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Probable Sources of Rainwater Contamination In A Rainwater Harvesting System and Remedial Options

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Abstract Rainwater harvesting and management was once a necessity. Rainwater catchment systems can be found in most regions of the world, with adaptations suited to local climatic conditions. Domestic RWH systems have been practiced for thousands of years. Though, RWH has been receiving increased attention worldwide, as an alternative source of non-potable water, its use as potable water supply is very limited and the main reason is obviously the quality of stored rainwater in domestic tanks that believe not to meet the drinking water quality standards. Assessments of roof runoff quality that can be found in the literature do have rather differing result. This paper challenges the viewpoint of rainwater being polluted based on initial microbial examination of stored rainwater in underground cisterns at one of the university in Seoul, Korea. The main objectives were to find out the effects of first flush removal on microbial quality enhancement of rainwater and the effects of different catchment sources on microbial quality of stored rainwater. These results show rainwater suitable even for potable use after very little treatment, in different parts of the world and highlights gaps in our understanding and finally recommend the future research work to further support the conclusion drawn. Microbiological investigations have revealed interesting results and low-cost microbial disinfection such as solar disinfection of stored rainwater for drinking purposes can be viewed as future research.

Key words: catchment, first flush, microbial, potability, rainwater harvesting, storage

INTRODUCTION

At least one-third of the population in developing countries is living with no access to safe drinking water resulting into major health problems (WHO, 2002) and about 6000 children die every day due to diarrhea (Ashbalt, 2004). The problems of inadequate supplies and insufficient treatment encourage searching for alternative approaches which are also decentralized systems, keeping in mind the technical and financial limitations of the poor living in underdeveloped areas (Amin and Han, 2009a).

In the face of decreasing water sources and increasing energy crises, rainwater harvesting (RWH) may be seen as one of the most appropriate alternatives for supplying freshwater at household or at community level. RWH has received increased attention worldwide as an alternative source of potable and non-potable water supplies (Hatibu *et al*., 2006; Heyworth *et al*., 2006; Ghisi and Ferreira, 2007; Han, 2007; Amin and Han, 2007). Potential applications of RWH do exist for roof catchments in areas where a centralized water supply and distribution system are not adequate, and such applications are increasing (Han, 2007, Amin and Han, 2011a).

RWH is an entirely new water supply rather than a conservation technique (Critchley and Siegert, 1991). Many regions around the world are adopting RWH to overcome the increasing demand of water besides the climate changes adaptation (Jackson *et al*., 2001). RWH offers benefits such as; it promotes self-sufficiency and encourages water and energy conservation (Retamal and Turner, 2010) and result permanent decrease in mains water demand (Grandet *et al*., 2010). For example, the rainwater use in the rural township of Western Australia has shown rainwater tanks much more effective in intercepting roof runoff with the maximum stormwater reduction of about 50% (Zhang *et al*., 2010). It has been used non-potable water supplies at many places in the world (Olem and Berthouex, 1989; Simmons *et al*., 2001). The use of rainwater in domestic hot water systems can produce optimal environmental and economic results for urban water cycle management (Spinks *et al*., 2006; Sturm *et al*., 2009). In Palestine, RWH systems have shown to reduce the annual environmental impact of the in-house water usage by about 40% (Nazer *et al*., 2010).

RWH for supplying drinking water for urban areas has a long history in semi-arid areas (Abdelkhaleq and Ahmed, 2007; Pandey *et al*., 2003). A recent case study in Sudan has shown RWH to provide an additional source of drinking water in a changing physical environment associated with urban population growth (Ibrahim, 2009). Roof catchment is an old method of RWH that has widely been used to provide urban dwellers with

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potable water supply in many parts of the developing world (Dillaha and Zolan, 1985; Kumar, 2004; Pinfold, 1993).

To date, RWH has been used mostly for water for nonpotable purposes, mainly because harvested water is microbiologically contaminated by a variety of indicator and pathogenic organisms, unless special care is taken during collection and storage of the rainwater (Meera and Ahammed, 2006). This requires the minimum treatment of stored rainwater in case it has to be used for potable purposes. There are simple home water purification devices available for the treatment of roof-harvested rainwater, which is generally contaminated by microorganisms and heavy metals (Ahammed and Meera, 2006).

Roof catchment is the common method of RWH and is widely used to provide urban populations with alternate water supplies (Handia *et al*., 2003; Preul, 1994; Thomas, 1998). The application of RWH has very limited use for potable water supply mainly due to the poor quality of stored rainwater in rainwater tanks (Amin and Han, 2011b). The quality of stored rainwater, however, can be improved by proper maintenance of the different components of RWH system which are discussed in this paper and guidelines are recommended for the efficient use of this valuable alternate of water supplies.

Problem Background:

Fresh water is a limiting resource in many parts of the world and will become even more limiting with time because of increased population, urbanization, and climate change (Pringle and Barber 2000, Robarts and Wetzel 2000, Vo¨ro¨smarty *et al*., 2000). This limitation could be due to increased water demand or due to more polluted freshwater ecosystems (Jackson *et al*., 2001). Postel *et al*. estimated 52% consumption in 4430 km3/y global water withdrawals in 1996.

Ground water is the primary source of water in arid and semiarid regions of the world (one-third of the earth's lands holding one-fifth of global population) while at least one-fourth of the world's population draws its water from underground aquifers (Ford and Williams 1989, White *et al*., 1995). These regions have many of the world's largest aquifers (Sahagian *et al*., 1994) and limited recharge makes such aquifers highly susceptible to groundwater depletion (Jackson *et al*., 2001).

It is expected that global population will rise at least three times faster than accessible freshwater runoff (United Nations, 1998) in next half century. As a consequence, improved water management due to the growing demands on freshwater resources and improving the efficiency of water use are the present and future research topics in the areas of water management (Dellapenna, 1999).

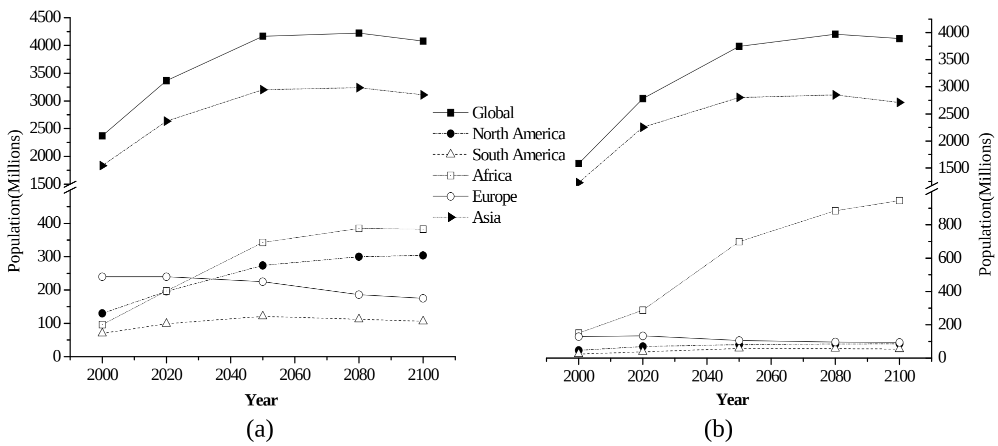

Fig. 1: The trends of population living in water stressed watersheds over the globe in 21st century Arnell *et al*., 2011

(a) Population living in water stressed watersheds having average annual runoff less than 1000m3/capita/year

(b) Population living in water-stressed watersheds have withdrawals >40% of average annual runoff

Rainwater harvesting and management (RWHM) can be a practical solution in the context of efficient water use and is receiving increased attention worldwide as an alternative source of water supply (Amin and Han, 2009b; Ibrahim, 2009). This approach can be considered for improved water management due to increased world population, urbanization in developing countries, and climate change (Murad *et al*., 2007; Ruth *et al*., 2007; Wheida and Verhoeven, 2007; O'Hara and Georgakakos, 2008). RWH is a technology used for collecting and storing rainwater from rooftops, the land surfaces, steep slopes, road surfaces or rock catchments using simple techniques such as pots, tanks and cisterns as well as more complex techniques such as underground check dams (Appan, 1999; Makoto, 1999; Prinz, 1999). Nowadays, commonly used systems are constructed of three principal components; namely, the catchment area, the collection device, and the conveyance system. Additionally, leaf screens and roofwashers are often used by householders to remove contaminants and debris (GDRC, 2002: TWDB, 1997).

In a roof-top RWH system, rainwater from rooftops, rock catchments and other surfaces is collected using simple technologies, such as storage tanks, pipes and gutters (Appan, 1999). A simple rooftop RWH system consists of its catchment area, a treatment facility, a storage tank, a supply facility and piping (Han and Mun, 2008), as shown in Figure 2. If the system is designed well, it requires little or no electricity, chemicals or maintenance. In these small scale and decentralized rooftop RWH systems, rainwater is collected from roofs/terraces and other suitable catchments and is stored in plastic, steel or concrete storage tanks and is used afterwards for potable or non-potable purposes thus providing an alternative water resource (Baguma *et al*., 2010).

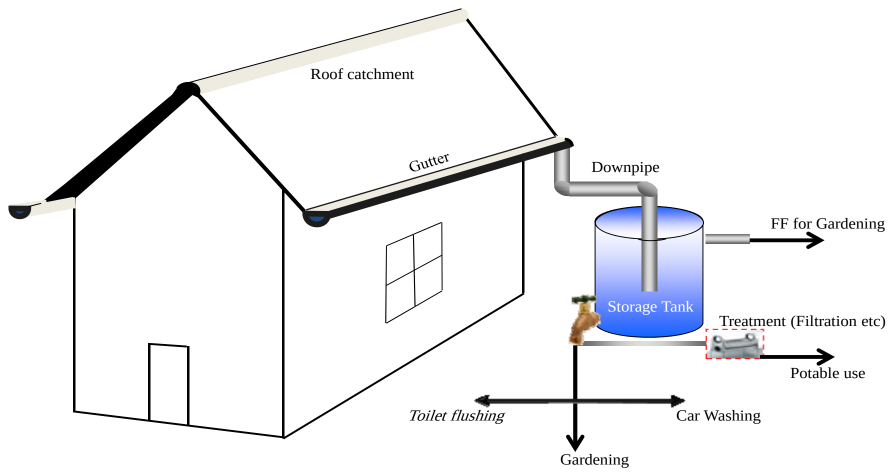

Fig. 2: Schematic of a typical rooftop RWH system

The European Commission also issued a recommendation for using rainwater in public and private buildings (EC, 1994). Other reasons for rainwater storage could be to mitigate various water problems, such as flooding and drought. Despite being an ancient practice in many parts of the world, RWH is used only on a limited scale at the household level (Thomas and Greene, 1993; UNEP, 1998) and has very limited use as a source of potable water, primarily because the quality of stored rainwater in domestic tanks is not believed to meet drinking water quality standards (Gould 1999; Lye 2002; Zhu *et al*., 2004, Lee *et al*., 2010).

The use of RWHM, however, especially for potable purposes, is limited because the quality of stored rainwater in domestic tanks is perceived as failing to meet drinking water quality standards (Amin and Han, 2009c). One of the major constraints for the potable use of rainwater is the microbial quality of stored rainwater which is not good mostly due to the possible contamination upon contact with roof catchment. This requires the minimum treatment by simple disinfection methods, pre-filtration or otherwise the proper maintenance of the entire RWH system from the collection of the rainfall to the use of stored rainwater.

Case studies of RWHM:

This section reviews some of the papers discussing RWH from mainly microbial quality aspects in some countries around the world including developed nations along with developing countries.

One of the studies carried out for roof runoff quality at Nacogdoches, Texas, America (Chang *et al*., 2004) shows that among the four different types of roof catchments (wood shingle, composition shingle, painted aluminum, and galvanized iron), runoff quality from wood shingles was the worst. St Thomas in the US Virgin Islands showed concentrations of all except Hg to be below the US EPA water quality standards (Lee and Jones, 1982) and one or both of the protozoa (Cryptosporidium and Giardia) were found in 81% of the public cisterns as compared to the private cisterns where 47% of the samples were positive (Crabtree *et al*., 1996). The cistern water quality in an area receiving acidic deposition, Kentucky and Tennessee (KT), America, were compared to cistern water chemistry St. Maarten, Netherlands Antilles (SM) which is not affected by acidic deposition (Olem and Berthouex, 1989). Rainwater was neutralized upon contact with cistern masonry in both regions Metal concentrations were below current drinking water limits in all but a few samples.

Roof-collected rainwater systems appear to provide a supply of relatively poor physicochemical and microbiological quality in Auckland, New Zealand (Simmons *et al*., 2001). Two types of roof catchment (galvanized iron and concrete tile roof) were evaluated for pH, temperature, FC and TC in Malaysia (Yaziz *et* *al*., 1989). Results shows that (1) longer the dry period in between rainfall events, the greater is the amount of pollutants deposited on the roof surfaces, (2) wash-out process occurs faster for a particular roof surface with increases in the rainfall intensity, (3) concentration of various pollutants were high in the first litre but decreased in subsequent samples with few exceptions with no FC and TC detection in the fourth and fifth litre samples from both roofs, (4) pH of rainwater collected from the open was acidic but increased slightly after falling on the roofs, (5) "foul flush" volume of 5L is safeguard against microbiological contamination but the high metals content need for some form of treatment.

Results by monitoring cistern and roof catchment water in Loess Plateau, China (Zhu *et al*., 2004) revealed that all samples failed for FC according to the WHO guidelines and the quality of the cistern water collected in rainy seasons was much worse than the rainwater stored in cistern through the dry seasons. Bulk free-fall and roof-intercepted rainwater samples analyzed in Ile-Ife, Nigeria (Adeniyi and Olabanji, 2005) revealed that values of different quality parameters for roof-intercepted samples were higher than those of free-fall samples with and enrichment factor within the range of 1 and 5, and the potability of bulk rainwater sources did not fall completely within the allowable guidelines of most international organizations showing rainwater sources are non-compliment with set drinking guideline in terms of bacteriological quality.

Most Rainwater catchment systems (RWCS) in Micronesia were found to provide water of acceptable quality for domestic purposes (Dillaha and Zolan, 1985). Presence of coliform bacteria in many catchments recommends disinfecting water before using it for drinking and food preparation. Rainwater is used as non-potable purposes for toilet flushing and clothes washing for saving drinking water resources in Denmark (Albrechtsen, 2002) as none of the investigated rainwater samples met the drinking water standards however the general microbiological quality in the toilets supplied with rainwater were approximately the same as in the reference toilets supplied with drinking water. The use of rainwater for WC flushing, laundry, irrigation, and car washing in Ringdansen, Sweden is analysed and the quality of roof runoff is acceptable to supply low quality domestic uses (Villarreal and Dixon, 2005).

In Zambia, samples from a roof water system showed that the water can be used for drinking (Handia *et al*., 2003). Potable water savings by using rainwater ranges from 34% to 92%, with an average potential for potable water savings of 69% in Brazil (Ghisi *et al*., 2006). Rainjars, in Thailand, provided a purer and more convenient source than shallow wells and bacteriological analysis showed rainjar water to be much purer than drinking water from alternative sources (Pinfold *et al*., 1993).

Quality of rain water is monitored from different tank types in Sri Lanka and it is found that as compared to other available water sources in rural Sri Lanka, quality of rain water is much higher both biologically and chemically (Ariyananda, 2005). Results after evaluating the quality of collected rainwater in Korea revealed that utilization of collected rainwater should be limited to non-potable use. (Yun and Choi, 2005).

Discussions:

4.1- First Flush (FF) of rainfall:

The FF of runoff water that occurs at the beginning of a storm event contains a high proportion of the pollutant load. The main cause of this phenomenon is the deposition and accumulation of pollutant material to the roof during dry periods. Exposure to UV, heat, and desiccation on the roof top destroy many bacteria, while wind removes some heavy metals accumulated from atmospheric fallout. Pollutant additions to roof runoff include organic matter, inert solids, faecal deposits from animals and birds, trace amounts of some metals, and even complex organic compounds. The longer the dry period, the greater the probability of a higher pollutant load in the FF. Factors such as type of roof material, dry period and surrounding environmental conditions influence rainwater quality. Pollutant additions to roof runoff include organic matter, inert solids, and fecal deposits from animals and birds.

For the effects of FF, rainwater samples were collected from the RWH systems installed at Seoul National University, Seoul, Korea. The choice of sites for sample collection was made mainly with regard to the availability of the rainwater facility. Two sites were selected namely the dormitory building and Building-39. In case of dormitory building the tank size is about 200 Ton and roof catchment area is comprised of 2098 m^2 of concrete surface. In Building 39, main tank size is about 250 ton with total roof catchment area of 3652 m^2 and small tank volume collecting water from roof-terrace collection is about 25 Ton.

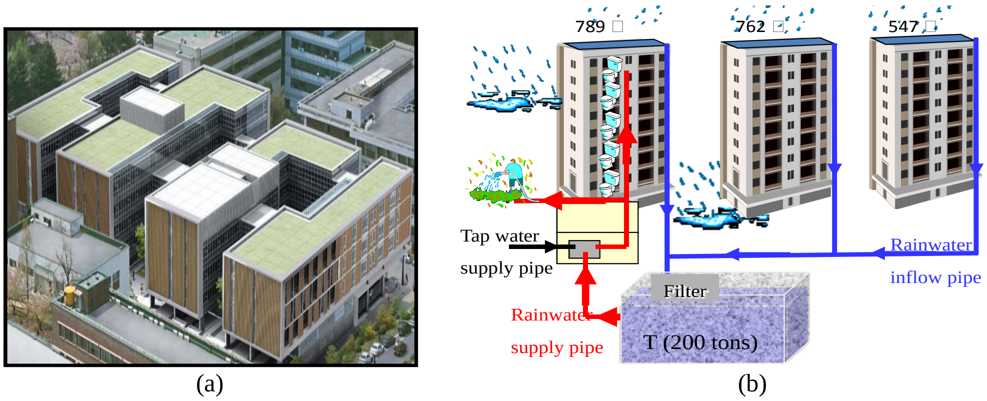

Fig. 3: Couple of RWH facilities at Seoul National University; (a) Building-39, (b) Dormitory building

Total and fecal coliform bacteria tests are used to assess bacteriological water quality. These tests are used to index hygienic quality because total and fecal coliform are usually associated with fecal contamination and thus their numbers reflect the degree of pathogenic risk. Also, the tests are relatively easy to perform in comparison with analyses for specific pathogens. Fecal coliform (FC) is the most widely used indicator to determine the possible presence of pathogenic organisms. Coliform bacteria originate from the feces of humans and warm-blooded animals in addition to be found in soils and other natural sources. The numbers of FC is often used as an indicator to judge water quality. The relationship among total coliform (TC), FC and *Escherichia coli (E. coli)* is shown in Figure 4.

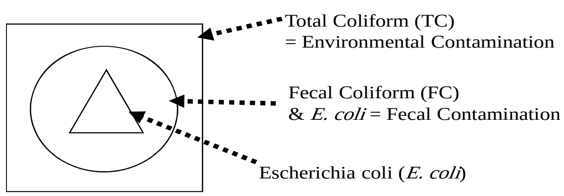

Fig. 4: Investigating microbial parameters for monitoring the rainwater quality

Microbiological samples were collected directly into individual sterile 1L bottles and transported to the laboratory. Samples were received and analyses usually commenced on the day they were taken or if that were not possible, within 24 h of sampling.

Roof-intercepted water during FF is highly contaminated in case roof-terrace surface, as shown in Figure 5. The quality is improved after FF of rainfall in case of roof catchment sample but still not good for roof-terrace surface although improved. The roof-intercepted sample is free of contamination after FF of rainwater (about 15 liters). Both *E. coli* and Heterotrophic Plate Count (HPC) are also observed in the FF of rainwater representing the contamination of catchment area by human activities.

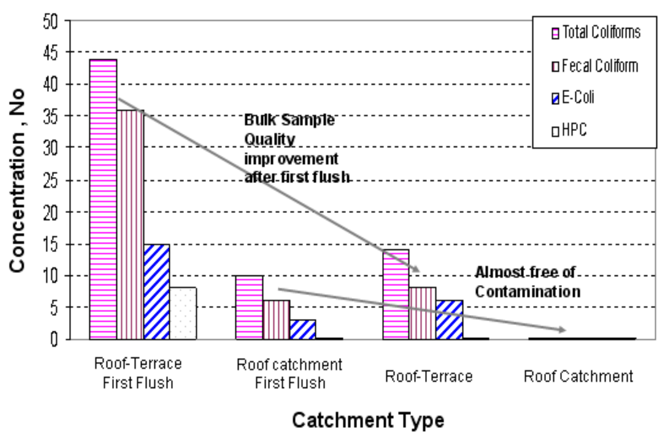

Fig. 5: Rainwater quality improvements after FF Building-39

But, given a long duration, integrated self-purification mechanisms apparently take place in cisterns. In particular, sedimentation, adsorption and biodegradation play a crucial role in improving water quality. Best practices are filters that have a separate outlet for dirt and reject the FF as a side effect. Another option is to divert the FF from entering into rainwater storage tank and use it separately for gardening and similar uses, as shown in Figure 6.

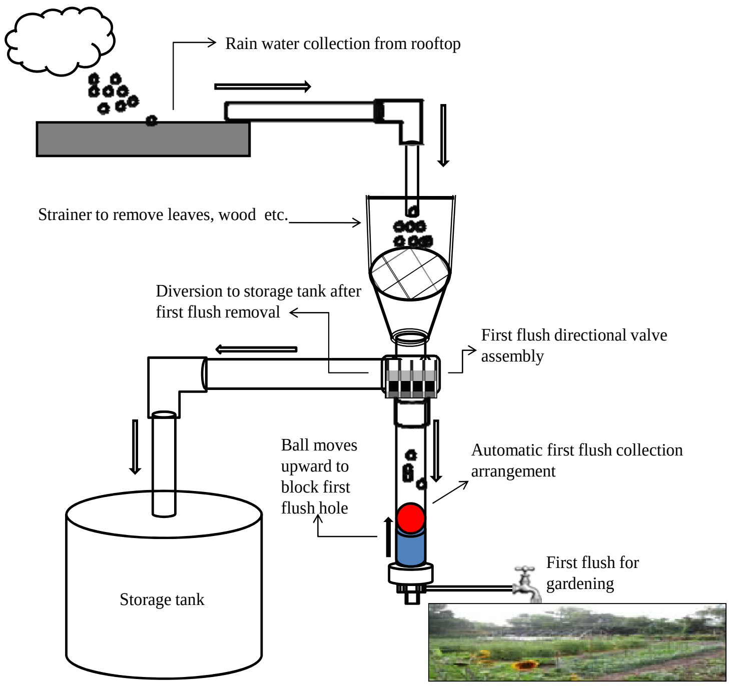

Fig. 6: FF device set-up and use in a RWH system

4.2 Catchment surfaces:

Rainwater not only adds a variety of chemicals and contaminants to the roof watershed, the acidic nature of rainwater will react with compounds retained in or by the roof and cause many elements in the roof-runoff to leach out (King and Bedient, 1982). Second, roof temperatures are much higher than temperatures of other surfaces, due to lower albedo, greater surface inclination to direct solar radiation, and less shading effects from surrounding trees (Chang and Crowley, 1993). The higher roof temperatures may accelerate chemical reactions and organic decomposition of the materials and compounds that have accumulated on rooftops. Combining these constituents from rooftops with elements from precipitation deposition, chemical decomposition, and acid leaching make the quality of roof runoff a great concern for the household cistern system (Ariyananda and Mawatha, 1999; Sharp and Young, 1982; Spinks *et al*., 2003) and on receiving streams (Che *et al*., 2001).

Quality of runoff may be ameliorated or become worse compared to the composition of atmospheric deposition depending on the kind of materials used for roof cover and drainage systems and their interaction with the atmospheric deposition. The variation of roof runoff quality seems to reflect differences in roofing materials, age and management, the surrounding environment, season, storm duration and intensity, and air quality conditions of the region.

Both *E. coli* and HPC are not observed apparently, as shown in Figure 7. Quality of rainwater in auxiliary tank which is collected from Roof-Terrace catchment is worse than rainwater in main tank where the water is mixed water from roof and roof-terrace catchments. Also the sample was comparatively dirty in appearance when collected from small tank.

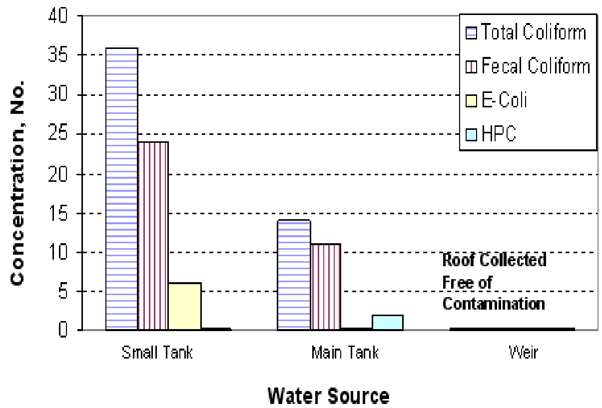

Fig. 7: Rainwater quality difference among different catchments

The roof-intercepted stored water is free of any microbial contamination and has acceptable turbidity with neutral pH. This shows that quality is improved much during storage. The water collected from small tank which is collected from terrace is alkaline with very high turbidity value. The mixed water of roof and terrace in main tank was also alkaline but with intermediate turbidity value.

While roof surfaces are often viewed as potential sources of contamination for rainwater, the storage tanks can be regarded as means of treatment, as they offer a range of beneficial processes. For example, rainwater is often slightly acidic and the pH can be further increased through contact with a concrete catchment and then during storage in a concrete tank. This rise in pH, for instance from 5.0 on the roof surface to 9.4 in the tank and then 10.3 for the tap water, can inhibit coliform growth. During sampling over a two year period, coliform bacteria were only detected during periods of low pH (Scott & Waller, 1987). Sedimentation can also play a primary role in reducing the contaminant load of stored rainwater. Spinks *et al*. observed sludge accumulation rates of up to 7.8 mm/yr and contaminant magnification rates of up to 1349 for biological parameters (Spinks *et al*., 2005).

4.3 Storage conditions and time:

The quality of water collected in a RWH system can be affected by numerous factors, including dry periods (Vazquez *et al*., 2003; Sazakli *et al*., 2007), the type of catchment (Nakata *et al*., 1995; Nair *et al*., 2001), and the storage conditions (Forster, 1999; Chang *et al*., 2004). Weather patterns can significantly influence the bacterial load in roof run-off (Evans *et al*., 2006). The catchment surfaces can significantly degrade the quality of rainwater and are often viewed as potential sources of contamination for rainwater. The storage tanks, however, can be regarded as means of treatment, as they offer a range of beneficial and natural treatment processes to improve the quality of the water while it is stored (Coombes *et al*., 2002).

Other factors that can improve the quality of rainwater include the use of filters or FF devices to treat roof runoff prior to storage, as well as ultra-violet (UV) disinfection, slow sand filtration and hot water systems (Yaziz *et al*., 1989; Ahammed and Meera, 2006; Kim *et al*., 2005). Sedimentation can also play a primary role in reducing the contaminant load of stored rainwater. Analysis of sludge samples identified tank sludge as an important sink for contaminants and a key aspect of the water quality improvement (Spinks *et al*., 2005).

Most of organic substances in water are biodegraded to varying extents. A part of organic compounds adsorbed on the suspended solids slowly falls to the bottom of the cistern, forming sediments to be removed from water body. Consequently, the quality of rainwater stored in a cistern is potentially improved with time. Rainwater is a valuable water resource if it has been stored in a cistern for half a year or, even longer.

The quality of roof runoff is improved in a rainwater tank by several processes. Biofilms adsorb heavy metals, organics, and pathogens from the water. Many bacteria conglomerate in a macro-layer on the water surface, whereas many of the heavy metals and other contaminants precipitate out the water column, and settle at the bottom of the tank.

Concluding Remarks and Future Recommendations:

It need to recognize at present that suitably harvested rainwater can represent an acceptable new water source and in some areas of extreme water shortage may even serve as the only source of potable water. After an extensive survey of rainwater tanks in South Australia, it is suggested that there is little understanding about the quality of rainwater stored in tanks in terms of potential health risks. Adequate selection of roof material, regular inspection and cleaning of the roof gutter system to limit contamination of rainwater, and correct implementation and maintenance of the rainwater tank secure the quality of the harvested rainwater.

RWH systems require few skills and little supervision to operate. Major concerns are the prevention of contamination of the tank during construction and while it is being replenished during a rainfall. Contamination of the water supply as a result of contact with certain materials can be avoided by the use of proper materials during construction of the system.

Roof and yard catchments should be cleaned regularly to remove dust, leaves and fowl droppings to maintain the quality of collected rainwater. Storage containers protected from daylight and placed in cool surroundings are generally adequate. Basement storage tanks are most suitable for existing buildings. The FF is often heavily polluted and should be treated in an appropriate way. Regular cleaning of the storage cistern is unnecessary if fine filters are used in the inlet to the storage cistern.

Rainwater could be used for both potable and non-potable purposes. It must be highlighted though that rainwater should go through proper treatment in order to be used for potable purposes. Hot water systems can be used which are pasteurizing rainwater to produce acceptable water quality. The water treatment processes of flocculation, settlement and bio-reaction appear to operate in rainwater tanks to improve water quality. Chlorination and ultra violet disinfection has been shown to be ineffective in inactivating Cryptosporidium oocysts. Giardia cysts are susceptible to inactivation with chlorine at extended contact times but are resistant to UV disinfection. Filtration may be the most appropriate barrier. It may be possible to use point-of-use or point-of-entry devices to remove protozoan cysts and oocysts from cistern waters. In order to improve the quality of roof runoff and enable its safe use for alternative drainage or closed water systems, research and development on the simple treatment methods, either biological or physiochemical and disinfection methods, are needed to be investigated in future for further propagation of RWH.

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