ASSESSING WATER QUALITY IMPLICATIONS OF CLIMATE CHANGE ON SEWER SYSTEMS

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ABSTRACT: *This paper presents a comprehensive assessment of the impacts of climate change on water quality in wastewater systems using InfoWorks ICM software. As climate change continues to pose significant challenges to urban infrastructure, understanding its impacts on water quality is critical to effective adaptation and management strategies. The study uses InfoWorks ICM, a robust integrated watershed modeling software, to simulate various climate change scenarios and analyse their impacts on water quality parameters such as pollutant concentrations, dissolved oxygen levels and microbial contamination. The analysis considers factors such as changing rainfall patterns, temperature fluctuations and their impact on the performance of wastewater treatment systems. The results highlight possible changes in water quality dynamics and identify areas of increased vulnerability and potential sources of pollution. In addition, adaptation strategies such as the introduction of green infrastructure, wastewater capacity building and real-time monitoring systems will be assessed to determine their effectiveness in mitigating the negative impacts of climate change on water quality. The results of this study contribute to the growing body of knowledge about the impacts of climate change on water quality in wastewater systems and provide valuable information for policymakers, engineers, and urban planners to develop sustainable and resilient water management strategies.*

Keywords: *Climate change; water quality; combined sewer overflow;*

1. Introduction

Climate change has become one of the most urgent and complex issues facing contemporary society. Its impact is felt in many aspects of our lives, including water resources and urban infrastructure. This paper is a significant contribution to the assessment of climate change impacts on water quality in wastewater systems, with a particular focus on the use of InfoWorks ICM software.

Climate change can no longer be ignored as it directly affects urban infrastructure and thus people's lives. In this regard, understanding the impact of these changes on water quality is essential for developing effective adaptation and water resource management strategies.

To make this complex assessment, researchers and engineers rely on InfoWorks ICM, a powerful integrated watershed modelling software. This sophisticated tool allows for the simulation of a wide range of climate change scenarios, making it possible to thoroughly analyse their impact on water quality. Critical parameters such as pollutant concentrations, dissolved oxygen levels and microbial contamination are monitored and assessed in this context.

The analysis covers a wide range of factors, such as changing rainfall patterns and temperature fluctuations, and examines how this influence the performance of wastewater treatment systems. In doing so, the research reveals possible changes in water quality dynamics, highlighting areas of increased vulnerability and potential sources of pollution.

Furthermore, the paper also focuses on assessing adaptation strategies such as the introduction of green infrastructure, strengthening wastewater treatment capacity and the implementation of real-time monitoring systems. These strategies are essential in efforts to mitigate the negative impacts of climate change on water quality and to ensure efficient management of this valuable resource.

The results of this study are not only theoretical but of significant practical importance. They add to the accumulated knowledge about the impact of climate change on water quality in wastewater systems and provide valuable information for policy makers, water infrastructure engineers and urban planners.

This information is essential for developing water management strategies that are sustainable and resilient in the face of increasingly evident and disruptive climate change.

In a world where climate change is a constant reality, this study is an important step towards ensuring that urban infrastructure remains adapted and functional, while guaranteeing access to quality water for our communities. It is clear proof that scientific research and technological innovation can provide practical solutions to cope with a rapidly changing world.

2. Research location

Amersfoort, a picturesque Dutch town in the province of Utrecht, is significant in discussions about climate change and sewage infrastructure. The city, with its long history and charming architecture, faces increasing challenges from the impact of climate change on water and sewage systems.

The city of Amersfoort lies in a flat geographical area and is crossed by numerous canals, which amplifies the impact of climate change on water levels. With the increasing frequency and intensity of extreme weather events such as heavy rainfall and flooding, efficient water management in the city is becoming a key priority. In this context, Amersfoort has embarked on substantial efforts to adapt and modernize its sewerage systems to meet the climate challenges.

Traditional sewerage systems, designed to manage surface water and wastewater, now face much more complex demands due to climate change. Excessive stormwater can lead to flooding, and water discharged into sewers can contain higher concentrations of pollutants due to soil run-off and erosion. In addition, temperature fluctuations can influence water quality and increase the risk of microbial contamination.

Amersfoort has implemented innovative measures and technologies to address these challenges. Green infrastructure, such as rain gardens and water absorption areas, has been developed to manage excess water and improve water quality. Such projects promote sustainable stormwater management and help reduce the risk of flooding. For wastewater, Amersfoort has upgraded water treatment systems to ensure that pollutants are removed efficiently. This is essential to protect water quality in sewers and prevent contamination of the aquatic environment. Another important aspect of climate change adaptation in Amersfoort is the implementation of real-time monitoring systems. These allow local authorities to monitor water quality and water levels in canals and react quickly in case of a threat.

In conclusion, Amersfoort provides a relevant case study and inspiration for other communities facing the challenges of climate change and water management. The city demonstrates that adapting to these challenges requires significant investments in infrastructure, innovative technologies, and efficient water resource management. Amersfoort's holistic approach to climate change and sanitation serves as an example for developing sustainable and climate-resilient water management strategies in urban contexts (Fig. 1).

Fig. 1. Location of the studied area

3. Methodology

The subject of this study is the sewage system located in the center of the Netherlands. This intricate network serves as the primary conduit for wastewater collection from the city of Amersfoort. The system is composed of roughly 130 kilometers of combined sewer and 810 kilometers of separate sewer lines, as well as 7917 hectares of impermeable surfaces. Additionally, it accommodates 157000 person equivalents, and the system exhibits an average slope of approximately 0.5%.

Within Amersfoort's historical center, a predominantly combined sewerage system is in place. This system connects seamlessly, relying on gravity-driven sewers, to a substantial portion of the mixed sewer system that extends southward from the city center. To facilitate drainage, there are six regular external outfalls distributed throughout the city center.

The utilization of these mixed overflows has given rise to a host of issues, with one of the most concerning being fish mortality. These incidents of fish fatalities have been a source of significant concern and consternation. These concerns have underscored the pressing need for a comprehensive strategy to address the challenges posed by the current sewage infrastructure (Fig. 2).

However, finding a feasible solution is not straightforward. The limitations of the existing infrastructure are compounded by the intensive use of Amersfoort's town center, the restricted subterranean space available for modifications, and the aging properties that have endured through time. As a result, the possibility of immediate

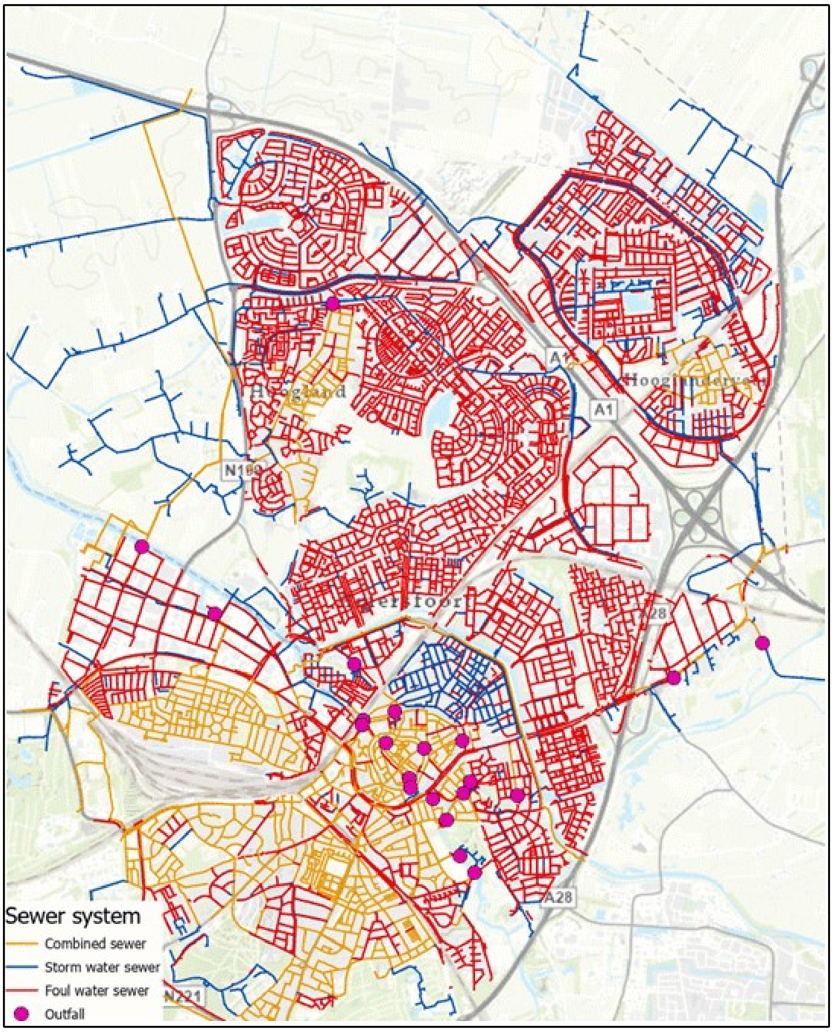

Fig. 2. Overview of sewer system and outfalls

interventions to overhaul the sewerage network remains elusive.

Considering these constraints, the most pragmatic approach to resolving these issues appears to be a long-term strategy. Such a strategy would involve a meticulous and thoughtful evaluation of the current sewage system's functioning, its vulnerabilities, and the environmental impacts associated with its operation. By taking a forward-looking perspective and formulating a comprehensive, forward- thinking plan, it is possible to chart a course toward a more effective solution to the challenges presented by the existing sewage infrastructure.

This long-term strategy would necessarily encompass several key elements. First and foremost, it would entail a detailed analysis of the existing combined sewer and separate sewer sections to identify areas where improvements could be made. This analysis would need to consider factors such as capacity, maintenance requirements, and the potential for reducing overflows.

Furthermore, the impermeable surfaces within the system would be evaluated to determine if there are opportunities to implement sustainable practices that can mitigate the adverse effects of stormwater runoff. Such measures may include permeable pavement, green roofs, and increased vegetation to absorb and filter rainwater.

In parallel, the population equivalent factor would be considered to assess the system's ability to handle current and projected future loads. This may involve identifying areas where population growth is expected and planning for necessary adjustments in sewage capacity.

The average slope of the system would also be examined to ensure that the sewage flows efficiently. Any areas with inadequate slope would be identified for potential modifications to enhance flow rates.

The historic center of Amersfoort, with its predominant combined sewerage system, would require particular attention in this long-term strategy. Options for transitioning to more modern and efficient sewer systems, while considering the constraints of space and historical properties, would be explored. Innovative solutions, such as trenchless sewer rehabilitation techniques or the integration of smart sewer technologies, could be considered to minimize disruption to the town center.

Simultaneously, the impact of the six regular external outfalls on the ecosystem and water quality would be thoroughly assessed. Strategies to mitigate these effects and protect aquatic life, such as the installation of fish-friendly infrastructure or the implementation of water treatment facilities, would be developed as part of the long-term plan.

Additionally, a robust community engagement process would be integral to the success of the long-term strategy. Collaboration with residents, businesses, and other stakeholders is vital to ensure that the proposed changes align with the community's values and priorities. Public input and feedback would be actively sought and incorporated into the planning process.

By adopting a comprehensive, forward-thinking, and community-inclusive approach, the long-term strategy aims to address the challenges posed by Amersfoort's sewage system. It seeks to safeguard the environment, enhance wastewater management, and ensure the continued vitality of the historic town center while mitigating the adverse effects of combined sewer overflows. Through careful planning, innovation, and the collective effort of the community, this strategy endeavours to pave the way for a more effective and sustainable sewage system for Amersfoort.

Infoworks ICM is a widely used software package for assessing water quality within sewer systems. Initially designed as a hydraulic network model, it has since evolved to include several sub-models that replicate diverse water quality processes. This versatile tool is crucial for predicting water quality, especially considering long-term climate change effects that can significantly influence sewer water quality.

Two primary factors associated with long-term climate change are poised to affect sewer water quality. The first factor revolves around alterations in rainfall patterns. This includes changes in rainfall intensity, volume, storm duration, and the time gaps between storms. For instance, in the Netherlands, predictions suggest that both rainfall volumes and intensities could surge by approximately 20% by 2085. Furthermore, the dry periods between storms, particularly in the summer, are anticipated to increase by up to 100%. These shifts in rainfall patterns are bound to have a profound impact on the dynamics of sewer water quality.

The second influential factor is the projected increase in air temperatures and alterations in wind patterns. These changes can result in variations in the quantity and characteristics of sediments present on catchment surfaces. Consequently, different types and amounts of sediments could potentially be washed into sewer systems, impacting the water quality. It's essential to consider these climate-related factors when making predictions and planning for future sewer water quality management.

Moreover, other long-term changes may be anticipated, such as shifts in the quantity and nature of wastewater and trade inflows. However, these changes are more likely to be driven by societal changes over time, rather than by direct climate impacts. Understanding and addressing these societal-driven changes are equally vital for effective sewer water quality management.

Currently, the runoff volumes in sewer systems are influenced by several factors, including rainfall intensity, duration, and initial losses. The initial losses are closely tied to catchment characteristics like slope, area, and the storage capabilities of impermeable and permeable areas. Typically, permeable areas exhibit initial losses approximately four times higher than those of impermeable areas. To comprehend the full implications of increased rainfall intensity and duration, these changes need to be assessed in conjunction with alterations in the ratio of impermeable to permeable areas. Models for rainfall routing often incorporate a relationship between storage and runoff to simulate surface depression storage effects. It's worth noting that the coefficient linking storage and runoff is only weakly dependent on rainfall intensity, so the modeling of this process is unlikely to be significantly affected by long-term changes in rainfall patterns.

In addition to this, various models factor in the percentage of runoff from different catchment surfaces. The extent of runoff is influenced by parameters like soil moisture depth and antecedent rainfall. In summary, the increasing rainfall volumes due to larger rainfall depths, the elevated runoff volume resulting from intensified rainfall, and the changes in impermeable areas, to a lesser extent, will all have an impact on the percentage of runoff. However, one aspect that remains less understood is the dynamics of local storage between rainfall events. This element can have a substantial influence on runoff volumes and continues to be a subject of ongoing study and research.

Pollutants can be represented in two ways: as either dissolved substances that follow the path of rainfall-runoff or as substances linked to sediments. Infoworks, which assumes conservative processes, breaks down the modeling of sediment-associated pollutants into three stages: build-up, wash off, and transportation through the sewer system to eventual treatment in a receiving watercourse. During the initial stage, changes in pollutant characteristics may occur due to climate change, whereas the wash off and transportation phases are more likely to be influenced by rainfall-runoff processes. Other significant in-sewer processes involve the onward movement of sewage solids to treatment, such as those retained by screens and larger CSO storage chambers, as well as flows that can cause issues downstream by overloading screens and increasing solid loads in clarifiers.

For climate change, the most crucial factors are non-conservative processes, which are not currently integrated into the Infoworks model. Extended sewer residence times could potentially lead to septic conditions, characterized by low levels of dissolved oxygen and the potential for in-sewer transformations affecting carbon oxygen demand and nitrogen. Prolonged, diluted loading during the decline of storm events may impact wastewater treatment by reducing the availability of essential substrates and nutrients needed for maintaining biomass.

4. Results

The assumed variation in the parameters listed considers the potential changes in sediment supply, sediment characteristics, and runoff behaviour that may arise due to shifts in climate conditions. Table 1 presents the values of BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) for different nodes, while Table 2 displays the corresponding values for conduits.

When it comes to DOC (Dissolved Organic Carbon), the quantity and characteristics of surface sediments play a pivotal role. A higher accumulation rate at the surface can result in an increase of over 100% in released COD. Climate change, characterized by elevated temperatures and longer intervals between storms, is expected to impact both surface sediment accumulation and sewage sediment characteristics. In the case of COD, it is highly sensitive to changes in sediment accumulation rate and potency factor. Soil moisture

Table 1. Cumulative results of the determinants for the nodes

Determinants	Nodes Bui10	Nodes CK05 2085
concentration BOD SF1 (kg)	0.290427	2.117065
concentration BOD total (kg)	2.95367	4.466335
concentration SF1 (kg)	11.926826	114.328463
concentration COD dissolved (kg)	16.018756	16.571367
concentration COD SF1 (kg)	2.865837	22.077152
concentration COD total (kg)	18.305867	34.393992
concentration TKN SF1 (kg)	0.085926	0.645635
concentration TKN total (kg)	0.085926	0.645635

Table 2. Cumulative results of the determinants for the conduits

Determinants	Conduits Bui10	Conduits CK05 2085
concentration BOD dissolved (kg/m3)	2.775294	2.838647
concentration BOD SF1 (kg/m3)	0.377214	2.714879
concentration BOD total (kg/m3)	3.081961	5.041271
concentration SF1 (kg/m3)	15.364168	148.008749
concentration COD dissolved (kg/m3)	16.318932	16.691339
concentration COD SF1 (kg/m3)	3.691694	28.620084
concentration COD total (kg/m3)	19.355473	40.818108
concentration TKN SF1 (kg/m3)	0.113258	0.820626
concentration TKN total (kg/m3)	0.113258	0.820626

depth and particle size, on the other hand, have a relatively lesser significance.

In essence, the modeling study suggests that the characteristics within the channel, accumulation rates of surface sediments, and the potential for pollutant fixation on surface sediments are crucial factors to consider when examining the fate of released pollutants. While the moisture depth parameter does have some influence on runoff in the case of BOD, its impact is minor compared to other parameters, particularly for COD. Clearly, sediment accumulation and its association with pollutants are of greater importance for sediment-related water quality parameters such as COD.

To elaborate, the variation in the listed parameters aims to account for the potential changes in sediment supply and characteristics, as well as the alterations in runoff behaviour that may arise due to climate changes. These parameters have been carefully considered to capture the dynamic nature of sediment-related processes and their impact on water quality. By considering these variations, the model enables a more comprehensive understanding of how changes in sediment supply and characteristics, as well as runoff behaviour, can influence the concentration of BOD and COD (Fig. 3).

In the context of COD, it is evident that the quantity and characteristics of surface sediments have the most significant impact. When the accumulation rates at the surface are higher, it can lead to a substantial increase of more than 100% in released COD. This highlights the importance of understanding and accounting for the role of surface sediments when assessing the fate of pollutants. Furthermore, the study acknowledges that climate change, characterized by higher temperatures and longer durations between storms, is likely to affect not only surface sediment accumulation but also sewage sediment characteristics.

These changes in sediment dynamics further emphasize the need to consider the potential impacts of climate change on water quality parameters (Fig. 4).

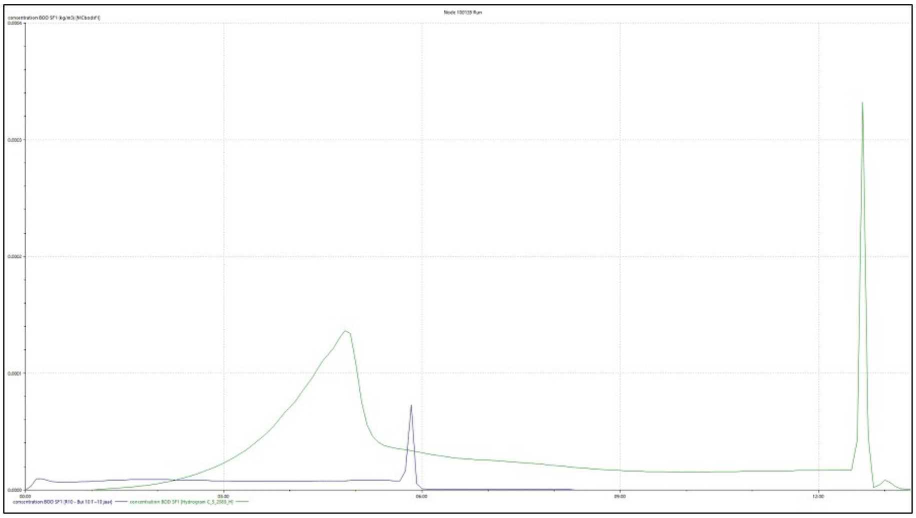

Fig. 3. Concentration of BOD in node 100139 (kg/m3)

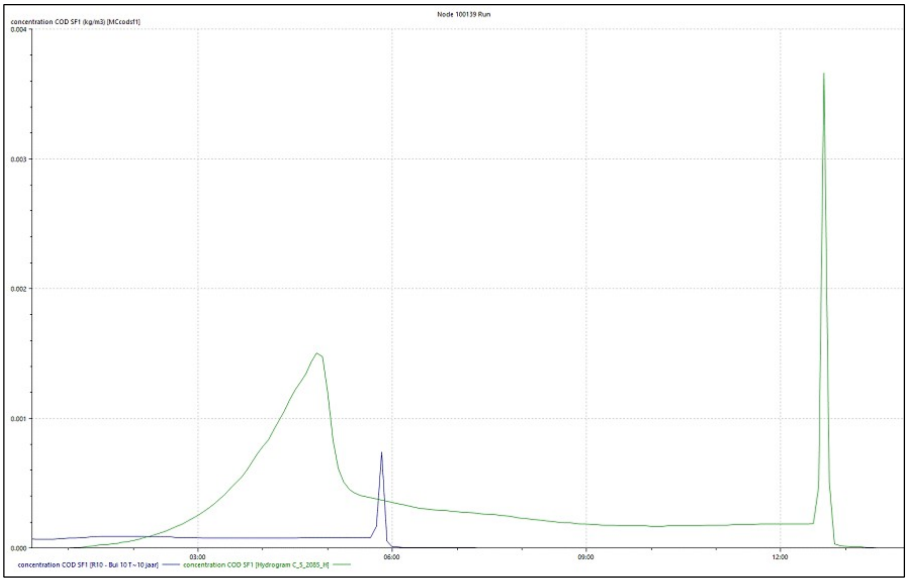

Fig. 4. Concentration of COD in node 100139 (kg/m3)

When examining the sensitivity of COD, it becomes apparent that changes in sediment accumulation rate and potency factor have the most significant influence. This implies that alterations in sediment supply and the potential for pollutant fixation on surface sediments play a critical role in determining the concentration of COD. On the other hand, parameters such as soil moisture depth and particle size have a relatively lesser importance in the context of COD. These findings highlight the need to prioritize the understanding and management of sediment accumulation and its association with pollutants, especially when addressing sediment-related water quality parameters like COD.

5. Conclusions

In conclusion, the utilization of mixed overflows in Amersfoort's sewage system has led to significant concerns regarding fish mortality. To address these challenges, a comprehensive long-term strategy is needed.

This strategy should involve analysing the existing sewer sections, identifying areas for improvement, and considering factors such as capacity and maintenance requirements. Implementing sustainable practices like permeable pavement and green roofs can mitigate the effects of stormwater runoff. Evaluating population growth and adjusting sewage capacity accordingly is crucial. Examining the system's average slope and making modifications for enhanced flow rates is also important. The historic center requires special attention, considering its combined sewerage system. Transitioning to more efficient sewer systems while considering space limitations and historical properties should be explored. Assessing the impact of external outfalls on the ecosystem and water quality is necessary, along with developing strategies to protect aquatic life. A community engagement process should be integral to the strategy's success, involving collaboration with residents and stakeholders.

The Infoworks ICM software is essential for assessing water quality within the sewer system and predicting long-term climate change effects.

Changes in rainfall patterns, air temperatures, and sediment supply due to climate change can significantly impact sewer water quality. Modeling the dynamics of sediment-associated pollutants and understanding in-sewer processes are crucial. Non-conservative processes and extended sewer residence times may affect water quality and wastewater treatment.

The modeling study emphasizes the importance of sediment accumulation, fixation of pollutants on surface sediments, and their association with water quality parameters like BOD and COD. The variation in parameters considered captures the dynamic nature of sediment-related processes and their influence on water quality. Understanding the role of surface sediments, accounting for climate change impacts, and managing sediment accumulation are vital for effective water quality management.

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