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Comparison of combined and separate sewer networks for cities with hot and dry climates using AHP method

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Abstract

Despite water regulations and standards that often favour separate sewer networks over combined ones, the substantial investments required-along with financial and economic limitations-make the selection of urban drainage systems particularly challenging for city managers, especially in developing countries. This study aims to identify the most suitable system for hot and dry regions by examining a real-world case in Ahvaz, Iran. Using Karizonai Sewer, an automated platform for designing and optimizing drainage systems, both combined and separate networks were planned with a focus on minimizing construction costs. Their performance under extreme loading conditions was then evaluated using SWMM software. Subsequently, a hierarchical framework of criteria and sub-criteria was established, and pairwise comparison matrices were developed based on modelling results and expert judgments. The final analysis reveals that the combined sewer network, is a better urban drainage solution for the given test case.

Highlights

- It is essential to align drainage solutions with the specific characteristics of each city.
- Employing optimization frameworks and multi-objective decision-making techniques can effectively balance varied criteria and aid in identifying the suitable urban drainage strategies.
- Our study in a hot, dry region show that a combined sewer network can offer more cost-effective solutions and better overall performance compared to a separate system.

Introduction

Today, urban drainage networks are considered one of the most vital infrastructures in urban areas (Afshar, 2006). In combined sewer systems, a relief mechanism called a combined sewer overflow (CSO) is used to prevent hydraulic overloading of WWTPs. CSOs direct excess flows, which include untreated raw sewage and urban runoff, to receiving waters (Bailey *et al.*, 2016). These overflows contain human and industrial waste, toxic materials, and untreated waste, posing significant threats to the environment and public health. Therefore, nearly all water regulations and standards worldwide pressure communities with combined sewer systems to implement CSO control strategies and preferably establish separate sewer systems (Bachmann-Machnik *et al.*, 2021). Despite the mentioned challenges, studies indicate that combined sewer systems perform better during weak rainfall (De Toffol, Engelhard and Rauch, 2007). Research indicates that the majority of studies on CSN issues have primarily focused on European communities and are utilized in strict European standards. These regulations are translated and applied without considering the unique characteristics of each region, such as local climates, physical constraints, financial restrictions, and social and environmental considerations. Thus, selecting an appropriate drainage system have to be aligned with the city's unique and influential characteristics.

This study compares combined and separate sewer systems using a multi-criteria decision-making model (AHP) for cities with hot and dry climates. The study aims to enable decision-makers to better understand conditions and make better choices according to their budget and execution limits.

Methodology

Network planning

The network design in this study is carried out using the Karizonai Sewer. Karizonai Sewer is a web application for automatic design of sewer networks. Traditional sewer systems are often designed using engineering software such as SWMM and SewerGEMS, taking into account hydraulic regulations, national and international standards, and some experiential values of design experts. These traditional designs are time-consuming, tedious, and heavily dependent on the expertise and engineering judgments of the designer, resulting in costly sewer system designs. The Karizonai Sewer software is based on complex algorithms from sewer system hydraulics, graph theory and artificial intelligence (Haghighi and Bakhshipour, 2012; Haghighi, 2013; Bakhshipour *et al.*, 2019).

Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is one of the most comprehensive systems designed for multi-criteria decision-making, as this technique allows for structuring the problem hierarchically. This process also enables the consideration of various quantitative and qualitative criteria (Saaty and Vargas, 2012). In this study, a AHP model was developed to compare combined and separate sewer systems. The comparative structure of this model is shown in the figure 1. This structure consists of four main criteria (economic, technical, environmental, and social) as regional policies, and twelve sub-criteria (construction and operation costs, feasibility, reliability, flexibility, resilience, pollutants, greenhouse gases, public inconvenience during construction and operation) for comparison, and at the final level, the existing options of combined and separate sewer systems.

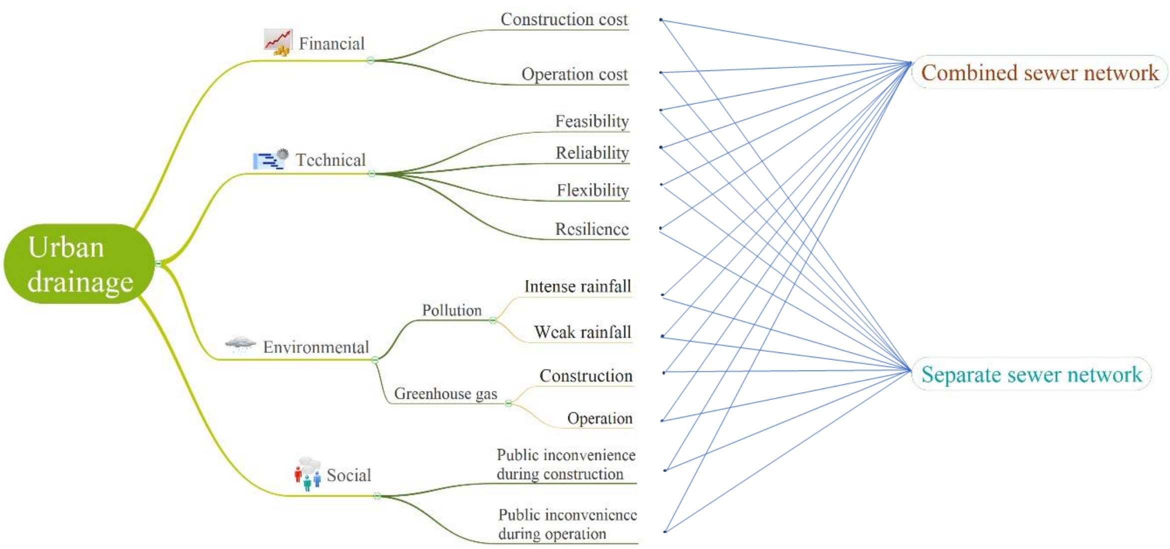

Figure 1. *The proposed AHP framework for comparison*

Case study

The test case is a section of Ahvaz, located in the southwestern part of Iran. This region covers an area of 500 hectares and is characterized by a hot and dry climate, with extremely hot summers and mild, short winters. Rainfall is rare, occurring primarily in the winter months, and intense rainfall events are infrequent. Based on the WWTP capacity, the maximum outflow at the outlet in wet weather conditions is limited to 1.4 m3/s. Topographically, the the area is flat, and the eastern boundary is marked by the Karun River, which serves as a significant natural drainage system, allowing for decentralized drainage network. This area is highly developed and densely populated, with an estimated population of 203,000 at the end of a 25-year planning period. The total length of the serviced lines is approximately 97 kilometres.

Results and discussion

In this study, the Karizonai Sewer was used to design both combined and separate, sewage and stormwater collection networks, with construction costs identified as the optimization target. The design results for the network layout are shown in the figure 2.

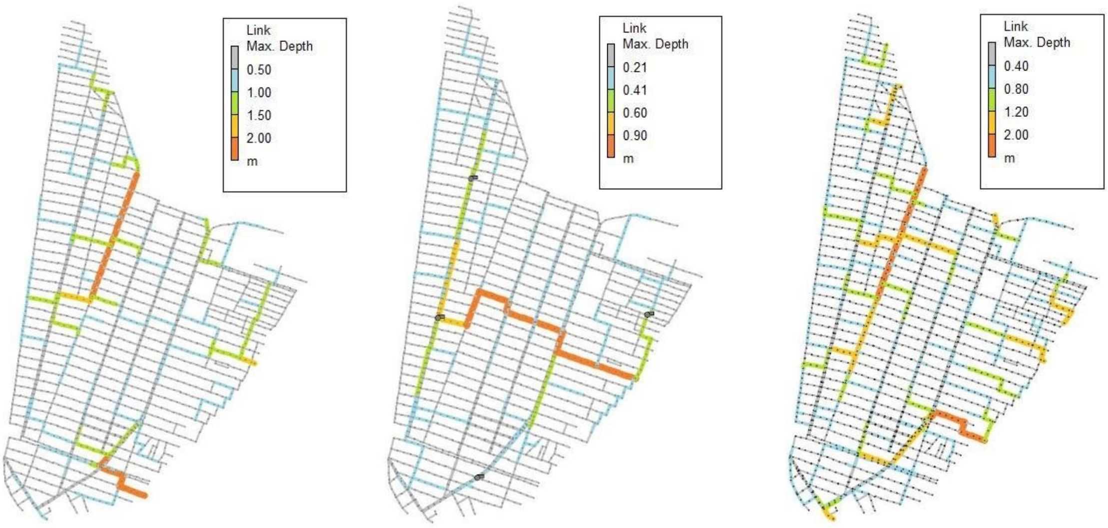

***Figure 2**. Optimal designs (from right to left: combined, sewage collection, and stormwater network)*

The construction cost of the combined sewer network is calculated to be 30.1% less than the separate sewer network, amounting to $1.14 million. The operation cost of the combined sewer network is 9.7% less than the separate networks, totalling $2.56 million for a 25-year. The volume of excavation for the combined sewer network is calculated to be 37.3% less than the separate sewer network, amounting to 261,000 cubic meters. Consequently, public inconvenience during the construction phase is higher for the separate networks. Correspondingly, the greenhouse gas emissions generated for the construction of the combined sewer network are 37.3% less than the two separate networks, amounting to 145 tons.

The energy consumed over the entire operation period by the combined sewer network was found to be 40% more than the separate sewer network, amounting to 2.9 gigawatt hours. Consequently, the greenhouse gas emissions generated during the 25-year operation period were calculated to be 2253 tons for the combined sewer network and 1609 tons for the separate sewer network. The study demonstrates that the separate sewer network has better reliability and resilience during heavy rainfall events compared to the combined sewer network. The flood volume in the separate sewer network during a 50-year rainfall was observed to be 40% less than in the combined sewer network. Therefore, public inconvenience during the operation phase is higher for the combined sewer network than for the separate sewer network.

Modelling showed that the storage and transfer capacity of the combined sewer network to the treatment plant is a maximum of 8 mm rainfall, after which the network overflows into receiving waters. After analysing 5-year rainfall data (2015-2020) on the same designed system (Figure 2) for Ahvaz, representing a low-rainfall climate, and Rasht, representing a high-rainfall climate, it was calculated that the average number of combined sewer overflows per year (CSO frequency) is 8 times in Ahvaz and 46 times in Rasht. This highlights the lesser environmental concerns related to combined sewer overflows in cities with hot and dry climates.

Based on network analysis results and the ratio of sanitary sewage to total runoff volume, the dilution rate for combined sewer overflows was calculated to be 0.12. Accordingly, after applying the dilution rate to the concentration of pollutants in the existing WWTP input, the new concentrations were compared to the Iranian standard of WWTP effluent to receiving waters. The results showed that pollutant concentrations did not exceed standards, even in the worst-case scenarios.

Table 1. *Concentration dilution of overflows*

Indicators	Sanitary Concentration (mg/lit)	Dilution rate	Over flow Concentration (mg/lit)	Standard (mg/lit)
BOD_5	104.2	0.12	12.5	30
COD	244.7	0.12	29.3	60
TSS	130.5	0.12	15.66	40

Finally, using the results and engineering judgments, all comparison matrices were formed, and criteria and sub-criteria were weighted and compared. The results of the Analytic Hierarchy Process (AHP) indicated that despite stringent standards and regulations, the combined sewer network, with a score of 59%, is a more suitable option for urban drainage system in cities like Ahvaz with hot and dry climates. These results are not general and it is necessary to do the same analysis in different cases.

Conclusions and future work

The results indicated that the combined sewer network is a more suitable option for urban drainage system in Ahvaz with hot and dry climates. Sensitivity analysis of the decision-making system used in this study showed that as the climate shifts towards cold and wet conditions, the weight of the sub criteria and the comparisons of options tend to favour the separate sewer systems. Additionally, with a shift towards the policies of developed countries, meaning a decrease in economic values and an increase in environmental values, the decision-making system tends to favour the separate sewer networks. Ultimately, the results of this study clearly demonstrate the need for a review and adaptation of the standards used in regions with hot and dry climates.

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