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Perceptions on the usability and applications of Rain Water Harvesting a Comprehensive Literature Review

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I. Introduction

As the global population continues to expand, the quest for access to safe and clean drinking water has emerged as a critical challenge. Amidst rapid urbanization, industrial expansion, and environmental degradation, the demand for this fundamental resource intensifies. Clean water scarcity, once confined to certain regions, has now become a pressing concern across continents, impacting communities worldwide. In many developing regions, the absence of accessible clean water perpetuates cycles of poverty and disease. Communities face the stark reality of water scarcity, often resorting to unsafe and unhygienic sources, leading to widespread health issues. Simultaneously, in more developed areas, rising water demands for industrial, agricultural, and domestic use further strain limited freshwater reservoirs, escalating competition and scarcity. Climate change adds an additional layer of complexity to this challenge. Erratic weather patterns, prolonged droughts, and intensified flooding disrupt water availability and quality, amplifying the difficulty of ensuring a consistent supply of potable water to growing populations.

Efforts to address this dilemma involve a multi-pronged approach encompassing technological advancements, policy interventions, community engagement, and sustainable water management practices. Among these, rainwater collection and use often becomes the most readily available yet cost effective method of sustainability for most communities below the poverty line.

Rainwater can prove a valuable commodity to communities needs to the access of water. However, an openly accepted notion might be that rainwater is safe to drink and, in all aspects considered clean. Whilst a multitude of aspects maybe involved into determining the safety of rainwater, this widely accepted notion does lead to rainwater storage and usage in communities that require it.

II. Rainwater Harvesting

Rainwater harvesting (RWH) can be defined as the basic act of collecting and storage of rainwater which could be done in a variety of manner. RWH is considered to be economical as well as viable to a large sector of people in need of access to clean water (Struk-Sokołowska et al 2020). RWH decreases the need for high tech and high-cost infrastructure and integration, further simplifying the process to excess to clean water (Steffen, J et al 2012). While the uses of RWH can depend exclusively on the RWH systems in place and the volume of water harvested (Stec, A.; Zeleňáková, M 2019) the ability to be integrated anywhere, the versatility of the digital approach and the prospect of connection and understanding for people of all manner of lives still prove it to be an essential solution contributing towards the access of safe water.

RWH has a global implementation rate (Ghaffarian Hoseini et al 2016) with some RWH systems fully equipped with filtration and storage vessels (Yannopoulos et al 2019) for further preservation of the purity of rain water. The most common forms of RWH includes the catchment of runoff water from surfaces such as roofs, terraces, guttering systems and funnel systems (Umapathi et al 2019)

RWH does have global implications however, the RWH systems vary greatly depending on the geographical location and population distribution. RWH systems vary greatly based on urban and rural settings as well factors such as a countries GDP and poverty rate. Urban settings may have a more civil uses and implications of rainwater such as flushing toilets, laundry, maintenance of lawns and gardens, cleaning of driveways and terraces and car washing (Alberto Campisano et al 2017). Furthermore, RWH in Urban areas can increase the efficiency of drainage systems (Ana Carolina Rodrigues de Sá Silva et al 2022) as it redirects and retains a significant amount of water into the harvesting system greatly decreasing the strain it has on drainage systems. While in a rural setting depending greatly upon the geographical remoteness and its proximity to urban facilities or access to treated water, RWH may be the primary source of obtaining water for any or all forms of uses.

Fig 1.0 Ashok et al (2019) Showing the various uses of rainwater in an urban setting (Ashok K. Sharma, Donald Begbie and Ted Gardner. Rainwater Tank Systems for Urban Water Supply IWA Publishing 2019

Moreover, the capability of a RWH system to support a population is once again completely dependent on its population demographic. There may be consistent fluctuation in water usage in an urban area (S. Ward et al 2012). These fluctuations may again be centered around holiday periods. These holiday periods may differ greatly between different population groups based on religion and popularity of certain public holidays in that particular setting. In rural settings these fluctuations will be tied closely to weather variables, taking into account periods of drought and periods of excessive rainfall.

III. Adoption of Rainwater harvesting.

There are a multitude of sources in terms of the availability of technologies involved in rainwater harvesting. The extent of use depends greatly on the geographical and socio-economic settings of the area. These factors may also determine the uses of harvested rain water. The adoption of rainwater harvesting may also depend greatly on the yearly weather patterns on different countries and areas. In places where rainfall can be witnessed all year round, residence of these areas may see rain water harvesting as a permanent solution or at the very least a method which may ensure excess to water on a year-round basis. Locations which may experience times of drought or seasonal rainfall may see rainwater as more of a temporary or seasonal solution to their fresh water needs.

In a study by (Li et al.2000) looking at the adoption of rainwater harvesting in China, a number of factors were discovered to influence the adoption of rainwater harvesting. These included Political, social, economic and cultural factors. Similar studies in Ethiopia (Tesfay 2008) showed things like insufficient excess to credit, negative perceptions and gender biases had significant negative effects on rainwater harvesting adoption. He et al (2007) noted the vast number of advantages rainwater harvesting could have in rural communities but also highlighted the adoption rate in these areas are lower due to socio-economic constraints. The Bureau of Statistics survey in Melbourne found that 31% of approximately 494,000 households had rainwater tanks installed with reasons varying from reduction of water usage and costs (Moglia M et al 2014). Furthermore, the amount of upkeep and maintenance attributed to rainwater collection systems has shown a significant effect of the adoption of these practices (Gardiner 2010). A survey conducted by Tucker et al also concluded that people's lack o
f knowledge on rainwater tanks and their maintenance is largely the cause of not adopting such practices. He et al. (2007) utilized a binary logistic regression model to assess the factors influencing farmers' choices in adopting rainwater harvesting and supplementary irrigation technology. The study focused on rain-fed farming systems in the semiarid regions of Loess Plateau, surveying 218 farmers. The research revealed the importance of 12 variables in understanding the decisions made by farmers regarding adoption. Key factors such as educational background, labor force size, interaction with extension services, involvement in the Grain-for-Green initiative, and favorable attitudes toward Rainwater Harvesting Systems were found to significantly impact adoption rates.

Jirde et al (2021) in research found that the socio-economic background of most adopters of rainwater harvesting were quite high. It was also reported that most adopters of rainwater harvesting have a secondary use which may be for livestock or crops. Finally concluding that (Jirde et al 2021) the education level and availability to training are among the major factors for the adoption of rainwater harvesting.

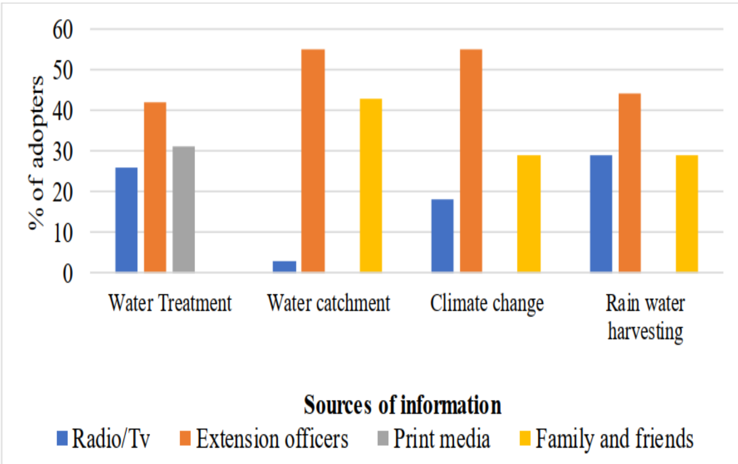

Fig 1.0 Shows the main sources of information for adopters of rainwater catchment and information on other factors. Jirde et al (2021). Mustafe Jirde*, O. K. Koech and Anne A. Karuma An analysis of perceptions, knowledge, and management of rainwater harvesting (rwh) technologies among agropastoral in odwayne district, Somaliland. Tropical AND Subtropical agroecosystems 24 (2021): 107

Ward S et al (2013) looked at the different factors which may affect the consideration of people to install RWH systems in a pilot study. While the responses given were in a controlled questionnaire form most leaned towards the provision of grants and subsidy for the installation

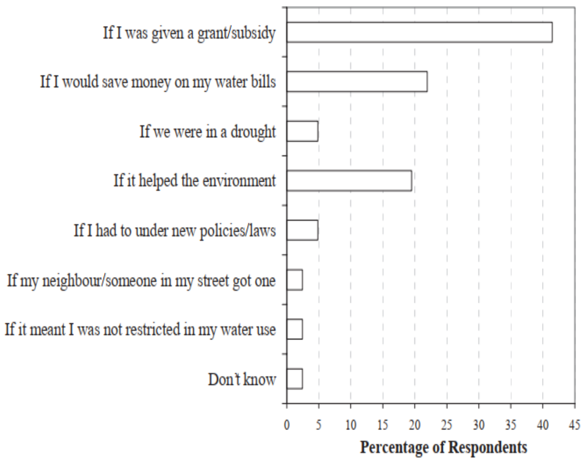

Figure 3.0 Factors affecting the consideration for installation of RWH systems. Ward, S., Butler, D., & Memon, F. (2013, January 1). A pilot study into attitudes towards and perceptions of rainwater harvesting in the UK. ORE Home. https://ore.exeter.ac.uk/repository/handle/10036/4251

Liang and van Dijk (2015) aimed to pinpoint the pivotal factors influencing the utilization of Rainwater Harvesting Systems (RWHs) for agricultural irrigation in Beijing, highlighting non-technological elements such as concerns regarding rainwater quality and the accessibility of groundwater as critical determinants influencing the continuity or cessation of RWH operation. Fielding et al. (2015), through a comprehensive survey involving 1200 Australian participants, gauged the comfort level associated with various water sources, revealing consistent preferences, wherein drinking rainwater ranked highest in comfort while consuming recycled water held the lowest comfort level, with treated stormwater and desalinated water falling in between these extremes. Demographic factors appeared less influential in predicting comfort with alternative water sources compared to psychological aspects. Age and gender were the relatively steady predictors for recycled water comfort, while comfort with technology in general, trust in science, and trust in government consistently emerged as significant positive predictors for recycled water, stormwater, and desalinated water comfort. Hurlimann and Dolnicar (2016), based on an online survey encompassing 200 participants, observed that public perception regarding various water sources, including rainwater harvesting, significantly varied based on intended usage and location. Neibaur and Anderson (2016) assessed the determinants affecting public perception of rainwater harvesting in San Jose, Mexico, revealing that proficiency in rainwater utilization and the absence of methods to ensure safe drinking water stood out as primary determinants impacting rainwater harvesting acceptance. Taffere et al. (2016) contended that the inefficiency in design (due to the oversight of rainfall's stochastic nature), household size, water demand, rooftop area, and storage tank dimensions primarily contributed to the unreliability of domestic rainwater harvesting systems in Maleke village, Ethiopia.

In a study by Lloyd James S Baiyegunhi (2015) the logistic regression analysis reveals that several factors—such as gender, age, educational level, income, social connections, engagement with extension agents, and perceptions/attitudes toward Rainwater Harvesting Technology (RWHT)—are statistically significant in elucidating the adoption of RWHT among farmers in the surveyed region. Thus, it is imperative for policymakers and the private sector to specifically target younger farmers in their initiatives aimed at promoting RWHT adoption.

Furthermore, the study highlighted the need for enhancing the educational attainment of rural farmers holds the potential to increase the likelihood of adopting agricultural technology. The data indicating a higher inclination among male farmers toward RWHT adoption compared to their female counterparts emphasizes the necessity of devising more suitable strategies tailored for women. Despite constituting the majority of farm labor, women encounter multiple obstacles hindering their utilization of sustainable agricultural practices and household resources. Consequently, concerted efforts are necessary to narrow the gender gap in RWHT adoption, addressing the disparities faced by women in agricultural technology uptake.

Sharma and Gardner (2020) present a comprehensive methodology to assess the effectiveness of urban residential rainwater tank policies. This methodology, developed through a case study in South East Queensland, Australia, encompasses biophysical, economic, environmental, and social dimensions. The methodology includes six steps: assessing mains water savings through desktop studies, modelling, and monitoring; auditing rainwater tank installations for compliance with regulations; evaluating rainwater quality; conducting social research to gauge community acceptance; developing management models for long-term operation; and performing a cost-effectiveness analysis of rainwater supply.

The authors found that, on average, rainwater tanks provided 49 kL/hh/yr of water savings, which was below the expected 70 kL/hh/yr due to issues such as non-compliance with roof catchment area requirements and tank sizes. The study also highlighted that rainwater quality was unsuitable for potable uses without treatment, and there was a significant lack of household engagement in tank maintenance. Despite higher costs compared to mains water, the methodology aims to aid water professionals worldwide in evaluating and enhancing the efficacy of similar policies (Sharma & Gardner, 2020). The abbreviation "kL/hh/yr" stands for kiloliters per household per year.

Aliabadi, Gholamrezai, and Ataei (2020) investigate the factors influencing rural people's intentions to adopt sustainable water management practices, specifically through rainwater harvesting, using the Theory of Planned Behavior (TPB) and the Health Belief Model (HBM). The study surveyed 480 villagers from Hamadan province, Iran, using a questionnaire validated by experts and tested for reliability through Cronbach's alpha, AVE, R^2, and CR.

The TPB model revealed that moral norms, attitude, and self-identity significantly accounted for 61% of the variance in the intention to adopt sustainable water management practices. Meanwhile, the HBM model showed that perceived benefits, perceived susceptibility, and perceived severity captured 49% of the variance. Both models were found to be effective in predicting the intention to engage in sustainable water management, with TPB offering a more robust prediction (Aliabadi, Gholamrezai, & Ataei, 2020).

The study's findings suggest that attitudes, moral norms, and self-identity are critical factors under TPB, whereas perceived benefits, severity, and susceptibility are vital under HBM. These insights can inform policymakers and practitioners aiming to promote sustainable water management practices among rural populations.

Mangisoni, Chigowo, and Katengeza (2019) explore the determinants influencing the adoption of rainwater-harvesting technologies in a rain shadow area of southern Malawi. The study focuses on both exsitu technologies (such as dams) and in situ technologies (such as box ridges, contour markers, and swales). The research reveals that adopters treated, on average, 80% of their farms with these technologies, significantly improving their food security and income.

The study identifies several key factors influencing the choice of rainwater-harvesting technologies: land slope and quality, farm size, soil texture, security of land tenure, the education level of the household head, and extension support. These findings underscore the potential of rainwater-harvesting technologies to enhance farmer income and food security. The authors argue for promoting these technologies as a package, allowing households to implement different technologies based on diverse social, economic, institutional, and environmental factors (Mangisoni, Chigowo, & Katengeza, 2019).

Moglia et al. (2014) present a comprehensive study on the savings and conditions of rainwater tanks across Melbourne. This survey, funded by the Smart Water Fund and CSIRO, aimed to assess the physical condition of household rainwater tanks and quantify the actual rainwater usage for 21 monitored households. Additionally, the study included a detailed inspection of 417 rainwater tank systems to evaluate their condition and potential health risks.

The results indicated significant issues with tank installations, including 13% of tanks leaning due to uneven foundations, 5% with non-functional pumps, and 9% with faulty automatic switches leading to exclusive mains water usage. The inspection also found that 57% of water samples showed discoloration, and 19% had an odor. Despite these issues, 96% of participants reported perceiving benefits from their rainwater tanks, such as water conservation during restrictions and environmental benefits.

The study highlights the need for improved installation practices and regular maintenance to maximize the potential water savings and minimize health risks associated with rainwater tanks. The authors recommend further research and development of strategies to manage rainwater tanks effectively (Moglia et al., 2014).

The study by Cardona (2016) presents an integrated approach to assessing the feasibility of domestic rainwater harvesting (RWH) in Malta. Historically, RWH was a prominent solution for water supply issues but has declined due to the advent of alternative technologies. The research explores the potential for small-scale RWH by examining Malta's physical, social, and economic environments. It highlights the historical significance of RWH in Malta and investigates its cost-effectiveness and the barriers to its adoption through interviews with residents and water professionals. The findings reveal that the island's small size, contested land, and inadequate planning and enforcement have contributed to the decline in RWH usage. Furthermore, low water prices and high construction costs for cisterns have limited its development. The study underscores the need for proper planning, education, and policy integration to promote RWH. Recommendations include enhancing public awareness, providing financial incentives, and fostering cooperation among stakeholders to effectively implement RWH systems and improve water resource management in Malta (Cardona, 2016).

The study by Roa, Sanchez, and Sobremisana (2019) assessed the community's perception and willingness to adopt rainwater harvesting (RWH) as a water source in Sitio Pulot-Bae, San Antonio, Kalayaan, Laguna, Philippines. This geographically isolated area primarily relies on artificial lakes and shallow springs for drinking and domestic water. The insufficient clean water supply has adversely affected the population's health and economic development. The research aimed to determine the community's perception and willingness to implement an RWH system. Out of 55 respondents, 49.1% rated the project as very effective, and 30.9% as effective, citing frequent nighttime rainfall as a key efficiency factor. Furthermore, 80% of the respondents strongly agreed, and 16.4% agreed to adopt the system. The study found that 98.2% of respondents wanted to use the system as their domestic water source, and 89.1% were willing to pay for its maintenance and repair. The high level of acceptance and willingness to pay highlights the community's support for RWH as a viable alternative water source. The findings suggest that the implementation of RWH could significantly improve water management and supply in rural areas, with the local government's support being crucial for its sustainability (Roa, Sanchez, & Sobremisana, 2019).

The study "Public perceptions of rainwater harvesting (RWH): comparing users and non-users of RWH systems" investigates public perceptions of RWH in the UK, focusing on non-potable uses of rainwater. Conducted by Snelling et al. (2023), this research compares explicit (stated) and implicit (subconscious) attitudes toward RWH among individuals with and without domestic RWH systems. The findings indicate that RWH is generally perceived positively, with implicit attitudes being more favorable than explicit ones, particularly among those who have RWH systems. This suggests a deeper, subconscious acceptance of RWH technology among users. The study also reveals a preference for outdoor uses of rainwater, highlighting the need for increased promotion of indoor applications to fully utilize the resource potential of UK rainfall. The research underscores the importance of understanding public preferences to enhance the uptake of RWH systems and contribute to sustainable water management practices (Snelling et al., 2023)

IV. Safety of Rainwater

Rainwater, often considered a pure and natural water source, can harbor various contaminants if not properly collected and stored. Factors such as environmental pollutants, animal droppings, and inadequate maintenance of catchment systems can significantly affect its quality. Ensuring the safety of rainwater for household use requires rigorous adherence to proper collection, filtration, and storage practices to minimize health risks associated with microbiological and chemical contamination.

In a five-year study by Abbott, Caughley, and Douwes (2016), the microbiological quality of roof-collected rainwater from 560 private dwellings in New Zealand was examined. The study found that over half of the samples exceeded the acceptable contamination standards, with 41% showing heavy faecal contamination. Sources of contamination included faecal material from birds, frogs, rodents, and possums, as well as decaying organic matter on roofs and gutters. Many deficiencies were noted in the rainwater catchment systems, including lack of maintenance, inadequate disinfection, poorly designed delivery systems, and failure to implement basic physical measures to prevent contamination. The study highlighted that the general public's perception of rainwater as pure and safe often led to neglect in proper maintenance and safety measures. Despite the popularity of roof-collected rainwater, especially in rural areas, there is a significant need for better dissemination of information on safe collection and storage practices. The researchers concluded that improvements in communication and public health strategies are necessary to ensure the safety of roof-collected rainwater supplies (Abbott, Caughley, & Douwes, 2016).

In a comprehensive study by Mosley (2005), the quality of rainwater harvested through rooftop systems in the Pacific Islands was investigated. This report outlines best practices to ensure safe and clean drinking water. The primary sources of contamination identified include dust and ash, pathogenic bacteria from bird and animal droppings, heavy metals from urban dust and roof materials, and inorganic contaminants like salt from sea spray. The study emphasizes the importance of maintaining clean roofs and gutters, selecting appropriate storage vessels, and employing first-flush devices and filtration screens to improve water quality. Tank maintenance, including regular cleaning and water disinfection by adding chlorine, is also crucial. Regular water quality testing is recommended to ensure the safety of rainwater for consumption. The report advocates for better public education and policy support to enhance the implementation and maintenance of rainwater harvesting systems, ensuring they provide a reliable and safe water source

In their comprehensive report, Pathak and Heijnen discuss the increasing popularity and health aspects of rainwater harvesting (RWH) due to diminishing supplies of high-quality water (Pathak & Heijnen, n.d.). The study acknowledges RWH as an environmentally sustainable water source, widely utilized for various domestic applications like drinking, bathing, and irrigation. The authors highlight the historical reliance on rainwater in regions like Rajasthan and Gujarat, where structures like kundis are used for water collection. The report also explores the potential of RWH in areas with saline or hard water, as well as its application in urban settings of New Zealand, Australia, and Germany for augmenting municipal water supplies.

The quality of harvested rainwater is influenced by atmospheric pollution, collection methods, and storage conditions. Pathak and Heijnen emphasize that while rainwater generally meets the quality of treated public water, it is susceptible to chemical and microbial contamination. The presence of pathogens from bird droppings and pollutants from roofing materials are notable risks. They advocate for effective maintenance, including first flush systems and proper inlet/outlet arrangements, to mitigate these risks.

The World Health Organization (WHO) is developing guidelines to address these concerns, including protocols for water quality testing and the implementation of water safety plans (WSPs). The report underscores the importance of regular water quality testing, particularly for microbial contaminants, to ensure the safety of harvested rainwater. Pathak and Heijnen conclude that while RWH offers significant benefits for water supply, it requires proper implementation, regular maintenance, and adherence to safety guidelines to mitigate health risks. They advocate for the widespread adoption of WSPs to ensure consistent water quality and protect public health (Pathak & Heijnen, n.d.).

In their study, Aiome, De Silva, Fernando, and Samarakoon explore the potential of rainwater as a safe water source in the North Central Province of Sri Lanka, particularly in areas affected by chronic kidney diseases (CKDu). The research was conducted in the Anuradhapura and Polonnaruwa districts, involving 300 households. Data were collected using structured questionnaires and water quality tests on 100 samples from various sources, including rainwater tanks and reverse osmosis (RO) plants.

The findings indicate that the quality of harvested rainwater is generally better than that of well water. Over 90% of the rainwater samples showed no significant biological contamination. Chemical parameters, such as total dissolved solids, total hardness, and fluoride content, were within acceptable limits according to Sri Lanka Standards (SLS 614:2013). Physical parameters like pH and turbidity also met the standards. In contrast, about 10% of the water samples from sellers did not meet safety standards. The study emphasizes the need for proper maintenance of rainwater harvesting systems to ensure water safety.

The authors recommend promoting rainwater harvesting as a viable solution for safe drinking water in the study area. They suggest that increasing awareness and providing government subsidies or credit facilities could enhance the adoption of rainwater harvesting systems, thereby mitigating water scarcity and reducing CKDu prevalence (Aiome, De Silva, Fernando, & Samarakoon, 2018).

The paper "A Review of Health Hazards Associated with Rainwater Harvested from Green, Conventional, and Photovoltaic Rooftops" by Gilbert Osayemwenre and Otolorin Adelaja Osibote comprehensively examines the potential health risks posed by rainwater harvested from different types of rooftops. The study highlights the increasing reliance on photovoltaic (PV) modules for both energy generation and water harvesting due to global freshwater and energy crises. However, the degradation of these PV modules can lead to leaching of toxic substances, such as cadmium and lead, into the harvested rainwater, posing significant health risks to consumers. The paper underscores the need for stringent regulations and proper maintenance of PV rooftops to mitigate these risks. Additionally, it discusses the contaminants that can be introduced from conventional and green roofs, including microbiological pathogens and chemical pollutants, emphasizing the importance of further research and robust data management systems to ensure the safety of harvested rainwater. This review is critical for developing sustainable water harvesting practices that safeguard public health (Osayemwenre & Osibote, 2021).

The article "Rainwater Harvesting and its Risk Assessment" by Zuzana Karelová, Zuzana Vranayová, Daniela Káposztasová, and Pavol Purcz presents a comprehensive risk assessment methodology for rainwater harvesting (RWH) systems in Slovakia. Using information from questionnaires completed by construction companies, architects, and other stakeholders, the authors identify and evaluate potential hazards associated with RWH systems. The study employs a semi-quantitative approach and the Analytic Hierarchy Process (AHP) to assess risks, focusing on the components of the system, including catchment, storage, distribution, and user sections. The results indicate that the riskiest parts of the RWH system are the pump, filter, and tank. The authors emphasize the importance of proper design, installation, and maintenance to mitigate these risks. They also highlight the need for users to be adequately informed about the operation and maintenance of RWH systems. The study concludes that a well-implemented risk management plan can significantly reduce potential hazards, ensuring the safety and reliability of RWH systems (Karelová, Vranayová, Káposztasová, & Purcz, 2013).

The study by Liu, Liu, Wu, Wu, and Huo (2016) addresses the challenges and solutions related to the safety of rainwater harvesting (RWH) for drinking purposes in China. Given China's severe water shortages, RWH has gained attention for its accessibility, simplicity, and low cost. The paper systematically analyzes the components of RWH systems, which include harvesting, delivering, processing, and storing rainwater. It identifies the sources of rainwater pollution, such as atmospheric deposition, fertilizers, pesticides, and waste on runoff-collecting surfaces, and emphasizes the need for pre-filtration, proper storage, and disinfection to ensure water quality.

The authors highlight the benefits of RWH, such as reducing investment and energy costs, conserving water, and minimizing erosion. However, they also note the issues of unprofessional project design, insufficient rainwater collection, and inadequate protection and pollution control measures. The study proposes a participatory management framework involving government, enterprises, and water-using associations to enhance the effectiveness and sustainability of RWH systems. The paper concludes by stressing the importance of developing appropriate technologies and guidelines to improve the efficiency and safety of RWH systems, thereby contributing to China's water security and public health (Liu, Liu, Wu, Wu, & Huo, 2016).

The "RAIN Rainwater Quality Policy and Guidelines 2008" document addresses the critical issue of water quality in rainwater harvesting systems, aiming to improve public health by ensuring access to safe drinking water. The document highlights the importance of maintaining acceptable water quality standards to prevent waterborne diseases, particularly in vulnerable populations in developing countries. It outlines comprehensive guidelines and practical measures for assessing and improving the quality of harvested rainwater. These include evaluating potential contamination risks, implementing water safety plans, and employing various treatment methods such as chlorination, filtration, and boiling. The guidelines emphasize the need for regular water quality monitoring and the adoption of hygienic practices to minimize health risks. Additionally, the document provides criteria for water quality based on WHO standards and offers tools for water quality sampling and testing to ensure consistency and reliability in the assessment process (RAIN Foundation, 2008).

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