Quality Issues of Rainwater Harvesting-A Review of the Current State of Knowledge and Practice

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Abstract— Knowledge about quality of rainwater is crutial for safeguarding human health. This review investigated harvested rainwater quality and hazardous health risk associated with it. Rain water results to physicochemical contamination and microbial contamination as it passes through atmosphere, also due to weathering and washing of roof materials, storage, faecal contamination and conveyance utilities. Rainwater is relatively free from impurities but it picks up impurities from atmosphere, also the rainwater quality deteriorates during harvesting and collection. Wind-blown dirt, faecal droppings from animals and birds, leaves, insects, contaminated litter on the catchment area are the sources of contamination of rainwater, leading some of the health risks. Coliform and E. coli were detected when the harvested rainwater was not treated with ultraviolet (UV) light. Results have shown apparent variation in the quality of rainwater by using different collection alternatives. The study shows that without proper treatment harvested rainwater may not be suitable for direct drinking, but could be used for other domestic purposes, but for direct drinking purpose it should be treated or disinfected .There are very many treatment methods, in which this review considers Solar Disinfection for investigation of its suitability in treated rainwater for portable water standards.

Key words: Contamination, Microbiological, Leaching, Physicochemical, Rainwater Harvesting, Solar Disinfection

I. Introduction

In developing countries the urban areas are rapidly increasing, so the demand of fresh water is also increasing day by day. To meet the daily needs of urban areas, water must be brought from distant reservoirs as most of the aquifer and urban springs are polluted and overexploited due excessive construction and industrialization. The use of water is over-exploited because it is used in many areas like human supply, irrigation, in industries, cattle etc. Also a huge amount of wateris used in hydroelectricity generation, especially semi-arid regions are threatened by concurrent droughts, so it has been involved in water conflicts, thus relating to scarcity of drinking water.

In this context, any technology that uses locally available (in the urban areas where it is consumed) any amount of water with an acceptable quality of drinking water, is acceptable. Among those alternatives, water reclamation, water use and rainwater harvesting have gained special attention. So water harvesting, is only a valid resource available in rural areas with no water mains coverage, has been regarded as convenient option for urban and already developed areas.

Rainwater harvesting is a technology which is used for collecting and storing stormwater or rainwaterfrom rooftops,steep slopes, the land surfaces, road surfaces or rock catchments using simple techniques such as tanks, pots and cisterns also some more complex techniques like underground check dams. Now some commonly used systems are constructed of three basic principal components; that are: catchment area, collection device, and conveyance system.

There are many advantages of rainwater over ground water and surface water regarding some of its physicochemical parameters as water from rain is more pure as compared to others because rainwater has lower hardness and lower total suspended solids which makes it suitable for many purposes like domestic, gardening and also for cooling towers.It could be also used for irrigation purposes due to its low sodicity. It also helps in many non-potable uses such as toilet flushing , surface washing in buildings, car washing etc. where a large part of the water is demanded. With the help of well-designed rainwater harvesting systems, with properly covered cisterns and storage tanks and clean catchments, used with some of the simple treatment being supported by good hygienic practices which can offer water for many non-potable uses with low human health risk.

There are many commonly available treatments practices for rainwater harvesting which are: using settling tanks, disinfection being combined with reverse osmosis or membrane filtration, heat treatment, solar disinfection-SODIS also using slow sand filtration process followed by chlorination or disinfection. As we know that slow sand filter and SODIS have very high efficiency in microbial disinfection, but slow sand filter is time taking and costly as compared to sodis so in this review paper we will recommend use of sodis for treating harvested rainwater and for its quality improvement.

II. Detoriation in Quality of Rainwater

A. Contamination of rainwater due to atmospheric deposition in urban areas

Atmospheric deposition is transfer of some of the atmospheric pollutants (particulate matter, dust, heavy metals, polycyclicaromatic, dioxins, hydrocarbons, furans, nitrates, sulphates etc.) to aquatic and terrestrial ecosystem from the atmosphere. Some of these pollutants are present in urban environment, at different rates varying accordingly with the intensity of road traffic, industrial cluster's proximity and many others. Their toxic presence in the atmosphere of the cities and subsequently in the storm rainwater runoff that flows from the roofs can have agreat spatial variability as the diffusion of these pollutants belongs to a scale that exceeds any local analysis. It also dependson meteorological factors such as temperature, wind velocity, relative humidity, particle shape and size that defines the time of concentration and traveling time of the particles in the environment, and the average interval of time between rain events, as the settled particles area accumulated within those intervals thus polluting rainwater.

B. Contamination in rain water due to the wash-off of particles settled on the surface of catchment-

Considering the washout of atmospheric as an unavoidable phenomenon, the best quality rainwater available in urban areas is the one that is harvested after the first roof interception, thus minimizing the effect of rainout and the contact with settled particles. After the initial interception of rainwater, the pollution process of rainwater keeps going on as the particles settled on urban surfaces are carried out by the storm water runoff, together with other pollutants that can be found in urban areas like oil, organic

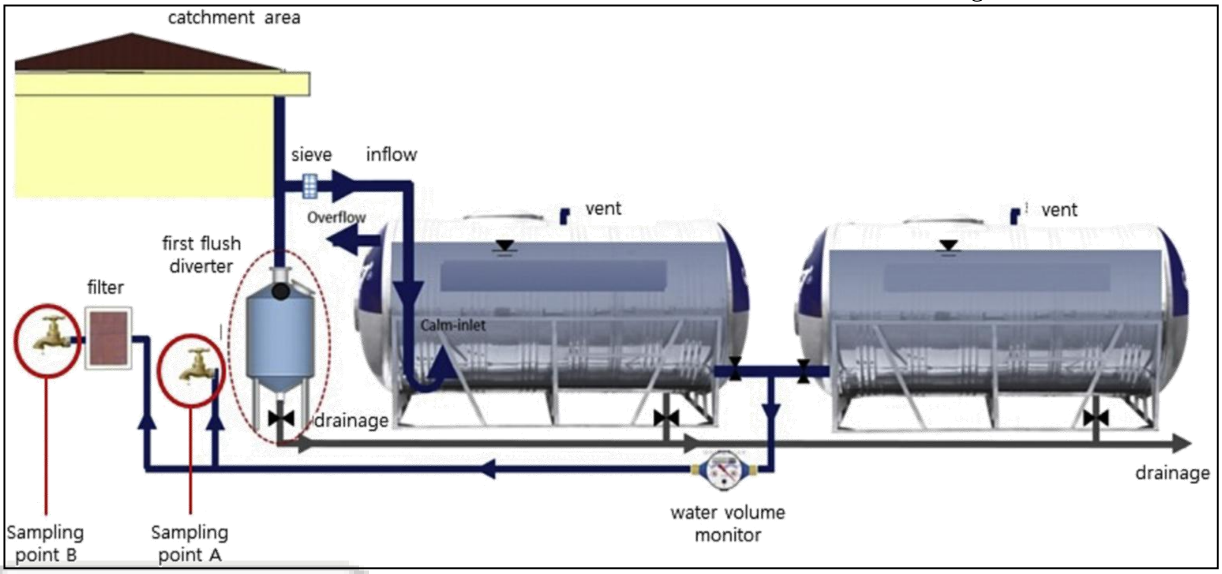

Fig 1. Description of rainwater harvesting system (RWHS)

Matter etc. that can drastically reduce the initial quality of rainwater. As the leaching or washing out of particles occur in early stages of a rain event, so if we discard the first-flush of roof runoff it becomes possible to increase the quality of the harvested rainwater. Another interesting result is that the amount of particulate matter on the roof surfaces is significantly high when there is less intense rainfall.

C. Bacteria and pathogens

Another type of contamination in the quality of rain water is due to airborne microorganisms and bacteria that are transferred to the harvested rainwater through atmospheric fallout of coarse particles such as dry deposition with the subsequent wash-off of the catchment's surface and through rainfall (wet deposition).Several microscopic organisms are found out either on the catchment surfaces or in the deposition layers associated to decomposing organic matter. Waterborne pathogens may also be present in roofs due to biological activity that is happening with depositions of windblown dirt, fecal droppings from animals and birds, insects and litter, mosses and lichens, fungus and also fallen vegetable material from the surroundings trees (leaves, seeds, flowers), even in clean metallic catchments leading to contamination.

III. MATERIALS AND METHODS

A rainwater harvesting system consists of —rainwater catchment area, storage tank and water distribution system or agriculture facilities. There are many alternatives for the rainwater collection depending upon the use of the harvested rainwater. Conventionally natural land slopes, soil roads and threshing floors were used as the rainwater catchments but they have very low efficiency in collection of rainwater. The new systems recommended are:

– By using cement paved courtyard and mortar roofs where the rainwater collection coefficient can be over 0.9, and thus rainwater is directed into a drinking water cistern by gravity flow.
– By using compacted land surface and hilly slopes covered with plastic film, the collected rainwater flows into cisterns through the help of ditches. The harvested water is stored mostly for irrigation, and occasionally for drinking as it has some contamination.

Quality of rainwater is further improved by discarding the first flush of rainwater by not letting it enter the storage tank as it contains atmospheric pollutants. Also there are a wide range of materials available like aluminum, galvanized steel, copper, polyethylene , plastic polyvinyl chloride etc. which are provided on the catchment surface but these components can suppose an additional source of chemical contaminants, as well as a source of additional bacteriological load if they not proper cleaned. We can calculate the contamination by measuring metal concentration in rainwater in both the catchment's runoff i.e. before the storage stage and the rainwater which is served in the household taps after the storage stage. Thus denoting that piping and tap materials contribute significantly to contaminant loads of harvested rainwater.

After all these methods like collection and storage, the next challenge is to improve the quality of stored water for safe drinking purposes we need a method from which we can improve the quality in all aspects. SODIS is a method in which we use UV rays for microbial treatment and also this method id economical and its efficiency is upto 98-99% and makes the safest for drinking purpose.SODIS is simple to use and inexpensive, the method has spread throughout the developing world and is in daily use in more than 50 countries in Asia, Latin America, and Africa. More than 5 million people disinfect their drinking water with the solar disinfection(SODIS) technique.

IV. SODIS TECHNOLOGY

Solar water disinfection(SODIS) is a type of portable water purification that uses solar energy to make biologically-contaminated (e.g. bacteria, viruses, protozoa and worms) water safe to drink. Polyethylene-terephthalate (PET) bottles,are subjected to UV rays. For best results the bottlesshould be PET bottles because it does not break and also bottles should be transparent and colourless. If the water is very turbid, the effectiveness of method is reduced. It is very easy to determine whether the water is sufficiently clear. Cloudiness affects the strength of solar radiation and thus also the effectiveness of the method. The bottles were exposed to the sun horizontally on a raised platform for a minimum of 6 hours if the day was bright and for two days if cloudy.The method does not work satisfactorily during lengthy periods of rain, on these days we recommend collecting rainwater. The treated water should be kept in the bottles and drunk directly from the bottle, or poured in to a glass immediately before it is drunk thus avoiding recontamination of water.

A. Solar radiation and cellular damage

The solar irradiance incident on the outer Earth atmosphere is approximately 1360 W m−2 – this value varies with position within the elliptical sidereal orbit of the Earth as it orbits the Sun. Water vapour, CO2, ozone and oxygen, in addition to pollutants in the atmosphere, scatter and absorb various portions of this such that for a typical cloudless atmosphere in summer at the equator, the received irradiance on a horizontal surface at ground level on the equator is reduced to roughly 1120 W m−2.

Fig. 2. SODIS enhanced batch reactor of 25 L containing water of 0 and 100 NTU

Thus we have 1.12 kJ m−2 of optical energy available in each second to in activate whatever microbial pathogens are present in water exposed to sunlight.This value reduces in a cosine fashion as latitude increases away from the equator. The wavelength ranges of UV are: 400–315 nm for UV-A;315–280 nm for UV-B; and 280–100 nm for UV-C. When DNA is irradiated with UV light, some of that light is absorbed by the pyrimidine rings of thymine and cytosine bases in the DNA. This energy can lead to the formation of new bonds between adjacent pyrimidine bases, forming pyrimidine dimers (pairs connected by covalent bonds) [23]. These dimers include cyclobutanepyrimidinedimers (CPDs) and 6–4 photoproducts, of which the latter can further photoisomerize to form Dewar isomers. Pyrimidinedimers are problematic for several reasons. They prevent base pairing with the complementary purines on the other strand of DNA, which changes the shape of the DNA molecule in the area of the dimer. This in turn, makes it difficult for polymerase enzymescopying the DNA to move through the region of the dimer. In addition, since the dimer is not making base pairs, the polymerase doesnot know what nucleotide to add to the new DNA strand when it encounters the dimer. In some cases, the polymerase skips over thedimer, resulting in the deletion of two bases from the DNA strand. Sometimes the polymerase “guesses” what base belongs in that position, and incorporates something at random

B. Water borne microbes which are known to be removed by SODIS:

MICROBES	SPECIES
Bacteria	Campylobacter jejuni,Enterococcus sp. ,Enteropathogenic E. coli ,Mycobacterium avium,Mycobacterium intracellulare,P. aeruginosa,Salmonella typhi,S. typhimurium ,Shigella dysenteriae Type I,Shigella flexneri,Streptococcus faecalis,Staphylococcus epidermidis ,Vibrio cholerae ,Yersinia enterocolitica
Fungi	C. albicans ,Fusarium sp.
Viruses	Bacteriophage f2 ,Encephalomyocarditis virus,Polio virus ,Rotavirus ,Norovirus
Protozoa	A. polyphaga (cyst) ,C. parvum (oocyst), Entamoeba sp. (cysts) Giardia sp (cysts)

Pathogenic waterborne bacteria and pathogen indicatorsformed the main focus of early laboratory based studies of SODIS efficacy. Due to the entirety of its genome mapping and its status as a faecal indicator organism , Escherichia coli is the most frequently studied species. Inactivation of this species by solar disinfection is caused by disrupting a sequence of normal cellular functions.
Thus solar rays could efficiently help in deactivating the microbial pathogens present in rainwater, improving the quality of rainwater

V. Result and Conclusion:

Results of protozoa and helminth inactivation during SODIS tests done in a solar simulator during 6 h exposure:

Protozoa	Illness	SODIS (6 h @ 550 W m−2)
Entamoeba invadens cysts	Amoebic dysentery (reptile model)	1.92 log kill
Naegleria gruberi cysts	Non-pathogenic Naegleria model	3.59 log kill
A. castellanii cysts	Encephalitis	2.16 log kill
G. lamblia cysts	Giardiasis	1.96 log kill
Ascaris suum ova	Ascariasis	1.42 log kill

One of the major problem with SODIS is that it does not rely on a product that has been commercially manufactured for the specific purpose of water disinfection there is usually no large manufacturing corporation funding advertising campaigns to promote either the product or technique. The standard bottles which are typically used for SODIS are used for a fundamentally different purpose than that originally intended and for this reason bottle manufacturersare often reluctant to support promotion of the technique.

The introduction of SODIS to stakeholders in a developing world region is usually greeted with considerable initial scepticism from people who may have hoped for a more technological solutionto their water contamination problem such as a ceramic or biosand filter. Instead they are presented with plastic bottles that in other circumstances might have been discarded as waste andconsigned to the rubbish tip. It can be difficult to convince someone who has had a lifetime of acclimatisation to strong sunlight and has never considered the possibility that sunshine could have a disinfecting effect. The task of promoting SODIS is further hampered by concerns centring on the possibility that harmful chemicals leach from the plastic after prolonged use. For these, and other, reasons it is not surprising that in 2011 the WHO/UNICEF Joint Monitoring Programme found that SODIS is used by less than 1% of the households using HWTS throughout the developing world. So in the developing countries government has to promote this technique and provide knowledge about the efficient use of this technique and awaring the people by campaigning in rural as well as urban areas. This is one of the best and economical method to use rainwater and overcome the scarcity of freshwater, also maximum utilization of rainwater.

Acknowledgement

We thank our colleagues from Madan Mohan Malaviya University who provided insight and expertise that greatly assisted the research.
We thank our professors for assistance with particular technique, methodology, and for their comments that greatly improved the review.

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