OXFORD BROOKES UNIVERSITY

Faculty of Technology, Design and Environment

MASTER OF SCIENCE DISSERTATION

Dissertation Title:	Analysis of England’s Water Quality Based on Statutory Reports
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Dissertation Module:	TECH7009
Course Title:	MSc. Data Analytics
Date Submitted:	26/09/2024

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ABSTRACT

This dissertation explores the sustainability efforts of England's water companies, with a specific focus on water pollution incidents and their relationship to household numbers. The research evaluates the performance of water companies in reducing pollution and improving water quality through a quantitative analysis of pollution data, water company reports, and government publications. The study draws on case studies and statutory reports to assess the effectiveness of these efforts, highlighting both successes and challenges within the sector. This study presents Thames Water Utilities Ltd is the largest polluter, releasing approximately 785 million kilograms of emissions, significantly surpassing Severn Trent Water Ltd and United Utilities Water Plc, which released 323 million and 234 million kilograms, respectively. Together, these companies account for nearly 74% of the total emissions from the top 10 water companies.

The analysis highlights the role of household concentration in driving pollution levels. In regions such as the South East and London, where household counts reach 3.78 million and 3.58 million, the pressure on wastewater infrastructure is substantial, contributing to frequent pollution incidents. Thames Water, serving the most densely populated area with over 9.4 million households, exemplifies the strain placed on water management systems.

Finally, the study aims to contribute to the growing body of knowledge on sustainable water management systems in relation to household density and pollution levels. This research provides helpful information for people who make decisions about the environment, businesses that use water, and people who live in areas affected by water pollution and problems with water infrastructure. By examining the relationship between household concentration, pollution incidents, and water system resilience, the study supports the broader objective of promoting sustainable and efficient water management practices in densely populated regions.

Key Words: Water Companies, Water Quality, Regulatory Frameworks Pollution Incidents, Privatisation, Reporting Thresholds.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to all the individuals who played a pivotal role in the completion of this dissertation.

First and foremost, I extend my heartfelt appreciation to my supervisor Dr Samuel Kamperis, for his invaluable guidance, continuous support, and constructive feedback throughout this journey. His insights and encouragement have been instrumental in shaping this work. I would also like to thank the module leader, Dr Samia Kamal, for her role in overseeing the module and for being available whenever needed.

I am also immensely grateful to Oxford Brookes University for providing access to essential resources, including data, library facilities, and various other support systems that have been indispensable throughout my research.

A special thank you goes to my partner, whose constant encouragement and unwavering support have been a source of strength throughout this process. I am also forever thankful to my family for their enduring love and support, which has kept me motivated and focused during this journey.

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1. INTRODUCTION

1.1 Context

In England, the management of water services has evolved significantly over time, following trends seen across Europe (Hall and Lobina, 2008). Historically, local authorities began assuming control of water services in the late nineteenth century, leading to a diverse landscape where some authorities managed water companies independently, while others formed larger inter-municipal operators (Spiller, 2010). A small number of private companies focused exclusively on water supply remained, strictly regulated with capped profit margins. A major reorganization occurred in 1974, creating 10 regional water authorities (RWAs) responsible for water quality, supply, and sanitation across designated river basin areas. These RWAs were appointed centrally by the government, marking a shift away from local municipal oversight (Lobina and Hall, 2001).

Water, which plays a vital role in human health, wildlife, and the economy, is recognized for its significance by the Department for Environment, Food & Rural Affairs (DEFRA), which has formulated the Plan for Water to secure plentiful and pristine water resources throughout England. (Gov.uk. 2020). This plan addresses the current and future challenges of water demand, which is expected to increase by 4 billion litters per day by 2050, and tackles significant issues such as pollution and outdated sewage systems (DEFRA, 2023; Environmental Audit Committee, 2022).

The Plan for Water incorporates a systematic, local, catchment-based approach that engages communities, water companies, and businesses. It emphasizes nature-based solutions and significant investment in infrastructure. Key actions include the modernization of the Victorianera sewage network, exemplified by projects like the Thames Tideway Tunnel, and the largest ever investment by water companies to address sewerage problems, including storm overflows (National Farmers' Union, 2023; Ashley, R. 2010). According to DEFRA, 2023, water companies have committed to significant investments in sewage system upgrades and pollution control measures as part of their sustainability efforts.

In 2015, the water environment was significantly impacted by serious pollution incidents, with 325 cases reported. Although this represented a 10% decrease from the 360 incidents recorded in 2014, the data highlights the ongoing vulnerability of water resources to pollution. Notably, 65% of all serious pollution incidents in 2015 affected the water environment, marking an increase from 59% in 2014 and 53% in 2013.

This trend underscores the growing prevalence of water-related pollution challenges (Environment Agency, 2015). Among the sectors responsible for these incidents, the water industry played a prominent role, accounting for 62 serious pollution incidents. Most of these were linked to activities requiring environmental permits, indicating that despite regulatory oversight, significant risks to water quality persist within this sector. The impact of the water industry is critical, as it manages a resource that is essential for public health, ecosystems, and overall environmental sustainability (Environmental Audit Committee, 2022). The challenges in mitigating water pollution are compounded by the fact that in 13% of incidents, the source of pollution could not be identified. This highlights gaps in monitoring and enforcement that need to be addressed to protect water resources effectively.

According to Li et al. (2023), one critical factor that may influence the frequency and severity of water pollution incidents is household density. Regions with higher concentrations of households are likely to experience increased wastewater production and potential pollutant discharge.

Therefore, understanding the relationship between household density and water pollution is essential for developing targeted and effective pollution management strategies. The goal should be to reduce the incidence of pollution and safeguard the quality of water for future generations, reflecting the critical importance of this resource in both human and environmental health (Environment Agency, 2015).

1.2 Research Aim

This dissertation aims to thoroughly investigate the sustainability efforts of England’s water companies by conducting a comprehensive analysis of their pollution incidents and associated controversies, alongside their water quality management practices. By examining case studies, regulatory document and statutory reports, this study seeks to provide a detailed understanding of the challenges, shortcomings, and successes within the England water sector, highlighting areas for improvement and the impact of these incidents on overall water sustainability

1.3 Research Objectives

To gain a comprehensive understanding of the current state of water quality and pollution in England, this research will employ a data collection and analysis strategy. This will involve:

1. Examining reports from England's water companies on their pollution incidents and water quality management practices.
2. Reviewing relevant government publications, including national and international water quality standards, environment agency reports, and sustainability indices.
3. Utilizing data from government database on water quality and pollution incident and find out the corelation between household density and pollution incidents to determine if higher population densities are associated with increased pollution.
4. Compare the performance of different England's water companies in managing water quality and reducing pollution, based on the water company performance report

1.4 Research Questions

1. What are the geographic areas with the highest frequency of pollution incidents and threshold exceedances?
2. What impact have these measures had on reducing pollution incidents and improving water quality?
3. How do different UK water companies compare in terms of their performance in managing water quality and controlling pollution?
4. Which companies are leading in terms of sustainability and regulatory compliance?

2. LITERATURE REVIEW

The management of water services in England has undergone significant changes over the years, with shifting governance structures, policy reforms, and privatization playing key roles in shaping the industry. This literature review outlines these historical developments and examines recent trends, focusing on pollution control measures, the regulatory framework, and the performance of water companies. England boasts a diverse array of water bodies, including rivers, lakes, wetlands, and coastlines, which support a variety of wildlife and human activities (UK Government,2018). However, the country faces significant challenges in maintaining clean and plentiful water due to pollution, climate change, and aging infrastructure (Environmental Audit Committee, 2022).

2.1 Historical Evolution of Water Management in England

The management of water services in England has evolved from localized oversight to a centralized system, reflecting broader trends in governance and public service delivery. Initially, water services were managed by local authorities, but this decentralized structure proved inefficient in handling the growing complexity of water supply, sanitation, and pollution control.

2.1.1 Early Management by Local Authorities

During the late 19th and early 20th centuries, local authorities were responsible for managing water supply and sanitation in England. This system was fragmented, with each local authority managing its own water services, often leading to disparities in service quality and efficiency (Hall, D. and Lobina, E., 2008). The decentralized nature of water management posed challenges, particularly in coordinating water resources across different regions and addressing pollution in a comprehensive manner.

2.1.2 Centralization and the Formation of Regional Water Authorities

In 1974, a major reorganization of the water sector occurred with the creation of 10 Regional Water Authorities (RWAs) under the Water Act of 1973 (Parker, D.J. and Penning-Rowsell, E.C., 2024). This shift marked a transition from local to centralized water management, with each RWA responsible for managing water quality, supply, and sanitation within specific river basin areas (Hall & Lobina, 2008; Spiller, 2010). The RWAs integrated water management under one authority, improving coordination and oversight while moving away from localized, fragmented governance. This centralization reflected a broader shift towards river basin management, which recognized the interconnectedness of water systems and the need for comprehensive oversight (Kromm, D.E., 1985). By managing water resources across entire river basins, RWAs aimed to ensure that water quality and supply were consistently maintained across regions.

2.1.3 Privatization of Water Companies

A pivotal moment in the history of water services management in England was the privatization of water companies in 1989 (Kraemer, R.A., 1999). This change aimed to improve efficiency and attract private investment in the water sector, addressing issues such as underfunded infrastructure and poor service quality. The privatization initiative resulted in the creation of private water and sewerage companies that operated under regulatory oversight (Lobina & Hall, 2001). While privatization brought about improvements in investment and infrastructure development, it also introduced new challenges.

Figure 1: Map of water companies in England (JSR Energy Consultancy, n.d.)

Figure 1, illustrates the current distribution of water companies operating in England.

2.2 Pollution Control Measures and Challenges

Pollution control has been a longstanding issue in England's water sector, with both historical and contemporary challenges complicating efforts to ensure water quality. As demand for water has increased, the sector has faced greater pressure to manage waste, storm overflows, and industrial discharges (Parker, D.J. and Penning-Rowsell, E.C., 2024).

2.2.1 Historic Challenges in Pollution Control

Historically, pollution control in England has been hindered by outdated infrastructure and weak regulatory enforcement. For much of the 20th century, sewage treatment systems were inadequate to handle the growing urban population, resulting in frequent discharges of untreated wastewater into rivers and coastal waters. Efforts to modernize the system were slow, often due to insufficient funding and the complexity of upgrading infrastructure on a national scale (Parker, D.J. and Penning-Rowsell, E.C., 2024). During the period of RWA control, significant progress was made in improving pollution control, but challenges persisted, particularly in managing stormwater and industrial discharges. Heavy rainfall often overwhelmed the sewerage systems, causing untreated water to be discharged into rivers (Environmental Audit Committee, 2022).

2.2.2 Pollution Trends and Data

In recent years, pollution incidents have continued to plague the water sector, despite improvements in infrastructure and regulatory oversight. Between 2021 and 2022, the number of pollution incidents involving water and sewerage companies increased from 1,883 to 2,026, indicating a troubling decline in performance (Environment Agency, 2022). This rise in pollution incidents reflects persistent challenges in managing wastewater and mitigating pollution, especially in the context of aging infrastructure and the increasing frequency of extreme weather events. The number of serious pollution incidents those classified as having a significant impact on water quality has also fluctuated in recent years. In 2022, the number of serious incidents decreased slightly from

62 to 44, yet the overall performance of the water sector in managing these high-impact incidents remains inconsistent (Ellis, 2013). While this reduction is encouraging, it underscores the need for more effective pollution control measures and greater investment in infrastructure improvements to sustain long-term progress.

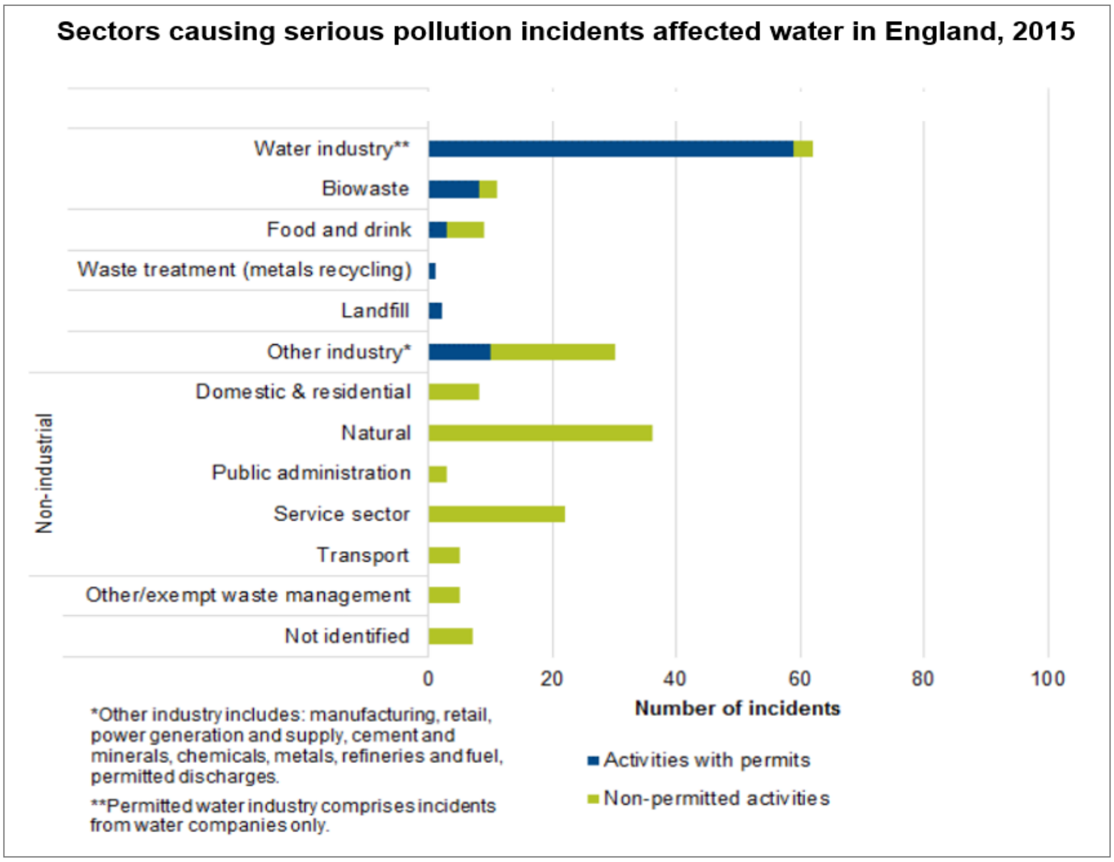

Figure 2: Sectors causing serious pollution Incidents affected water in England, 2015 (Environment Agency, 2015)

To provide context, Figure 2 illustrated the historical challenges faced by the water sector. In that year, containment, and control failures, such as malfunctioning pipes, spillages, and sewer overflows, were the leading causes of serious water pollution incidents, accounting for 52% of all cases. The water industry was responsible for 46 serious incidents, second only to the farming sector. This historical data reflects the ongoing challenges in effectively managing infrastructure and preventing pollution incidents, which remain a concern in the present day.

2.2.3 Water Companies and Pollution

Water companies play a central role in managing wastewater treatment and preventing pollution (Kraemer, R.A., 1999). However, their performance has been inconsistent, with notable issues in compliance and infrastructure maintenance. Research indicates that water companies were responsible for a significant portion of pollution incidents, with serious incidents often linked to inadequate wastewater treatment processes (Environment Agency, 2020).

Despite improvements, serious pollution incidents caused by water companies remain a persistent problem. In 2015, activities requiring environmental permits accounted for 170 serious pollution incidents, with water companies responsible for 59 of these incidents the highest number recorded among all sectors (Environment Agency, 2015).

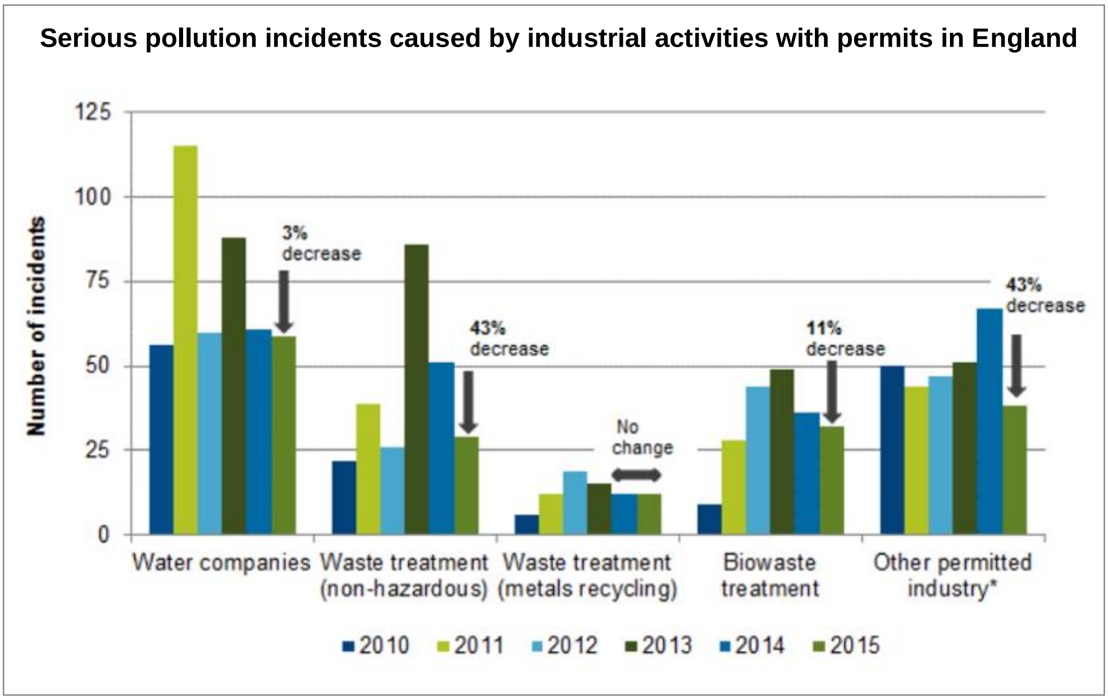

Figure 3: Serious pollution incidents caused by industrial activities with permits in England (Environment Agency, 2015)

2.2.4 Comparative Performance of Water Companies

Comparative studies of water companies reveal varying levels of efficiency in managing pollution and maintaining environmental standards. Performance often depends on factors such as the extent of infrastructure investment, adherence to regulatory requirements, and innovative practices in water conservation and pollution control (Hunt & Lynk, 1995). While some water companies have made strides in reducing pollution, others continue to struggle with compliance and infrastructure maintenance. The varying performance of these companies suggests that regulatory oversight and enforcement play a critical role in ensuring that all water providers meet the required environmental standards.

2.3 Government and Regulatory Actions

Regulatory frameworks have been central to efforts to manage water quality and reduce pollution in England. Over the years, the government has introduced a range of laws, policies, and monitoring systems to oversee water management and ensure compliance with environmental standards.

2.3.1 Regulatory Framework for Water Quality

Water quality in England is governed by both national and European Union directives, with the EU Water Framework Directive (WFD). It is playing a key role in setting comprehensive water quality standards. The WFD requires member states to achieve good ecological and chemical status for all water bodies (European Commission, 2000). Although the UK has left the EU, the WFD continues to influence water management policies in England, with similar standards incorporated into national law. Organizations like the Environment Agency and Ofwat make sure that water companies follow these rules, ensuring they meet their responsibilities for water quality and protecting the environment. The Environment Act 2021 further strengthened regulatory measures, providing the government with additional tools to enforce water quality standards and promote environmental sustainability (DEFRA, 2023).

2.3.2 The Plan for Water: A Strategic Response

In response to growing concerns about water sustainability and pollution, DEFRA introduced the "Plan for Water," which outlines a comprehensive strategy to address water quality challenges in England. The plan focuses on modernizing outdated infrastructure, particularly the Victorian-era sewerage systems that continue to pose significant problems for water management (DEFRA, 2023). One of the key initiatives under the Plan for Water is the Thames Tideway Tunnel project, which aims to reduce storm overflows and improve the overall resilience of the sewerage network. This initiative reflects a broader trend toward integrating nature-based solutions and investing in infrastructure to address water quality issues (National Farmers' Union, 2023; Ashley, 2010).

2.4 Water Quality Standards and Sustainability Indices

Performance measurement in the water sector is crucial for ensuring that companies meet water quality standards and operate sustainably (Newson, M., 2008). Various performance metrics and sustainability indices are used to evaluate the environmental performance of water companies, with a particular focus on pollution control, infrastructure reliability, and customer service.

2.4.1 Water Quality Standards

Water quality standards in England are established through both national regulations and European Union directives, which set specific requirements for maintaining and improving water quality. The European Union Water Framework Directive (WFD) has been a cornerstone of water quality regulation since its introduction in 2000, requiring member states to achieve "good" ecological and chemical status for all water bodies (European Commission, 2000). Even after the UK's exit from the European Union, the principles of the WFD continue to influence water management policies in England, with the goal of ensuring long-term sustainability of water resources (Ellis, J.B., 2013).

In England, these standards are enforced through a comprehensive system of monitoring and reporting, which is primarily managed by water companies. These companies are required to regularly assess the quality of water bodies under their management and report their findings to regulatory bodies. The two key organizations responsible for overseeing compliance with these standards are the Environment Agency (EA) and Ofwat.

The Environment Agency plays a crucial role in monitoring water quality, issuing permits for discharges, and taking enforcement actions against non-compliant water companies. Ofwat, the economic regulator, ensures that water companies balance their environmental obligations with providing cost-effective services to consumers (Ofwat, 2021). Together, these agencies work to uphold water quality standards and ensure that companies are meeting their obligations under both national law and European-inspired regulations like the WFD (European Commission, 2000).

Despite these rigorous frameworks, research has highlighted some gaps in enforcement. For example, while many water bodies have shown improvement, a significant number still fail to meet the "good" status, especially in areas with high levels of agricultural runoff and industrial discharges (DEFRA, 2023). This suggests a need for continued investment in pollution control and a more effective regulatory approach to ensure that water companies meet their environmental obligations.

2.5 Trends and Patterns in Pollution Incidents

Historical data on pollution incidents reveals fluctuations in pollution levels across England, with significant increases often linked to infrastructure failures, regulatory changes, and shifts in environmental enforcement practices. This trend underscores the complexity of managing pollution effectively, especially as it relates to the aging infrastructure and climate-driven weather events that have intensified the pressure on the water sector.

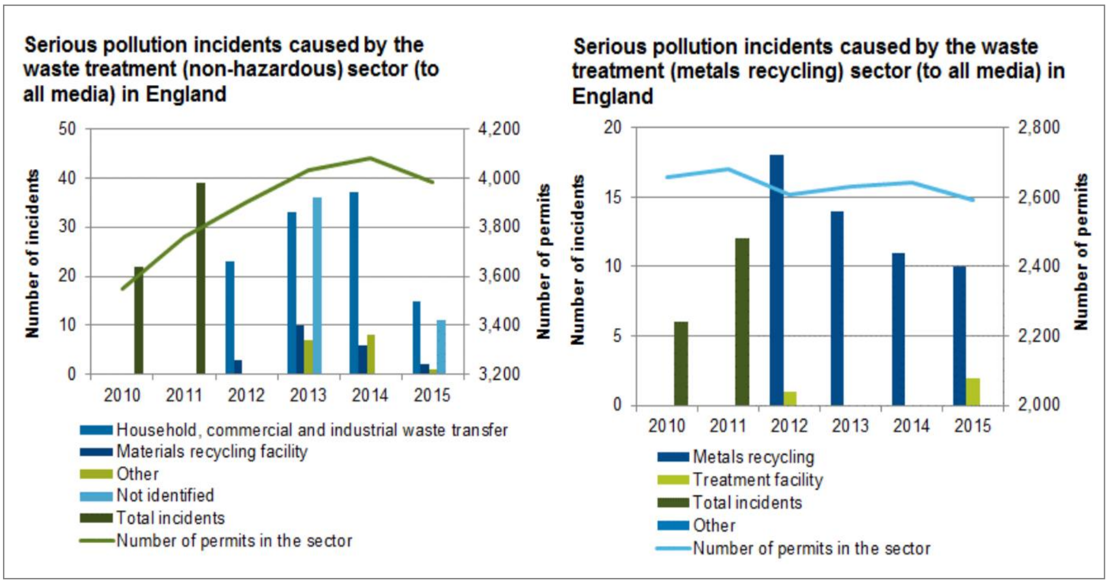

Figure 4: Serious pollution incidents caused by the waste treatment (Environment Agency, 2015)

In Figure 4, data from the Environment Agency highlights a decrease in the number of permits issued for the waste treatment sector, with a reduction of 1.9% for metals recycling and 2.4% for non-hazardous waste treatment. This reduction in permits was accompanied by a notable decrease in pollution incidents, particularly those stemming from industrial activities. In the metals recycling sector, two specific sites accounted for seven pollution incidents that year, alongside a rise in noise-related issues. However, the frequency of explosions in this sector also declined, largely attributed to the widespread installation of pre-shredders and the ongoing re-permitting process under the Industrial Emissions Directive (Environment Agency, 2015).

Despite these improvements in certain sectors, pollution incidents have remained a persistent issue for the water industry. Notably, water companies have been responsible for a significant share of serious pollution incidents over the years. These incidents are often caused by infrastructure failures, such as malfunctioning pipes, sewer overflows, and untreated wastewater discharges (Parker, D.J. and Penning-Rowsell, E.C., 2024). In 2015, containment and control failures were responsible for 169 out of 325 serious water pollution incidents, representing 52% of the total. The water sector accounted for 46 of these incidents, second only to the farming sector, which contributed the highest number of pollution incidents (Environment Agency, 2015).

More recent data points to fluctuations in pollution levels, with occasional spikes linked to severe weather conditions and infrastructure challenges. Between 2021 and 2022, there was a notable increase in pollution incidents involving water companies, with the total number of incidents rising from 1,883 to 2,026 (Environment Agency, 2022). This increase in pollution incidents is largely attributed to aging infrastructure and storm overflows during periods of heavy rainfall. The surge highlights the need for substantial investment in infrastructure modernization and more stringent enforcement of regulations.

At the same time, serious pollution incidents those that have a substantial impact on water quality have also fluctuated. In 2022, there was a slight decrease in the number of serious incidents, dropping from 62 to 44 (Ellis, 2013). While this reduction is encouraging, the water sector's performance in addressing these incidents remains inconsistent, indicating that more effective pollution control measures are still needed.

3. RESEARCH METHODS AND METHODOLOGY

3.1 Approach

The research methodology for this study is designed to provide a comprehensive analysis of water pollution incidents and water quality in the UK, employing a multifaceted approach that integrates descriptive, analytical, and applied research strategies. The descriptive research component aims to offer a thorough overview of pollution incidents and water quality management practices by utilizing historical data and current reports. This foundational understanding sets the stage for the analytical research phase, where statistical and spatial analysis techniques are applied to uncover trends, patterns, and correlations within the data, enabling a deeper interpretation of the factors influencing water pollution.

To achieve these objectives, a combination of quantitative and qualitative data analysis techniques is employed. Quantitative analysis includes statistical methods to analyse numerical data on pollution incidents and water quality metrics, as well as data aggregation across various time periods and regions to identify broader trends. Qualitative analysis involves document review and case studies to contextualize the data, exploring the causes, effects, and responses to specific pollution incidents. Throughout the research process, ethical considerations are paramount, with strict adherence to data privacy regulations such as GDPR, anonymization of sensitive information, and maintaining transparency in reporting methods and findings. Additionally, the environmental impact of research activities is considered, with efforts made to minimize the research's ecological footprint.

3.2 Technology

The initial data exploration was conducted using Excel, which allowed for efficient data organization and preliminary analysis. For more advanced statistical analysis, R and Python were utilized as the primary tools. These programming languages provided powerful libraries and functions, enabling a deeper and more comprehensive exploration of the data. Following the analysis, impactful visualizations were created using R, given its versatility in handling complex data visualization tasks. This combination of tools ensured that the insights were clearly communicated, supporting the effective presentation of findings.

3.3 Data Collection

To conduct a comprehensive analysis of water pollution and regulatory management in the UK, a multi-source approach was employed to gather diverse datasets. This included:

Water Companies' Reports: Annual and periodic reports from major UK water companies were collected. These reports contained crucial data on pollution incidents, water quality metrics, and compliance with environmental standards. The reports provided detailed insights into the operational performance of water companies and their adherence to regulatory guidelines (Environment Agency, 2022).

Government Databases: Extensive databases maintained by the Department for Environment, Food & Rural Affairs (DEFRA) and other relevant regulatory bodies were accessed. These databases provided comprehensive records on water quality, pollution incidents, and infrastructure investments. The data was critical for analysing the broader regulatory framework and assessing its effectiveness in managing water resources (DEFRA, 2023).

Media and Documentaries: Relevant documentaries and media reports were reviewed to gain qualitative insights into the societal and environmental impacts of water pollution. These sources highlighted public perceptions, community reactions, and the broader effects of pollution on industries and ecosystems. This qualitative data complemented the quantitative findings and provided a well-rounded perspective (BBC Panorama, 2023, Channel 4 dispatches 2022).

3.4 Data Extraction

The data extraction process focused on key variables related to water pollution and water quality, drawn from the collected sources. This allowed for a structured and detailed analysis of the issues affecting water management in the UK. The following key datasets were extracted:

Pollution Incidents: Detailed data on pollution incidents, including their frequency, severity, and classification, was extracted. These incidents were categorized based on their impact level (major, significant, minor) to enable focused analysis and comparisons across different regions and time periods. This dataset provided insight into the scale of pollution challenges and the effectiveness of mitigation measures implemented over time (UK Government, 2023).

Measurements: Data on key water quality indicators, including chemical concentrations, biological parameters, and physical properties such as turbidity and temperature, was gathered. These metrics were essential for assessing the overall health of water bodies. Through the analysis of these indicators, trends and anomalies in water quality were identified, informing conclusions about the long-term sustainability of water resources (Environment Agency, 2024).

3.5 Data Verification

The accuracy of the data was verified by cross-referencing information from multiple sources. This step ensured the reliability of the data and minimized the risk of errors in subsequent analyses. Efforts were made to ensure that the data collected was current and reflected recent trends and developments. Regular updates were incorporated to maintain the relevance of the analysis, particularly in the context of rapidly changing environmental conditions and evolving regulatory landscapes.

3.6 Datasets Overview

In this section, the datasets used for the analysis are introduced, focusing on their structure, key variables, and preparation process. The primary dataset contained detailed records of pollution incidents reported across various regions, providing essential information on the location, timing, and environmental impact of each event.

These datasets were crucial in assessing the trends, severity, and geographic distribution of pollution incidents, as well as in evaluating the performance of water companies and the effectiveness of regulatory frameworks.

3.6.1 Pollution Incident Data

The pollution incident dataset was composed of multiple variables, each providing specific information related to the incidents. Key columns included identifiers, geographical locations, impact categories, and environmental consequences.

Column Name	Description
NOT_ID	A unique number assigned to each incident or event in the dataset.
NOT_DATE	The date and time when the incident or event occurred.
REGION_WM	The region under the Waste Management (WM) classification where the incident occurred.
AREA_WM	This specifies a more localized area within the WM region where the incident occurred.
REGION_PF	Region under the Pollution Framework (PF) classification where the incident occurred.
AREA_PF	Localized area within the PF region where the incident occurred.
COUNTY	County where the incident took place.
UNITARY	A unitary authority area, which is a local government structure in the UK that combines the functions of counties and districts.
DISTRICT	The district where the incident occurred. Districts are subdivisions within counties or unitary authorities.
NGR_CONF	This refers to the National Grid Reference (NGR) for the location of the incident.
X_CONF	Easting coordinate of the incident location in the National Grid Reference system.
Y_CONF	Northing coordinate of the incident location in the National Grid Reference system.
EP_INC	Indicates whether the incident is classified as an environmental protection incident, often marked with (Yes/No).
EIL_AIR	The impact category of the incident on air quality. Categories typically range from "No Impact" to "Major Impact".
EIL_LAND	The impact category of the incident on land.
EIL_WATER	The impact category of the incident on water bodies.
LATITUDE	This is the latitude coordinate of the incident location.
LONGITUDE	This is the longitude coordinate of the incident location.

Table 1: Pollution Incident Dataset (UK Government, 2023)

The dataset enabled an in-depth exploration of pollution patterns and regulatory responses over time (UK Government, 2023). The dataset was meticulously cleaned and prepared for analysis to ensure its integrity and accuracy. Initially, unnecessary columns, such as REGION_PF and AREA_PF, were removed to streamline the dataset and focus on the most relevant information. Records with missing values in key columns, such as REGION_WM, were filtered out to maintain the quality of the dataset. The NOT_DATE column, which contained the notification dates of the incidents, was converted from a string format to a datetime object, facilitating precise time-based analyses. The spatial coordinates (X_CONF and Y_CONF) were transformed from the British National Grid system (EPSG:27700) into latitude and longitude values in the WGS84 format (EPSG:4326), ensuring accurate geographical mapping of incidents. These new coordinates were stored in the LATITUDE and LONGITUDE columns. Additionally, a YEAR column was created by extracting the year from the NOT_DATE field, allowing for year-wise analysis of pollution trends and incidents. This preparatory work was essential for ensuring the dataset's suitability for further statistical analysis and geographic visualizations.

3.6.2 Pollution Inventory Data

The second dataset provided critical information related to pollution measurements and the regulatory management of industrial activities. This dataset contained detailed records on permits issued to operators, the substances released into the environment, and the quantities of those substances. It also included geographical data that allowed for spatial analysis of pollution incidents and their sources.

These records were essential for evaluating compliance with environmental regulations and understanding the distribution of pollution sources across different regions. To ensure the dataset was suitable for detailed analysis and visualization, a comprehensive data cleaning process was applied. Initially, missing values in non-numeric fields were replaced with the placeholder "NA," preventing issues that could arise during analysis. This step was essential for maintaining the integrity of categorical data, such as *ACTIVITY DESCRIPTION* and *SUBSTANCE NAME*, while ensuring consistency throughout the dataset.

The geographical coordinates, originally provided in the *EASTING* and *NORTHING* columns (using the British National Grid system, EPSG:27700), were converted into latitude and longitude coordinates in the WGS84 format (EPSG:4326). This conversion allowed for accurate geographical plotting, enabling spatial analysis and visualization. Any rows with invalid or missing coordinates were filtered out to ensure that only valid data points were included, enhancing the reliability of the dataset.

Column Name	**Description**
AUTHORISATION ID / PERMIT ID	A unique number for the permit given to the operator.
ACTIVITY DESCRIPTION	What kind of work or process is being done at the site
OPERATOR NAME	The name of the company running the site.
SITE ADDRESS	The physical location of the site.
SITE POSTCODE	The postal code of the site's location.
EASTING	A map coordinate showing how far east the site is.
NORTHING	A map coordinate showing how far north the site is
EA AREA NAME	The name of the regional Environment Agency office overseeing the site.
ROUTE NAME	How the substance is released into the environment
SUBSTANCE NAME	The name of the chemical or material released.
REPORTING THRESHOLD (kg)	The amount of the substance that must be reported if exceeded.
QUANTITY RELEASED (kg)	The actual amount of the substance released.
REGULATED INDUSTRY SECTOR	The general industry category the activity falls under.
REGULATED INDUSTRY SUB SECTOR	A more specific category within the general industry.

Table 2: Pollution Inventory (UK Government. n.d.)

The cleaned dataset was utilized to create an interactive density map using Dash and Plotly, allowing for dynamic filtering and exploration of operator locations and the associated pollution data. This interactive tool enabled users to analyse spatial patterns and relationships within the dataset by providing real-time updates based on user interactions with the map.

3.7 Data Analysis

The data analysis focused on evaluating the performance of different UK water companies in managing water quality and controlling pollution in different regions. A benchmarking approach was employed to compare these companies based on key performance indicators, allowing for the identification of best practices and areas requiring improvement. This analysis aimed to provide a comprehensive understanding of how well water companies adhered to regulatory standards and managed environmental risks.

3.7.1 Performance Indicators

The analysis was grounded in the use of specific indicators from the Environmental Performance Assessment (EPA), which served as a framework for assessing the effectiveness of pollution control measures implemented by the water companies. These performance indicators included:

Pollution Incident Frequency: The number of pollution incidents reported by each company over a given period, categorized by severity. This metric allowed for the comparison of the incidence rate of environmental breaches among companies.

Compliance with Water Quality Standards: Evaluating each company's ability to maintain water quality within regulatory limits, based on key parameters such as chemical concentrations, biological contamination, and physical properties like turbidity. This provided insights into how effectively companies met statutory water quality standards.

Investment in Infrastructure: Analysis of the financial investments made by each company towards improving and upgrading infrastructure, which directly influenced their ability to prevent and respond to pollution incidents. This indicator helped to identify companies that prioritized long-term solutions for sustainable water management.

3.7.2 Comparative Analysis and Recommendations

The comparative analysis of these performance indicators revealed trends and disparities in the way different water companies managed pollution risks. Companies that consistently performed well across the key indicators were identified as models for best practices in the industry. Conversely, companies with higher frequencies of pollution incidents or lower compliance rates highlighted areas where improvements were needed.

This benchmarking exercise informed a set of recommendations for improving water management practices across the industry. Suggestions included increased investment in infrastructure, enhanced monitoring, and reporting mechanisms, and adopting technologies that enable proactive pollution control measures. Additionally, fostering greater transparency and communication with the public was emphasized as a strategy for improving public trust and ensuring accountability in water management.

3.7.3 Data Visualization

To enhance the accessibility and visualization of the data on water pollution incidents, an interactive web application was developed using the R Shiny framework. The application, hosted at:
https://omnenk-sonam-chavan.shinyapps.io/shyniapp/

It provides users with an intuitive interface to explore pollution data across different regions of the UK from 2015 to 2023. The app integrates various data visualization features, including an interactive heatmap for geospatial analysis of pollution incidents, a time series plot of incidents per year, and a bar chart to show the correlation between pollution categories and incident severity. Users can dynamically filter the data by region, year, and pollution category, allowing for targeted analysis and insight generation. This interactive tool greatly enhances the ability to monitor and analyse water pollution trends, offering a valuable resource for environmental researchers, policymakers, and the public. By making complex data accessible in an easy-to-use format, the application supports better-informed decision-making and encourages active engagement with environmental data.

3.7.3.1 User Interface

The user interface of the application was meticulously designed to be both functional and visually appealing. Custom CSS was incorporated to enhance the layout and improve the overall user experience, ensuring that users could navigate the dashboard with ease. The UI was divided into several key components:

i. **Title Panel**: The title panel prominently displayed the heading "Water Pollution Incidents Analysis," setting a clear context and focus for users from the outset.

ii. **Sidebar Panel:** This section provided a dropdown menu that allowed users to filter the dataset by region. By selecting a specific region, users could instantly update the visualizations in the main panel, ensuring the data presented was relevant to their focus area.

iii. **Main Panel:** The main panel was organized into three interactive tabs.

3.7.3.2 Interactive Tabs

i. Heatmap

The heatmap was generated using the leaflet package, an interactive mapping tool that allowed users to visually explore the geographical spread of pollution incidents. Each incident was marked with a circle, color-coded to represent the severity of water pollution based on the EIL_WATER classification. The map was fully interactive, with users able to click on markers to view detailed information about each pollution incident, including its date, severity, and location.

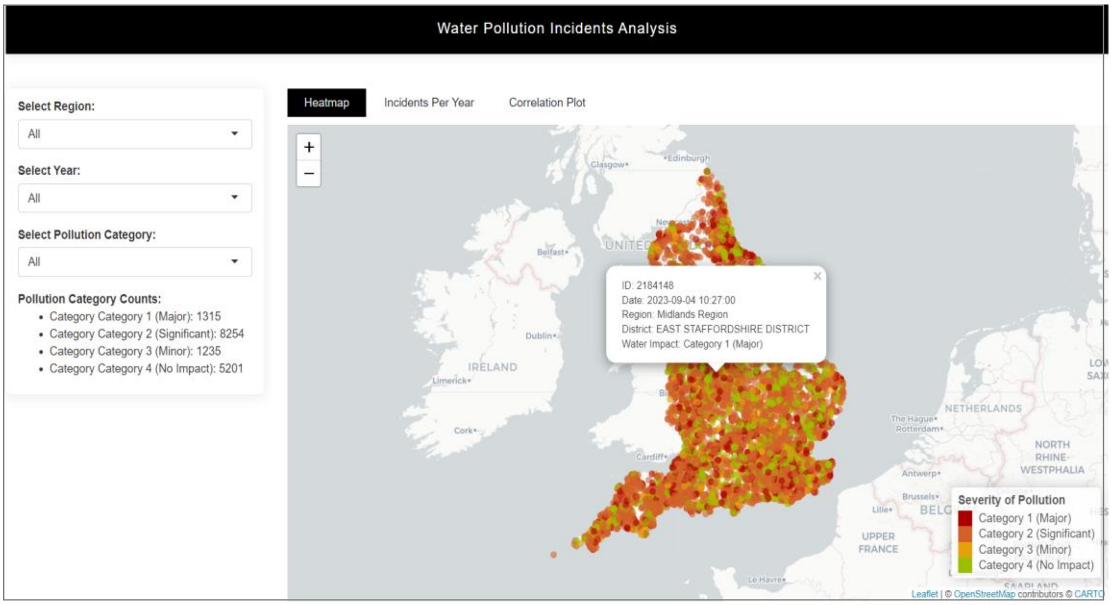

Figure 5: Heatmap of Water Pollution Incident Analysis

The heatmap helped users understand the spatial distribution of pollution incidents, making it easier to identify regions with higher frequencies or severities of pollution events. This feature was particularly useful for identifying geographical hotspots of environmental degradation, supporting regional environmental planning and policy decisions.

ii. Incidents Per Year Plot

The Number of Water Pollution Incidents per Year from 2001 to 2023, based on a time series plot. Let us analyse this graph from a data analyst's perspective:

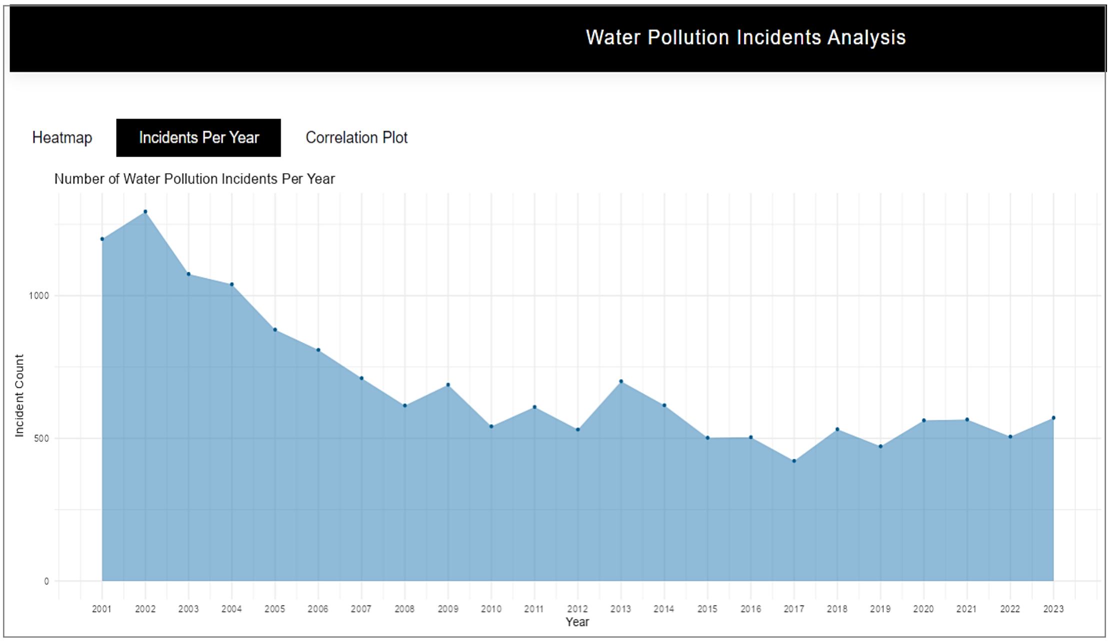

Figure 6: Incidents Per Year Plot

The graph shows the incident count of water pollution incidents per year on the Y-axis, while the X-axis represents the years, starting from 2001 to 2023. The blue area plot provides a visual of the fluctuations in the number of incidents across the 22-year period, with the total incident count displayed as points in each year.

Observations

In 2001, the number of pollution incidents was significantly high, just over 1000 incidents. From 2001 to 2005, there was a steady decline in the number of incidents, dropping below 500 incidents per year in 2007. This suggests improved pollution control mechanisms or better regulatory enforcement during this period. From 2005 to 2008, the downward trend continues, reaching its lowest around 400 incidents per year. The sharp decline could indicate substantial improvement in managing water pollution incidents or better compliance with environmental standards. After the significant decrease in incidents up to 2008, there's noticeable fluctuation in the data from 2009 onward. The number of incidents seems to oscillate between 400 and 700 incidents annually. This indicates that while major improvements were sustained, occasional increases in pollution incidents occurred. It may imply that certain factors or crises during these years led to periodic surges in incidents. From 2015 onwards, there is a plateau, with the number of pollution incidents remaining relatively stable between 500 and 600 incidents per year. This period lacks significant improvement or worsening, suggesting that after initial improvements, the pollution control measures reached a level of stagnation.

The slight increase in the years 2022 and 2023 could point to emerging challenges in water management or specific events that led to a rise in incidents. Comparing the early 2000s to the recent years, there is a marked improvement in managing pollution incidents. However, the lack of a consistent downward trend after 2015 shows that further efforts might be required to continue improving water quality and pollution management.

The graph presents a story of initial improvement, followed by a period of stability but with some fluctuations. As a data analyst, this trend would prompt further investigation into external factors (such as policy changes, environmental events, or industry behaviors) that could explain the plateaus and fluctuations. It also indicates a need for renewed efforts to push pollution levels down further and maintain consistency in pollution control across the UK.

iii. Correlation Plot

Figure 7, presents the distribution of water pollution incidents by impact level.

Category 1 (Major) Incidents: The bar chart shows that major incidents, categorized as Category 1 and represented by dark blue, remained consistently low throughout the years, generally staying below 100 incidents per year. This stability suggests that serious pollution events are being effectively managed. The slight increase in major incidents in 2023, with 57 reported cases, indicates a small uptick from 2022. Despite this, the overall count for major incidents remains low compared to other impact levels, reflecting successful control measures in place.

Category 2 (Significant) Incidents: The number of significant incidents, indicated by the light blue bars, has remained relatively stable with only minor fluctuations over the years. These incidents typically number below 100 annually and have not shown drastic changes from year to year. This stability could be attributed to consistent environmental management practices or stable external conditions affecting pollution levels.

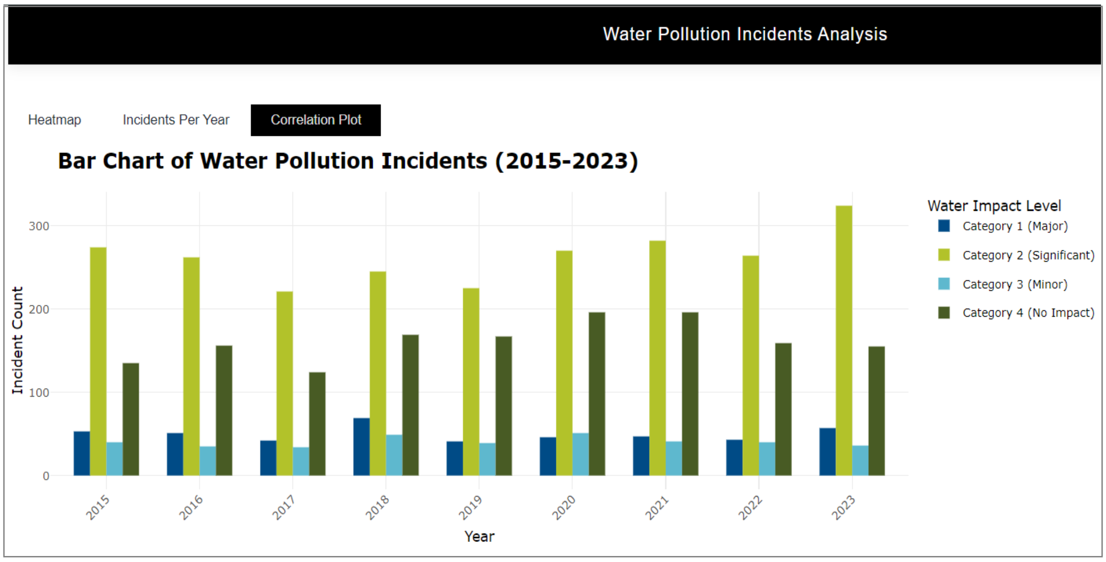

Figure 7: Correlation Plot of Water Pollution Incidents Over the Years

Category 3 (Minor) Incidents: Minor incidents, shown in olive green, exhibit noticeable fluctuations throughout the period. Years such as 2017, 2019, and 2021 experienced higher counts of minor incidents, while 2020 and 2022 saw a decline. This volatility suggests that minor pollution events are more variable and might be influenced by factors such as changes in environmental policies, seasonal variations, or differing levels of enforcement and reporting.

Category 4 (No Impact) Incidents: The yellow-green bars representing incidents with no significant environmental impact show the highest numbers each year, ranging between 200 and 300 incidents. This high count reflects a rigorous reporting system. The increase in no-impact incidents in 2023 compared to previous years could be indicative of improved detection methods or a rise in minor pollution events that, while not impactful, are still being reported.

Observations

In 2015, the number of no-impact incidents was notably high almost 300 incidents, which might suggest a focus on thorough reporting of minor issues or initial stages of enhanced monitoring practices. From 2017 to 2019, there was a noticeable decrease in no-impact incidents, possibly reflecting better pollution management or fewer incidents during this period.

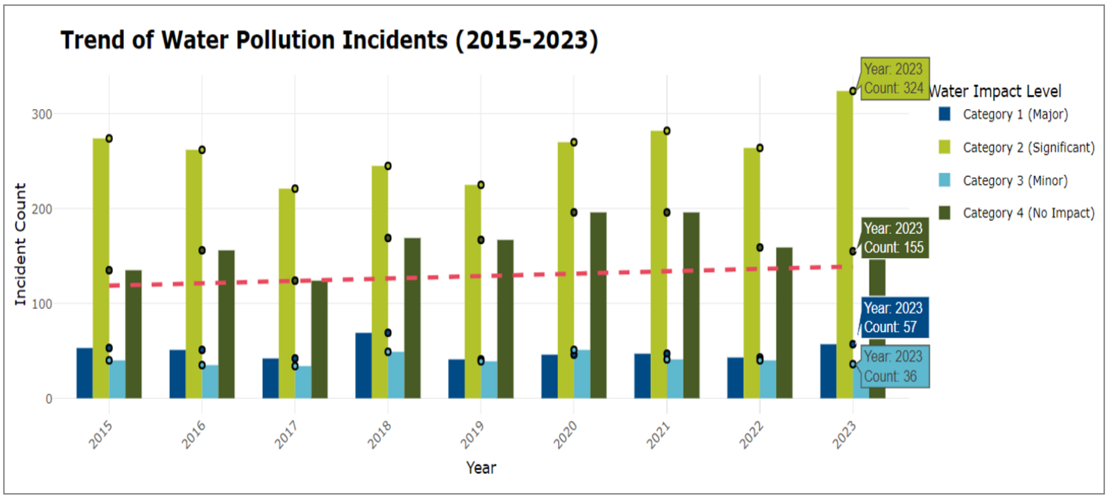

Figure 8: Trend of Water Pollution Incidents

Between 2020 and 2022, figure 8, reveals a decline in minor incidents, alongside an increase in no-impact incidents. The rise in no-impact incidents could suggest either a genuine increase in minor pollution events or improved reporting mechanisms.

In 2023, there was an overall increase in incidents across all categories, especially in minor and no-impact categories. This increase indicates a rise in reported incidents, which might be attributed to improved reporting systems or an increase in minor pollution events.

3.7.3.3 Potential Implications

The stability in major and significant incidents indicates that the control measures for severe pollution events are effective. The consistent low levels of these categories suggest that serious pollution is well-managed. The fluctuations in minor incidents point to possible variability in reporting or management practices. This variability might reflect changing environmental conditions or inconsistent enforcement. The high number of no-impact incidents underscores the effectiveness of the reporting system but also raises questions about whether this reflects actual increases in minor pollution or just improved monitoring. The rise in no-impact incidents in 2023 should be examined to determine if it signals a new trend or an anomaly due to enhanced reporting practices.

3.8 Usability and Accessibility

User Feedback: Usability testing was carried out with potential users and industry professionals to ensure the dashboard met their specific needs. Feedback from these sessions was utilized to refine the design and functionality of the tool, enhancing its effectiveness, and ensuring ease of navigation.

Accessibility Compliance: Accessibility testing was performed using an accessibility chrome extension to confirm the tool's usability for individuals with disabilities. This testing followed web accessibility standards, ensuring the dashboard was inclusive and accessible to a wide range of stakeholders.

3.9 Risk Management

In the dissertation Analysis of England's Water Companies Based on Statutory Reports, several risks were identified and managed to ensure the accuracy, fairness, and integrity of the analysis. The following sections outline the key risks related to legal, social, and data management aspects, along with the mitigation strategies that were implemented.

3.9.1. Legal Risks

A significant legal risk involved ensuring that the analysis and commentary regarding different water companies were both accurate and fair. Given the highly regulated nature of the industry, any misrepresentation of data or unfair conclusions could have resulted in potential legal consequences, including defamation. Additionally, the statutory reports used in the analysis required careful interpretation to avoid legal missteps.

To mitigate this risk, all data derived from statutory reports were cross-referenced and validated to ensure accuracy. The analysis focused strictly on factual, verifiable data, and all conclusions were drawn objectively, avoiding any speculative or subjective assertions. The information was presented transparently and fairly to ensure compliance with legal standards.

3.9.2. Social and Ethical Risks

The monopolized nature of the water industry poses social and ethical risks, as these companies provide essential services and are held to high environmental and social standards. If the analysis portrayed these companies in an unbalanced or overly critical manner, it could have led to public backlash or harm to their reputations. Additionally, socially, and ethically, water companies are expected to act responsibly, and this aspect needed careful consideration. To address these risks, the analysis was conducted with a focus on balance and fairness, considering factors such as company size and operational scale when interpreting pollution levels. Contextualizing the findings and ensuring that the conclusions were presented without bias helped to mitigate potential negative social impacts.

3.9.3 Data Management Risks

Risks related to data management, such as data loss or inaccuracies in interpretation, were also critical. Given the reliance on statutory reports, it was essential to ensure the integrity of the data throughout the research process. To mitigate these risks, a robust data management strategy was implemented. This included regular data backups and validation checks to prevent data loss or errors. By implementing proper data handling protocols, the accuracy and reliability of the analysis were maintained throughout the dissertation.

3.9.4 Impact of Mitigation Strategies

After applying these mitigation strategies, the likelihood of legal, social, and data management risks affecting the dissertation was significantly reduced. Legal risks were minimized through accurate, unbiased reporting, while social and ethical risks were mitigated by maintaining balanced and transparent analysis. Additionally, proper data management protocols ensured the reliability of the research findings, contributing to the overall robustness of the dissertation.

4. RESULT

In the following section, results from the analysis are presented, focusing on the pollution contributions of water companies. This section evaluates the significant environmental impact of the number of households and highlights the disparities in pollution levels between different companies.

4.1 Measurement Dashboard

Untreated sewage from water companies is the second-largest contributor to water pollution, following agricultural runoff. The released sewage produces toxins that can harm fish and other aquatic life, and poses health risks to dogs, wildlife, and even people who come into contact with or consume the contaminated water (HouseGrail, 2024).

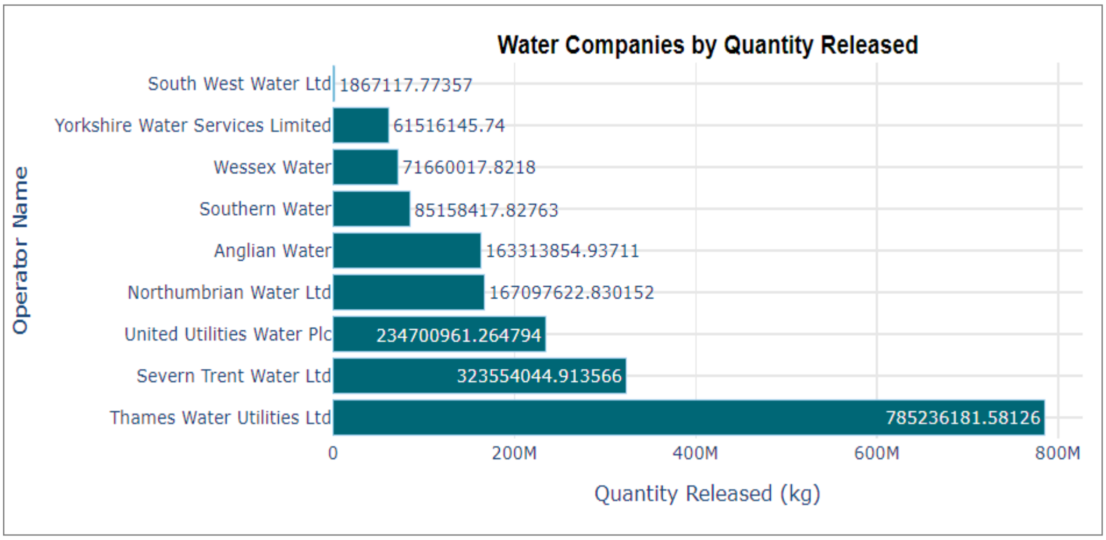

Figure 9: Water Companies by Quantity Released

Figure 9 highlights the pollution emissions from the water companies, exposing significant disparities in the quantities released.

Thames Water Utilities Ltd is the largest polluter by a wide margin, releasing around 785 million kilograms, far exceeding other companies. Severn Trent Water Ltd and United Utilities Water Plc are the next largest contributors, with emissions of approximately 323 million kilograms and 234 million kilograms, respectively. This stark contrast is clearly visible in Figure 9, where Thames Water's emission level dominates, highlighting its substantial role in the industry's total pollution output.

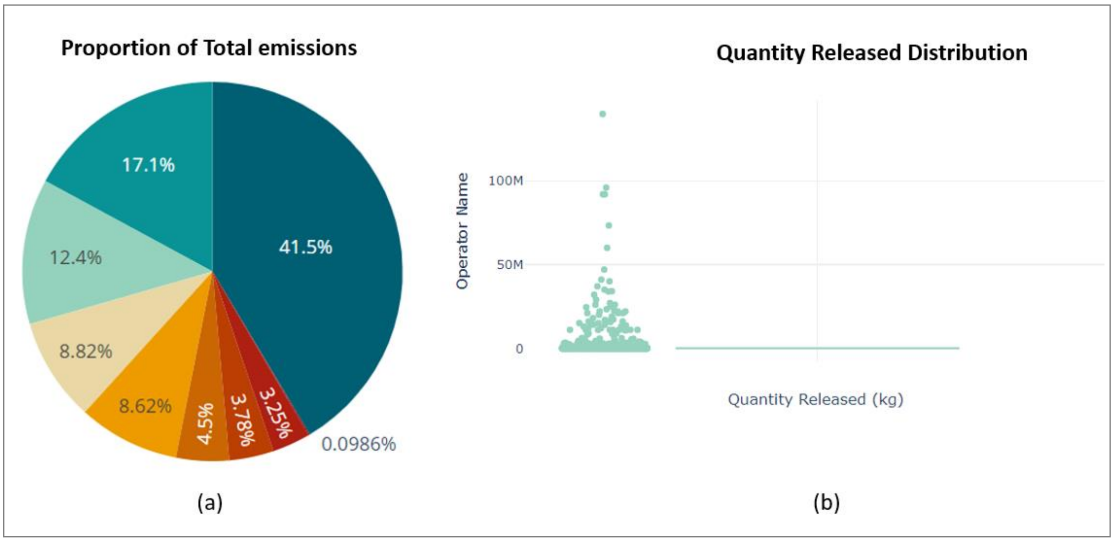

Figure 10: Proportion of total emission and Quantity released distribution

Figure 10 (a) highlights this distribution by showing the proportional share of emissions for each company. Thames Water alone is responsible for 41.5% of the total emissions from the top 10 companies, with Severn Trent Water contributing 32.5%. Together, these two companies account for nearly 74% of all emissions, underscoring their outsized impact on overall pollution levels. In comparison, smaller companies like Yorkshire Water Services Ltd, Wessex Water, and Southern Water contribute between 4.5% to 8.8%, which are relatively minor portions of the total.

Figure 10 (b) reveals the distribution of emissions across the entire dataset, showing that most companies release smaller quantities of emissions. However, the presence of significant outliers particularly the largest emitters skew the overall distribution, with a few companies pushing the upper range far beyond the median. This indicates that while most water companies have relatively few pollution incidents, Thames Water and Severn Trent Water stand out because they are responsible for the majority of these incidents. Their significant contributions to pollution highlight a serious problem within the sector that needs urgent attention.

4.2 Household Distribution

Table 3 and Figure 11 show how the population is spread out and how dense it is in different regions of England in 2022. This clearly illustrates how number of households concentration can affect environmental issues, particularly water pollution.

Region	Land Area (km²)	Population	Population (%)	Density (/km²)
North East	8,581	2,683,040	5%	313
North West	14,108	7,516,113	13%	533
Yorkshire and the Humber	15,404	5,541,262	10%	360
East Midlands	15,624	4,934,939	9%	316
West Midlands	12,998	6,021,653	11%	463
East of England	19,116	6,398,497	11%	335
London	1,572	8,866,180	16%	5,640
South East	19,072	9,379,833	16%	492
South West	23,836	5,764,881	10%	242
England	130,310	57,106,398	100%	438

Table 3: Population in different regions of England in year 2022 (Wikipedia, n.d.)

Regions such as the South East, with 9.38 million people, and London, with 8.87 million people, stand out as having the highest population densities and the largest numbers of households, with 3.78 million and 3.58 million households respectively. These regions also report significant environmental pressures, particularly related to wastewater management, due to the high concentration of people. The large number of households in densely populated areas like the South East and London increases the potential for environmental issues, particularly water pollution.

The volume of wastewater generated by these households directly correlates with the number of potential pollutants, such as biochemical oxygen demand (BOD), ammoniacal nitrogen (NH4-N), and phosphorus (PO4-P), that enter surface waters. Even minor issues, such as household misconnections to drainage systems, can escalate into significant pollution incidents when multiplied across millions of households (Ellis, J.B., 2013). This underlines the critical need for robust wastewater management systems in regions with high household densities to mitigate the risk of pollutants entering natural water systems. Figure 11, presented the number of households in different regions of England in year 2022.

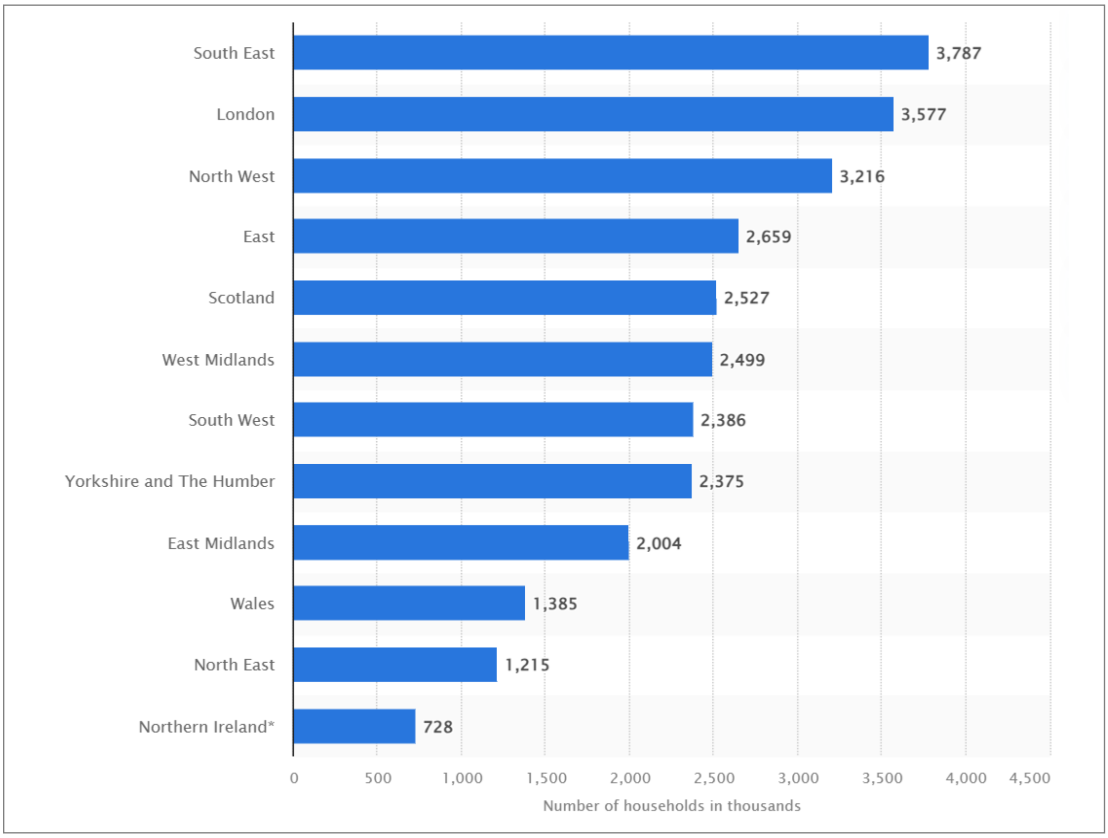

Figure 11: No. of Households in different regions of England, (Statista, 2023)

Beyond wastewater management, the growing gap between water supply and demand is a critical challenge. Water companies currently supply approximately 14 billion litres of water daily to the public, with households using an average of 144 litres per person per day.

However, by 2050, an additional 4 billion litres of water per day will be required due to increasing population pressures, climate change, and industrial demands (UK Government, 2023). Addressing this gap requires a dual approach: increasing water supply and improving water efficiency. Regional variations in water use further complicate this issue. According to Figure 12, water consumption varies significantly across England. The areas with the highest household consumption, exceeding 155 litres per person per day, are concentrated in the extreme south-west, the home counties, the central southern coast, and the north-east.

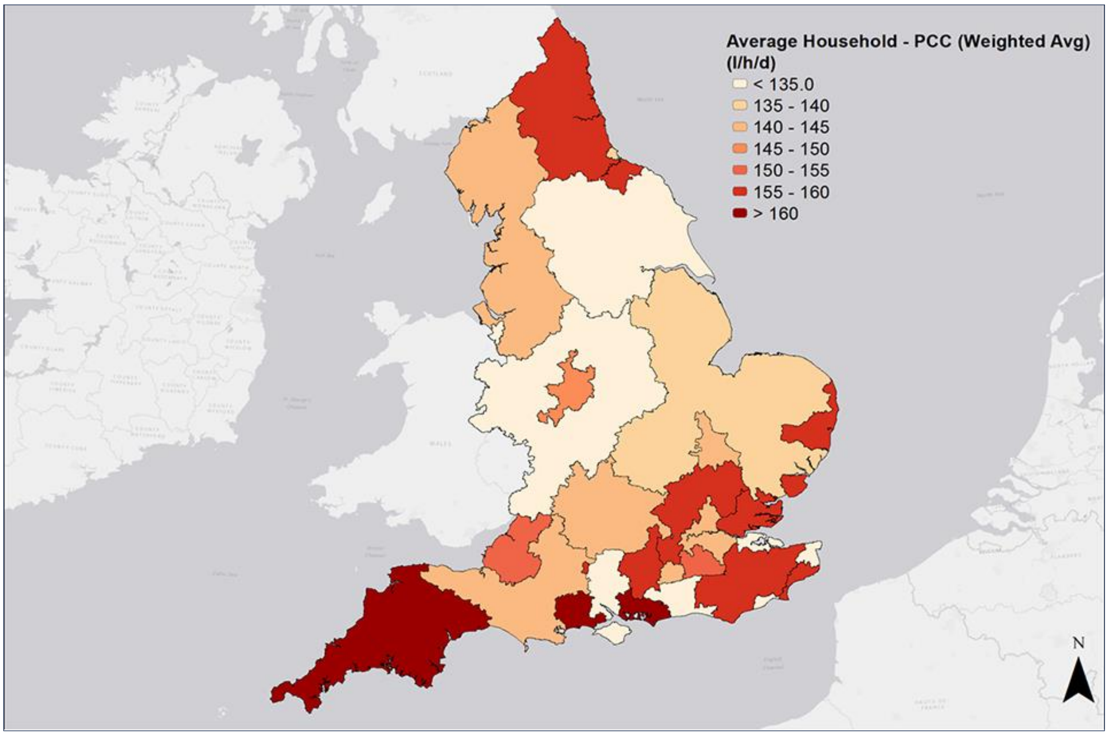

Figure 12: Water consumption in litres per person per day, mapped by water company in England (average for metered and non-metered households) in the period 2021 to 2022 (UK Government, 2023)

Conversely, the lowest consumption, below 140 litres per person per day, is identified in regions of the South East, the West Midlands, and Yorkshire. The disparity in consumption reflects differences in industrial activity, population density, and water company leakage levels.

4.3 Water Quality Risks in the Thames Region

The Thames Water region, which covers parts of London, the South East, and the East of England, serves a combined population of 24.6 million people (Wikipedia, n.d.). making it the most densely populated water service area in England. With its high concentration of households in urban and suburban areas, this region experiences significant pressure on its water infrastructure, which often leads to a higher frequency of pollution incidents.

The data in Table 3 backs this up, showing that areas like London, with 5,640 people per square kilometre, and the South East, with 492 people per square kilometre, are facing a lot of pressure. The correlation between population density and pollution incidents is particularly strong in these regions. Storm overflow discharges, which are legally permitted during periods of heavy rainfall to prevent urban flooding, are a key contributor to water pollution. As the volume of wastewater generated by households increases, particularly in densely populated regions, the threshold for triggering these discharges is often reached, resulting in untreated sewage being released into rivers and lakes. This practice, while necessary to prevent flooding, significantly impacts water quality.

4.4 Urban Strain and Reporting Thresholds

In regions like London, where the population density exceeds 5,600 people per square kilometre, the sheer volume of households connected to the water system exacerbates the risk of pollution incidents. The strain on the water infrastructure, combined with increasing urbanization, raises the likelihood of reaching regulatory reporting thresholds for storm overflows. These thresholds are critical triggers that lead to the discharge of untreated sewage into waterways when the system becomes overwhelmed. As seen in the data from the Office for National Statistics (ONS, 2021), areas with high household numbers like those serviced by Thames Water report a higher number of pollution incidents due to the increased wastewater volume and infrastructure strain.

The strain on water infrastructure in these regions is evident, and robust wastewater management strategies are essential to mitigate the environmental impact. The Thames Water region serves as a prime example of how population growth and urbanization increase the risk of pollution incidents, demonstrating the need for more resilient infrastructure and stricter pollution controls to maintain water quality in the face of growing environmental pressures.

The evidence presented in the visualization supports the observation that the South East region experienced the highest number of pollution incidents in 2023, which aligns with its larger household count. As shown in the regression analysis, the correlation between the number of households and pollution incidents highlights how densely populated areas tend to contribute to increased environmental strain, particularly on water systems. This emphasizes the need for stronger infrastructure and pollution management in high-density regions.

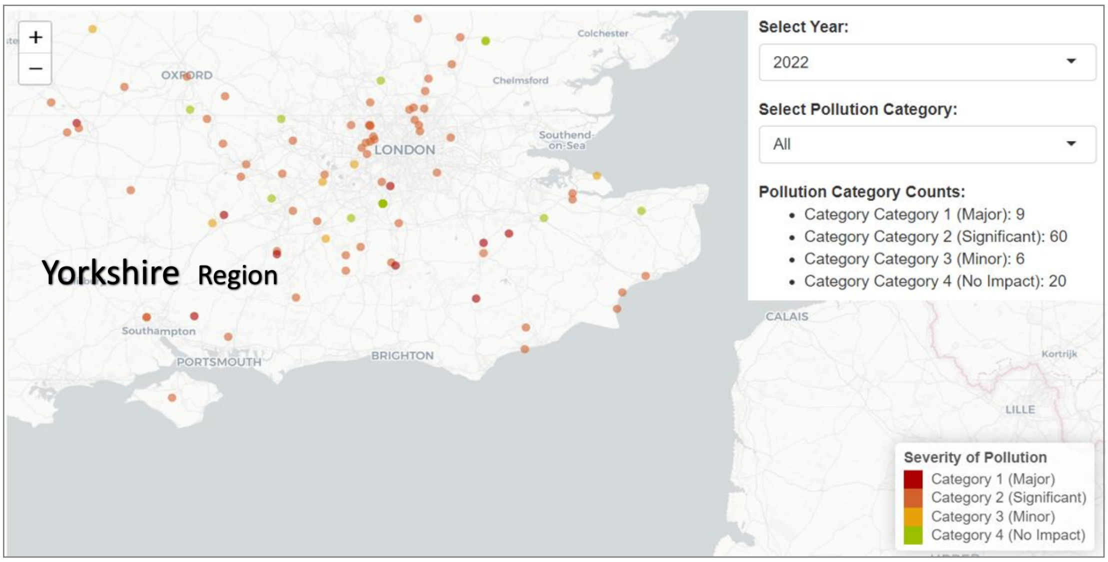

Figure 13: Reported Pollution Incidents in Yorkshire in year 2022

In contrast, Yorkshire Water has demonstrated a successful reduction in pollution incidents over the past five years, even though the region maintains a substantial household base. In year 2022, Yorkshire reported only 10 instances of minor pollutant releases below the reporting thresholds, far fewer than the North East's 204 instances. This significant reduction showcases the company’s effective strategies in addressing environmental issues such as combined sewer overflows (CSOs) and upgrading treatment facilities.

Yorkshire Water's commitment to sustainability goes beyond pollution control. Their focus on reducing water leakage, investing in renewable energy, and implementing nature-based solutions enhances not only their operational efficiency but also their contribution to environmental conservation. These initiatives have positioned Yorkshire Water as an industry leader in environmental stewardship, with forward-thinking approaches that other regions could adopt to improve their pollution management (Ofwat, 2020).

This comparison between regions underscores how targeted efforts in water management and sustainable practices can lead to better environmental outcomes, even in areas with substantial populations.

4.5 Influence of Household Concentration on Pollution Levels

Recent analysis highlights a complex narrative regarding the performance of the water sector in England with respect to pollution incidents and the influence of household numbers. Despite achieving a 15% reduction in category 1-3 pollution incidents since 2019, the sector has fallen short of performance commitments, with less than half of the companies meeting their 2022 targets. This shortfall raises concerns about the sector's ability to achieve its broader environmental goals. Notably, this reduction may have been influenced by drier weather conditions rather than sustained improvements in pollution management.

Despite these concerns, there are notable success stories among water companies. Yorkshire Water, United Utilities, and Northumbrian Water have demonstrated significant progress. Yorkshire Water, in particular, achieved over a 10% reduction in pollution incidents. This success is attributed to targeted infrastructure investments and environmental campaigns aimed at reducing combined sewer overflows (CSOs) and enhancing treatment facilities (Environment Agency, 2023).

United Utilities stands out as an exemplary performer. Serving approximately 3.2 million households in highly urbanized areas like Manchester and Liverpool, the company has managed to maintain lower-than-expected pollution incident rates. This achievement is due to strategic investments in upgrading sewerage networks and wastewater treatment plants, as well as a robust environmental action plan focused on reducing pollution and increasing biodiversity. United Utilities' commitment led to zero serious pollution incidents in 2022, positioning it as a leader in the sector (Environment Agency, 2023, Natural Resources Wales, 2023).

In contrast, Thames Water and Wessex Water have faced significant challenges. Thames Water reported a 22% increase in pollution incidents, while Wessex Water experienced a troubling 53% rise. These results indicate a pressing need for stronger infrastructure investments and more effective environmental management strategies, particularly given the large number of households served by Thames Water (Environment Agency, 2023).

The analysis of the relationship between the number of households and pollution incidents across various regions reveals several key insights. The descriptive statistics highlight that the number of households in thousands ranges from a minimum of 1,200 to a maximum of 4,500, with a mean of approximately 2,933 households. Pollution incidents vary more significantly, with a minimum of 13 incidents and a maximum of 331, resulting in a mean of 142.6 incidents.

4.5.1 Descriptive Statistics

A linear regression analysis was conducted to assess the impact of household numbers on pollution incidents. The regression coefficient for the number of households was found to be approximately 0.0456, indicating a positive relationship; specifically, for every additional thousand households, pollution incidents increased by about 0.046.

Measure	Value
Min	2200
1st Quartile	2500
Median	3203
Mean	3292
3rd Quartile	3680
Max	4580

Table 5: Households (in Thousands)

Measure	Value
Min	13.0
1st Quartile	100.6
Median	148.2
Mean	162.6
3rd Quartile	126.0
Max	331

Table 4: Pollution Incident Summary

Metric	Value
Intercept	8.9356
Correlation Coefficient	-0.4855

Table 6: Coefficients

According to Table 6, the intercept of the regression model was 8.9326, suggesting a baseline level of pollution incidents when there are no households present. The correlation coefficient was calculated to be 0.4855, which indicates a moderate positive correlation between the number of households and pollution incidents.

4.5.2 Regression Analysis of Households and Pollution Incidents

The residuals, which reflect the differences between observed and predicted values, range from -114 to 149, highlighting considerable variability in pollution incidents that the model does not fully capture. The model explains about 23.57% of the variation in pollution incidents based on household numbers, indicating that other significant factors likely influence pollution levels. Overall, the findings suggest that while a relationship between households and pollution incidents exists, it is not strong enough to draw definitive conclusions, warranting further exploration of additional influencing factors.

```
> summary(model)

Call:
lm(formula = y ~ X)

Residuals:
    Min      1Q  Median      3Q     Max
-113.92  -59.71  -28.70   57.40  148.97

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  8.93256   96.53821   0.093    0.929
X            0.04555    0.03100   1.469    0.185

Residual standard error: 97.16 on 7 degrees of freedom
Multiple R-squared:  0.2357,	Adjusted R-squared:  0.1265
F-statistic: 2.159 on 1 and 7 DF,  p-value: 0.1852
```

Figure 14: Summary of the Linear Regression model

Figure 14 and Figure 15 reinforce the significant link between urbanization and pollution. The positive correlation depicted indicates that as the number of households increases, so does the frequency of pollution incidents. This trend is particularly evident in regions such as the Thames, where high rates of pollution incidents correspond with densely populated areas, highlighting the substantial environmental challenges faced by these urban centres.

In contrast, the region of EA Wales presents a unique case. Despite having a substantial number of households, it reports fewer pollution incidents compared to other similarly populated areas. This anomaly suggests that factors beyond mere population density, such as effective pollution control strategies and favourable environmental conditions, play crucial roles in managing pollution levels. The success of EA Wales indicates that proactive measures can mitigate the impact of urbanization on water quality.

These observations underscore the need for differentiated pollution management approaches. Regions like the Thames, characterized by a high incidence of pollution relative to household numbers, may benefit from targeted interventions. Enhanced waste management systems, stricter environmental regulations, and improved infrastructure are essential for addressing the pollution challenges inherent in these densely populated areas. The data suggests that a one-size-fits-all approach may not be effective; rather, tailored strategies must be developed based on regional characteristics.

On the other hand, the performance of EA Wales serves as a valuable lesson for other regions facing similar challenges. The effective management practices implemented in EA Wales could be adopted elsewhere to improve pollution control. By analysing the strategies that have led to their success, other regions can develop best practices that balance the demands of urban growth with the need for environmental protection. Figure 15 further reveals insights regarding outliers in the dataset.

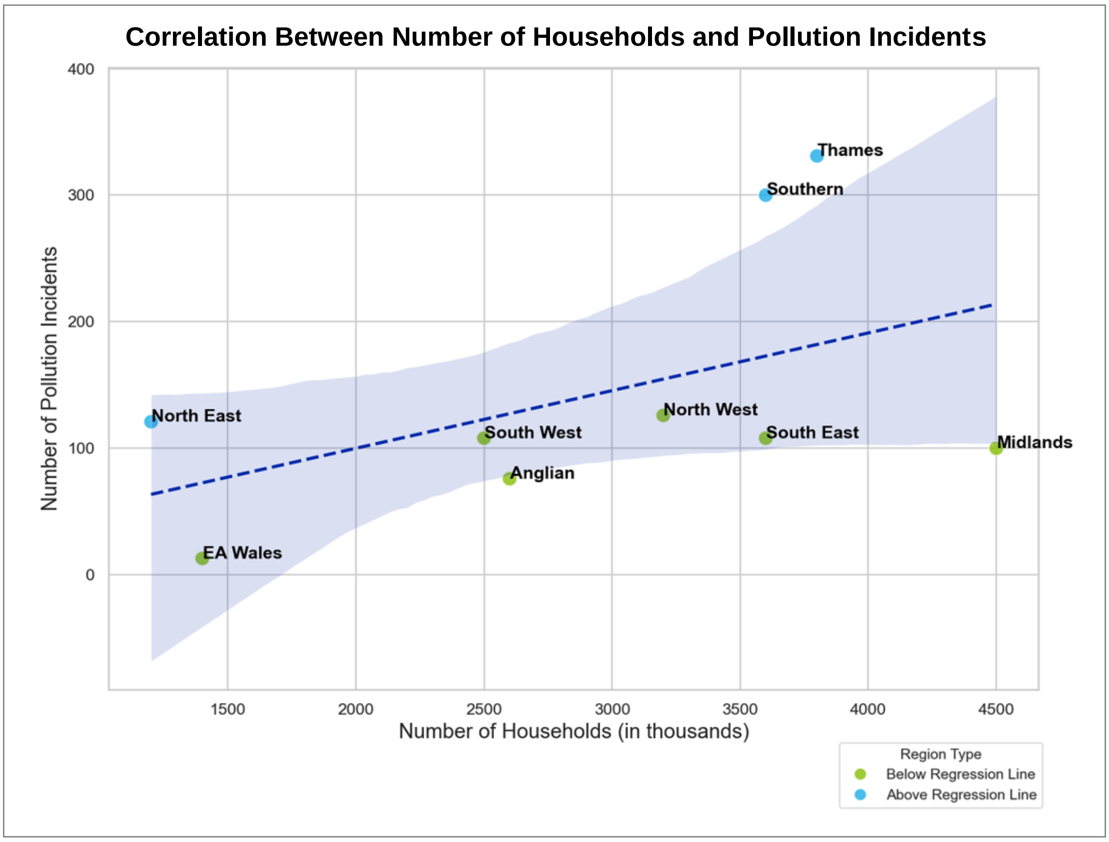

Figure 15: Correlation Between Number of Households and Pollution Incidents

The Midlands region, for example, stands out as a notable outlier with a high number of households (approximately 4,500 thousand) but comparatively few pollution incidents. This disparity may indicate superior management practices or less infrastructure stress, emphasizing the potential for successful strategies in areas facing significant population pressures.

In addition, both Thames and Southern regions exhibit high household numbers alongside elevated pollution incidents. This correlation suggests that these areas may struggle with challenges related to population density and industrial activity, which contribute to their elevated pollution levels. Such insights highlight the importance of not only considering household numbers but also evaluating the specific environmental and industrial contexts of each region. Regions falling below the trendline, such as South West, Anglian, and EA Wales, are performing better than expected given their substantial household numbers. This performance reflects effective pollution control measures or less strain on their water infrastructure, showcasing the potential for success even in densely populated areas. The comparison between the North East and North West further illustrates the variability in pollution management. Despite having similar household numbers, the North West experiences significantly more pollution incidents.

5. LIMITATIONS

The research has some limitations, including issues with data availability, such as incomplete or inaccurate information, which could affect the reliability of the findings. Additionally, focusing on specific regions or water companies may limit how broadly the results can be applied. Despite these challenges, the study is designed to be robust and aims to deliver valuable insights into water quality and pollution management in the UK, contributing to a better understanding of the current situation and potential improvements.

6. CONCLUSION

This research has achieved its objectives by thoroughly examining the pollution incidents and water quality management practices of England's water companies, reviewing relevant government publications, and analysing the correlation between household density and pollution incidents.

The comprehensive analysis of water pollution emissions across England reveals a complex interplay between population density, household numbers, and pollution incidents. The correlation graph depicting the relationship between the number of households and pollution incidents clearly illustrates a positive trend. As household numbers increase, so does the frequency of pollution incidents.

Thames Water Utilities Ltd, as the largest polluter, exemplifies the challenges faced by densely populated regions where infrastructure is often strained. With over 785 million kilograms of emissions, Thames Water’s substantial contribution to pollution levels necessitates immediate attention and action to mitigate environmental impacts. In contrast, companies like Yorkshire Water demonstrate how effective management practices can lead to notable reductions in pollution incidents, even amidst similar household densities. Their commitment to sustainability and proactive strategies for reducing combined sewer overflows and enhancing treatment facilities serve as a model for other water companies.

The identification of outliers, such as the Midlands, which has a high household count but fewer pollution incidents, raises important questions about best practices in wastewater management. Conversely, regions like the North West, despite having similar household numbers to the North East, experience significantly more pollution incidents, pointing to the influence of regional governance and operational efficiency in managing water resources.

Furthermore, regions that fall below the trendline, such as South West, Anglian, and EA Wales, exemplify effective pollution control measures. These regions provide valuable benchmarks for others striving to improve their pollution management strategies.

The findings highlight the importance of understanding regional factors that contribute to pollution levels. As urbanization continues to intensify, the pressure on water management systems will only grow.

In conclusion, while the correlation between household numbers and pollution incidents suggests a clear relationship, the variations observed among regions illustrate that effective management can break this trend. The evidence presented in this analysis underscores the necessity for a multifaceted approach to water pollution management that embraces both the challenges of urbanization and the opportunities presented by successful practices.

The future scope of this research emphasizes the role of data-driven approaches and innovative sustainable practices in enhancing water quality management in England. A key area for exploration is the application of data analytics to optimize water treatment processes and predict pollution incidents. By integrating real-time data from IoT sensors with advanced analytics, water companies can develop predictive models that identify potential pollution risks and enable proactive interventions. This approach can be complemented using nature-based solutions, such as phytoremediation with plants like common reed (Phragmites australis) and cattail (Typha latifolia), which can naturally filter and absorb contaminants from water bodies. Additionally, implementing floating treatment wetlands (FTWs) with species like water hyacinth (Eichhornia crassipes) and duckweed (Lemna minor) can help reduce nutrient levels and prevent harmful algal blooms. The integration of these sustainable practices, along with advanced data analytics, can support more effective water quality management, enabling water companies to address environmental challenges more efficiently and contribute to a more resilient and sustainable water system.

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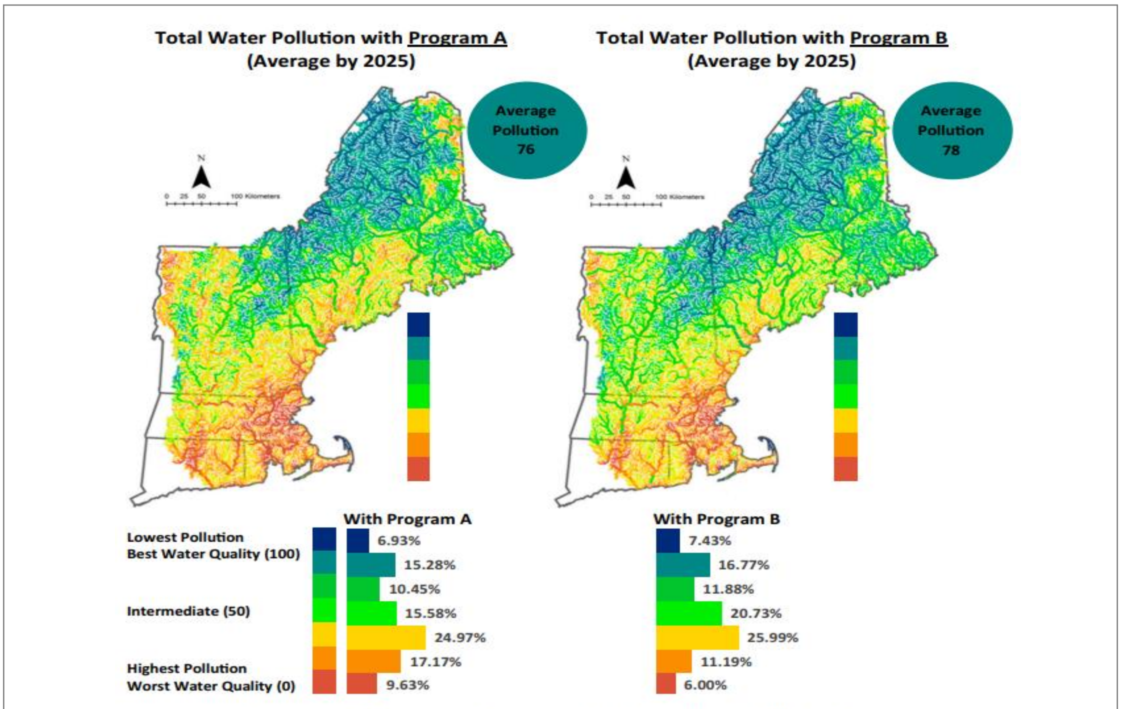
8. APPENDIX

Live Dashboard link: https://omnenk-sonam-chavan.shinyapps.io/shyniapp/

GitHub Repository link: https://github.com/sonam1666/Dissertation_Report

Google Drive link: https://drive.google.com/drive/home

Percentage of Rivers and Streams in Each Total Water Pollution Category (Program A versus Program B)



Percentage of Rivers and Streams in Each Total Water Pollution Category (Program A versus Program B)

Water and sewerage companies in England: environmental performance report 2022

Metric and units[1]	Total pollution incidents (sewerage) - per 10,000km of sewer	Serious pollution incidents (sewerage and water supply assets) - actual number	Self-reporting of pollution incidents (sewerage and water supply assets)[3] - percentage	Discharge permit compliance numeric limits (STW[4] and WTW[6] treated wastewater) - percentage	Satisfactory sludge use and disposal - percentage	Delivery of the WINEP[7] - percentage of plan delivered on time	Supply Demand Balance Index (SDBI) - score	Performance star rating (out of 4)
Red, amber, green thresholds	≥40 red >22 and <40 amber ≤22 green	Group 1[2]: ≥6 red, 4 or 5 amber, ≤3 green Group 2[2]: ≥4 red, 2 or 3 amber, ≤1 green	≤65 red <80 and >65 amber ≥80 (and ≥90% for just STW[4] and PS[5] combined)[3] green	≤98 red <99 and >98 amber ≥99 green	≤98 red <98.2 and >98 amber ≥98.2 green	≤98 red >98 and <100 amber 100 green	<99 red <100 and ≥99 amber 100 green	
Anglian Water	33	11	73 (83)	98.6	99.96	99.8	100	2 stars
Northumbrian Water	20	0	91 (92)	98.9	100	100	100	3 stars[8]
Severn Trent Water	21	1	87 (93)	99.3	100	100	100	4 stars
Southern Water	90	5	90 (95)	98.2	100	100	100	2 stars
South West Water	62	2	78 (87)	99.4	99.14	99.6	86	2 stars
Thames Water	30	17	74 (94)	99.5	100.0	95.2	100	2 stars
United Utilities	16	0	88 (90)	98.5	98.93	100	100	3 stars[8]
Wessex Water	31	5	92 (97)	99.4	100	100	100	2 stars
Yorkshire Water	22	3	77 (95)	99.7	99.91	100	100	3 stars
Sector	31	44	82 (92)	99.0	99.79	99.5	98.4 (average)	

Metric status key

Metric status	Performance description
Red	Significantly below target
Amber	Below target
Green	Achieved target or better

Serious pollution incidents water and sewerage company groupings key

Groups	Water and sewerage company
Group 1	Larger asset base size: Anglian Water, Severn Trent Water, Thames Water and United Utilities
Group 2	Smaller asset base size: Northumbrian Water, Southern Water, South West Water, Wessex Water and Yorkshire Water

Performance star rating key

Star rating	Description
4 stars	Industry leading company - 6 or more green metrics and no red metrics, including core metric at green
3 stars	Good company - 3 or more green metrics and no red metrics
2 stars	Company requires improvement - 1 or 2 red metrics and/or 2 or less green metrics
1 star	Poor performing company - 3 or more red metrics