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Review Article

RAINWATER HARVESTING FOR HUMAN CONSUMPTION – A REVIEW OF THE PUBLIC HEALTH IMPLICATIONS AND PERSPECTIVES

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ABSTRACT

Rainwater is relatively free from impurities (except those picked up by rain from the atmosphere), but the quality of rainwater may deteriorate during harvesting, storage and household use and often does not meet World Health Organization (WHO) guideline standards for drinking water particularly the microbiological quality. Dirt aided by wind, leaves, faecal droppings from flying and landing birds and insects, animals and contaminated litter, brought to the catchment areas also accumulates to form sources of contamination of rainwater. Poor hygiene in storing and in abstracting water from tanks or at the point of use can also pose a health concern. More so, the microbial contamination of collected rainwater indicated by Escherichia coli is quite common in samples collected shortly after rainfall. Pathogens such as Cryptosporidium, Giardia, Campylobacter, Vibrio, Salmonella, Shigella and Pseudomonas have also been detected in rainwater. Also, rainwater is slightly acidic and very low in dissolved minerals, such as calcium, magnesium, iron and fluoride considered essential in appropriate concentrations for health and this means that rainwater has a specific taste that may not be acceptable to people used to drinking other mineral-rich natural waters. It can dissolve heavy metals and other impurities from materials of the catchment and storage tank. This paper reviews some of these occasional rainwater related diseases previously detected and other potential health risks and recommends possible ways of managing and maintaining standards of rainwater quality from collection, storage and final consumption.

1. INTRODUCTION

Rainwater harvesting is a technology used to collect, transport and store rainwater for later use from fairly clean surfaces such as a roof, land surface or rock catchment (DeBusk and Hunt, 2014). The water is generally stored in a rainwater tank or directed to recharge groundwater as the case may be (Mbugua, 2002; Abdulla and Al-Shareef, 2009; Helmreich and Horn, 2009). Rainwater harvesting has been practiced for over 4,000 years throughout the world, traditionally in arid and semi-arid areas, and has provided drinking water, domestic water and water for livestock and small irrigation (Falkenmark *et al.,* 2001; Khoury-Nolde, 2016). Today, rainwater harvesting has gained much significance as a modern, water-saving technology.

People have consumed rainwater kept temporarily in natural surface depressions, artificial reservoirs and household containers since ancient times (Gould, 1999; Tobin *et al.,* 2013; Chidamba, 2015; Gould, 2015). In almost all regions and traditional cultures, rainwater is collectively recognized as a pure and clean source of water (Gould, 1999; Gould, 2015; Zhu *et al.,* 2015). In recent decades, however, there has been a growing concern regarding the quality of small-scale drinking water supplies around the world. Since rainwater is increasingly been used for potable purposes mainly by individual households, or small scattered rural communities especially in developing countries, the issue of the safety of rainwater supplies has until recently been largely overlooked (Gould, 1999; Gould, 2015; Zhu *et al.,* 2015; Belay *et al.,* 2016).

There is no simple answer to the question "Is rainwater safe to drink”? No water supply is 100 % safe all the time and the issue is really one of what is a tolerable level of risk based on cultural and socio-economic standards and the quality of other water supply (Gould, 2015). The level of risk associated with drinking rainwater is a product of the concentration of pathogens/toxins present, the level of exposure and impact of the infective agent/toxin, and the vulnerability of the individual or population exposed (Medema *et al.,* 2006; WHO, 2011). Local situations and in particular environmental factors are also precarious, such as the amount of atmospheric pollution, the type of construction materials and the maintenance practices applied to the rainwater catchment system (Thomas and Costa, 2017). In rural areas where atmospheric pollution is not generally a problem, several simple steps to reduce contamination of rainwater supplies can be taken and, in most cases, require little or no extra cost (Kibert, 2016).

In situations where atmospheric pollution is not considered a problem, it is possible to safeguard the quality of water in roof catchment tanks. For ground catchment systems, serious contamination by the catchment surface is common and use of any water collected is not suggested for drinking unless first treated (Mosley, 2005; Stewart *et al.,* 2016). The water is, however, suitable for most non-consumptive purposes without treatment e.g. irrigation (Clemmens *et al.,* 2008).

1.1. Sources of Rainwater Contamination

In most industrialized urban areas of the world, the air has often been polluted to such a degree that the rainwater itself is considered dangerous to drink (Mohammed *et al.,* 2007; Rydin *et al.,* 2012). In the United States for instance, the drinking water within 48 km of urban centres is not allowed to be used, except if there are no other source accessible (Cairncross and Valdmanis, 2004; Padowski and Jawitz, 2012; Rothwell *et al.,* 2015). Heavy metals such as lead are potential hazards principally in areas of high traffic density or in the neighbourhood of dense industrial locations (Khanna, 2011; Karrari *et al.,* 2012; Mahmood and Malik, 2014; Staszewski *et al.,* 2015). Emerging organic chemical contaminants such as organochlorines and organophosphates used in biocides also find their way into rainwater. It has been reported that atmospheric contamination of rainwater is usually restricted to urban and industrial settings (WHO, 2003; Vergucht *et al.,* 2006; Zacharia, 2011). Studies in the north-eastern United States revealing the presence of pesticides and herbicides in rainwater lend credence to this and is a cause for concern (Mollah and MacGregor, 2002; Entine, 2011; Milwain, 2014). Regardless of the abundant sources of atmospheric pollution, in most parts of the world, especially in rural and island locations, levels of contamination of rainfall are still very low. Most contamination of rainwater follows after contact with the catchment surfaces (roof or ground) and during succeeding delivery and storage (Lye, 1992; Chukwuma *et al.,* 2012).

1.1.1. Microbial contamination

The quality of rainwater used for domestic supply is of particular importance because in most cases, it is used for drinking without any form of treatment (Li *et al.,* 2010; Freitas *et al.,* 2011). The issue of water quality is a complex and sometimes controversial one. Several studies have shown that rainwater supplies frequently do not meet WHO and other national drinking water standards particularly with respect to bacteriological water quality (WHO, 2008; WHO, 2011). But this does not mean that the water is dangerous to drink, it only requires extra examinations that is directed towards determining both the sources and effects of any contamination and arrived at a less strict bacteriological water quality standards for potable rainwater (Lye, 1992; Cabral, 2010; Nguendo-Yongsi, 2011; O'Hogain *et al.,* 2011; Zhu *et al.,* 2015). Drinking water quality guidelines more suitable for rural conditions in developing countries have been suggested and these guidelines paved way for water with mean *E. coli* counts of up to 10 per 100 ml to be recognised for drinking (Gwimbi, 2011; WHO, 2011). This not comparable to the WHO recommended limit of 0 per 100 ml (Tallon *et al.,* 2005; de la Santé, 2008; Snozzi, *et al.,* 2013). When the quality of stored rainwater samples is assessed based on a more realistic criterion, the number of rainwater supplies with water thought to be within acceptable limits for drinking is significantly increased (Gould, 1999; Michael, 2006). A direct source of evidence implicating a rainwater supply as a potential health risk comes from identifying the presence of specific pathogens. There are many references to pathogens including *Salmonella, Pseudomonas* spp., *Ecoli, Aeromonas, Vibrio parahaemolyticus, Enterococci, Cryptosporidium, Giardia* having been identified in rainwater samples (Chidamba, 2015). Studies establishing the linkages between rainwater consumption and illness are shown in Table 1.

Proving direct causation between microbial contamination and health is, however, more challenging especially when contamination levels are low. The insufficiency of studies mentioning proven relations between disease outbreaks and rainwater sources is perhaps not unexpected given this difficulty and the fact that many individual cases are not documented or result in no additional investigation for record purposes and this might be not unconnected with the fact that most rainwater supplies are used by single families thus decreasing the chances of large numbers of people being affected in any single eruption at a particular time (Gould, 1999; Dobrowsky *et al.,* 2014; Zakaria, 2014; Hamilton *et al.,* 2018).

One of the best reported outbreak of gastrointestinal illness including diarrhoea, headaches, fever and vomiting was amongst 63 individuals from a group of 83, mainly children between the ages of 5 and 19 years, who attended a rural camp in Trinidad, West Indies (Pinfold *et al.,* 1993; Gould, 1999; Evans *et al.,* 2008). The likely cause for the outbreak was assumed to be *Salmonella arechevalata* enclosed in animal or bird excrement on the camp roof and washed into the rainwater tank, from which water was used for drinking (Franklin *et al.,* 2009; Ahmed *et al.,* 2011; Sharma *et al.,* 2015).

1.1.2 Chemical contamination

Several studies, investigating the chemical constituents of stored rainwater, have found that these commonly meet WHO drinking water quality standards for a wide range of parameters (Sayre, 1988; DeBusk and Hunt, 2014; Stewart *et al.,* 2016; Chubaka *et al.,* 2018). In a few cases, slightly higher levels of magnesium and zinc above WHO guideline standards for drinking water have been noticed but these do not pose any serious health concern (Kožíšek, 2003). Higher levels of lead are the most common cause for concern. A recent pilot study of 25 potable household rainwater supplies around Auckland in New Zealand found lead exceeding national drinking water standards in 12 % of the tanks surveyed (Rodrigo *et al.,* 2009). Lead levels beyond 3.5 times WHO drinking water standards have also been noted in Selangor, Malaysia (Lim *et al.,* 2013).

Table 1: Microbiological data from numerous studies on rooftop runoff (DeBusk and Hunt, 2014)

References	Study Location	Site Description	Data
Evans et al. (2006)	Australia	Figtree place development; 11 rain events sampled; Colourbond roof and gutter system	**Mean microbial counts for all samples CFU/mL):** Heterotrophs: 1,362 ± 194 *Pseudomonas* spp.: 593 ± 132 Total coliforms: < 4 ± 0.76 Fecal coliforms: < 2 ± 0.42
Evans et al. (2007)	Australia	Roof swab	Plate count: 102 CFU/mL Percent of plate count gram +ve: 13% Number of difference gram +ve species: 2 Percent of plate count gram -ve: 0% Number of difference gram +ve species: 0 Percent of plate count that is fungi: 87% Percent of plate count that is fecal coliforms: 0% Number of different FC species: 9
Lee et al. (2012)	Roof runoff, wooden shingle (WS), concrete tile (CT), clay tile (CL), galvanized steel (GS)	Roof runoff; wooden shingle (WS), concrete tile (CT), clay tile (CL), galvanized steel (GS)	**Total coliform counts (CFU/100 mL)** WS CT CL GS First flush 131 197 76 70 After first flush 12 12 2 <1 ***E-coli* (CFU/100 mL)** First flush 14 18 8 4 After first flush 1 2 <1 0 ***Enterococci* (CFU/100 mL)** First flush 1 2 <1 <1 After first flush 0 0 0 0 Percent positive: ***Pseudomonas* spp.** First flush 12.5% 7.5% 2% 0% ***Salmonella* spp.** First flush 5% 5% 0% 0% ***Cryptosporidium*** First flush 0% 0% 0% 0%
Mendez et al. (2011)	3 pilot-scale roofs, 4 storm events; 3 residential roofs, 3 storm events	3 pilot-scale roofs, 4 storm events; 3 residential roofs, 3 storm events	-------------Metal---------- -----------Shingle---------- Pilot-scale Full-scale Pilot-scale Full-scale TC 117-770 64-173 177-1,367 102-353 FC <1-8 37-127 9-87 73-253 Values reported in CFU/100mL

Potentially, the hostile health implications of the long term consumption of rainwater containing elevated levels of heavy metals such as lead pose a serious health threat. Lead is a cumulative poison which can cause serious damage to the central nervous system and infants and foetuses are particularly susceptible (Ramlogan, 1997; Njagi, 2013). There exist numerous potential sources of lead contamination for roof catchment systems. These include the use of lead flashing, lead headed nails, lead based paints/primers for roof construction and the deposition of lead particles on the catchment surface in regions prone to heavy industrial or traffic pollution for example countries still using leaded petrol (Uba and Aghogho, 2000; Jacobs *et al.,* 2002; Kennedy and Pennington, 2008; Magyar *et al.,* 2014).

The poor maintenance of the catchment systems brings about the build-up of leaf litter in the tank and can make stored water to become more acidic. When the pH is low rainwater turns out to be more hostile and can leach out metals and other constituents from storage tanks, taps, fittings and sludge deposits on the tank floor (Thomas, 1998; Younos *et al.,* 1998). Studies conducted in Halifax, Nova Scotia also discovered high lead concentrations in runoff water collected from an old roof with substantial amounts of lead flashing from rainwater with pH4 (Magyar *et al.,* 2014).

Evidence of the potential health dangers of extreme lead levels in stored rainwater was also reported in a study in Port Pirie, an industrial port in South Australia and location of one of the world's largest smelters (Wilson *et al.,* 1986; Gould, 1999; Chubaka *et al.,* 2018). The study revealed a correlation between blood lead levels in children under 7 and lead in tank waters, one source of which may have been highly leaded roof paint (Donovan, 1996; Gould, 1999). The effect of acidic (pH 3) water and presence of leaf litter in the tank was also shown to increase the rate of dissolution of lead from tank sludges by up to 50 times (Gould, 1999).

1.2. Rainwater Quality Standards

The quality of rainwater used for domestic supply is of vital significance because in most cases, it is used for drinking. Rainwater does not constantly meet drinking water standards especially with respect to bacteriological water quality (Pathak and Heijnen, 2004; Akharaiyi *et al.,* 2007). Conversely, just because water quality does not meet some arbitrary national or international standards, it does not directly imply that the water is unsafe for drinking (WHO, 2001; Khoury-Nolde, 2016). Compared with most insecure traditional water resources, drinking rainwater from well-maintained roof catchments is generally safe, even if it is unprocessed (Gould, 1999; Nichols, 2015). The official policy of the Australian Government towards the question “Is rainwater safe to drink?” is as follows: “Provided the rainwater is clear, has slight taste or smell and is from a well-maintained system, it is probably safe and not likely to cause any illness for most users”. For immuno-compromised persons, however, it is suggested that rainwater is sterilised through boiling before consumption (Bada *et al.,* 2012; Khoury-Nolde, 2016).

2. SAFEGUARDING AND IMPROVING RAINWATER QUALITY

A number of methods are normally applied to protect or increase rainwater quality and these include developing a suitable system design, wide-ranging operation and maintenance, the use of first flush strategies and treatment (Doyle, 2008; Garrison *et al.,* 2011; Hofman and Paalman, 2014). The first rain drains the dust, bird droppings, leaves, etc. which are found on the roof surface and to prevent these pollutants from entering the storage tank, the first rainwater containing the debris should be diverted or flushed (Forasté and Hirschman, 2010; Golay, 2011). Devices that automatically prevent the first 20 - 25 litres of runoff from being collected in the storage tank are suggested, with built-in screens that hold bigger debris such as leaves are fixed in the down-pipe or at the tank inlet (Khoury-Nolde, 2016). The same applies to the collection of rain runoff from a hard ground surface. In this case, simple gravel-sand filters can be installed at the entrance of the storage tank to filter the first rain (Uddin *et al.,* 2017).

In some occasions, treatment is mostly necessary as a corrective measure where contamination is suspected. First flush strategies can be effective in reducing levels of contamination if properly maintained. Good system design, operation and maintenance are generally the simplest and most effective means of protecting water quality (Nissen-Petersen, 1999; WHO, 2011).

2.1. Appropriate System Design

The most important initial step to protecting water quality is to guarantee good system design. Water quality will generally improve during storage so long as light and living organisms are omitted from the tank, and fresh inflows do not mix up any sediment (WHO, 1997; Medema *et al.,* 2003). The design should include a clean impermeable roof made from smooth, clean non-toxic material (Ding *et al.,* 2018). The catchment should be devoid of above over-hanging branches. Taps or draw-off pipes on tanks should be situated at least 5 cm above the tank floor (more if debris accumulation rates are high). The tank is always encouraged to slope towards the sump as this could greatly enhance tank cleaning as well as well-fitting access to the manhole (Shakya and Thanju, 2013). Wire or nylon mesh should cover all inlets to stop any insects, frogs, toads, snakes, small mammals or birds from entering the tank (Zhu *et al.,* 2015). The growth and development of algae should be discouraged through covering of the tank so as to eliminate all path through which light penetrate (Thomas, 1998; Abdulla and Al-Shareef, 2009; Li *et al.,* 2010). Finally, a coarse filter and/or foul flush device should be built-in to interrupt water before it enters the tank for eliminating leaves and other debris that may be transported along.

3. OPERATION AND MAINTENANCE

Proper operation and maintenance of rainwater systems helps to preserve water quality in a number of ways. Regular inspection and cleaning of the gutters and tanks reduce the likelihood of contamination. The removal of leaves and other organic matter from the gutters and tank also helps to prevent the stored rainwater from becoming too acidic and potentially dissolving metals from the tank, tap fittings and sludge deposits (Gould, 2015). Water should not, if possible, be consumed directly from the tank without treatment for the first few days following major rainfall (Gould, 2015).

3.1. First flush devices

The proper operation and maintenance of the foul flush and filter systems can considerably increase the quality of roof runoff, even though it is not an important aspect of supply of portable water (Mwami, 1999; Zhu *et al.,* 2015). When poorly operated and maintained, such systems may result in the loss of rainwater runoff, through excessive diversion or overspill and even the pollution of the supply. If any kind of first flush (foul flush) device is to be taken into consideration, it should be very simple, and should not entail regular attention concerning its operation and maintenance (Cunliffe, 2004; South Pacific Applied Geoscience Commission, 2005; Odevik and Nordström, 2010).

4. SIMPLE TREATMENT FOR RAINWATER

The logical treatment of stored rainwater should be adopted and that makes sense if it is done correctly and if hygienic collection and use of the water will guarantee it does not suffer from re-contamination (Igbinosa and Osemwengie, 2016). There are several types of simple treatment which are highly promising and the most common being: chlorination, boiling, filtration and exposure to ultra-violet or natural sunlight. Chlorination is most suitably used to treat rainwater if contamination is suspected due to the rainwater being coloured or if bad odour is experienced. It should only be done if the rainwater is the only source of supply and the tank should first be thoroughly inspected to try to determine the cause of any contamination (Gould, 2015; Zhu *et al.,* 2015). Boiling water thoroughly for at least 1 minute normally ensures it is free from harmful bacteria and pathogens (Lye, 1992; WHO, 2004; Helmreich and Horn, 2009). This method of treatment is readily used on a daily basis except for situations where emergency treatment is required. Filtration is commonly used both to prevent material from getting into the storage tank, during extraction of water from the tank or before consumption. If filters are well maintained, there is high tendency for it to improve water quality (Mosley, 2005; USEPA, 2013). Direct sunlight can also be used to kill many of the harmful bacteria in water by exposing it in clear glass or plastic bottles for some hours (Sobsey *et al.,* 2008; Okpara *et al.,* 2011). Although, practicable in some circumstances, the water must be clear, and operating under fine weather conditions and the water must be cooled overnight before consumption. A solar powered ultraviolet unit is able to process 1.5 litres of water per minute was developed and evaluated on rainwater cistern water in Hawaii and established to be 99.9% promising in removing indicator bacteria (Joklik, 1995; Wong, 2014).

5. CONCLUSIONS

A widely adopted practice of untreated roof runoff has been used for drinking purposes particularly in the developing nations where rainwater harvesting has been mostly practiced for many years with very few accounts of serious health problems. Though health risk is minimal, effort is still required to minimize rainwater contamination. Likened with most unprotected traditional water sources, drinking rainwater from well-maintained roof catchments usually represents a substantial improvement and even if it is untreated it is generally safe to drink. Rainwater collected from ground catchment systems is generally subject to high levels of microbial contamination and its consumption without treatment is not recommended, but rather be used in some instances for irrigation purposes. The most important measures to adopt in protecting the quality of water collected from any roof catchment system include; good system design and consistent system inspection and maintenance. First flush devices can also be used and, if these are well maintained and operated, can greatly improve the quality of the initial roof wash arriving the tank. Treatment should be used if rainwater contamination is doubted and no other potable water source is available. Maintenance is generally limited to annual cleaning of tank and regular inspection of the gutter and down pipes-maintenance typically consist of the removal of dirt, leaves and other accumulated materials. Such cleaning should take place annually before the start of major rainfall season.

6. RECOMMENDATIONS

Provided the rainwater is from properly maintained rooftop catchment systems and stored in good containers and good covers is generally suitable for drinking and frequently meets WHO guidelines for drinking water and coupled with the fact that, the only water source available to both the rich and poor of the same location to remain self-sufficient is rainwater. This gives the opportunity to arrive at the following recommendations:

1. Standard Codes of practice for rainwater harvesting and reuse should be developed and its application be encouraged in order to address various related public health concerns.
2. In practicing rainwater harvesting for water consumption, there's need to uphold the first flush procedure to drain the dust, bird droppings, leaves, etc. which are found on roof surfaces and install filter screens in the down-pipe or at the tank inlet that would help in retaining larger debris such as leaves.
3. Sanitary inspections should be a focus of operational monitoring. This should include checking the cleanliness of the catchment area and storage, the structural integrity of the system and the physical quality of rainwater (turbidity, colour and smell). The level of pH should be monitored frequently in case of new concrete, ferrocement or masonry storage tanks constructed.
4. Microbial quality of rainwater needs to be monitored as part of verification. Rainwater, like all water supplies, should be tested for *E. coli* or thermotolerant coliforms. The levels of lead, zinc or other heavy metals in rainwater should also be measured occasionally when it is in contact with metallic surfaces during collection or storage.
5. Management plans should document all procedures applied during normal operation as well as actions in the event of failures. In the case of rainwater harvesting, remedial actions will generally involve physical repair of faults and cleaning of catchment areas, filters or storage systems. Disinfection of rainwater should be practised when microbial contamination is detected or sanitary inspections indicate a likelihood of contamination. Disinfection with chlorine can make rainwater safe for drinking.
6. Independent surveillance is desirable for ensuring the quality, safety and acceptability of water supply based on rainwater. The principal focus of surveillance apart from verification of compliance should be geared more towards evaluation of hygienic practices in collection, storage and use of rainwater.

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8. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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