Rainwater Harvesting and Health Aspects-
Working on WHO guidance

Namrata Pathak[1] & Han Heijnen[2]

[1]Consultant, RWH & Health Aspects, India, pathaknamrata2000@yahoo.com
[2]Advisor,Environmental Health, WHO, Nepal, heijnenh@searo.who.int

Introduction

Rainwater harvesting is becoming increasingly popular as the availability of good quality water decreases. Rainwater harvesting is acknowledged as a sustainable source of water that has less impact on the environment. In 2004, 17% of households in Australia had rainwater as a source of water. In rural Western Australia 62% of the households owned rainwater tanks and 53% had rainwater as their main drinking source. (A*ustralian Bureau of Statistics, 2004*).

Rainwater is nowadays used as a source for numerous domestic applications like drinking, bathing, laundry, toilet flushing, hot water supply and for gardening purposes. Around the world rainwater has been used since time immemorial to augment the supply of water or even form the main store, depending on the situation:

a) Dry Areas

Rainwater has traditionally been a security in areas where water has been scarce. In our region, Rajasthan, Gujarat, various areas in Pakistan, India and Sri Lanka are located in dry zone areas with 500-600 mm of rainfall or less a year. People have survived by collecting rainwater and accommodating their agricultural patterns and crops to suit the available rain and reduce evaporation.
In Rajasthan, *kundis,* are unique structures which look like huge concrete saucers on the landscape. These are used for collecting rainwater to meet the needs of the local people and animals. Similarly, in the karstic central areas of Jamaica cemented catchment areas were constructed to collect the rain and lead it into community tanks.

b) Bad Taste

Islands or coastal areas may have plenty of water, but most of it will be saline and not tasty to drink. Rainwater collection can provide water for drinking and making a decent cup of tea. In hard water areas or where water contains a lot of iron, people may also be more inclined to use rainwater for drinking and cooking purposes.

c) Better Service

Hilly wet zone areas in Sri Lanka and Uganda have offered interesting prospects for the application of rainwater collection. As population pressures increase, people are forced to move uphill into areas that remained uninhabited before. Water points will be available only

below the level where people live and daily drudgery in collecting water is the consequence. In Sri Lanka this does not have to be the case as 2 monsoons provide for an excellent rainwater collection regime, even with small roof surface or storage.
Use rainwater!

NGO Forum, Nepal

In the last few years increased attention has been given to augmentation of urban water supply through collection of rainwater. In New Zealand and Australia long-term experience has been gained with urban water supply, also for drinking water. In Europe, notably in Germany, run-off management needs and recycling interests have seen a proliferation of retrofitting solutions for rainwater collection and associated water quality management for domestic purposes. The experiences and technological developments of these countries can be used to advantage when promoting urban rainwater harvesting in India (CSE, and many local institutes) or Nepal (NGO Forum for Urban Water & Sanitation).

d) Subsititution

Recently the potential of rainwater for substitution of chemically contaminated water has come to the fore. In Bangladesh where ground water in many areas has been found to be contaminated with tasteless, odorless and colorless toxic arsenic, rainwater for drinking and cooking can very well act as a safe substitute for the consumption of contaminated groundwater. The potential for substitution of arsenic contaminated water in Southern Nepal is being explored as well.

Quality of Rainwater

The quality of the rainwater can vary depending on the atmospheric pollution, harvesting method and storage. While the quality of collected rainwater may vary, on the whole, harvested quality is found to be equal to that of the regular treated water supplied through the public mains. Heyworth (*2001*) showed that under-fives in rainwater supplied, rural households were at no greater risk to diarrhea than those who drank the treated piped water of Adelaide.

Rainwater catchment systems are open to environmental hazards because of the nature of the catchment area. There are several ways contaminants can enter the rainwater system and compromise the water quality. For instance, chemical contaminants may dissolve during precipitation and leach due to characteristics of the rainwater system components while microbial risks can be introduced through bird droppings, or poor collection and storage design.

It is very important that users understand the potential hazards and risks of neglect in rainwater harvesting. Local health authorities often have developed suitable guidance. Nowadays simple maintenance schedules based on water safety plan approaches are being developed to assist householders and institutional users to get a good water quality, consistently.

WHO is currently engaged in developing guidance that will eventually be reflected in and be part of the 3d edition of the WHO Guidelines for Drinking Water Quality. It is expected that in addition to appropriate entries in the summary document of the Guidelines, a stand alone document will be published that will address the microbial and chemical quality concerns, a protocol on testing water quality and guidance on water safety plans for rain water collection systems. In the following sections an initial description is provided of these elements.

Rainwater System Components

Roof

The type and condition of the roofing material is known to affect the water quality. Paint coatings on the roofing tiles may oxidise through weathering. When degrading these coatings can be washed into the rainwater tank. Depending on the material used, this will not be a problem if it is left to settle down to the bottom of the tank. Tiles with colour impregnated into them will not encounter this problem *(Urban Rainwater Systems Pty Ltd 2004)*.
Roofs painted with lead based paints and lead and copper piping for conveying water to or from, storage tank may however result in unacceptable concentration of heavy metals in rainwater supply.

If asbestos/fibro-cement roofing is used, it should be left undisturbed. Working with asbestos is hazardous to health because of inhalation of fibres. In most countries, the use of asbestos as a roofing material is discouraged. The risk posed by long-term consumption of drinking water contaminated with asbestos has been studied extensively. The evidence indicates that water collected from asbestos roofs unlikely to be associated with longer-term health effects.
Chimneys which are present on the roof were found to emit hydrocarbons, such as phenanthrene (*Kennedy et al.2001*) which may affect health.

Tank Materials

The water storage system can also impact the quality of water. When cement and ferrocement tanks are new they can increase the alkalinity of the stored water, and also the calcium content. Water from concrete tanks tends to have a lower pH due to the release of excess lime. While low pH does not pose a threat to health, the slight acidity may increase the rate of dissolution of metal tanks, pipes and fittings.
Depending on the tank material, the water is affected differently. New tanks tend to have a problem with odour and taste due to the leaching of excess tank material *(Urban Rainwater Systems Pty Ltd 2004).* Flushing the tank before use can reduce the bad taste and odour.

Underground Tanks

One of the routes of contamination is through ground run-off. This is particularly significant for underground water tanks, when agricultural and environmental effluents that contains *Cryptosporidium*, *Giardia*, *Campylobacter* and *Salmonella* spp. leaks into the tanks. If the tanks are not sealed properly, the contaminated run-off might enter and contaminate the tank (*Urban Rainwater Systems Pty Ltd 2004*). A study conducted in Jordan of 225 tanks had shown that *C. parvum* was only present in underground cisterns but not aboveground tanks. Two factors relating to the presence of *C.parvum* mentioned by Abo-Shehada et al. (*2004*) that were significant ($P<0.05$) were:

- Opening of cistern raised from floor level; and
- Presence of animals in the cistern surroundings.

However, Crabtree et al (*1996*) have shown that there were no significant difference in the rates of contamination of underground cisterns and aboveground cisterns. All the aboveground tanks sampled showed *Cryptosporidium* and/or *Giardia* contamination on at least one sampling time point.

First Flush, Inlet and Outflow Arrangements

In recent years attention has been given to improve the quality of the water collected and stored in the tank through appropriate inlet-filters, first flush.

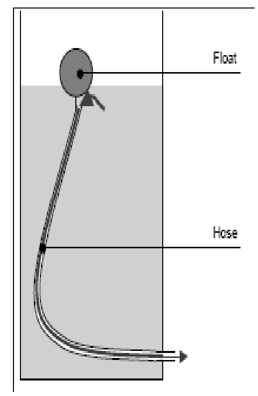

Fig 2. Outlet arrangement

University of Warwick (DTU) has published important and challenging papers on these developments. While it requires another paper to do justice to this work, it is worthwhile to mention that adequate first flush can reduce incoming contaminant load quite considerably. It seems though that the first flush arrangements are often undersized.

As water quality improves with storage, DTU also advocates that inlet arrangements should be such that incoming water should not disturb the settled material. Similarly, as the water at the bottom may be dirtier, it would be adviseable to have a outlet arrangement with a floating inlet, taking water from the upper part of the tank (*as in figure 2, Martinson, D.B. & Thomas, T, 2003*).

Further research is on going on the feasibility of these suggestions and how these could be incorporated in designs for low-income communities.

Microbiological Quality

Tank rainwater is usually harvested from a roof catchment area. This catchment area is open to the environment and can be accessed by birds, insects and animals. Faecal droppings from birds, lizards, rodents and cats, which can access the roof catchment, may contain pathogenic micro-organisms which are harmful to health when ingested.

> *The results of a pilot study in the Maldives (MWSA 2005) indicated that 45 percent of the samples tested positive for faecal coliforms. As cats in the Maldives are well known to use roofs as a resting place, it is very likely that they will defecate on these roofs. Forty percent of the households indicate evidence of faecal contamination on the roof. This is a very strong association with the 45 percent indicating positive for faecal coliforms. Despite these results, none of the households had any incidence of diarrhea within the past 3 months. Maybe, as Maldivians have been drinking rainwater*

for generations, people would have been exposed to contaminated drinking water and hence become immune to low doses.

In recent years, several cases of toxoplasmosis have been reported and are on the rise. It is assumed that the infection is transmitted by the consumption of water contaminated with cat droppings. As cats in the Maldives are well known to use roofs as a resting place, it is very likely that they will defecate on these roofs. 65 percent of the households said cats had access to the roof.

Microorganisms that are washed into the tank may be present in the water column, or the sediment if attached to particles that settle to the bottom of the tank. The sediment may be re-suspended when new water enters the tank, particularly after heavy rains and disturbs the equilibrium. Microorganisms found to be carried by birds and animal vectors include, *Cryptosporidium*, *Giardia*, *Campylobacter* and *Salmonella* spp. Each of these microorganisms is known to cause gastroenteritis.

There are several recent studies that have used thermotolerant coliforms and *E.coli* as indicator organisms to predict the presence of pathogenic organisms. These have shown that either there was no correlation between thermotolerant coliforms and the presence of pathogens or there were no pathogens present when thermotolerant coliforms were detected. On the other hand, the absence of thermotolerant coliforms does not indicate the absence of *Cryptosporidium* and *Giardia* spp. (*Crabtree et al*, *1996*). If water treatment is undertaken, thermotolerant coliforms could be destroyed but high resistant organisms like *Cryptosporidium* and *Giardia* spp. can survive (*Gadgil 1998*).

The presence of thermotolerant coliforms and *E.coli* suggests faecal contamination which is most likely to be from vectors that have access to the roof and rainwater tank.

The aim of a recent study by Henry Tan et al (*2005*) was to identify the presence of pathogenic species of *Cryptosporidium*, *Giardia*, *Campylobacter* and *Salmonella* in private rainwater supplies in a rural community in Western Australia. In conclusion, this study found no pathogenic species of *Cryptosporidium*, *Giardia*, *Campylobacter* and *Salmonella* spp. in the 10 tanks sampled at Mount Barker in the late winter, early spring period. However, the tanks sampled in this study were a good representation of the tanks that were in Mount Barker and its health risk associated with its usage during winter-spring months. This adds to the evidence supporting that rainwater is a potential alternate source of drinking water.

There are few reported outbreak investigations that have linked illness to tank rainwater consumption. This maybe because the rainwater systems usually supplies only a few persons in a household, therefore sporadic cases of illness will be more likely to result rather than an outbreak. However, outbreaks have occurred. Not all the outbreak investigations have confirmed that the tank rainwater is positive for the microorganism of interest. Only Taylor et al *(2000*) confirmed that one of the two tanks that supplied the water was contaminated with *S.* Saintpaul, which was the cause of the outbreak.

Air-borne Micro-organisms

Previous literature reports on roof water quality have given little consideration to the relative significance of airborne micro-organisms. Evans et al (*2006*) analysed direct roof run-off at an urban housing development in Newcastle, on the east coast of Australia. Results indicated that airborne micro-organisms represented a significant contribution to the bacterial load of roof water at this site, and that the overall contaminant load was influenced by wind velocities, while the profile (composition) of the load varied with wind direction.

Chemical Contaminants

While rainwater is considered pure, there are a large number of atmospheric pollutants such as sulphur dioxide, nitrogen oxides and hydrocarbons, which together are the principal causes of anthropogenic acid rain. Apart from causing acid rain, this water can be unsafe to drink, especially in areas of heavy pollution such as industrialized urban areas. Numerous man-made atmospheric pollutants exist, of which the most prevalent and damaging to rainwater quality are sulphur dioxide, nitrogen dioxide and various hydrocarbons.

Although most serious contaminants are normally limited to urban and industrial locations, pollutants can be transported over great distances before being washed out in the rain. Nonetheless precipitation is known to wash away pollutants from the air thereby improving water quality (*Gould-Petersen, 1999*).

The potential chemical contaminants include pesticides through agricultural spray drift, aromatic hydrocarbons through wood smoke emissions and deposits from urban and industrial emissions.
Coombes P.J., Kuczera et al (*2000*) monitored water quality (physico-chemical and microbial) over a 2 year period and assessed compliance with Australian Drinking Water Quality guidelines. Even under the “worst case” scenario at Figtree Place and apparently high traffic density, the physico-chemical water quality of water from tanks was generally good!

One of the dominant processes in the rainwater treatment train appears to be flocculation of organic, metallic and chemical parameters at the tank water surface with subsequent settlement of flocs to the sludge at the bottom of the tank or attachment to the walls of the tank. These flocs form biofilms at the interface between tank surfaces and stored rainwater potentially improving the quality of stored rainwater by removing contaminants. Elemental analysis using high resolution ICP-MS revealed accumulation of metals including lead, zinc, copper, manganese, chromium, mercury and arsenic in the biofilms in all tanks. Significant concentrations of metals were not found in the tank water indicating that the action of biofilms may be removing metals from the tank water. (*Coombes P.J et al, 2005*).

Aesthetic Quality: tastes and odors

It is important that the water is acceptable to the consumer in terms of its colour, turbidity and taste. As rainwater do not contain any minerals and also doesn’t carry any taste it is not yet well accepted widely in Rural Sri Lanka as means of drinking water (Ariyananda, 2001).

An area that could be of some adverse health concern would be the low mineral contents of the water. This however would be relevant only for those people and communities dependent exclusively on rainwater for fulfilling their drinking water needs (*Gould-Petersen, 1999)*

There is a range of factors/or conditions that can cause deterioration of water during collection, storage and piping. The principal sources of taste and odour (other than dead animals) are:

- Sediments and slimes at the bottom of tanks or in pipework that can hold stagnant water
- Soil and decaying vegetation allowed to accumulate in guttering
- Algal growth in pipework or open tanks
- Pollen

Vector Breeding

Apart from the chemical and microbiological problems there is also a concern of vector breeding in the cisterns used for storing the harvested rainwater. The major vector issue is that of mosquito breeding, although rats, lizards and some other small animals do sometimes enter the water Vasudevan et al, (*Report C4*) While in some areas the breeding of mosquitoes may only be a public nuisance, in the tropics they can be vectors of diseases like malaria, filariasis, dengue and yellow fever (*Gould-Petersen, 1999).* The case of the link with dengue was confirmed in Bangladesh where it was found that a rural coastal community that had been using uncovered traditional earthen pots for rainwater storage since 1989 , was found to be severely affected during the 2002 national dengue outbreak. As this was the first time that the health authorities did a national survey on dengue cases, it is likely that this community will have suffered earlier as well (*Heijnen, pers. comm*)

Biofilms and Heavy Metals

Biofilms are formed when microorganisms bind together with sticky polysaccharide fibres to maximize their ability to extract nutrients and accumulate microbes from surrounding water bodies. Coliforms and *Pseudomonas Spp*. bacteria are commonly found in biofilms.

Biofilms have been shown to increase the adsorption of heavy metals, nitrogen and phosphorus. Their resistance to such toxic metals, organic toxins, and chlorine, have meant that these substances which are toxic to humans can be actively removed from water.

Spinks et al. (2003) discuss some of the microbiological and elemental contaminants in water, their pathways into domestic rainwater catchment system, and focuses on the roles of roof processes, biofilms, sedimentation, pumps, and hotwater systems as potential water treatment mechanisms for improving tank water quality. Biofilms are deemed to actively remove heavy metals and organics from the water column in the tank, while sedimentation and surface flocculation also remove contaminants from the available water supply.

Testing Rain Water for microbial contamination

If water quality testing is possible, the main focus should be on microbiological testing using tests such as thermotolerant coliform count (also known as faecal coliform count), Escherichia coli (E. coli) count, or the simple H2S test. World Health Organization guidelines (*WHO 2004*) state that indicators of faecal pollution, E. coli or thermotolerant coliforms should not be detectable per 100 ml of sample. However, Fujioka (*1994*) stated that a more realistic standard may be 10 thermotolerant coliforms/100ml where a sanitary survey determines that the rainwater tank is unlikely to have contamination from human faecal wastes.

The H2S test has been shown to correlate well with thermotolerant coliform levels in rainwater tanks (*Faisst & Fujioka 1994*). The results of most comparative studies suggest that the H2S test detects faecally-contaminated water with about the same frequency and magnitude as traditional test methods such as Most Probable Number (MPN) and membrane-filtration methods (*Sobsey & Pfaender 2002).*

In providing this guideline, WHO is cognizant of the very large difference between the reality in the rural developing world and the guidelines. WHO adds that in the great majority of rural water supplies in the developing countries, fecal contamination is wide spread. Under these conditions, the national surveillance agency should set medium-term targets for the progressive improvement of water supplies, as recommended in WHO’s 3d edition of *Guidelines for Drinking Water Quality* (*WHO, 2004*).

Bacteriological quality of water continues to be a matter of serious concern. There is a need for water quality monitoring and surveillance on such a larger scale that only a simple, inexpensive and reliable test can monitor and assure water quality in rural areas. This need is especially great for small community and household water supplies that lack access to and cannot afford conventional bacteriological testing occasionally done by a more complicated test or series of tests of drinking water. On-site testing using portable equipment and use of simplified tests such as the use of the H2S Strip Test had the potential of meeting this need.

Water Safety Plans

Water safety plans (WSPs) are an effective means of ensuring water safety is controlled within water supplies. This is achieved through undertaking a systematic and detailed assessment and prioritisation of hazards and hazardous events.

The basic concept within a WSP is that the focus should be on the operational processes and actions that are undertaken to ensure safe drinking water is provided rather than testing the water that is delivered. This does not mean that water quality testing is not important - it is a fundamental component of the WSP in verification.

The advantage of this approach is clear. Where action can be taken to restore deterioration operational performance to the required level to ensure water safety remains controlled before contamination has occurred, unsafe water should not be delivered by the system. By contrast, if action is only taken once contamination has been detected the water delivered is likely to be already consumed and the users exposed to health risks.

Figure 3, IEC material supportive to the Water Safety Plan (Bangladesh)

Water safety plans have been developed in recent years for all kind of water supply technologies and systems. The first edition of the model water safety plan for Rain Water Harvesting Systems was prepared in December 2004 for use in Bangladesh. The experience of the pilots has been captured and documented in March 2006. Based on the experience and lessons gained from the pilots projects the first edition has been revised. (*Copies are available for download at the http://www.apsu-bd.org/ website*)

Epidemiological Evidence/Outbreaks

There have been few reports of illness associated with the use of rainwater. This may well be because in many instances illness may not be associated with consumption of rainwater. In small island communities rainwater is often an important, if not the only, source of drinking water. Analysis of public health data of such communities may inform about public health risks of rainwater. There is a need to link water quality and public health data to better understand risks, if any. This is not easy as demonstrated by a study in the Virgin Islands where *Cryptosporidium* and *Giardia* was detected in a large number of rainwater cisterns, but were the public health significance of this occurrence was not established. (*Crabtree et al., 1996*).

Epidemiological studies on rainwater systems are relatively uncommon because outbreaks tend to involve few individuals, and illness is often isolated at individual catchment systems.

Conclusion

Analysis of literature data available on the physico-chemical quality of water stored in DRWH systems, indicated that generally, the physico-chemical quality of water in terms of colour, odour and taste, pH, total dissolved solids (TDS) and total hardness (TH), meet the prescribed standards. Occasionally pH has been reported to be low (acidic) or high (alkaline).Toxic metal ions and toxic chemicals are reported only in some cases and may arise from material used for the roof , atmospheric pollutants adsorbed on dust , industrial & urban traffic emissions and pesticides-agricultural pollution etc.

The information indicates that the quality of most cistern waters cannot meet national microbial standards, and consumption of untreated rainwater could therefore be a risk to human health. However, detection of E.Coli in the stored rainwater does not always mean that disease-causing bacteria are present. Epidemiological studies on these type of water sources are relatively uncommon because outbreaks tend to involve small individuals, and illness is often isolated to individual catchment systems.

Simmons G. and Heyworth J, (*2003*) have also provided a schematic model for considering health impacts of rainwater with microbial contamination .The issues that need to be addressed in a microbial risk assessment (MRA) include: the numbers of pathogens in tank rainwater, their ability to survive and multiply, the extent of individual exposure and the measure of health outcomes. The MRA framework enables a systematic estimation of health risk as a consequence of potable tank rainwater contamination and has important implications for the setting of microbial standards for potable rainwater.

At the present time, the most practical approach to the problem of improving and maintaining the quality of water delivered in water supply schemes (including RWH) is not to impose a set standard, but rather to insist on adequate measures of sanitary protection, systematic monitoring and treatment. The water safety plans methodology described in the 3d edition of the WHO Guidelines for Drinking Water Quality, offers a good approach to be incorporated in good practice at the household level. WSPs also offer Health Inspectors a higher level of confidence with respect to the quality of the water delivered. In combination with the occasional use of H2S bottles/strips, a good confidence level on the quality of the rainwater stored can be achieved.

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