Integrating Rainwater Harvesting Systems (RWHS) into Canadian urban planning: A multidisciplinary approach

Intégration des systèmes de récupération de l'eau de pluie (SREP) dans la planification urbaine canadienne : Une approche multidisciplinaire

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RÉSUMÉ

Les systèmes de récupération d'eau de pluie (SREP) visent à transformer les précipitations en source en eau. Bien qu'il faille garantir une réutilisation sécuritaire grâce à une surveillance continue de la qualité, le potentiel des systèmes pour contrôler le ruissellement urbain reste intéressant à valoriser. L'intégration des SREP dans les environnements urbains, en tant que type d'infrastructure verte, nécessite une prise de décision multicritère qui exige la participation des parties prenantes et des services municipaux aux processus de planification. Cette étude a intégré une approche multidisciplinaire afin de faciliter l'adoption à plus grande échelle des SREP dans le contexte urbain canadien. La surveillance de la qualité de l'eau collectée dans plusieurs systèmes sur deux ans a démontré l'influence clé de la conception des systèmes, soulignant la nécessité d'élaborer des recommandations sur la conception, le fonctionnement et l'entretien des systèmes. L'étude des perceptions du public et l'analyse de l'adéquation spatiale ont également souligné l'importance des contraintes de conception des systèmes et leur influence sur la qualité de l'approvisionnement en eau comme critères essentiels à intégrer dans la planification urbaine des SREP. La satisfaction générale des utilisateurs des systèmes présente un lien modéré mais statistiquement significatif avec leur satisfaction à l'égard de la qualité de l'eau collectée. Par ailleurs, du point de vue des parties prenantes, l'implantation spatiale des SREP devrait être optimisée sur les sites qui minimisent l'exposition du système aux contaminants.

ABSTRACT

Rainwater harvesting systems (RWHS) primarily aim to turn precipitation into a supply source. While safe reuse must be ensured through continuous quality monitoring, the potential of systems to control urban runoff remains valid. Integration of RWHS into urban environments, as a type of green infrastructure, requires a multi-criteria decision-making that urges the inclusion of stakeholders and municipal departments in planning processes. This study incorporated a multi-disciplinary approach to facilitate the broader adoption of RWHSs in the Canadian urban context. Monitoring harvested water quality across multiple systems over two years demonstrated the key influence of the systems' design, highlighting the need to develop detailed recommendations on the design, operation, and maintenance of the systems. The study of public perceptions and the spatial suitability analysis through stakeholders' participation also emphasized the significance of systems' design constraints and their influence on supply quality as essential criteria to be integrated in RWHSs' urban planning. The general satisfaction of users with the systems has a moderate but statistically significant association with their satisfaction with the harvested water quality. Moreover, from the stakeholder's point of view, the spatial placement of RWHS should be maximized in the sites that minimize the system's exposure to contaminants.

KEYWORDS

Public perception, rainwater harvesting, spatial suitability, urban environment, water quality

1.

Rainwater harvesting systems (RWHS) are structural climate change adaptation measures that aim to control runoff after heavy rainfall and provide an alternative water source for non-potable use. They are becoming increasingly popular in large buildings across Canada, with some municipalities mandating the system's installation in new residential buildings. Using rainwater for non-potable applications, including toilet flushing and outdoor watering, can reduce drinking water consumption up to 30% in a mid-rise building located in Canada (Tokar et al., 2021).

However, Canada lacks comprehensive national guidelines and detailed instructions on the design, operation, and maintenance of RWHSs, leading to uncertainties regarding water quality and the potential health risks associated. The systems generally demonstrate significant variability in supply quality depending on their geographical location, design characteristics, and treatment methods. Untreated systems commonly show contamination with microorganisms (Ahmed et al., 2018; Kirs et al., 2017), and treatment methods, including filtration, UV disinfection, sedimentation, and a first-flush diverter, effectively reduce microbial loads (Despins et al., 2009; Morgado et al., 2022).

On the other hand, physicochemical characteristics can be influenced by atmospheric depositions, urban roof catchments, and storage tanks. Key parameters such as pH (4.92–7.5), dissolved oxygen (4–9.5 mg/L), conductivity (1–287.26 µS/cm), and turbidity (<14 NTU) showed variability across different studies (Okudo et al., 2023; Tengan & Akoto, 2022). These findings underscore the need for proper design and planning of RWHSs to ensure water quality and safe reuse (Hamilton et al., 2018). Another research gap lies in the geographical and socio-demographic context of implementing RWHSs. RWHS is a type of green infrastructure, and when considering green infrastructure as part of urban design, there is a potential to promote stakeholder involvement in the decision-making process (Kuller et al., 2017).

On the other hand, users' perception is a key factor in ensuring the success of a sustainable water supply project. Resistance to water reuse can be associated with several psychological factors, including environmental concerns, health risk perceptions, social norms, financial considerations, and prior experiences. (Callaghan et al., 2012; Campisano et al., 2017). This study involved a multidisciplinary approach to bring together the general public and key stakeholders in supporting the broader adoption of RWHSs across Canadian urban environments.

2.

RWHSs were studied for a broader integration in the Canadian urban context, considering the following perspectives:

2.1 Design adequacy

The quality of harvested rainwater is directly impacted by the system's design characteristics, including the size and material of the catchment surface and storage tank, and the attached treatment system. Water quality was evaluated through 130 samples collected from five operational systems in the province of Quebec, Canada, from June 2024 to September 2025. Water quality parameters, including dissolved oxygen, pH, turbidity, alkalinity, color, dissolved organic carbon (DOC), *Legionella pneumophila*, total coliforms, *Escherichia coli*, heterotrophic plate count (HPC), and metals (aluminum, chromium, copper, lead, sodium, iron, and cadmium), were assessed for all samples. Furthermore, continuous water flow and tank level monitoring were performed to understand the effect of the storage tank's capacity, catchment surface area, and household water consumption on the system performance.

System scale (i.e., single housing, large institutional), design characteristics (i.e., water treatment, water collection and storage, end-use), and maintenance (e.g., for treatment systems and storage tanks) were the key variables in quality monitoring. DOC levels ranged from 0.64 mg/L to 19.35 mg/L. Large building systems with chlorination contained less than 1 MPN/100 mL of coliforms and *E. coli*, whereas single housing systems harbored up to 7,490 MPN/100 mL coliforms and 630 MPN/100 mL *E. coli*. The association of microbial water quality with the potential stagnation in the storage tank highlighted that the design and planning of RWHSs must be tailored to the needs of Canadian residents, their water consumption rates, and the current and future hydrometeorological patterns in the country.

2.2 Social acceptability

A questionnaire survey was developed and distributed to Quebec residents to assess their perceptions of rainwater reuse. The study comprised 226 participants, of whom 55 were current or past RWHS users. The study population, regardless of whether they are system users or not, was asked about their knowledge, perceptions, and attitudes towards water supply and RWHSs, appropriate uses and concerns, advantages and disadvantages, motivations, and financial aspects. The actual system users then had the opportunity to express their viewpoints on their system characteristics, level of satisfaction, and the operational and maintenance aspects. The survey closed in September 2025, and the results are currently being analyzed. The initial outcomes highlighted that more than 80% of Quebec residents are aware of the impact of climate change on water availability and quality, and the necessity of water conservation for future generations.

They also believe that RWHSs highly contribute to sustainable water management, and adopting systems in the urban context is advantageous. These perceptions were irrespective of their sociodemographic characteristics, such as age, gender, income, and education level (ordinal regression, $p > 0.05$). However, the noticeable proportion of individuals who do not use the system and have no interest in adopting it (about 34%) highlights the importance of carefully addressing population concerns and assessing the experiences of existing RWHS users. The rate of general satisfaction with the systems was high (3.95 out of 5), and it had a statistically significant association with the satisfaction with the harvested water quality (3.81 out of 5) (Spearman's $\rho = 0.56$, $p < 0.05$, Cronbach's $\alpha = 0.68$). The main constraints against RWHSs' adoption perceived by the study population were as follows: installation cost (69.3%), maintenance cost (42.2%), time and effort required for maintenance (50.6%), uncertainties about water quality and the risk of contamination (34.3%), simplicity of using municipal water instead (55.4%), lower cost of municipal water (20.5%), water resources abundancy in Quebec (i.e., using rainwater is not justified) (11.5%), and lack of information (10.2%).

This is aligned with the findings of Leidl et al. (2010), who demonstrated that the capital cost is the main barrier against rainwater harvesting in urban households in Ontario, followed by potential health risks, end-use limitations, the Building Code insufficiency, and lack of public commitment from the stakeholders' point of view. Despite being initially perceived as the most important factor, the questionnaire survey demonstrated that financial concerns were less significant among actual system users. Instead, insufficient design, including inadequate storage tank capacity, became the key challenge.

2.3 Spatial placement

Spatial suitability of RWHSs in urban settings is being studied through the development of a multi-criteria decision-making tool, formerly tested for different types of green infrastructures, such as bioretention swales or raingardens in Canada and Australia. The study involves establishing a hierarchy of objectives that comprises a core set of fundamental objectives, followed by their corresponding means objectives, and a range of quantifiable attributes.

The aim is to identify sites that either have a strong need for these systems or offer the greatest opportunities for their implementation. To develop the hierarchy of objectives, two series of workshops were conducted. 15 Stakeholders were invited from Quebec municipalities, Quebec Building Authority (RBQ), Ministry of Agriculture, Fisheries, and Food (MAPAQ), Ministry of the Environment, Quebec National Institute of Public Health (INSPQ), NGOs, and among system suppliers, manufacturers, engineers, consultants, designers, and system users. The objective hierarchy was constructed through individual and team brainstorming activities and validated with the literature. The current hierarchy of objectives (Figure 1) can be applicable Canada-wide.

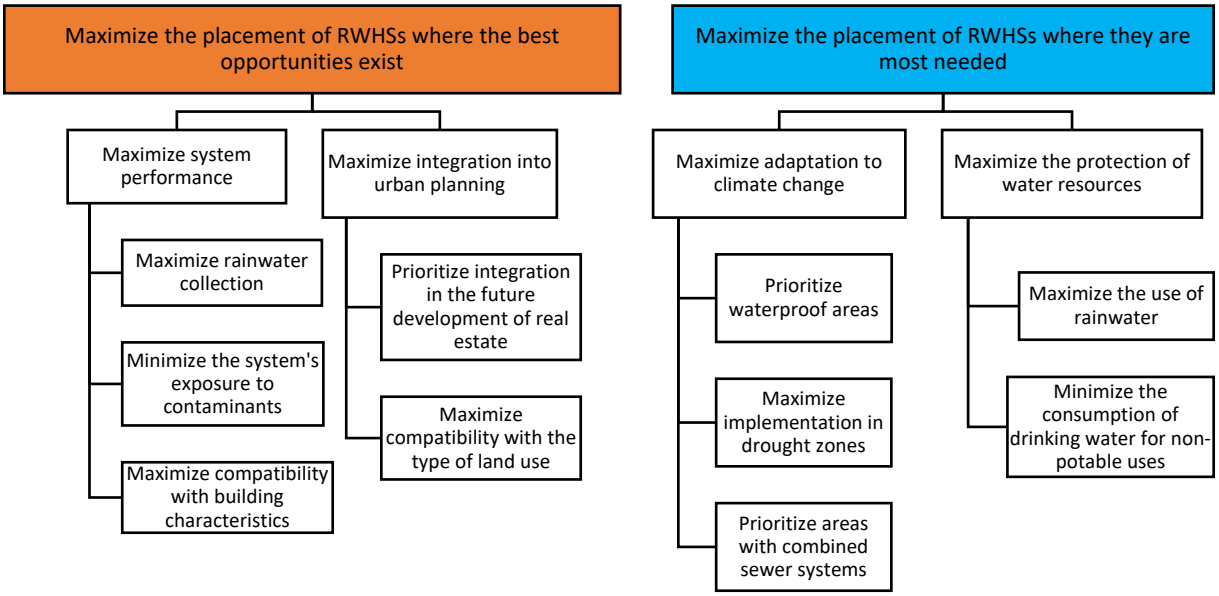

Figure 1: Stakeholder-driven spatial suitability criteria for RWHSs in Canadian urban contexts

Following the establishment of objectives, value scales must be defined for the various objectives identified through interviews. The process of defining value scales will involve the utilization of literature studies, recommendations from experts, and the input of relevant stakeholders through a subsequent series of workshops. The objectives will be finally weighted according to participants' preferences. Value-scaling and objective-weighting workshops are currently being organized.

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