Rooftop Rainwater Harvesting: Issues and Challenges

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ABSTRACT

Issues and challenges related to rooftop rainwater harvesting system have been discussed to highlight present knowledge. Issues such as benefit of RWH system, design considerations such as optimum tank size, efficiency of RWh system, water quality related issues and available technologies for disinfection and filtration of rainwater, economic considerations, social challenges and effect of climate change have been discussed. Before designing a RWH system, it is important to know all these considerations so as to arrive at a RWH solution which is optimal, meets the quality requirements and is economical viable.

KEY WORDS: Rainwater harvesting; rooftop rainwater harvesting, design, water quality, economic benefit, social issues, climate change

INTRODUCTION

Rainwater harvesting (RWH) is increasingly becoming an integral part of the sustainable water management toolkit (Ward et al., 2012). It is a technology where surface runoff is effectively collected during the periods when enough rainfall occurs. Rainwater can be collected and stored from rooftops, land surfaces or rock catchments using simple techniques such as natural and/or artificial ponds and reservoirs (Helmreich and Horn, 2009). Such technologies are really important for a country like India where effective rainfall is available only for 3-4 months of the year during the monsoon period. Basic premise is that the rainwater falling at a particular location, if not harvested, would flow as surface runoff and may not be available at that location for later use. Harvested rain water can be used for rainfed agriculture or water supply for households. Present paper focuses on rooftop rainwater harvesting (RRWH) for household needs. For RRWH, rainwater is collected from rooftops, court yards and low frequented streets and can be stored close to households.

Attempts are made to highlight issues and challenges faced and to highlight present research work to overcome these challenges. There are some pertinent questions that need to be answered before an attempt is made to use RRWH technology; such as; 1. What are the benefits of the RRWH? 2. What are the design related issues? 3. What are the water qualities related issues? 4. What are the different treatment technologies available? 5. Is it economical to use RRWH? 6. What are the social issues? and 7. Is climate change affecting the design and performance of RRWH?

BENEFITS OF RRWH

The main advantage of RRWH is to provide water right near the household, lowering the long distance walks burden of water collecting (Kahinda et al., 2007). Harvested rainwater is a renewable source of clean water which can be used for domestic purposes, garden watering and small scale productive activities. It also contributes to reducing flood risks and the load on sewer systems.

The greater attraction of a rainwater harvesting system is the low cost, accessibility and easy maintenance at the household level. Though the capital costs are high but neither operation nor maintenance usually involves significant expenditure. Rainwater harvesting seems to be a beneficial method for minimizing water scarcity in developing countries.

DESIGN RELATED ISSUES

The main design related issues are how to design the storage tank and efficient RRWH system. The appropriate design and evaluation of RRWH system is necessary to improve system performance and the stability of the water supply (Mun and Han, 2012). The main design parameters of an RWH system are rainfall, catchment area, collection efficiency, tank volume and water demand. Rainfall often varies in a range of 200– 600 mm/year from arid to semi-arid areas (Falkenmark et al., 2001). As per Helmreich and Horn (2009), one millimeter of harvested rainwater is equivalent to one litre water per square metre.

Fig.1 shows the water demand satisfied by a tank as compared to its size (Development Technology Unit, 2001). The benefit of a tank is not strictly proportional to its size. The reason is that a smaller tank will be filled and emptied often whereas a larger tank will only be cycled rarely.

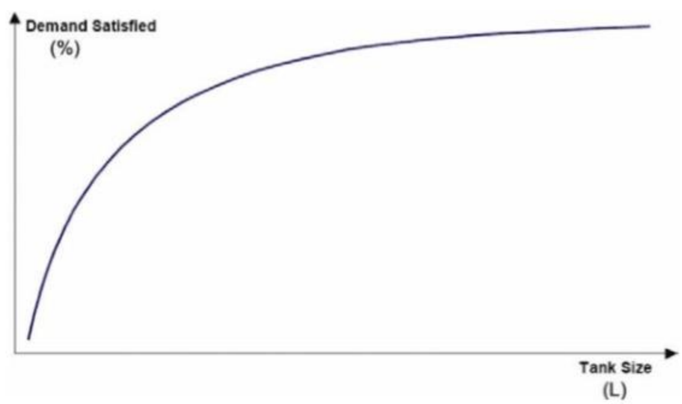

Fig. 1: Benefits of Tank Sizing (Development Technology Unit, 2001)

Ward et al., (2012) have presented the results of a longitudinal empirical performance assessment of a non-domestic RWH system located in an office building in the UK. It compares actual performance with the estimated performance and their result highlighted that the average measured water saving efficiency of the office-based RWH system was 87% across an 8-month period, due to the system being over-sized for the actual occupancy level. Consequently, same level of performance could have been achieved using a smaller-sized tank leading to reduction of capital payback period to only 6 years from presently 11 years. Therefore proper design could lead to significant water and cost savings.

Imteaz et al. (2011) have evaluated the design of rainwater tank for large roof areas, located in Melbourne, Australia, based on observed daily rainfall data representing three different climatic regimes. They developed a Decision Support Tool for the performance analysis and design of rainwater tanks. Campisano and Modica (2012) have presented the dimensionless methodology for the optimal design of domestic rainwater harvesting systems. Results of their analysis shows that the economical convenience of large tanks decreases as rainwater availability decreases. Santos and Pinto (2013) evaluated six different calculation methods, which are based on daily simulations of the system's operation using daily rainfall data and non-potable demand to size storage tanks in rainwater harvesting systems. Their results show that methods based on the maximum rainwater use and 100% efficiency criteria result in very large storage volumes and very long payback periods and therefore 80% efficiency criteria is most appropriate to size a rainwater harvesting system.

Kim et al. (2012) modified an existing analytic model for estimating the runoff in urban areas to provide a more economical and effective model that can be used for calculating rainfall–runoff reduction and designing the storage tank capacity by taking into account the catchment, storage tank, and infiltration facility of a water harvesting system. The storage tanks can be built underground or aboveground. For storage smaller storage tanks made of bricks, stabilized soil, rammed earth, plastic sheets and mortar jars are common. For larger quantities rainfall water containers can be made of pottery, ferro-cement, or polyethylene. The polyethylene tanks are compact but have a large storage capacity (Helmreich and Horn, 2009). In order to be cost effective RRWH systems should always be based on local skills, materials and equipment.

There remains a significant gap in knowledge in relation to detailed empirical assessments of performance of RRWH systems (Ward et al., 2012). Additionally, there are few studies comparing estimated and actual performance. Palla et al. (2012) evaluated the performance of rainwater harvesting systems under various precipitation regimes. Their results demonstrate that the antecedent dry weather period is the main hydrologic parameter affecting the system behavior. Mehrabadi et al. (2013) assessed the applicability and performance of rainwater harvesting (RWH) systems to supply daily non-potable water under different climatic conditions. According to their results it is possible to supply at least 75% of non-potable water demand by storing rainwater from larger roof areas for a maximum duration of 70% of the times in humid climate and only 23% times in arid climate.

WATER QUALITY RELATED ISSUES

Water security has been defined as "accessibility, reliability and timely availability of adequate safe water to satisfy basic human need". The question is how safe is rain water? Pure rainwater is mostly low polluted depending on the quality of the atmosphere. Atmospheric pollutants including particles, microorganisms, heavy metals and organic substances, accumulate on the catchment areas as dry deposition and are washed out from the atmosphere during rainfall events. Rainwater in rural areas – being situated far from atmospheric and industrial pollution – is fairly clean except for some dissolved gases. On the other hand urban areas are characterized by a high traffic and industry impact and are therefore contaminated by particles, heavy metals and organic air pollutants (Helmreich and Horn, 2009).

Unfortunately, rainwater might be polluted by bacteria and hazardous chemicals requiring a vigilant choice of the catchment area and treatment before usage. Precautions required in the use of storage tanks include provision of an adequate enclosure to minimize contamination from human, animal or other environmental contaminants, and a tight cover to prevent algal growth and breeding of mosquitoes (Helmreich and Horn, 2009).

To harvest rainwater of good quality for human consumption, householders are encouraged to use one of the various alternatives for roof washing, and collection or disposal of the first flush of rainwater from roofs since the first flush picks up most of the dirt, debris and bird droppings and contaminants from the roof and gutters during dry periods (Abdulla and Al-Shareef, 2009). The simplest of these systems consists of a standpipe and a gutter down-spout located ahead of the down-spout from gutter to the tanks or cisterns (Global Development Research Center, 2002).

The safety of water is determined at the household level by people's perception and in the laboratory by absolute measurements. Taste plays a major role in drinking water. As rainwater does not contain any minerals and does not carry any taste, it is not well widely accepted in urban areas as drinking water. Consumption is related to the perception of quality. Most of the rainwater tanks are generally not tested for water quality; therefore, householders have no knowledge of true water quality and only have the perception of water quality (Abdulla and Al-Shareef, 2009).

Rainfall intensity and the number of dry days preceding a rainfall event significantly affect the quality of harvested rainfall. The quality of rainwater collected depends on when it is collected (after the first rain), how it is stored as well as method of use. The stored rainwater will not always meet WHO standards (WHO, 1993). Rainwater is usually free from physical and chemical contaminants such as pesticides, lead, and arsenic, color and suspended materials and it is low in salt and hardness. Regular maintenance assists in gaining good quality water from rainwater tanks. The storage tank should be cleaned periodically, inner walls and floor should be scrubbed, and then cleaning of the cistern using chlorine, followed by a thorough rinsing. Cracks should be patched with a non-toxic material, and access to the cistern should be taken into consideration while designing the tank (WHO, 1993). Lim and Jiang (2013) have discussed about the health risk concerns associated with household use of rooftop-harvested rainwater. The collected water should be chlorinated at least once every rainy season and preferably after the cisterns are full of rainwater. The sources of microbiological contamination are the human and animal waste present in the cistern catchment area. Cleaning the catchment area before the rainy season starts is a must and people should be aware of that all the time.

Mendez et al. (2011) examined the effect of conventional roofing materials (i.e., asphalt fiberglass shingle, Galvalume® metal, and concrete tile) and alternative roofing materials (i.e., cool and green) on the quality of harvested rainwater. Results indicate that rainwater harvested from any of these roofing materials would require treatment if the consumer wanted to meet United States Environmental Protection Agency primary and secondary drinking water standards or non-potable water reuse guidelines. They have mentioned that at a minimum, first-flush diversion, filtration, and disinfection are recommended. Metal roofs tend to have lower concentrations of fecal indicator bacteria as compared to other roofing materials. Roofing material is an important consideration when designing a rainwater catchment. According to Metre and Mahler (2003), rooftops are both a source of and a pathway for contaminated runoff in urban environments. They found that concentrations of zinc, lead, pyrene, and chrysene in a majority of rooftop samples exceeded established sediment quality guidelines. Lye (2009) has discussed about the heavy metal contamination specific to runoff from rooftop catchment areas containing exposed metal surfaces. Lee et al. (2012) assess the quality of harvested rainwater on the basis of the roofing materials used and the presence of lichens/mosses on the roofing surface. According to them, galvanized steel was found to be the most suitable for rainwater harvesting applications due to the fact that ultraviolet light and the high temperature effectively disinfect the harvested rainwater.

TREATMENT OF RRWH WATER

For disinfection purposes there are many techniques available, some of these utilizing natural sources such as solar energy. Slow sand filtration and solar technology are methods to reduce the pollution. Membrane technology would also be a potential disinfection technique for a safe drinking water supply.

As per Amin and Han (2009), solar disinfection (SODIS) has been recommended by the World Health Organization for rainwater disinfection. They have determined the efficiency of SODIS and solar collector disinfection (SOCO-DIS) for rainwater disinfection, and its potential benefits and limitations. As per their finding SOCO-DIS system, disinfection improved by 20–30% compared with the SODIS system, and rainwater was fully disinfected even under moderate weather conditions, due to the effects of concentrated sunlight radiation and the synergistic effects of thermal and optical inactivation. Microbial inactivation increased by 10–20% simply by reducing the initial pH value of the rainwater to 5. However high turbidities affected the SOCO-DIS system and the disinfection efficiency decreased by 10–15%, which indicated that rainwater needed to be filtered before treatment.

Nawaz et al. (2012) used silver as antimicrobial agent to improve the quality of harvested rainwater. The efficiency of silver disinfection was evaluated at concentrations, ranging from 0.01 to 0.1 mg/l. Results of their study indicated that higher inactivation and long term residual effect can be achieved with the application of silver at 0.08 mg/l or higher under safe limit. Vieira et al. (2013) developed a novel concept for the filtration of particles in raw rainwater with no energy usage, self-cleaning mechanism, and simple installation and operation in buildings. They have utilized up-flow filtration with down-flow backwashing operation.

ECONOMIC ISSUES

Rainwater does not require chemical, physical nor biological treatment before use for most non-potable demands. This makes maintenance of rainwater harvesting systems generally easy and cheap (Environment Agency, 2003). It has been reported that rainwater harvesting can promote significant water saving in residences in different countries (Abdulla and Al-Shareef, 2009). In Germany, a study performed by Herrmann and Schmida (200) showed that the potential of potable water saving in a house might vary from 30% to 60%, depending on the demand and roof area. In Australia, Coombes et al. (2000) analyzed 27 houses in Newcastle and concluded that rainwater usage would promote potable water saving of 60%. In Brazil, a study performed by Ghisi et al. (2006) showed the potential water saving by using water harvesting in 62 cities ranges from 34% to 92%, with an average potential for potable saving of 69%.

The capital cost of rainwater harvesting systems is highly dependent on the type of catchment, conveyance, cistern or tank size and storage tank materials used. In addition to the cost of components, there is the cost of having the system installed. The most expensive part of a rainwater system is usually the cistern itself (Abdulla and Al-Shareef, 2009). Before making the decision whether or not to go ahead with a system at home, it is worth considering the water needs against the cost of installing and maintaining it. While the startup cost of a rooftop catchment system may be significant, the long-term operation and maintenance costs are reasonable.

Farreny et al. (2011) have determined the cost efficiency of rainwater harvesting in dense Mediterranean neighbourhoods. There results indicate that RWH strategies in dense urban areas under Mediterranean conditions appear to be economically advantageous only if carried out at the appropriate scale in order to enable economies of scale, and considering the expected evolution of water prices. Imteaz et al. (2011) have performed the payback period analysis of the tanks, which reveals that the total construction cost of the tanks can be recovered within 15–21 years’ time depending on tank size, climatic conditions and future water price increase rates. Rahman et al. (2012) investigated the water savings potential of rainwater tanks fitted in detached houses at 10 different locations in Greater Sydney, Australia. It was found that the average annual water savings from rainwater tanks are strongly correlated with average annual rainfall. It was also found that the benefit cost ratios for the rainwater tanks are smaller than 1.00 without government rebate. Chiu et al. (2009) have proposed methodology for optimized rooftop rainwater harvesting systems and provides an energy-saving approach for hilly communities. Their results also revealed that rainwater harvesting becomes economically feasible when both energy and water savings are addressed together.

SOCIAL ISSUES

Even though RWH is a helpful technique for areas with scarce water resources there are some problems hindering the integration and implementation (Helmreich and Horn, 2009). Often the technology used is inadequate to meet the requirements of the region or else is too expensive. Sometimes there is a lack of acceptance, motivation and involvement among users. Hydrological data and information for confident planning, design and implementation of RWH systems are missing. Additionally there is often an insufficient attention to social and economic aspects such as land tenure and unemployment. Often the people's knowledge with regard to RWH and use is inadequate and outdated giving away the benefits of rain water resources. Absence of long-term government strategies is also a handicap.

Domènech and Saurí (2011) suggested that both regulations and subsidies are good strategies to advocate and expand rainwater harvesting technologies in residential areas. However, a multidirectional learning environment needs to be promoted to ensure a proper use of rainwater harvesting systems and risk minimisation.

CLIMATE CHANGE RELATED ISSUES

According to Youn et al. (2012), recent precipitation patterns have changed due to climate change and will likely continue to do so, RWHS designs must take future precipitation forecasts into account. They developed a methodology for establishing the probabilistic relationships between the storage capacity and deficit rate of an RWHS when considering climate change.

CONCLUSIONS

It is well established that RWH is a water management strategy for increasing the availability of water at water scarce regions. RRWH has been discussed and issues and challenges related to its benefits, design, quality considerations, economical and social issues and climate change have been discussed and latest research has been reported. It is highlighted that significant cost cutting can be achieved by proper design of RRWH system. It is important to be conscious of water quality related issues specially if harvested water is used for drinking purpose. It should be properly evaluated for meeting the drinking water specifications.

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