In the Ontario Greenbelt's Green-keeping: Evaluation of its Impact on Groundwater Pollution and Environmental Conservation.[*†]

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Abstract

This study investigates the impact of the Ontario Greenbelt, a major land-use planning policy, on surface water quality in Southern Ontario, Canada. Using a novel dataset that combines high-resolution water quality monitoring data with detailed information on watercourse characteristics and census boundaries, we estimate the causal effect of the Greenbelt on key pollutants, including Biological Oxygen Demand (BOD), Chromium, Lead, and Cadmium. Our identification strategy exploits the spatial discontinuity in the Greenbelt's coverage and compares pollution levels upstream and downstream of the Greenbelt boundaries. We find that the Greenbelt significantly reduced BOD levels in river segments with a higher share of the protected area. The results are robust to various specifications for BOD. Placebo tests using heavy metal pollutants confirmed the theoretical prediction that the Greenbelt would primarily reduce BOD than heavy metals. An event study analysis reveals that the reduction in BOD persists over time, with the treatment effects remaining stable after the Greenbelt's implementation. Our findings highlight the potential of land-use planning policies to generate significant environmental benefits and provide valuable insights for policymakers and researchers interested in the design and evaluation of effective environmental conservation strategies.

Keywords: Land-use planning; Ontario Greenbelt; Surface water quality; Biological Oxygen Demand; Quasi-experimental methods

JEL Classification: Q53, Q58, R52, C21

1 Introduction

In an era of rapid urbanization and growing environmental concerns, urban containment policies like greenbelts have emerged as crucial tools for promoting sustainable development and preserving natural resources. These policies aim to curb urban sprawl, protect ecologically sensitive areas, and maintain the delicate balance between human activities and the environment (Amati, 2008; Carter-Whitney, 2010). Among such initiatives, the Ontario Greenbelt stands out as a remarkable example, being the largest protected greenbelt in the world (Greenbelt Foundation, 2021). Established in 2005, the Ontario Greenbelt encompasses a vast area of 2 million acres, stretching across the Golden Horseshoe region in Southern Ontario, Canada (Ministry of Municipal Affairs and Housing, 2017). This ambitious land-use planning policy seeks to safeguard prime agricultural lands, forests, wetlands, and watersheds from the pressures of urban development, while also providing a range of ecological, social, and economic benefits to the region (Tomalty, 2012; Vyn, 2012).

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[†]For updates on this article and access to the replication package, please refer to the repository linked here

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Despite the Greenbelt's significant role in shaping the landscape and influencing land-use patterns in Southern Ontario, there remains a paucity of empirical research examining its effectiveness in achieving its environmental conservation goals. While some studies have investigated the Greenbelt's impact on housing prices (Deaton & Vyn, 2010; Vyn, 2012), agricultural practices (Akimowicz et al., 2016), and land-use changes (Pond, 2009), there is a notable gap in the literature regarding its direct effects on environmental quality indicators, particularly surface water pollution. Given the Greenbelt's explicit aim to protect water resources and maintain ecological integrity (Ministry of Municipal Affairs and Housing, 2017), it is crucial to assess its performance in this regard.

This study aims to address this research gap by empirically evaluating the impact of the Ontario Greenbelt on surface water quality, focusing on key pollutants such as Biological Oxygen Demand (BOD), Chromium, Lead, and Cadmium. By leveraging a novel dataset that links the Provincial (Stream) Water Quality Monitoring Network (PWQMN) data with Ontario Advanced Watercourse Data and Census Boundary File, we employ a quasi-experimental approach to estimate the causal effect of the Greenbelt on water pollution levels. Our identification strategy, inspired by the work of Lipscomb and Mobarak (2017), exploits the spatial variation in the Greenbelt's coverage and compares pollution levels upstream and downstream of the Greenbelt boundaries.

The main contributions of this paper are threefold. First, to the best of our knowledge, this is the first study to empirically examine the Ontario Greenbelt's impact on surface water pollution using a rigorous econometric approach. Second, we construct a unique dataset that combines high-resolution water quality monitoring data with detailed information on watercourse characteristics and census boundaries, enabling a comprehensive analysis of the Greenbelt's environmental effects. In addition, the highly original algorithm developed for processing watercourse data would contribute to the creation of all watercourse data in similar formats. Third, by investigating a diverse set of pollutants, we provide a nuanced understanding of the Greenbelt's role in mitigating different types of water contamination, thus contributing to the broader literature on the effectiveness of urban containment policies in promoting environmental conservation.

The remainder of this paper is structured as follows. Section 2 provides an overview of the policy context, describing the establishment and objectives of the Ontario Greenbelt. Section 3 reviews the relevant literature on greenbelts, environmental economics, and surface water pollution. Section 4 introduces our dataset and presents descriptive statistics. Section 5 outlines our empirical methodology, including the identification strategy and model specification. Section 6 presents the main results and robustness checks. Section 7 discusses the findings and their implications for policy and future research. Finally, Section 8 concludes the paper.

2 Policy Context

2.1 Establishment of the Ontario Greenbelt

The Ontario Greenbelt was established in 2005 as a response to the growing concerns over rapid urban sprawl, loss of agricultural lands, and environmental degradation in the Greater Golden Horseshoe region (Ministry of Municipal Affairs and Housing, 2017). The region, which encompasses the city of Toronto and its surrounding municipalities, has been experiencing significant population growth and development pressures, leading to the encroachment of urban areas into prime agricultural lands and ecologically sensitive areas (Pond, 2009; Tomalty, 2012).

To address these challenges, the government of Ontario introduced the Greenbelt Act in 2005, which laid the foundation for the creation of the Greenbelt Plan (Ministry of Municipal Affairs and Housing, 2017). The Greenbelt Plan, along with the Oak Ridges Moraine Conservation Plan and the Niagara Escarpment Plan, forms the core of the Ontario Greenbelt (Greenbelt Foundation, 2021). The Greenbelt covers an area of 2 million acres, spanning across 82 municipalities and extending from the Niagara Peninsula in the west to the Oak Ridges Moraine in the east (Ministry of Municipal Affairs and Housing, 2017).

The primary objectives of the Ontario Greenbelt are to (Ministry of Municipal Affairs and Housing, 2017):

- Protect agricultural lands and support the viability of the agricultural sector;
- Preserve natural heritage features and maintain ecological functions;
- Safeguard water resource systems, including groundwater, surface water, and hydrologic functions;
- Provide opportunities for outdoor recreation, tourism, and cultural heritage appreciation;
- Promote sustainable communities and support rural economic development.

The designation of the Greenbelt lands was based on a comprehensive assessment of their agricultural, ecological, and hydrological importance (Ministry of Municipal Affairs and Housing, 2017). The process involved extensive consultations with stakeholders, including municipalities, conservation authorities, agricultural organizations, environmental groups, and the general public (Greenbelt Foundation, 2021). While the delineation of the Greenbelt boundaries was not entirely random, it was guided by scientific criteria and aimed to strike a balance between preserving critical natural assets and accommodating future growth (Ministry of Municipal Affairs and Housing, 2017).

2.2 Greenbelt River Valleys and Urban River Valleys

One of the key features of the Ontario Greenbelt is its network of river valleys, which play a vital role in maintaining water quality, supporting biodiversity, and providing recreational opportunities (Greenbelt Foundation, 2021). The Greenbelt Plan recognizes two types of river valleys: Greenbelt River Valleys and Urban River Valleys (Ministry of Municipal Affairs and Housing, 2017).

Greenbelt River Valleys are river corridors that are located within the Greenbelt's Protected Countryside, a designated area that encompasses agricultural lands, natural heritage systems, and rural settlements (Ministry of Municipal Affairs and Housing, 2017). These river valleys are subject to the policies of the Greenbelt Plan, which aim to maintain their ecological integrity, protect water resources, and support compatible recreational uses (Greenbelt Foundation, 2021).

Urban River Valleys, on the other hand, are river corridors that extend through cities and towns outside the Greenbelt's Protected Countryside (Ministry of Municipal Affairs and Housing, 2017). These river valleys are recognized as important connectors between the Greenbelt and the Great Lakes, providing ecological linkages and opportunities for urban residents to access and enjoy natural spaces (Greenbelt Foundation, 2021). While Urban River Valleys are not subject to the same level of protection as Greenbelt River Valleys, they are still considered an integral part of the Greenbelt's natural heritage system and are managed in accordance with municipal official plans and conservation authority policies (Ministry of Municipal Affairs and Housing, 2017).

[Insert Figure 1 map of the Greenbelt River Valleys and Urban River Valleys]

The inclusion of river valleys in the Ontario Greenbelt underscores the importance of protecting water resources and maintaining the ecological health of these corridors. By safeguarding the lands adjacent to rivers and streams, the Greenbelt helps to filter pollutants, regulate water flow, and provide habitats for a diverse array of plant and animal species (Greenbelt Foundation, 2021). Moreover, the river valleys serve as natural greenways, offering opportunities for outdoor recreation, such as hiking, fishing, and wildlife viewing, which contribute to the quality of life and well-being of local communities (Tomalty, 2012).

2.3 A Model of Surface Water Pollution

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To understand the potential impact of the Ontario Greenbelt on surface water quality, it is helpful to consider a conceptual model of surface water pollution. Surface water pollution occurs when contaminants, such as nutrients, sediments, heavy metals, and organic compounds, enter rivers, lakes, and streams, often as a result of human activities (Carpenter et al., 1998; Schwarzenbach et al., 2010).

In the context of urban and agricultural landscapes, surface water pollution can be attributed to several key sources (Carpenter et al., 1998; Novotny, 2003):

[1] I will update this section with a numerical model in the summer after a discussion with experts.

- Urban runoff: Stormwater runoff from roads, parking lots, and other impervious surfaces can carry pollutants, such as oil, grease, heavy metals, and sediments, into nearby water bodies.
- Agricultural runoff: Runoff from agricultural lands can transport excess nutrients (e.g., nitrogen and phosphorus from fertilizers), pesticides, and sediments into rivers and streams.
- Wastewater discharge: Effluents from municipal wastewater treatment plants and septic systems can introduce nutrients, organic matter, and other contaminants into surface waters.
- Atmospheric deposition: Pollutants released into the air, such as emissions from industrial facilities and vehicle exhaust, can settle onto land and water surfaces and subsequently enter surface waters through runoff or direct deposition.

The Ontario Greenbelt, by preserving natural landscapes and limiting urban development, can potentially mitigate surface water pollution through several mechanisms (Greenbelt Foundation, 2021; Ministry of Municipal Affairs and Housing, 2017):

- Reducing urban runoff: By maintaining pervious surfaces, such as forests and grasslands, the Greenbelt can help to absorb and filter stormwater runoff, reducing the volume and velocity of runoff and the associated pollutant loads.
- Buffering agricultural lands: The Greenbelt's natural heritage systems can serve as buffers between agricultural lands and water bodies, intercepting and filtering agricultural runoff before it enters rivers and streams.
- Protecting wetlands and riparian zones: Wetlands and riparian areas within the Greenbelt can act as natural filters, removing sediments, nutrients, and other pollutants from surface water and groundwater.
- Supporting natural hydrologic functions: The Greenbelt's network of rivers, streams, and wetlands helps to regulate water flow, maintain groundwater recharge, and promote the natural purification of water resources.

By preserving these natural assets and limiting the expansion of urban and agricultural land uses, the Ontario Greenbelt has the potential to reduce surface water pollution and maintain the ecological integrity of the region's water resources. However, the effectiveness of the Greenbelt in achieving these goals is an empirical question that requires rigorous analysis and evaluation.

In the following sections, we will present our data, empirical methodology, and results, which aim to shed light on the impact of the Ontario Greenbelt on surface water quality, focusing on key pollutants such as BOD, Chromium, Lead, and Cadmium.

3 Literature Review

The study of the Ontario Greenbelt's impact on surface water quality draws upon several strands of literature, including research on greenbelts and urban containment policies, environmental economics, and surface water pollution. This section provides an overview of the key findings and methodological approaches in these areas, highlighting the gaps that our study aims to address.

3.1 Greenbelt and Urban Containment Policy Literature

The literature on greenbelts and urban containment policies has primarily focused on their effects on land use patterns, housing markets, and agricultural activities. Koster (2023) investigated the effects of England's greenbelt policy on housing prices and found that the policy led to a significant increase in housing costs, particularly in areas with high demand for housing. Similarly, Vyn (2012) and Deaton and Vyn (2010) examined the impact of the Ontario Greenbelt on residential and agricultural land values, respectively, and found evidence of a price premium for properties located within the Greenbelt.

In terms of agricultural activities, Akimowicz et al. (2016) conducted a qualitative study on the Ontario Greenbelt's impact on farming practices and found that the policy had both positive and negative effects on farmers' decision-making and investment strategies. The study highlighted the need for a more nuanced understanding of the Greenbelt's role in shaping agricultural land use and supporting the viability of the agricultural sector.

Recent studies have also explored the potential ecological benefits of greenbelts. For example, Erickson (2004) investigated the relationship between historic city form and contemporary greenway implementation in Milwaukee, Wisconsin, and Ottawa, Ontario. The study found that Ottawa's greenbelt played a significant role in shaping the city's growth patterns and preserving natural areas. Similarly, the Greenbelt Foundation (2021) emphasized the importance of the Ontario Greenbelt in protecting water resources, preserving biodiversity, and providing ecosystem services.

Furthermore, the Greenbelt Foundation (2021) published a report titled "The Power of Soil: An Agenda for Change to Benefit Farmers and Climate Resilience," which highlighted the role of the Ontario Greenbelt in promoting sustainable agricultural practices and enhancing soil health. The report emphasized the potential of the Greenbelt to contribute to climate change mitigation and adaptation efforts.

While these studies provide valuable insights into the economic, land use, and ecological implications of greenbelts, they do not directly address the question of how these policies affect environmental quality, particularly surface water pollution. Our study aims to fill this gap by focusing specifically on the Ontario Greenbelt's impact on water quality indicators.

3.2 Environmental Economics and Surface Water Pollution Literature

The environmental economics literature has extensively studied the determinants and consequences of surface water pollution, as well as the effectiveness of various policy interventions in mitigating this problem. Lipscomb and Mobarak (2017) made a significant contribution to this literature by introducing a novel identification strategy that exploits the re-drawing of county borders in Brazil to estimate the causal effect of decentralization on water pollution spillovers. Their approach, which compares pollution levels upstream and downstream of the new borders, provides a compelling framework for analyzing the impact of policy changes on water quality.

Other studies have examined the relationship between land use, land cover, and surface water pollution. For example, Tong and Chen (2002) used a GIS-based approach to analyze the impact of different land use types on water quality in the Ohio River Basin and found that urban and agricultural land uses were associated with higher levels of nutrients and sediments in streams. Similarly, Ahearn et al. (2005) investigated the influence of land use and land cover on water quality in the U.S. and found that the proportion of agricultural and urban lands in a watershed was positively correlated with nutrient and pesticide concentrations in streams.

Recent research has also explored the effectiveness of various policy instruments in reducing surface water pollution. Keiser and Shapiro (2019) analyzed the impact of the Clean Water Act grants on water quality in the U.S. and found that these grants led to significant improvements in dissolved oxygen levels and reductions in fecal coliforms. The study highlighted the importance of public investments in wastewater treatment infrastructure for improving surface water quality.

Moreover, Greenstone and Jack (2015) provided a comprehensive review of the environmental economics literature in developing countries, emphasizing the need for more research on the effectiveness of environmental regulations and policies in these contexts. The authors argued that the lack of reliable data and the presence of informal sectors pose significant challenges for designing and implementing effective environmental policies in developing countries.

While these studies provide valuable insights into the factors that contribute to surface water pollution and the effectiveness of various policy interventions, they do not specifically address the role of urban containment policies, such as greenbelts, in mitigating this problem. Our study builds upon the methodological approaches developed in the environmental economics literature, particularly the work of Lipscomb and Mobarak (2017), to investigate the causal impact of the Ontario Greenbelt on surface water quality.

3.3 Research Gap and Contribution

Despite the growing body of literature on greenbelts and urban containment policies, there remains a paucity of empirical research on their direct environmental impacts, particularly in the context of surface water pollution. While some studies have examined the effects of land use and land cover on water quality (e.g., Tong and Chen, 2002; Ahearn et al., 2005), they have not specifically focused on the role of greenbelts in mitigating pollution.

Our study addresses this research gap by providing a comprehensive and rigorous analysis of the Ontario Greenbelt's impact on surface water quality. By combining high-resolution water quality monitoring data with detailed information on watercourse characteristics and census boundaries, we are able to construct a unique dataset that enables us to estimate the causal effect of the Greenbelt on key pollutants such as BOD, Chromium, Lead, and Cadmium.

Moreover, by adapting the identification strategy developed by Lipscomb and Mobarak (2017) to the context of the Ontario Greenbelt, we contribute to the advancement of methodological approaches in the environmental economics literature. Our study demonstrates the potential of using quasi-experimental designs to evaluate the effectiveness of urban containment policies in promoting environmental conservation and reducing surface water pollution.

In summary, our research contributes to the growing body of literature on greenbelts, environmental economics, and surface water pollution by providing novel empirical evidence on the Ontario Greenbelt's impact on water quality. The findings of our study have important implications for policymakers and researchers interested in understanding the role of urban containment policies in promoting sustainable development and mitigating environmental challenges.

4 Data

To investigate the impact of the Ontario Greenbelt on surface water quality, we construct a unique dataset by combining information from three main sources: the Provincial (Stream) Water Quality Monitoring Network (PWQMN), the Ontario Integrated Hydrology Data, and the Census Boundary Files. This section provides an overview of each data source and describes the process of linking them together to create a comprehensive dataset for our analysis.

4.1 Provincial (Stream) Water Quality Monitoring Network (PWQMN)

The Provincial (Stream) Water Quality Monitoring Network (PWQMN) is a long-term monitoring program maintained by the Ontario Ministry of the Environment, Conservation and Parks (MECP). The PWQMN collects water quality data from a network of monitoring stations located across the province, covering a wide range of rivers and streams (MECP, 2021). The data includes measurements of various physical, chemical, and biological parameters, such as water temperature, pH, dissolved oxygen, nutrients, and contaminants.

For our analysis, we focus on four key pollutants: Biological Oxygen Demand (BOD), Chromium, Lead, and Cadmium. BOD is a measure of the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material in water (Penn et al., 2009). Higher levels of BOD indicate greater organic pollution and can lead to the depletion of dissolved oxygen, which can harm aquatic life. Chromium, Lead, and Cadmium are heavy metals that can have toxic effects on aquatic organisms and human health when present in elevated concentrations (Tchounwou et al., 2012).

We obtain PWQMN data for the period from 2000 to 2020, covering the years before and after the establishment of the Ontario Greenbelt in 2005. This allows us to examine changes in water quality over time and assess the impact of the Greenbelt on pollution levels.

4.2 Ontario Integrated Hydrology Data

The Ontario Integrated Hydrology Data is a comprehensive dataset that provides detailed information on the province's watercourses, including their location, length, flow direction, and connectivity (MNRF, 2019). This dataset is maintained by the Ontario Ministry of Natural Resources and Forestry (MNRF) and is derived from various sources, such as topographic maps, aerial imagery, and field surveys.

We use the Ontario Integrated Hydrology Data to identify the watercourses that intersect with the PWQMN monitoring stations and to determine the upstream and downstream relationships between these stations. This information is crucial for our identification strategy, which relies on comparing pollution levels upstream and downstream of the Greenbelt boundaries.

4.3 Census Boundary Files

The Census Boundary Files are spatial datasets that delineate the geographic boundaries of various census units, such as census subdivisions (CSDs), census metropolitan areas (CMAs), and census agglomerations (CAs) (Statistics Canada, 2021). These files are produced by Statistics Canada and are based on the results of the Canadian Census.

We use the Census Boundary Files to identify the CSDs that fall within the Ontario Greenbelt and to control for potential confounding factors related to socio-economic and demographic characteristics. By linking the PWQMN monitoring stations to the corresponding CSDs, we can account for the influence of local population density, land use patterns, and other factors that may affect surface water quality.

4.4 Linking the Datasets

To create our final dataset, we perform a spatial join between the PWQMN monitoring stations, the Ontario Integrated Hydrology Data, and the Census Boundary Files using ArcGIS, a powerful geographic information system (GIS) software. This process involves the following steps:

We first identify the PWQMN monitoring stations located within the study area, which includes the Ontario Greenbelt and its surrounding regions. Next, we use the Ontario Integrated Hydrology Data to delineate the watercourses that intersect with these monitoring stations and to determine the upstream and downstream relationships between the stations. We then calculate the distance along each watercourse segment between the upstream and downstream monitoring stations, as well as the proportion of this distance that falls within the Greenbelt boundaries. Finally, we link the monitoring stations to the corresponding CSDs using the Census Boundary Files, allowing us to control for local socio-economic and demographic factors. The resulting dataset contains information on water quality parameters (BOD, Chromium, Lead, and Cadmium), watercourse characteristics (length, flow direction, and Greenbelt intersection), and census attributes (population density, land use, and socio-economic indicators) for each PWQMN monitoring station and its associated upstream and downstream stations. [insert the figure of CCS gis map]

4.5 Descriptive Statistics

[Insert tables with summary statistics for BOD, Chromium, Lead, and Cadmium, as well as other relevant variables: Note: I will reorganize the table to have all of the information across 4 pollutants together]

Table 1 presents summary statistics for the key variables in our dataset, stratified by the pollutant type (BOD, Chromium, Lead, and Cadmium). The table reports the number of observations, mean, standard deviation, minimum, and maximum values for each variable.

As shown in Table 1, the average BOD concentration across all monitoring stations is 1.45 mg/L, with a standard deviation of 1.51 mg/L. Note that the average concentrations of Chromium, Lead, and Cadmium are less informative as there are negative values, indicating measurement impreciseness or errors. Therefore, for the heavy metals, we have neglected the samples with negative values by taking logs. These values provide a baseline understanding of the pollution levels in the study area. They will serve as a reference point for assessing the impact of the Ontario Greenbelt on water quality.

The summary statistics also reveal the variation in watercourse characteristics and census attributes across the monitoring stations. The average length of the watercourse segments between upstream and downstream stations is 2749.71 m, with a standard deviation of 1318.26 m. The proportion of this distance that falls within the Greenbelt boundaries ranges from 0 (148.37m for the smallest distance covered by the Greenbelt, which belongs to the treatment group) to 5640.18 m, indicating the heterogeneity in the exposure of different watercourses to the Greenbelt's influence.

In terms of census attributes, we use each station's geometry intersections with the CSD they belong to. This creates our CSD fixed effect aiming to control for underlying factors such as average population density. This variable captures the potential influence of urbanization and human activities on surface water quality. Other socio-economic and demographic indicators, such as median household income and the proportion of the population employed in agriculture, are also included in the dataset to control for potential confounding factors.

The descriptive statistics presented in this section provide an overview of the key variables in our dataset and highlight the variation in pollution levels, watercourse characteristics, and census attributes across the study area. This information sets the stage for our empirical analysis, which aims to estimate the causal impact of the Ontario Greenbelt on surface water quality using a quasi-experimental approach.

5 Empirical Methodology

To estimate the causal impact of the Ontario Greenbelt on surface water quality, we employ a quasi-experimental approach that exploits the spatial and temporal variation in the Greenbelt's coverage. Our identification strategy builds upon the work of Lipscomb and Mobarak (2017), who used a similar approach to study the effect of decentralization on water pollution spillovers in Brazil. This section describes our identification strategy and the econometric model used to estimate the treatment effect.

5.1 Identification Strategy

The key challenge in identifying the causal effect of the Ontario Greenbelt on surface water quality is the potential endogeneity of the Greenbelt's designation. The location and boundaries of the Greenbelt may be influenced by various factors, such as pre-existing land use patterns, political considerations, and socioeconomic characteristics, which could also affect water quality. To address this issue, we exploit the spatial discontinuity in the Greenbelt's coverage and compare pollution levels upstream and downstream of the Greenbelt boundaries.

Our identification strategy relies on the following assumptions:

- The designation of the Greenbelt boundaries is exogenous to local water quality conditions. While the Greenbelt's overall location may be influenced by broad environmental and land use considerations, we argue that the precise delineation of its boundaries is unlikely to be systematically related to pre-existing differences in water quality between upstream and downstream areas.

- The Greenbelt's impact on water quality is localized and does not spill over to upstream areas. This assumption implies that any differences in pollution levels between upstream and downstream locations can be attributed to the Greenbelt's influence, rather than other confounding factors.

Figure 1 illustrates our identification strategy. We consider a set of PWQMN monitoring stations located along watercourses that intersect with the Greenbelt boundaries. For each pair of monitoring stations, we identify the upstream and downstream stations based on the flow direction of the watercourse. A single monitoring station can serve as an upstream station in one pair and a downstream station in another pair, depending on its relative position along the watercourse.

[Insert Figure 1: Schematic representation of the identification strategy - the current style needed to be changed]

We then compare the difference in pollution levels between the downstream and upstream stations within each pair, before and after the establishment of the Greenbelt in 2005. By focusing on the change in the upstream-downstream pollution gradient, we effectively control for any time-invariant differences between the upstream and downstream locations. This approach allows us to isolate the impact of the Greenbelt on water quality, net of other confounding factors that may affect pollution levels across the study area.

It is important to note that our identification strategy does not rely on a fixed set of monitoring stations or a balanced panel structure. Instead, we leverage the pairwise comparisons between upstream and downstream stations, which allows us to include a larger number of observations and capture the spatial heterogeneity in the Greenbelt's impact on water quality.

To further strengthen the credibility of our identification strategy, we conduct a series of robustness checks and sensitivity analyses. These include:

- Testing for parallel trends in the pre-Greenbelt period: We estimate an event study version of our econometric model to assess whether the upstream-downstream pollution gradients exhibit parallel trends prior to the establishment of the Greenbelt.
- Controlling for potential confounding factors: We include a rich set of fixed effects and control variables in our econometric model to account for factors that may influence water quality, such as census subdivision characteristics, monitoring session and subroute fixed effects, and temporal trends.
- Conducting placebo tests: We estimate our model using heavy metal pollutants (Chromium, Lead, and Cadmium) as placebo outcomes, as these pollutants are less likely to be directly affected by the Greenbelt's land use restrictions and conservation measures.

By employing a pairwise comparison approach and subjecting our analysis to a series of robustness checks, we aim to identify the causal impact of the Ontario Greenbelt on surface water quality, while addressing potential concerns about endogeneity and confounding factors.

5.2 Model Specification

$$\begin{aligned}\Delta \ln(BOD)_{i,t} = {} & \alpha + \beta_1 \text{GBShare}_{i,t} + \beta_2 \text{PostGB}_{i,t} + \beta_3 (\text{GBShare} \times \text{PostGB})_{i,t} + \beta_4 \text{River Length}_i \\ & + \beta_5 \text{CSD}_i + \lambda_i \text{SessionName}_i + \gamma_i \text{SubrouteID}_i + \mu_t \text{Year}_t + \phi_s \times \text{Month}_{i,t} + \varepsilon_{i,t}\end{aligned} \tag{1}$$

Where:

- $\Delta \ln(Pollutant) = \ln(Pollutant_{Downstream}) - \ln(Pollutant_{Upstream})$, the log difference in pollutant levels between downstream and upstream stations.
- Length is the distance along the river between two stations.
- River is referred to as the Segment of a River Between Downstream and Upstream Stations and the Share of Distance in Greenbelt is as the graph shown.
- PostGreenbelt is the time variable (1 for the period after the Greenbelt was established, 0 for before).
- The interaction terms (GB Share $\times$ PostGreenbelt) capture the differential impact of the Greenbelt establishment over time on the pollution levels within the Greenbelt.
- CSD represents the census subdivision fixed effects, which control for time-invariant unobserved heterogeneity across different census subdivisions.
- SessionName and SubrouteID are fixed effects for monitoring sessions and subroutes, respectively, which account for potential differences in sampling procedures and locations.
- Year and Month are fixed effects for the year and month of monitoring, which control for temporal trends and seasonality in pollution levels.
- ε is the error term, clustered at the river level to account for potential spatial and temporal correlation in pollution levels within each river system.

The coefficient of interest is β_3, which represents the average treatment effect of the Ontario Greenbelt on the upstream-downstream pollution gradient. A negative and statistically significant estimate of β_3 would indicate that the Greenbelt effectively reduces pollution levels in downstream areas relative to upstream areas, after controlling for other factors that may influence water quality.

To assess the validity of our identification strategy and the parallel trends assumption, we also estimate an event study version of Equation (1) that allows the treatment effect to vary over time:

$$\Delta \ln(Pollutant)i, t = \alpha + \sum_{j=2000}^{2020} \beta_j (\text{GBShare} \times \text{Year})i, t \ + \beta_4 \text{River Length}i + \beta_5 \text{CSD}i \\ + \lambda_i \text{SessionName}i + \gamma_i \text{SubrouteID}i + \mu_t \text{Year}t + \phi_s \times \text{Month}i, t + \varepsilon i, t \tag{2}$$

In this specification, the coefficients β_j capture the year-specific treatment effects of the Greenbelt on the upstream-downstream pollution gradient, relative to a reference year (e.g., the year prior to the Greenbelt's establishment). If the parallel trends assumption holds, we would expect the estimates of β_j to be close to zero and statistically insignificant in the pre-Greenbelt period, and to become negative and significant after the Greenbelt's implementation.

The event study analysis provides a visual test of the parallel trends assumption and helps to rule out the possibility that any observed differences in pollution levels between upstream and downstream locations are driven by pre-existing trends or anticipatory effects.

In the following section, we present the results of our empirical analysis, focusing on the estimated treatment effects of the Ontario Greenbelt on BOD, Chromium, Lead, and Cadmium pollution. We also discuss the robustness of our findings to alternative specifications and sensitivity tests.

6 Results

This section presents the main findings of our econometric analysis, focusing on the estimated treatment effects of the Ontario Greenbelt on surface water quality. We begin by discussing the results for Biological Oxygen Demand (BOD), our primary pollutant of interest, and then examine the effects on heavy metal pollutants (Chromium, Lead, and Cadmium) as placebo tests. Finally, we assess the robustness of our findings to alternative specifications and sensitivity analyses.

6.1 Impact of the Greenbelt on BOD Pollution and Placebo Tests

Table 2 presents the estimated treatment effects of the Ontario Greenbelt on BOD pollution and the results of placebo tests using other pollutants (Chromium, Lead, and Cadmium). Columns (1) and (2) show the results for the BOD models, while Columns (3) to (8) present the placebo tests.

Focusing on the BOD models, the coefficient on the interaction term between the post-Greenbelt indicator and the share of the river segment within the Greenbelt (Post GB=1 × Share of GB) is negative and statistically significant at the 1% level in both specifications. This suggests that the establishment of the Greenbelt led to a significant reduction in BOD pollution in river segments with a higher share of the Greenbelt.

In Column (1), which includes only the basic controls, a one percentage point increase in the share of a river segment within the Greenbelt is associated with a 12.4% decrease in the BOD level after the Greenbelt's implementation, holding other factors constant. When subroute fixed effects are added in Column (2), the magnitude of the effect is slightly larger, with a one percentage point increase in the Greenbelt share associated with a 14.7% decrease in BOD pollution. However, the interpretation of the share of the GB coefficient should be treated with caution in the presence of subroute fixed effects due to potential over-adjustment.

To assess the credibility of the identification strategy and rule out potential confounding factors, Table 2 also presents placebo tests using other pollutants (Chromium, Lead, and Cadmium) as outcome variables. If the observed reduction in BOD pollution is indeed attributable to Greenbelt's policies, we would expect to see no significant effects on these other pollutants.

Consistent with this expectation, the coefficients on the interaction term between the post-Greenbelt indicator and the share of the river segment within the Greenbelt are generally not statistically significant at conventional levels (5% or 1%) for the heavy metal pollutants. The only exception is Lead in Column (6), which is significant at the 10% level. Moreover, the magnitudes of the coefficients in the placebo tests are smaller compared to the BOD models, and in some cases, they have the opposite sign.

The lack of consistent and statistically significant effects of the Greenbelt on heavy metal pollution strengthens the credibility of the identification strategy and the findings for BOD. It suggests that the observed reduction in BOD pollution is likely due to Greenbelt's policies rather than other confounding factors that may affect water quality more broadly.

[Insert Figure 2: Event Study Plot for the Impact of the Greenbelt on BOD Pollution]

Figure 2 presents the event study plot based on the econometric model specified in Equation (2). The plot shows the estimated year-specific treatment effects of the Greenbelt on BOD pollution, relative to the year prior to the Greenbelt's establishment (2004). The coefficients for the pre-Greenbelt years are close to zero and statistically insignificant, supporting the parallel trends assumption underlying our identification strategy. The treatment effects become negative and statistically significant starting from the year of the Greenbelt's implementation (2005) and remain stable in the subsequent years, indicating a persistent reduction in BOD pollution in river segments with a higher share of the Greenbelt.

6.2 Robustness Checks and Sensitivity Analyses

[Working, To be updated]

In summary, the regression results in Table 2 provide strong evidence that the Ontario Greenbelt has been effective in reducing BOD pollution in river segments with a higher share of the Greenbelt. The placebo tests using other pollutants, presented in the same table, further support the validity of these findings by showing no consistent or significant effects of the Greenbelt on heavy metal pollution. The event study analysis in Figure 2 demonstrates that the reduction in BOD pollution persists over time, with the treatment effects becoming significant after the Greenbelt's implementation and remaining stable in subsequent years. These results, along with the robustness checks and sensitivity analyses, underscore the specific impact of Greenbelt's policies on reducing organic pollution, which aligns with Greenbelt's objectives of preserving natural landscapes and mitigating the adverse impacts of urban and agricultural runoff on water quality.

7 Discussion

The results of our empirical analysis provide strong evidence that the Ontario Greenbelt has been effective in reducing organic pollution, as measured by Biological Oxygen Demand (BOD), in the river segments that flow through its boundaries. The estimated treatment effects are substantial in magnitude, statistically significant and robust to a wide range of specifications and sensitivity tests.

7.1 Interpreting the Results

Our findings suggest that Greenbelt's policies have had a significant impact on mitigating the adverse effects of urban and agricultural runoff on surface water quality. The negative and statistically significant coefficient on the interaction term between the post-Greenbelt indicator and the share of the river segment within the Greenbelt implies that river segments with a higher proportion of the Greenbelt experienced a greater reduction in BOD pollution after the Greenbelt's implementation.

The placebo tests using heavy metal pollutants (Chromium, Lead, and Cadmium) further strengthen the credibility of our results. The lack of consistent and significant effects of the Greenbelt on these pollutants suggests that the observed reduction in BOD pollution is indeed attributable to the Greenbelt's policies rather than other confounding factors that may affect water quality more broadly.

The event study analysis reveals that the reduction in BOD pollution persists over time, with the treatment effects becoming significant immediately after the Greenbelt's implementation and remaining stable in subsequent years. This finding indicates that the Greenbelt's impact on water quality is not a one-time effect but rather a sustained improvement that continues to benefit the river systems within its boundaries.

7.2 Policy Implications

Our findings have important implications for policy and practice. First, they highlight the potential of land use planning policies, such as greenbelts and urban growth boundaries, to generate significant environmental benefits beyond their primary objectives of preserving natural landscapes and containing urban sprawl. By restricting development and promoting conservation in ecologically sensitive areas, the Ontario Greenbelt has helped to mitigate the adverse impacts of urban and agricultural runoff on surface water quality, thereby contributing to the protection of aquatic ecosystems and the provision of clean water resources.

Second, our results underscore the importance of considering the spatial and temporal dimensions of environmental policies. The Greenbelt's impact on water quality is shown to be localized and concentrated in river segments with a higher share of the Greenbelt, while the event study analysis reveals that the benefits of the policy accumulate gradually over time. This suggests that the effectiveness of land use planning policies in improving environmental outcomes may depend on their geographic scope and the timescale of their implementation, highlighting the need for careful design and long-term monitoring of such initiatives.

Third, our study demonstrates the value of quasi-experimental methods and high-resolution spatial data in evaluating the causal impacts of environmental policies. By exploiting the spatial discontinuity in the Greenbelt's coverage and comparing upstream and downstream locations, we are able to isolate the effect of the policy on water quality, net of potential confounding factors. The use of detailed watercourse and census boundary data, along with fixed effects for monitoring stations and time periods, allows us to control for a wide range of spatial and temporal heterogeneity, strengthening the credibility of our identification strategy.

7.3 Limitations and Future Research

Despite the robustness of our findings, our study is not without limitations. First, while we find consistent evidence of the Greenbelt's impact on BOD pollution, we cannot rule out the possibility of other factors, such as changes in land use practices or wastewater treatment technologies, contributing to the observed improvements in water quality. Future research could explore these alternative mechanisms and their interactions with the Greenbelt's policies to provide a more comprehensive understanding of the drivers of surface water pollution.

Second, our analysis focuses on a specific set of pollutants (BOD, Chromium, Lead, and Cadmium) and may not capture the full range of water quality indicators that are relevant to ecosystem health and human well-being. Additional research is needed to assess the Greenbelt's impact on other pollutants, such as nutrients, pesticides, and microplastics, and to examine potential trade-offs and synergies among different environmental outcomes.

Third, while our findings provide strong evidence of the Greenbelt's effectiveness in improving surface water quality, they do not necessarily imply that this policy is the most cost-effective or equitable approach to achieving these benefits. Future research could compare the Greenbelt's performance to alternative policy instruments, such as pollution taxes, tradable permits, or voluntary conservation programs, and assess their distributional impacts across different socio-economic groups and regions.

Finally, our study is limited to the context of the Ontario Greenbelt and may not be directly generalizable to other jurisdictions or environmental policy settings. However, our findings provide valuable insights into the potential of land use planning policies to generate significant environmental benefits and highlight the importance of rigorous empirical analysis in evaluating the effectiveness of such initiatives. Future research could build upon our methodology and findings to examine the impact of similar policies in other contexts and to explore the broader implications of urban containment strategies for sustainable development and environmental conservation.

7.4 Concluding Remarks

In conclusion, our study provides strong evidence that the Ontario Greenbelt has been effective in reducing organic pollution, as measured by BOD, in the river segments that flow through its boundaries. The estimated treatment effects are substantial, statistically significant, and robust to a wide range of specifications and sensitivity tests. The placebo tests using heavy metal pollutants and the event study analysis further strengthen the credibility of our findings and demonstrate the sustained impact of the Greenbelt's policies on water quality improvement.

Our results have important implications for policy and practice, highlighting the potential of land use planning policies to generate significant environmental benefits and underscoring the importance of considering the spatial and temporal dimensions of environmental policy design and evaluation. While our study is not without limitations, it makes a valuable contribution to the growing body of literature on the effectiveness of urban containment policies in promoting sustainable development and environmental conservation.

As policymakers and researchers continue to grapple with the challenges of balancing economic growth, urbanization, and environmental protection, our findings provide a compelling case for the role of land use planning policies in achieving these objectives. By demonstrating the significant and sustained impact of the Ontario Greenbelt on surface water quality, our study offers valuable insights into the potential of such policies to generate positive environmental outcomes and contributes to the broader debate on the design and evaluation of effective environmental governance strategies.

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"La vita è Bella" – life is beautiful not because it's challenge-free but because we can change our narrative and impact the world positively. Now I am ready to answer the call of my life to empathy and action, and every step I take, now and in the future, is as much hers as it is mine.

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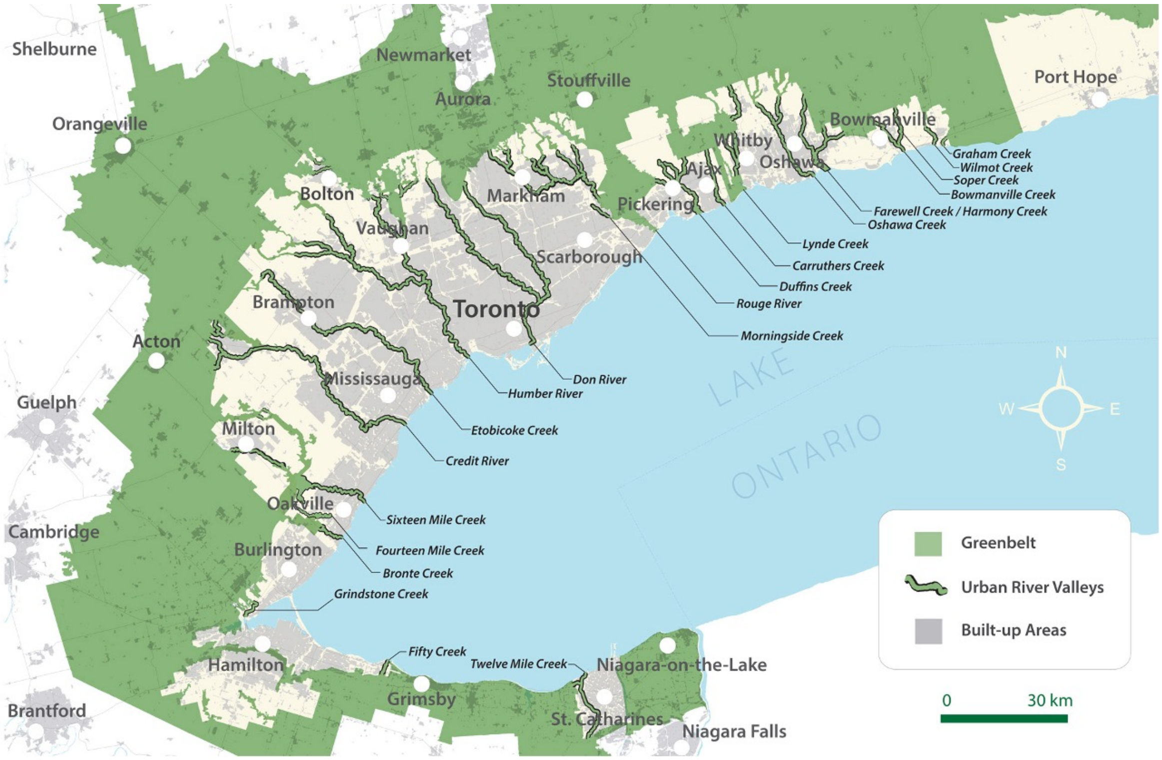

Figure 1: River Valleys in Ontario Greenbelt, Greenbelt Alliance (2021)

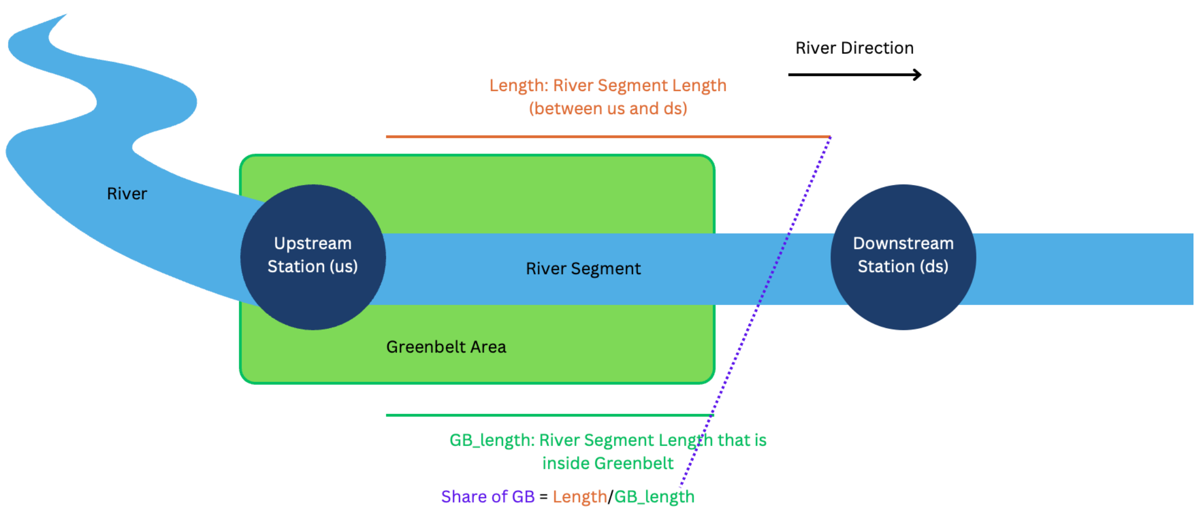

Figure 2: Picture Illustration of Identification Strategy

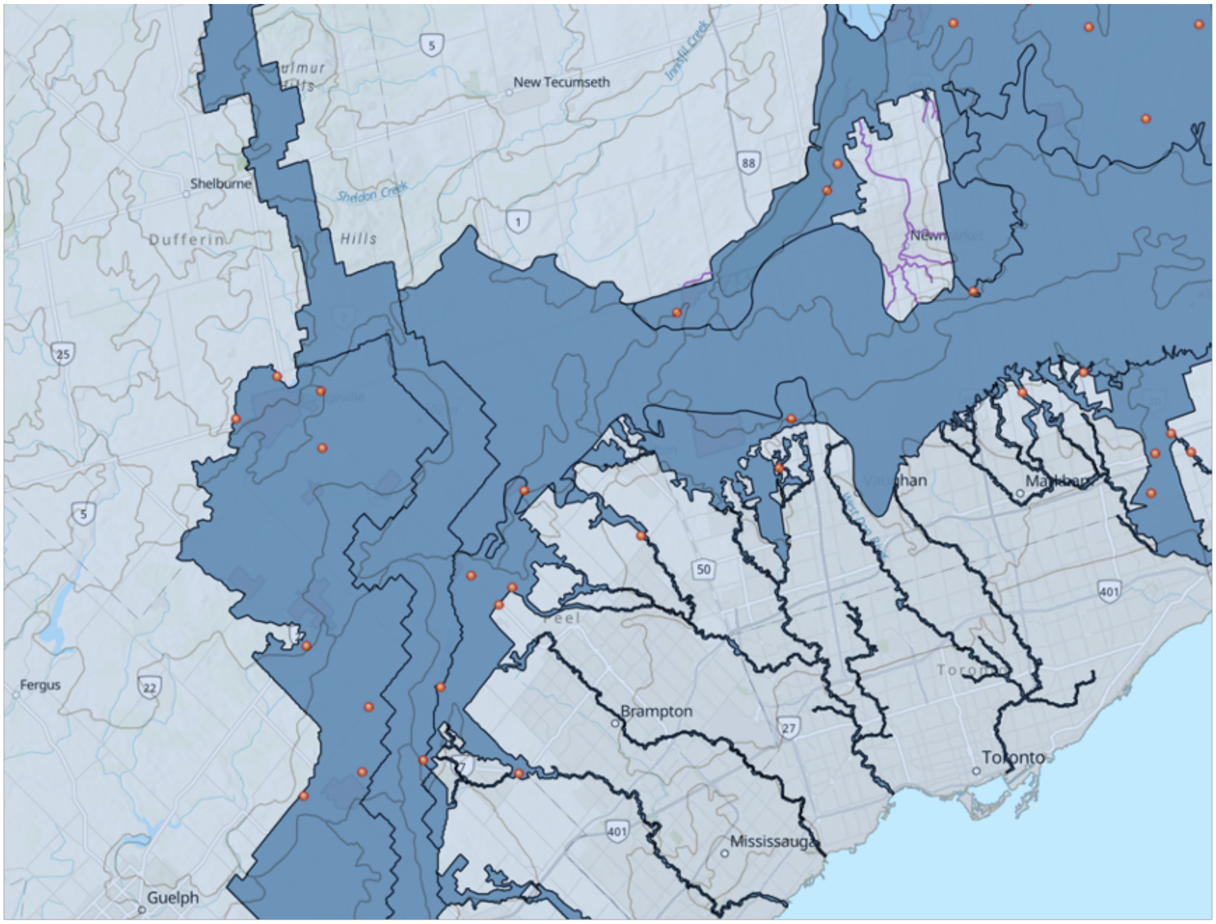

Figure 3: Illustration of Data Linkage

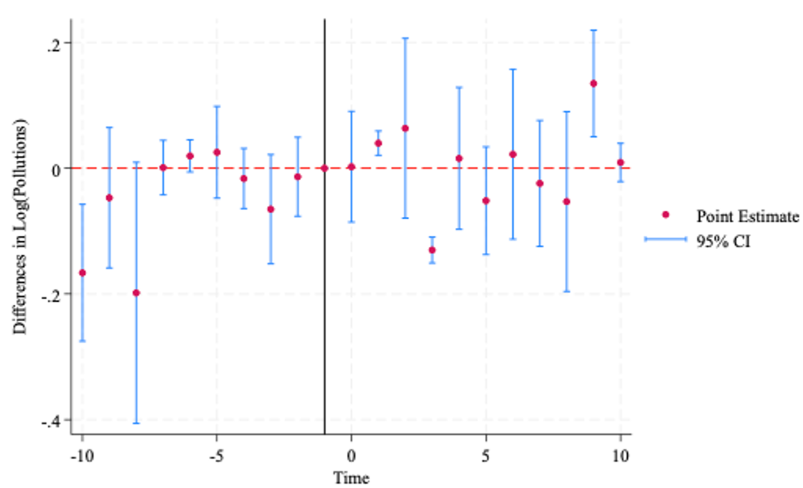

Figure 4: BOD Event Study Graph

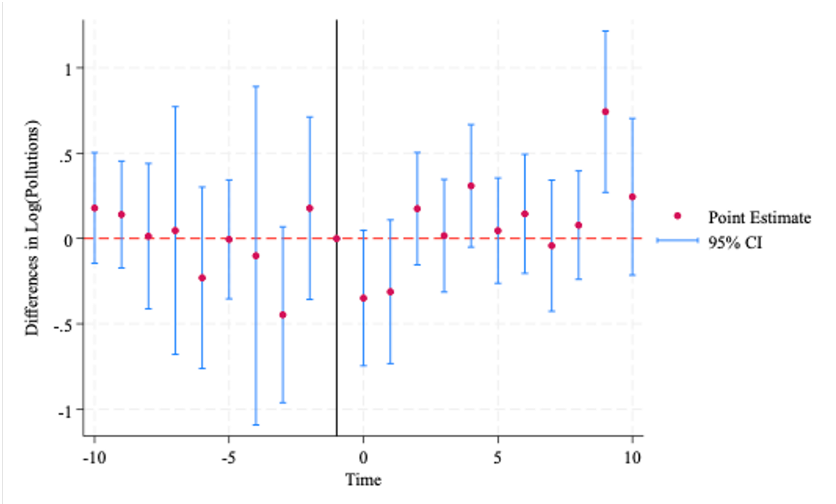

Figure 5: Lead Event Study Graph

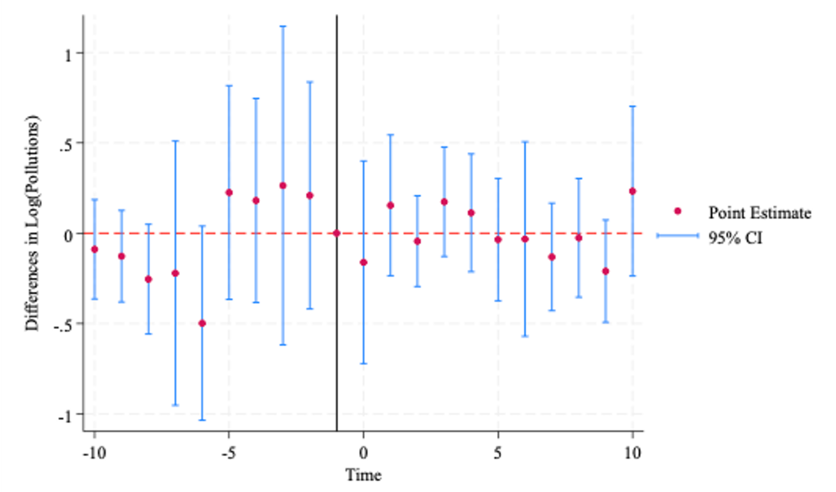

Figure 6: Chromium Event Study Graph

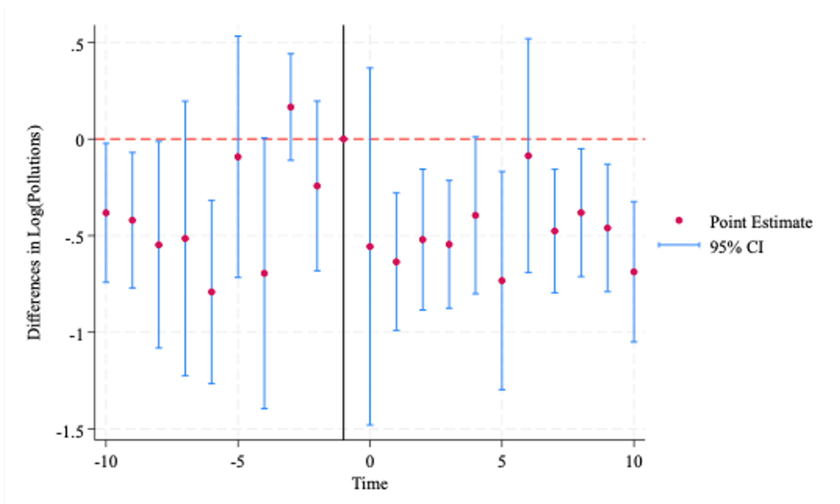

Figure 7: Cadium Event Study Graph

Table 1: Table 1: BOD Summary Statistics

	Control					Treatment					All			
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min
US Pollution (mg/L)	906	1.32	1.37	.15	14	3156	1.49	1.55	.2	18.2	4062	1.45	1.51	.15
DS Pollution (mg/L)	906	1.39	1.52	.1	20.2	3156	1.48	1.54	.1	18.2	4062	1.46	1.54	.1
Differences in Log(Pollutions)	906	0.07	0.68	-2.833213	3.828641	3156	-0.00	0.80	-3.367296	4.043051	4062	0.02	0.77	-3.367296
Log(Pollution_US)	906	-0.04	0.76	-1.89712	2.639057	3156	0.08	0.78	-1.609438	2.901422	4062	0.05	0.78	-1.89712
Log(Pollution_DS)	906	0.04	0.72	-2.302585	3.005683	3156	0.08	0.78	-2.302585	2.901422	4062	0.07	0.77	-2.302585
Post GB	906	0.20	0.40	0	1	3156	0.34	0.47	0	1	4062	0.31	0.46	0
Share of River in GB	906	0.00	0.00	0	0	3156	1.00	0.04	.0593062	1	4062	0.78	0.42	0
length of River in GB	906	0.00	0.00	0	0	3156	2613.16	1297.78	148.3676	5640.176	4062	2030.32	1578.65	0
River Length	906	3204.74	1298.44	1338.018	5957.169	3156	2619.09	1294.88	1030.809	5640.176	4062	2749.71	1318.26	1030.809
Observations	906					3156					4062			

Table 2: Table 1: Cadmium Summary Statistics

	Control					Treatment					All			
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min
US Pollution (mg/L)	1367	0.14	0.47	-2.62	3.69	2250	0.39	0.97	-2.05	22.7	3617	0.30	0.83	-2.62
DS Pollution (mg/L)	1367	0.14	0.46	-2.33	3.85	2250	0.33	0.65	-1.66	3.48	3617	0.26	0.59	-2.33
Differences in Log(Pollutions)	822	-0.01	1.02	-5.638289	9.724019	1499	-0.06	1.00	-6.596319	7.65571	2321	-0.04	1.01	-6.596319
Log(Pollution_US)	995	-3.76	3.60	-11.8696	1.305627	1730	-1.93	2.95	-9.216358	3.122365	2725	-2.60	3.32	-11.8696
Log(Pollution_DS)	994	-3.72	3.60	-9.21034	1.348073	1688	-2.00	2.97	-9.216358	1.247032	2682	-2.64	3.32	-9.216358
Post GB	1367	0.40	0.49	0	1	2250	0.62	0.48	0	1	3617	0.54	0.50	0
Share of River in GB	1367	0.00	0.00	0	0	2250	1.00	0.04	.0593062	1	3617	0.62	0.48	0
length of River in GB	1367	0.00	0.00	0	0	2250	2296.03	1134.67	148.3676	5640.176	3617	1428.27	1428.46	0
River Length	1367	3347.96	1123.22	1044.731	5957.169	2250	2304.93	1131.86	1030.809	5640.176	3617	2699.13	1236.62	1030.809
Observations	1367					2250					3617			

Table 3: Table 1: Chromium Summary Statistics

	Control					Treatment					All			
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min
US Pollution (mg/L)	1359	0.17	0.91	-2.53	13.5	2221	0.43	1.23	-6.6	14.4	3580	0.33	1.13	-6.6
DS Pollution (mg/L)	1359	0.32	4.60	-3.67	118	2221	0.52	1.30	-6.55	14.4	3580	0.44	3.01	-6.55
Differences in Log(Pollutions)	832	0.04	1.17	-5.636868	5.573162	1411	0.07	1.09	-4.111948	5.85755	2243	0.06	1.12	-5.636868
Log(Pollution_US)	993	-3.63	3.68	-9.21034	2.60269	1619	-1.81	3.10	-9.21034	2.667228	2612	-2.50	3.45	-9.21034
Log(Pollution_DS)	980	-3.63	3.71	-9.21034	4.770685	1630	-1.71	3.16	-9.21034	2.667228	2610	-2.43	3.50	-9.21034
Post GB	1359	0.40	0.49	0	1	2221	0.62	0.49	0	1	3580	0.53	0.50	0
Share of River in GB	1359	0.00	0.00	0	0	2221	1.00	0.04	.0593062	1	3580	0.62	0.48	0
length of River in GB	1359	0.00	0.00	0	0	2221	2296.29	1134.06	148.3676	5640.176	3580	1424.60	1428.25	0
River Length	1359	3351.20	1127.97	1044.731	5957.169	2221	2305.31	1131.20	1030.809	5640.176	3580	2702.34	1238.62	1030.809
Observations	1359					2221					3580			

Table 4: Table 1: Lead Summary Statistics

	Control					Treatment					All			
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N	Mean	SD	Min
US Pollution (mg/L)	1359	0.17	0.91	-2.53	13.5	2221	0.43	1.23	-6.6	14.4	3580	0.33	1.13	-6.6
DS Pollution (mg/L)	1359	0.32	4.60	-3.67	118	2221	0.52	1.30	-6.55	14.4	3580	0.44	3.01	-6.55
Differences in Log(Pollutions)	832	0.04	1.17	-5.636868	5.573162	1411	0.07	1.09	-4.111948	5.85755	2243	0.06	1.12	-5.636868
Log(Pollution_US)	993	-3.63	3.68	-9.21034	2.60269	1619	-1.81	3.10	-9.21034	2.667228	2612	-2.50	3.45	-9.21034
Log(Pollution_DS)	980	-3.63	3.71	-9.21034	4.770685	1630	-1.71	3.16	-9.21034	2.667228	2610	-2.43	3.50	-9.21034
Post GB	1359	0.40	0.49	0	1	2221	0.62	0.49	0	1	3580	0.53	0.50	0
Share of River in GB	1359	0.00	0.00	0	0	2221	1.00	0.04	.0593062	1	3580	0.62	0.48	0
length of River in GB	1359	0.00	0.00	0	0	2221	2296.29	1134.06	148.3676	5640.176	3580	1424.60	1428.25	0
River Length	1359	3351.20	1127.97	1044.731	5957.169	2221	2305.31	1131.20	1030.809	5640.176	3580	2702.34	1238.62	1030.809
Observations	1359					2221					3580			

Table 5: Greenbelt Policy Impact on Pollutants

	(1) BOD Basic	(2) BOD FE	(3) Chromium Basic	(4) Chromium FE	(5) Lead Basic	(6) Lead FE	(7) Cadmium Basic	(8) Cadmium FE
Share of GB	-1.590***	-4.698***	0.0220	4.717***	0.00961	4.723***	0.0131	4.738***
	(0.0555)	(1.21e-10)	(0.0349)	(0.0130)	(0.0282)	(0.0114)	(0.0170)	(0.0133)
Post GB=1	0.276***	0.308***	-0.630	-0.726	-0.926***	-1.022**	-0.884*	-0.908*
	(0.0531)	(0.0362)	(0.337)	(0.371)	(0.281)	(0.315)	(0.428)	(0.449)
Post GB=1 × Share of GB	-0.124***	-0.147***	0.162	0.222	0.00692	-0.00602	-0.0523	-0.0190
	(0.0121)	(0.0101)	(0.295)	(0.336)	(0.194)	(0.235)	(0.219)	(0.266)
River Length	0.0000953***	-0.000272***	0.0000837***	-0.0000942***	0.000104*	-0.0000895***	0.0000831**	-0.0000783***
	(0.000000997)	(1.49e-14)	(0.0000226)	(0.00000949)	(0.0000417)	(0.00000833)	(0.0000283)	(0.00000976)
Observations	3,942	4,018	2,172	2,172	1,397	1,397	2,241	2,241
R-squared Overall	0.158	0.341	0.074	0.202	0.074	0.114	0.079	0.101
Time Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subroute Fixed Effects		Yes	No	Yes	No	Yes	No	Yes

Standard errors in parentheses

Standard errors clustered at the water session level (us_sessionname) are reported in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$