quality, and the cost of drinking water services. Our preliminary findings emphasize that both natural and institutional factors jointly shape outcomes in this sector. Agricultural intensification and urban expansion exert pressure on water quality, while forested landscapes offer valuable ecosystem services that help maintain clean sources.

From an economic standpoint, poor water quality leads to significant cost externalities that are reflected in consumer prices. Furthermore, spatial interdependencies across municipalities call for cooperative governance models that transcend administrative boundaries.

Policy implications include: (i) integrating land-use planning into water management strategies, (ii) promoting afforestation or buffer zones near catchment areas, (iii) incentivizing pollution reduction in agriculture, and (iv) strengthening inter-municipal collaboration, especially under public management schemes, to ensure equitable and sustainable water services.

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