

Analysing the Relationship Between Rainfall, Combined Sewer Overflows (CSOs), and River Water Quality in Carmarthenshire

Prepared for

ACBA5024

Research Project Design

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April 20, 2025

Abstract

This research proposal investigates the relationship between rainfall intensity, combined sewer overflow (CSO) activity, and river water quality in Carmarthenshire. Heavy rainfall can place pressure on sewer systems, leading to the discharge of untreated wastewater into rivers, which can negatively impact water quality. Understanding the relationship is important, particularly as climate change is expected to increase the frequency and intensity of rainfall events.

The study aims to examine the extent to which rainfall intensity influences the frequency and duration of CSO discharges and associated changes in river water quality. A quantitative approach will be used, based on secondary data sources including rainfall records, CSO data, and river water quality data from organisations such as Natural Resources Wales (NRW). Data will be analysed using graphs and statistical methods to identify patterns and relationships over time and across various locations.

The research is expected to show a positive relationship between rainfall intensity and CSO activity, along with declines in water quality during storm events. The study will help improve understanding of how rainfall influences river pollution and support better water management.

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1. Introduction

1.1 Background of the study

Carmarthenshire is an ideal study area because of its mix of urban and rural catchments, making it valuable for analysing how rainfall influences CSO activity and river pollution. The fact that it contains both built-up areas and rural landscapes means that rainfall can affect drainage systems and river processes differently across the county. CSOs release untreated wastewater during periods of heavy rainfall when system capacity is exceeded, contributing to river pollution and leading to a decline in river water quality. These discharges usually carry nutrients, organic matter, and bacteria, which can harm aquatic ecosystems and reduce the recreational and ecological value of rivers.

Understanding the relationship between rainfall intensity, CSO events, and river quality is important for managing water resources sustainably. This is particularly relevant as climate change is expected to increase the frequency and intensity of heavy rainfall events, placing additional pressure on existing sewer systems. As a result, CSOs may operate more frequently, increasing the risk of pollution in rivers during wet weather conditions. Examining these relationships at a local scale can help improve understanding of how rainfall-driven pressures affect river environments.

Carmarthenshire experiences high rainfall and contains several wastewater overflow sites, particularly around Carmarthen, Llanelli, and Ammanford. These towns have higher population densities and more developed drainage networks, which can increase the likelihood of CSO discharges during periods of intense rainfall. Meanwhile, rural areas contribute to varied runoff patterns, further influencing river responses to rainfall events.

Major rivers within the county, such as the River Towy and the River Loughor, are well monitored by NRW, providing reliable data on water quality responses to wet weather. This regular monitoring allows changes in river conditions to be examined in relation to rainfall and potential overflow activity. Carmarthenshire, therefore, offers good-quality data from a range of sources suitable for quantitative analysis and regression methods. These include rainfall records from the Met Office and NRW, CSO data from Dŵr Cymru Welsh Water, and river quality indicators from NRW. The availability of these datasets makes it possible to

analyse patterns and relationships between rainfall intensity, CSO activity, and river water quality across the study area.

This research also has wider relevance for understanding how combined sewer systems respond to increasing rainfall pressures across the UK, supporting improved water management and pollution mitigation strategies.

1.2 Research question

To what extent does rainfall intensity influence the frequency and duration of CSO discharges and associated changes in river water quality in Carmarthenshire?

1.3 Aims / Objectives of the study

Aims

This research aims to examine the relationship between rainfall intensity, CSO discharges, and river quality in Carmarthenshire.

Objectives:

- To critically review existing research on the effects of rainfall intensity on CSOs and river water quality.
- To analyse temporal patterns of rainfall intensity in Carmarthenshire over the selected study period.
- To analyse the relationship between rainfall events and the frequency and duration of CSO discharges.
- To evaluate the extent to which rainfall intensity is associated with variations in river water quality indicators.
- To apply quantitative statistical analysis to identify relationships between rainfall, CSO activity, and water quality.

2. Literature Review

2.1 Review of relevant literature

2.1.1 Rainfall intensity and hydrological context

Long-term rainfall patterns provide important context for understanding the hydrological behaviour of combined sewer systems. In Wales, climate data from the Met Office indicate clear seasonal variability in precipitation, with higher rainfall totals typically occurring during autumn and winter months, increasing the likelihood of surface runoff and sewer system exceedance (Met Office (UKMO)a, 2020). Recent climatological averages in Wales (1991-2020) also suggest increasing rainfall distribution compared to earlier baseline periods (1961-1990), reflecting trends associated with climate change. This increases the likelihood of high-intensity precipitation events, which can drive runoff and storm overflow activity in catchments such as Carmarthenshire. Catchment characteristics in Carmarthenshire already reflect these pressures. Steep topography and rivers with rapid runoff responses ('flashy' rivers) quickly convert rainfall into runoff, causing water levels to rise and fall within short time periods, which can trigger storm overflow discharges (Carmarthenshire County Council, 2019). High-resolution precipitation datasets like the Met Office MIDAS support quantitative assessment of rainfall-driven overflow events.

Rainfall intensity is a key driver of CSO activity, as high-intensity precipitation can exceed the hydraulic capacity of urban drainage systems. Modelling research conducted in northwest England used downscaled global climate models (HadCM3, CSIRO, CGCM2) to simulate future rainfall conditions for the year 2080 under high (A1FI) and low (B1) emission scenarios, representing different climate pathways (Abdellatif, et al., 2015). The study assessed the CSO behaviour using spill volume, duration, and frequency, and showed that intensified precipitation under a high-emissions scenario could increase total spill volume by approximately 37%, spill duration by 32%, and spill frequency by 12%. However, variation between climate models resulted in varying projections, highlighting uncertainty in long-term rainfall predictions and infrastructure planning. Although the drainage system was projected to cope with future conditions, the anticipated increase in discharge activity suggests increased pressure on sewer networks and potential risks to water quality, particularly in environmentally sensitive waters such as shellfish and bathing areas. These findings highlight the hydraulic limitations of combined sewer systems. However, these projections rely on

model assumptions about future emissions, so there is uncertainty when applying them to a specific area like Carmarthenshire.

2.1.2 CSOs and sewer system mechanisms

Combined sewer systems are designed to transport both wastewater and surface runoff within a single pipe network, with storm overflows acting as pressure-release points during periods of intense rainfall. This design remains common in older UK urban areas, including Carmarthenshire. In Carmarthenshire, the dominant use of combined sewer systems means that during periods of heavy rainfall, system capacity can be exceeded, increasing the likelihood of flooding and overflow events (Carmarthenshire County Council, 2019). CSOs temporarily release diluted wastewater into receiving waters to prevent internal flooding (Natural Resources Wales (NRW), 2023a). This reflects a trade-off between the risk of flooding and environmental protection. While these systems are designed to manage excess flow, they may not perform as effectively under increasing rainfall, especially where infrastructure has not been upgraded.

To improve transparency and regulatory oversight, Event Duration Monitors (EDMs) have been installed on permitted overflows to record the frequency and duration of spill events, providing valuable data for environmental assessment (Natural Resources Wales (NRW), 2023a). Despite these advancements, monitoring coverage is not always comprehensive, and overflow events, such as unpermitted or emergency discharges, may not be captured. The design limitations of combined sewer systems mean the system is vulnerable to increases in rainfall intensity and urban runoff, which raises concerns about their long-term effectiveness under changing climatic conditions. In many existing urban areas, including parts of Carmarthenshire, efforts are focused on upgrading and retrofitting existing systems to improve capacity and reduce overflow frequency (Defra, 2023).

2.1.3 Environmental and water quality impacts

CSOs discharge a mixture of pollutants into receiving waters, including nutrients, pathogens, suspended solids, and organic micropollutants such as pharmaceuticals and personal care products, originating from both wastewater and urban runoff sources. The contribution of these pollutants can vary, with some originating from wastewater and others from stormwater runoff during rainfall events (Launay, et al., 2016). The first flush effect is the initial phase of runoff during rainfall that carries the highest concentration of accumulated pollutants. Pollutant concentrations can increase significantly during storm events, particularly due to

first-flush effects, contributing to short-term but substantial deterioration in water quality. Micropollutants may persist and pose risks to aquatic organisms, but their impacts are difficult to estimate due to the variability and short duration of overflow events, highlighting limitations in current monitoring approaches. High-intensity rainfall events can directly drive CSO activity, linking precipitation patterns to spikes in pollutant discharges. These pollutants can significantly disrupt aquatic communities, with localised ecological impacts (Launay, et al., 2016). However, much of the research focuses on short-term changes in water quality, meaning longer-term ecological impacts are still not fully understood.

A study in a Mediterranean river basin demonstrated that mixtures of multiple pollutants could potentially affect over 50% of aquatic species at certain sites, with toxicity hotspots often corresponding to urban and agricultural pressures (Carafa, et al., 2011). It also showed that conventional monitoring may underestimate ecological risks, as bioavailable fractions and mixture effects are not always captured, reinforcing concerns about limitations of current CSO monitoring approaches.

Environmental performance data reported by NRW (2025b) provides further evidence of these impacts, with pollution incidents exceeding target levels in recent years. Although permit compliance remains high, overall company performance has declined, with EPA star ratings falling to two stars. Due to CSO events not happening continuously and on a short-duration basis, this complicates monitoring, meaning peak pollution levels and ecological effects are not always captured, highlighting gaps in understanding the localised and long-term impacts of CSO discharges on water quality in mixed urban-rural catchments such as Carmarthenshire.

2.1.4 Monitoring, regulation, and data limitations

Event Duration Monitoring (EDM) has been implemented widely to improve the monitoring and reporting of CSO activity, to provide data on the frequency and duration of discharge events. However, significant limitations remain, as recent research analysing EDM data across England has highlighted that assessing CSOs based on only spill frequency and duration provides limited insight into the drivers of CSO events or environmental impacts (Giakoumis & Voulvoulis, 2023). As a result, EDM data may oversimplify the variability between overflow events and fail to capture high-intensity discharges such as first-flush events.

CSO performance is strongly influenced by rainfall intensity and hydrological conditions, as high-intensity precipitation can exceed the hydraulic capacity of drainage systems (Abdellatif, et al., 2015). However, EDM datasets are often not combined with detailed rainfall data, making it difficult to distinguish between weather-driven overflow events and system performance issues (Giakoumis & Voulvoulis, 2023). This is particularly relevant in catchments such as Carmarthenshire, where rapid runoff and capacity exceedance can occur over short timescales, making it difficult for current monitoring approaches to capture the full extent of overflow events (Carmarthenshire County Council, 2019).

In addition, practical constraints limit monitoring effectiveness even further. The substantial number of CSO structures within sewer networks makes comprehensive monitoring costly and challenging, often resulting in incomplete spatial coverage (Montserrat, et al., 2013). As a result, current monitoring approaches may not fully capture the overall extent of CSO impacts, highlighting a disconnection between regulatory reporting measures and actual environmental risk (Giakoumis & Voulvoulis, 2023). Taken together, these limitations show a gap between monitoring practices and the accurate assessment of CSO-related environmental risk, making it harder to fully understand the environmental impact of CSOs, particularly during short, high-intensity events that may not be fully recorded.

2.2 Identification of gaps in current research

Despite extensive research into rainfall, CSOs, and water quality, significant gaps remain in understanding the relationships between these processes, particularly in the context of monitoring and data integration. Current monitoring approaches are limited in their ability to capture the full impacts of CSOs, as regulatory frameworks such as EDM focus primarily on simplified indicators such as spill frequency and duration. These datasets do not capture key elements, including pollution intensity and event drivers, meaning that short-duration, high-impact events, such as first-flush events, may be underestimated. In addition, there is limited integration between rainfall data, EDM records, and water quality data, making it difficult to establish clear links between rainfall intensity, CSO activity and environmental impact. The substantial number of CSO structures further constrains monitoring, resulting in coverage and gaps across locations, which limits understanding of localised impacts and the overall extent of pollution. Furthermore, existing datasets have limited capacity to capture short-term pollution spikes, as well as micropollutant and mixture effects, while long-term ecological impacts remain uncertain. There is also a lack of catchment-scale studies, particularly in

mixed urban-rural areas such as Carmarthenshire. A clear disconnect remains between commonly reported indicators, such as spill frequency and duration, and actual environmental impact. This highlights the need for integrated, high-resolution analysis that links rainfall, CSO activity, and water quality.

2.3 How this research will address these gaps

This study focuses on gaps in data integration, monitoring limitations, and the lack of catchment-scale studies. Rainfall data from the Met Office and MIDAS will be combined with EDM CSO data and water quality indicators to enable a comprehensive analysis of the relationship between rainfall and CSO activity. Rainfall intensity and temporal patterns, such as timing and seasonality, will be examined to identify high-intensity events and potential triggers for overflows. CSO data will be analysed in terms of spill frequency and duration to understand how these relate to rainfall events. The study will also investigate the links between CSO activity and river quality indicators, addressing the gap between monitoring data and actual environmental impact. By applying this analysis to Carmarthenshire, the study will account for mixed urban-rural catchment characteristics and local conditions. This approach helps bring the different datasets together to better understand how rainfall, CSOs and water quality are linked at a catchment scale.

3. Research Design and Methodology

3.1 Research design

A quantitative approach will be used, incorporating both spatial and temporal analysis. Quantitative methods are suitable for examining rainfall, CSO activity, and river quality because all variables are measurable and can be statistically analysed. Focusing on temporal patterns and spatial patterns, as well as correlations, allows the identification of high CSO activity, the location of pollution hotspots and the measurement of relationships between rainfall intensity, overflow events, and river water quality. This helps show when and where rainfall affects CSO activity and water quality, addressing the gaps in current monitoring and supporting evidence-based conclusions.

The study will analyse Carmarthenshire at the catchment scale and capture the interactions between rainfall, CSOs and river water quality across urban and rural areas. This scale allows spatial variability in land use, drainage infrastructure and pollutant loads to be considered, providing a comprehensive understanding of how rainfall triggers CSO events and influences water quality in mixed urban-rural environments. Multiple datasets, including rainfall, CSO, and water quality data, will be integrated to examine the extent to which rainfall influences CSO activity and river conditions. This research design helps address the gaps identified in the literature by linking rainfall events with CSO activity and water quality at a catchment scale.

3.2 Data collection methods

Daily rainfall data will be obtained from the Met Office MIDAS Open Dataset via the Centre of Environmental Data Analysis (CEDA) (2025). The dataset provides quality-controlled observational data from meteorological stations across Carmarthenshire, including daily precipitation measurements (mm). These data will be used to analyse rainfall intensity and temporal patterns, with multiple stations improving spatial representation across the study area.

Data on CSO discharges will be obtained from Dŵr Cymru Welsh Water (2025), which provides Event Duration Monitoring (EDM) records for CSOs across Carmarthenshire. This dataset includes spill counts, spill durations, and monitored asset locations for the period 2021-2024. This will enable analysis of the frequency and duration of overflow events and

allow comparison with rainfall data to identify relationships between precipitation and CSO activity. While the dataset provides reliable and regulated information, it is limited to monitored overflows and may not capture unmonitored or emergency discharges.

River water quality data will be taken from NRW (2026c), using monitoring records from sites across Carmarthenshire and surrounding catchments. The dataset includes sampling locations, dates, and a range of water quality parameters recorded as quantitative values, such as nutrient concentrations and physicochemical indicators. To make sure the analysis reflects environmental conditions, the dataset will be filtered to include only samples classified as river or running surface water, excluding effluent and sewage samples. Even though some monitoring stations are located near sewage treatment works, the measurements represent river conditions instead of direct discharges, allowing the assessment of water quality potentially influenced by overflow events. The dataset will be temporally aligned with rainfall and CSO data (2021-2024) to enable analysis of spatial and temporal variations and to examine the relationship between rainfall intensity, CSO activity, and river water quality.

3.3 Sampling methods

A purposive sampling strategy will be used to select linked datasets, including rainfall, CSO activity, and river water quality, to allow the relationship between the variables to be analysed. Monitoring sites within catchments will be used as the primary sampling units, with locations selected based on where datasets spatially and temporally overlap. Sites will be chosen according to the availability of all three datasets and consistent temporal coverage between 2021 and 2024. In addition, the spatial proximity between rainfall stations, CSOs and river monitoring sites will be considered, along with hydrological relevance, such as where CSOs are likely to influence downstream river conditions. Data completeness will also be a key criterion, with preferences given to sites with minimal missing records.

The sample size is expected to be 10-15 matched sites, and multiple rainfall stations will be used to improve spatial representation across the study area. This sample size will allow a balance between representativeness and analytical manageability. Datasets will be filtered to the 2021-2024 period, and incomplete or irrelevant records will be excluded. CSO sites will then be matched with the nearest rainfall stations and relevant downstream water quality monitoring sites. The number of sites should be enough to identify patterns across the study area while still being manageable within the time available.

This purposive approach focuses on locations where data is both available and comparable, helping to support a more reliable analysis of the links between rainfall intensity, CSO activity, and river water quality. However, it may limit how far the findings can be applied elsewhere. There is also reliance on secondary data, which can vary in quality, and there may be slight spatial mismatches between datasets.

3.4 Data analysis plan

Quantitative statistical and spatial analysis will be used to examine relationships between rainfall intensity, CSO activity, and river water quality, enabling the extent of influence to be measured. Datasets will be cleaned by removing missing or invalid data and will be aligned both temporally (2021-2024) and spatially across matched sites. Descriptive analysis will be conducted to calculate rainfall intensity patterns, CSO frequency and duration, and water quality parameters, with results presented using tables and graphical methods such as line graphs or bar charts.

Temporal analysis will be used to identify trends, seasonal patterns, and peak events in rainfall and overflow activity over the study period. Spatial analysis will involve a comparison between sites across Carmarthenshire to identify pollution hotspots and areas of high CSO activity. Geographic Information Systems (GIS), using software such as QGIS, will be applied to map the distribution of CSO sites, rainfall stations and water quality monitoring locations, supporting the visual identification of spatial patterns.

Statistical analysis will include correlation techniques, such as Pearson correlation, to assess relationships between rainfall intensity and CSO activity, as well as CSO activity and water quality. Pearson correlation is used because it allows the strength of relationships between continuous variables to be measured. Hypothesis testing will be conducted to determine the statistical significance of these relationships, with a null hypothesis stating that no relationship exists, tested against an alternative hypothesis. Comparative analysis will also be undertaken to contrast periods of high and low rainfall, and sites with varying levels of CSO activity. Results will be presented using graphs, tables, and maps.

A key limitation is that correlation analysis cannot prove causation, along with potential data gaps in secondary datasets. There are also issues with temporal resolution, such as differences between daily data and event-based records. This means short-term changes, especially during storm events, may not be fully captured.

3.5 Ethical considerations

This research is entirely based on using secondary data obtained from publicly available sources, including datasets published by NRW and similar agencies. As no primary data collection involving human participants is undertaken, there are no ethical concerns relating to consent, privacy, or confidentiality. Furthermore, the study does not pose any direct harm or risk to individuals, communities, or ecosystems.

Data integrity and accuracy are maintained by ensuring that all datasets are analysed and are not manipulated to support predetermined conclusions. This reduces the risk of bias and ensures that findings are dependable. All data sources will be fully acknowledged and appropriately referenced to avoid plagiarism and to maintain academic integrity.

In addition, transparency is upheld by recognising limitations within the data, such as missing values, temporal gaps, or inconsistencies in spatial coverage. Acknowledging these uncertainties ensures honest reporting and supports the overall credibility and ethical standards of the research.

4. Timeline

4.1 Detailed timeline of research activities

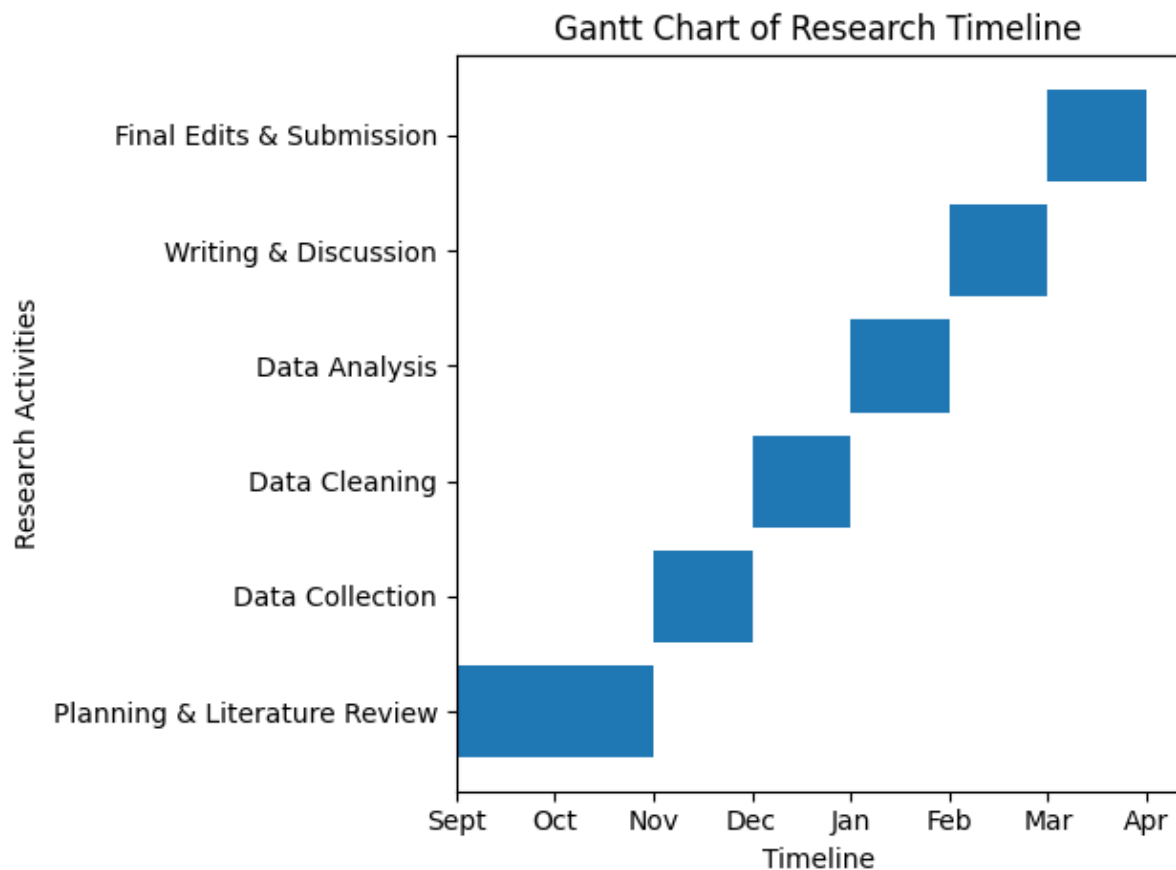


Figure 1: Gantt chart showing a proposed timetable of research activities.

A detailed timeline (Figure 1) has been developed to ensure the research is completed within the available period. The proposed project would begin with research planning and a literature review to establish a strong theoretical foundation. This is followed by the collection of secondary datasets from sources such as NRW.

The stages that follow involve data processing and cleaning to ensure accuracy and consistency, before quantitative analysis is conducted to examine relationships between rainfall, CSO activity, and water quality. The final stages focus on interpreting results, writing the discussion, and completing the report. This timeline helps keep the research manageable and well organised.

5. Expected Outcomes

5.1 Potential findings

A positive relationship is likely between rainfall intensity and CSO activity, with higher rainfall events likely to lead to more frequent and longer discharges. Consequently, water quality is anticipated to decline during and following these events, with increased concentrations of nutrients such as nitrates and phosphates, higher levels of suspended solids, and greater presence of pathogens and microbial contamination, supporting existing research. Given the potential for data inconsistencies, these results should be interpreted with caution.

Temporal patterns are also expected to emerge, with water quality deteriorating during storm events and gradually recovering during drier periods. Spatial variation is likely, with downstream sites located near CSOs experiencing more significant impacts, while upstream or more rural locations may show reduced effects.

However, the strength of these relationships may vary depending on rainfall thresholds and catchment characteristics, including differences between urban and rural areas. Variations in dataset selection may also influence the results. Additionally, weaker correlations may occur due to missing or inconsistent data, as well as differences in monitoring frequency.

Together, these findings should support existing research that CSO activity negatively impacts river water quality, while also highlighting the complexity of interactions between hydrological and environmental processes.

These anticipated findings will support the aims of the study by quantifying the relationship between rainfall, CSO activity, and water quality, while addressing the gaps identified in current research.

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