PERSPECTIVE

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Rainwater Harvesting Systems in Urban Areas and the Potential Value of Incorporating Community Engagement

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ABSTRACT Rainwater harvesting (RWH) is a water catchment technique used in urban areas globally. RWH has a deep history rooted in indigenous practices and has recently become more accepted in urban areas. The quality and quantity of harvested water depends both on the geographical location of the system with respect to nearby land-use, seasonality, and rainfall intensity, as well as the material of the catchment surface. The economic viability of RWH systems is dependent on initial expenses, operation and maintenance costs, and water fees. Furthermore, government subsidies and clear, concise policy may improve water tank installation, usage, and maintenance. Policy may also help the general public install and use RWH systems through the promotion of education that improves RWH-specific knowledge. While community engagement (CE), stakeholder participation, and increased community knowledge of RWH may potentially yield increases in system use and sustainability, there is a general paucity of this research in peer-reviewed literature. Future studies should explore community engagement within the context of rainwater harvesting systems in urban areas.

INTRODUCTION

Water insecurity is a global issue (Hanasaki et al., 2013). As of 2000, over 1.1 billion people lack access to improved water sources (Zhu et al., 2015). Rainwater harvesting (RWH) is a sustainable and inexpensive method of water collection that reduces unnecessary water use and labor (Campisano et al., 2017; Staddon et al., 2018). RWH is viable for potable and non-potable purposes in urban areas, especially when supported by policy, proper construction materials, and tank maintenance, and may be encouraged through community engagement (CE). However, further research is required to understand the relationship between CE and RWH. This paper explores indigenous RWH practices, community engagement, factors that affect rainwater quality, and barriers and facilitators to RWH.

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INDIGENOUS RWH PRACTICES

Historically, the practice of RWH was performed within indigenous communities (Oweis, 2017). As RWH is adopted globally, implementation of RWH should recognize these roots and credit these communities (Rahman et al., 2012). RWH's relevance in many indigenous communities has motivated other water-insecure indigenous populations to implement RWH, leading to reductions in disease and water costs (Gonzalez-Padron et al., 2019). We describe two examples of RWH within indigenous communities below.

The *Rod Kohi* System

Zia and Hasnain (2000) review RWH methods used by indigenous, Pakistani communities to combat water insecurity. *Rod kohi* water harvesting, the most common regional technique, involves hill torrents that bring water through a network of dams and tunnels and into terraced fields; landowners can use this water for agricultural and domestic purposes. The system is governed by a set of centuries-old regulations detailing water distribution guidelines (Zia & Hasnain, 2000).

The Black Tickle-Domino Inuit Community

Many indigenous communities adopt RWH even if it is not traditional to their roots (Mbilinyi et al., 2005). Using a CE framework, Mercer and Hanrahan (2017) worked with the Black Tickle-Domino Inuit community in Canada to understand RWH and water accessibility. Results show a 17% increase in water consumption and a 41% decrease in water retrieval efforts indicating that CE benefits the implementation of RWH (Mercer & Hanrahan, 2017).

As RWH is further adopted, acknowledging its historical roots is essential (Rahman et al., 2012). Although there is limited research on CE and RWH, understanding the roots of RWH may improve future research on incorporating CE.

COMMUNITY ENGAGEMENT

While research on the value of CE when considering RWH is limited, preliminary findings show promise. Through stakeholder participation and capacity building, CE can improve RWH acceptance and sustainability by allowing system adaptation to specific contexts (Zimmermann et al., 2012). CE can also facilitate collective learning and knowledge generation to promote RWH sustainability (Suleiman et al., 2019).

Educational workshops, focus group discussions, stakeholder participation, and capacity building in RWH design and construction are CE methods that can promote RWH sustainability and increase water access (Mercer & Hanrahan, 2017; Zimmermann et al., 2012; Mwamila et al., 2016; Kim et al., 2016). Educational workshops can improve community member knowledge of RWH and allow individuals to make informed decisions (Zimmermann et al., 2012). Focus groups allow communities to outline water access barriers and their RWH needs and wants (Mercer & Hanrahan, 2017; Zimmermann et al., 2012). To promote CE, RWH systems should be designed in collaboration with local government and community partners, members, and stakeholders (Zimmermann et al., 2012). In a study conducted in Namibia, community members chose the specific system, location, and people tasked with construction, and the community had final say in all aspects of construction, operation, and maintenance (Zimmermann et al., 2012). Studies that explore the effects of CE on RWH have found there is greater ownership, more regular usage, and improvements in long-term sustainability (Mercer & Hanrahan, 2017; Zimmermann et al., 2012) and show that CE is an innovative way to increase access to water (Kim et al., 2016).

RAINWATER QUALITY

Land Use and Spatial Effects

Rainwater microbial and physicochemical quality depends on nearby land use and pollutants (Gwenzi et al., 2015). Rainwater pollution can occur during collection, treatment, storage, and consumption (Meera & Ahammed, 2006). Gwenzi et al. (2015) outline how land uses and geographical differences affect rainwater quality. Rainwater from industrial areas may contain more dangerous contaminants than rainwater from rural areas, likely because rural areas are farther from machine exhaust and industrial waste. Industrialization, traffic emissions, and fossil fuel combustion have deleterious effects on water quality; in Brisbane, Australia, 21% of the incidence of high lead levels in water was attributed to human activity (Gwenzi et al., 2015). However, other studies reveal similar levels of contamination among water samples, regardless of proximity to traffic and industry emissions (Mendez et al., 2010; Farreny et al., 2011), suggesting the effect of land-use activities on rainwater quality depends on the level of nearby pollution (Gwenzi et al., 2015). Using CE principles, such as educational workshops and focus group discussions, may educate community members and policymakers on how to improve, and maintain, rainwater quality.

Seasonality and Rainfall Intensity

There can be seasonal variations in the microbial and physicochemical quality of water from RWH (Meera & Ahammed, 2006; Gwenzi et al., 2015). Seasonal variability in quality can be attributed to length of dry season, rainfall intensity, and wind strength (Meera & Ahammed, 2006; Gwenzi et al., 2015). Areas that have well-defined wet and dry seasons can experience high variability in water quality as the length of dry periods is positively associated with contamination (Meera & Ahammed, 2006). The seasonal "first-flush" has greater levels of contamination than later rainfall events because longer dry periods allow for increased build-up of contamination on RWH surfaces resulting in a high contaminant load once rainfall occurs (Meera & Ahammed, 2006). "First-flush" also refers to the change in quality from the start of rainfall compared to later during that same event; typically, the contaminant concentration is highest at the onset of rainfall (Gwenzi et al., 2015). Winds can also transfer pollutants into catchment areas on a seasonal basis and affect water quality (Gwenzi et al., 2015).

While CE cannot change seasonal weather patterns, Zimmermann et al. (2012) discuss ways that CE can aid capacity development in the form of education, which can improve the process of collective learning and promote the adaptation of systems to a community's context. If capacity development and knowledge generation included information on seasonal variations in quality, community members may be able to make improved decisions about water use and strategies to mitigate water contamination. While there are optimistic preliminary findings, we advocate for the intentional incorporation of CE into RWH practices.

Roof Characteristics and Water Quality

Roof characteristics like material, weatherability, and age can affect water quality (Meera & Ahammed, 2006; Chapa et al., 2020; Nasif & Roslan, 2015; Bae et al., 2019). Water from metal rooftops is generally of better microbial quality than water collected from other roof materials, likely because the heat produced can destroy bacteria (Meera & Ahammed, 2006). However, water collected from metal rooftops has been associated with hazardous metal levels, likely due to material disintegration (Meera & Ahammed, 2006; Gwenzi et al., 2015). However, other studies do not show these increased metal concentrations (Gwenzi et al., 2015). Roofs with wooden shingles and concrete have also been associated with increased levels of zinc and copper (Gwenzi et al., 2015). Collectively, these studies indicate that unknown confounding variables may affect the concentration of metals in rainwater (Gwenzi et al., 2015).

Roof material can affect water quality, and regular water testing is recommended to ensure potability; when treatment is infeasible, water should be considered non-potable (Rahman et al., 2014). While there is insufficient research on CE in regard to RWH materials, CE may offer value by facilitating material-specific knowledge, capacity development, and opportunities for community members to make informed, locally-appropriate decisions.

Runoff Quantity

Urbanization increases the water stress on cities; implementing RWH can reduce this stress, allow aquifers to recharge, and reduce use of contaminated water (Barthwal et al., 2014). Angrill et al. (2017) analyzed the quantity of rainwater collected from pedestrian areas, traffic roads, and parking lots made from asphalt, concrete, and precast concrete slabs in Spain and found that 89% of rainwater falling on concrete surfaces may be captured for domestic use. Abdulla and Al-Shareef (2008) studied the effects of RWH in Jordan and found that widespread RWH could supply 5.6% of Jordan's total water in 2005. We argue that CE strategies may improve community knowledge on which surfaces are best for rainwater collection and encourage installation of high-yielding, sanitary surfaces in urban areas globally. Further, encouraging community-led projects may result in RWH tailored to specific communities, rather than systems that do not align with local circumstances.

BARRIERS AND FACILITATORS TO RWH

Economic Barriers

Despite limited research on CE specific to RWH financing, the findings of Mercer and Hanrahan (2017) indicate that CE promotes sustainability. Based on review of the literature, we believe that CE geared towards education and capacity development could inform community members of practical investment plans and government financing options.

Economic viability impacts the potential for global implementation of RWH (Farreny et al., 2011; Ward et al., 2013). High initial construction and installation costs can discourage RWH implementation (Temesgen et al., 2016; Sousa et al., 2018; Campisano et al., 2017). Operation, maintenance, and treatment also influence affordability (Roebuck et al., 2011). RWH system design prior to implementation can maximize benefits and minimize costs; for instance, gravity-based, instead of pump-based, systems can reduce expenses (Hafizi Md Lani et al., 2018). Governments can also provide subsidies, low interest rates, and rebates to reduce costs (Sheikh, 2020; Barthwal et al., 2014).

Despite the barriers, RWH is economically feasible. Gomez & Teixeira (2017) determined that economic feasibility is highest in households with higher water demand, regardless of the size of the system. RWH can also be cost-efficient when implemented in large-scale settings (Morales-Pinzón et al., 2012; Parsons et al., 2010). As water production costs increase, RWH will become more appealing, particularly when coupled with subsidized implementation costs that center the community's financial situation (Gomez & Teixeira, 2017; Farreny et al., 2011).

Tank Maintenance Facilitators

RWH tank maintenance helps ensure clean water. During long-term storage, bacteria concentrations can increase, and tanks can harbor mosquito breeding (Mankad & Greenhill, 2014; Moglia et al., 2016). Mankad and Greenhill (2014) analyzed the tank-cleaning motivations of system owners and found that those who were not intrinsically motivated could benefit from extrinsic motivation like government subsidies. Encouraging stakeholder participation and mutual accountability may also encourage the tank maintenance necessary for safe water.

Political Factors

Political support through public policy legitimizes RWH and increases the likelihood of a project's success, highlighting the need for RWH-specific public policy (Suleiman et al., 2019; Campisano et al., 2017; Ndeketeya & Dundu, 2019). Temesgen et al. (2016) found that clear policy may aid the establishment of RWH as a legitimate practice. Zia and Hasnain (2000) found that subsidies for machinery, like *Rod Kohi*, increase RWH success; the authors encourage federal subsidies and complementary localized policy to promote RWH. While there is limited research, the findings of Zimmerman et al. (2012) and Elder and Gerlak (2019) indicate that intentional incorporation of CE may be able to promote RWH through policy.

CONCLUSION

This literature review highlights the dearth of information regarding the benefits of CE on successful implementation of urban RWH. As RWH becomes more prominent in urban areas (Mankad & Greenhill, 2017; Suleiman et al., 2019), it is wise to model the indigenous CE practices that yield increased water consumption and decreased retrieval efforts (Mercer & Hanrahan, 2017), as well as incorporate knowledge of RWH catchment locations, surfaces, and maintenance to capture high quality water. Focus group discussions, stakeholder participation, and increased ownership via community-led projects are CE principles that will allow for the sustainable implementation of successful RWH catchment systems. The literature shows that CE may foster successful RWH, but further research is required to specifically determine the best methods to employ. In this way, future research should study how best to incorporate CE in RWH in urban areas and the resulting benefits of centering the community's needs, values, and knowledge on rainwater harvesting.

TABLES

TABLE 1. RAINWATER HARVESTING POTENTIAL QUANTITY AND QUALITY FOR VARIOUS SURFACES AND POTENTIAL RATIONALES FOR POLLUTANT LEVELS

Surface	*Quality Rank*[1]	*Quality Rank*[2]	*Potential Quality Rational*
Concrete parking lot	1	2	○ Smooth surface prevents particle deposition[1] ○ Nearby traffic emissions associated with higher pollution[2]
Asphalt road	2	3	○ Cracked asphalt accumulates particulate matter[2] ○ Nearby traffic emissions associated with higher pollution[2]
Pedestrian concrete slabs	3	1	○ Smooth surface prevents particle deposition[1] ○ Lower traffic emissions associated with lower pollution[2]

Angril et al. (2017) 1 ; Gwenzi et al. (2015)[2]

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