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Health and environmental considerations of rooftop catchment systems (Case study: Aq Ghala, Golestan Province, Iran)

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Abstract

The world has a long experience of using harvested rainwater from rooftop catchments in urbanized regions. There are also many studies about the technical, health, and environmental details of such systems. The gradual prevalence of rainwater harvesting systems in the country exposes a necessity to determine and define some guidelines and instructions for health and environmental considerations of these systems. Therefore, this study was aimed at introducing some existing health and environmental instructions regarding extracted water from rooftop catchments for drinking purposes in Aq Ghala, Golestan province, Iran. Results revealed that water samples had a good physical and chemical quality for drinking purposes which was established by another work in Golestan province with 140 samples' analysis. This work confirms that there is a need to prepare health and environmental instructions for rooftop catchment systems before developing them.

Keywords: *Rainwater harvesting, rooftop catchment, environmental concerns, cistern.*

1. Introduction

In many countries worldwide, where water resources are unsatisfactory in terms of quality for residents, rainwater is used as an alternative resource. On the other hand, due to frequent droughts, lack of water supply network, rationing in the network, and high costs of transporting water from other basins, critical shortage of fresh water has become a serious issue in the country (Ismaeili et al., 2009). Since the vast surface area of cities is covered by rooftops of residential buildings, the volume of water harvested from the rooftops of residential buildings is significant and can supply a proportion of non-drinking water requirements of the residents (Rashidi Mehrabadi et al., 2012). Use of rainwater harvested from the rooftop catchment surfaces in residential, administrative buildings, and impervious urban areas around the world has always been considered an old tradition. Moreover, many researches have been conducted on its technical, health, environmental, and usage details through previous redesigns during recent years. In recent years, several pilot projects and studies have also been conducted in the country with the aim of utilizing surfaces of rooftop catchments of residential and administrative buildings with a growing tendency to use this system in the country. However, despite numerous studies on the subject, no study has been specifically conducted on environmental regulations and standards in implementation of the systems in residential buildings within the country. Therefore, considering the domestic limited experience, it seems necessary to conduct complementary studies in this area in order to introduce global experiences and considerations and to localize those results. According to the previous investigations, rainwater harvesting from rooftops is not limited to specific locations on Earth such that this method has been used for a long time in many parts of the world.

Harvesting rainwater from the rooftops has been considered a common method for supplying drinking water and for domestic consumption in countries such as China, India, Thailand, Malaysia, Singapore, Guam, the United Kingdom, Germany, Taiwan, Fujian, and even Iran. In this regard, few studies have been done in Iran and other countries on the environmental considerations and standards for implementation of rainwater harvesting systems in buildings, which are mostly used as guidelines or regional regulations and standards. For example, in one of the important islands of Tanzania named Zanzibar in 2010, the guideline on the use of rainwater was prepared and codified by Regional Water Authority (ZAWA) with the participation of the United Nations (UN-HABITAT) for local promoters. A total of about 30% of the residents of this region do not have access to piped water facilities and using rainwater catchment systems can supply clean water in these areas.

The following environmental and health considerations and regulations are also investigated in this guideline:

❖ ***Rooftop catchment surface:*** It is recommended to use metal surfaces due to their ability to absorb solar heat and clear bacteria. Great care must be taken into account in selecting the type and color of the roof, which must be lead-free and risk-free for drinking. Moreover, it is recommended to clean and disinfect the rooftops before the start of precipitation.

❖ ***Water-courses:*** It is necessary to clean the surfaces of catchments, water-courses, and gutters before rainy season.

❖ ***Gutters*****:** The following measures are recommended: embedding the input filter to the entrance of the water-course of the gutter to prevent waste from entering the reservoir (mesh size of 5 mm or less), periodical cleaning and inspection, embedding a filter at the gutters of the reservoir entrance.

❖ ***Reservoir:*** The reservoir material must be durable, affordable, and non-contaminating as well as be selected in accordance with the local environmental conditions. Also, a special emphasis must be made on training the operators on how to use the system as well as teaching health problems and how to identify and deal with particular circumstances of contamination (UN- HABITAT & ZAWA, 2010).

Another experience of using rainwater relates to Zimbabwe in 2012, in which a guideline on the rooftop catchment system was prepared by World Relief and Development (IRD) with the participation of US Foreign Disaster Assistance (USAID) for use by local promoters. Zimbabwe with an average rainfall of 560 mm is climatically similar to conditions of some areas of North and West of Iran. The most important health and environmental considerations presented in this guideline are summarized as follows (IRD-USAID, 2010):

❖ ***Reservoir:*** The reservoir must be easily cleaned and disinfected by embedding a door at the entrance. The structural quality of the reservoir must be monitored from the building during operation phases. Also, it is recommended to embed a filter at the entrance of the reservoir.

❖ ***Rooftop catchment surface:*** It is recommended to select tin or ceramic roof and not to use asbestos sheets; unless necessary, in which case we should ensure that the sheets are not perforated. It is also recommended no to use surfaces contaminated with lead or asphalt.

❖ ***Gutters:*** The following recommendations should be taken into consideration:

Using gutters with suitable material (galvanized steel is preferred over the plastic because it is possible to use pumps to clear clogged pipes), embedding an angled outlet pipe in the cases where the pipes entering the reservoir are clogged to remove the existing residues. It is also recommended to use mobile gutters to prevent the entry of the first flush into the reservoir.

❖ ***Water-courses:*** Galvanized water-courses are durable and do not rust;

PVC water-courses are suitable for small rooftop surfaces but are easily broken or bent after a while due to exposure to sun radiation. Aluminum water-courses are vulnerable against rust. They also lose their shape over time after being combined with other elements. Moreover, high risk of perforation exists during their handling.

The other prepared guidebook on the use of rainwater catchment surfaces relates to the small islands of the Caribbean. The guidebook has been prepared by Caribbean Environmental Health Institute (CEHI) with the support of the United Nations Environment Programme (UNEP) in 2009. The climate of these islands is subtropical and more than 80% of the rainfall occurs during eight months. Rainfall height fluctuates between 1,500 to 3,000 mm in the region. The most important health and environmental considerations presented in this guidebook are summarized as follows (CEHI and UNEP, 2009):

❖ ***Rooftop catchment surface:*** The following recommendations should be taken into consideration: using galvanized steel and aluminum roofs and preventing water harvest from rooftops with contaminated material such as bitumen, leaded coating, etc., replacement of corroded and damaged parts of the roofs; regular pruning and cutting branches and leaves of trees placed on the rooftop.

❖ ***Transfer system:*** Embedding a first flush transfer pipe to the outside of the reservoir; embedding a filter to purify water entering from gutters to the water-course as well as from the gutters into the reservoir. The filter should be easily accessible, replaceable, clearable, and affordable. It is recommended to use stainless steel and synthetic mesh for the water-course filter and use a cloth filter at the entrance of the reservoir. Use of filters with self-purification ability after considering the required gradient for them; investigating and cleaning up water-courses and not using lead connections are also amongst recommendations of this guidebook.

❖ ***Reservoir:*** Embedding the primary settling reservoir and transferring its overflow from the upper layer of water to the main reservoir , harvesting water from the surface layer, which is cleaner, ensuring that no insects or reptiles enter the reservoir, disinfecting the reservoir, blocking direct sunlight which creates a favorable environment for algae growth, embedding a filter for the reservoir overflow pipe to prevent entry of insects, embedding manhole valves and ladders inside the reservoir for cleaning purposes, designing the gradient needed for the water harvesting and pumping, using dark-colored fiberglass reservoirs (to block the sunlight), as well as preventing the direct sunlight, pumping water from the bottom by extending the inlet pipe and harvesting water from the upper surface using a buoyant, preventing flooding and water accumulation around the reservoir which is conducive to the growth of mosquitoes and insects.

Other points, which are referred to in the above guideline are as follow:

Assessment of environmental pollutants in the region such as atmosphere pollution, contamination at the time of rainwater harvesting, contamination during storage, contamination during the cleaning and disinfection phases, as well as use of water purifiers, boiling water before consumption, use of Ultra Violet (UV) rays for disinfection, if possible, or use of chlorine (Table 1) for drinking.

Table 1. Amount of disinfectant and bleach for different tank volumes (Adopted from CEHI & UNEP, 2009*)*

Capacity		The approximate amount of bleach (With 4% active ingredient)
M^2	**Gallon**	
909	200	½
1818	400	1
3637	800	2
4546	1000	½2
11365	2500	5½
22730	5000	11½
45461	10000	22½
90922	20000	45½

Another guidebook was prepared by the center for reduction of developmental effects of the US Environmental Protection Agency (EPA). The guidebook was prepared in 2008 to assist local authorities in implementing green infrastructures in their communities. This guidebook according to its audiences, who are municipal officials and municipal legislators, refers to most of the existing laws for the design and use of rainwater catchment surfaces in various states in US (EPA, 2008).

In Iran, Zehtabian et al. (2012) also investigated the domestic roof water harvesting method (DRWH) as well as the efficiency and cost effectiveness of this method compared with other methods in Golestan Province, Iran. Their results show that rainwater harvesting by tin roofs is less expensive than other methods and is structurally suitable for arid regions. Moreover, the quality of rainwater is preferred over other systems, such as surface water of rivers or dams in terms of microbial and chemical quality. However, this method is mostly used as a scientific approach. In the research project of Zafarzadeh et al. (2007) at Gorgan University of Medical Sciences titled "Determining the chemical quality of water in water cisterns in rural areas of Golestan Province", 140 water samples were collected using standard methods to determine the chemical quality of water in rural cisterns, including pH, electrical conductivity, alkalinity, hardness, chloride, nitrate, phosphate, iron, magnesium, lead, and chromium concentrations. Based on the results, the concentrations of phosphate, iron, lead, and chromium were over the limit in 15%, 12%, 51% and 6% of the collected samples, respectively. The other parameters were less than the maximum allowed amount. The pH values of the tested samples were in the acceptable range based on national standard and EPA. The electrical conductivity of samples was less than the maximum allowed amount. Rooftop materials (tin or asbestos roofs) had no significant effect on the electrical conductivity. In most samples, the alkalinity rate of phenolphthalein was zero. Furthermore, the chloride amount of these samples was within the acceptable limits. Phosphorous, iron, and lead quantities had exceeded the drinking water standard in a limited number of water cisterns and were not be suitable for drinking and cooking. However, this kind of water can be used for other purposes. According to the results of a project carried out by Zafarzadeh et al. (2007), the cause of chemical contamination is possibly due to penetration of surface and agriculture water supply of Gorganrud water in low rainfall seasons in water storages, air pollution, and the falling of polluted particles on catchment surfaces (rooftops of houses) .

Although, valuable studies have been conducted on water harvesting from urban impervious surfaces and rooftops in the country, unfortunately, there has been no comprehensive study on the environmental and health considerations. Thus, considering that the dimensions of this issue requires further extensive and location-based researches, this study aims to identify experiences in the field of environmental and health standards and considerations of rooftop catchment systems, including rainwater harvesting reservoirs in Aq Qala area (Golestan Province). Also, the present study can help the urban and rural planners and managers to understand the potential of this resource for securing water supply.

2. Materials and Methods

Golestan Province with an area of 20438 square kilometers has covered approximately 1.3 percent of the country's total area (Planning Department of Golestan Provice, 2011).

After considering records and sources in the field of residential rainwater storage systems in counties of Kalaleh, Bandar-e-Torkaman and Aq Qala in Golestan province, Aq Qala County was defined as the study area (Figure 1). The average monthly rainfall of the studied city is shown in Table 2. After visiting Aq Qala City and interviewing with informed residents, attempts were made to visit at least one sample from each case based on the diversity in implementation of the existing systems in terms of manner of rainwater harvesting and storage, land use, area, and type of use.

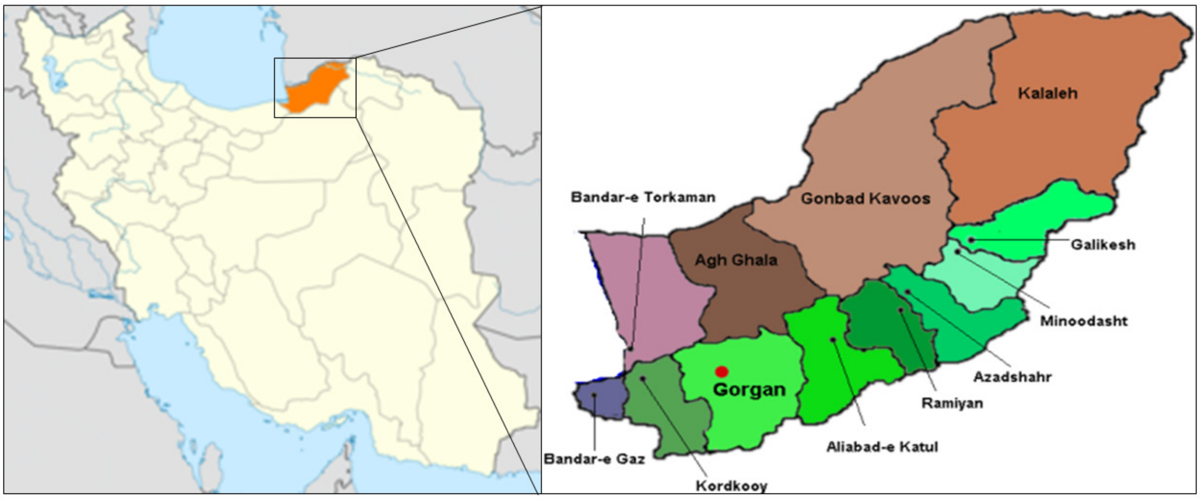

Fig. 1. Geographic location of study area

Table 2. Mean monthly precipitation of Aq Qala

City	March	April	May	June	July	August	September	October	November	December	January	February
Aq Qala	37.5	16.8	11.8	8.1	9.1	2.6	5.1	41.1	45.4	29.9	22.0	71.3

After conducting studies and field surveys, a total of two sites were sampled and assessed (Table 3). Moreover, a questionnaire was prepared as a means of obtaining the required information. The questionnaire contained all the information required for full recognition of the visited system, including design, implementation, operation, and maintenance with respect to its environmental and health considerations.

According to the definition provided by WHO (2008) and the Institute of Standards and Industrial Research of Iran (2009), drinking water is defined as water with physical, chemical, biological features, and radioactive substances that causes no occasional short-term or long-term effects to human health. Accordingly, the cisterns in the study area of Aq Qala were sampled in order to perform qualitative investigations on them. Also, the characteristics of the sampling sites are presented in the in Table 3. In the analysis of sampled water, it is necessary to note that due to the limitations of the project, the sampling was conducted only once during the project implementation period and the results were provided based on this sampling.

Table 3. Properties of sampling sites (sampling date: 27/12/2014)

Item / Sample#	1	2
Land use	Mosque	Home
Location	Aq Qala, Sari mosque	Lari region, Aq Qala
Coordinate (UTM)	X=272885 Y= 4099714	X=253568 Y= 4101093
Altitude	-22	-14
Roof type	tin	tin and asbestos
Cleaning method of catchment surface	sweeping before rainy season	by sweeping, nets are cleaned and replaced before rainy season
type of gutter	open	Open
Type of down pipe	tin	Plastic
The filter material at the junction of the drains	fine metal mesh	fine metal mesh
Reservoir type	underground	underground
Reservoir material	concrete	concrete
Reservoir cover	concrete-yard of mosque	concrete-mosaic-terrace of house
Reservoir depth (m)	2.5	2
Volume (m^3)	66	24
Harvesting type	pump-activated faucet	picked by the bucket and rope
Filter material at the entrance to the reservoir	no filter	fine mesh cloth
Tank cleaning time	Summer	summer
Reservoir cleaning method	by water and sweep-chlorination and discharge of sediments with a cloth and sponge	by salt, disinfection by chloride, sponge drainage, remained empty until a week after the first rain to wash tank
Form and quantity of sediments in the tank	very fine sediments with a thickness of about 2 mm	very small
Type of use	Drinking	drinking
System lifetime (years)	8	28
Taste and smell of water	no taste and smell	no taste and smell

Schoeller Diagram was employed for classification of drinking water. In Schoeller Diagram, separate axes were considered for values of each cation (Na+K, Mg, Ca) and anion (Hco3, So4, Cl) and water hardness (TH), which were determined through laboratory experiments. By connecting their corresponding points on these axes, the degree of suitability of the water for drinking can be observed.

3. Results

Results of the laboratory analyses are presented in tables 4-6. As shown in Table 4, according to the maximum allowable salinity of 1800 μmhos, water samples from the study sites had no drinking limitations in terms of salinity. T.D.S has a direct relationship with the electrical conductivity, which in accordance with ISO 1053 of Institute of Standards and Industrial Research of Iran (fifth revision, 2009), its optimal maximum and maximum allowable amounts are 1000 and 1,500 mg/l for drinking water, respectively. Thus, there was no limitation for drinking the analyzed water samples from this perspective. According to the 1053 standard, the optimum and the permissible limit of pH are 6.5 to 8.5 and 6.5 to 9, respectively. According to analytical results of water samples, it was shown that the pH value was also appropriate and there was no problem in this respect. According to the World Health Organization (WHO) (Table 7) and the 1053 standard, drinking water hardness must not exceed 500 and should not be less than 200. According to the measurements (Table 5), the analyzed samples had no limitation in terms of drinking considering total hardness and were placed in the category of soft or light waters. According to the same standards, the maximum optimum and the maximum allowable amounts of sulphate are 250 and 400 mg /l for drinking water, in which no restriction was found for drinking the samples under study. Moreover, the optimum maximum amount of magnesium and the maximum allowable amount of sodium were 30 and 200 mg /l, respectively. Therefore, there was no limit given the low levels of magnesium and sodium in the study samples. Considering the allowable limit of 12 Mg/l obtained for potassium, the element does not create any restrictions in drinking the water samples. The optimum maximum amount of calcium is detected to be 300 Mg/l in drinking water (Institute of Standards and Industrial Research of Iran, 2009), which was much higher than the amount of calcium presented in the tested water samples. Of course, the lack of calcium in drinking water must be compensated through consumption of foods containing calcium. The amount of chloride ion was also much less than the optimum level (250 Mg/l) and the allowable limit (400 Mg/l). According to international standards and the 1053 standard, the maximum allowable amount of nitrate in the drinking water is estimated to be 50 Mg/l, which was higher than the amount of nitrate in the analyzed water samples. Water samples were of bicarbonate type and the facies was determined as calcic (Table 6). Results showed that the turbidity level of analyzed samples was much lower than the maximum level of 5 NTU defined in the 1053 standard. According to the Schoeller Diagram, samples collected from the reservoirs were in the good category in terms of drinking uses.

Table 4. Results of chemical analysis of water samples

Sample#	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$HCO3^{-}$	Cl^{-}	$SO4^{2-}$	NO3	pH	T.D.S	EC
	ppm									Mg/l	µm/cm
1	18.4	0	2.7	2.8	40.3	2.5	7.22	7.05	7.1	60.47	97.1
2	25.6	0.976	5.1	2	50	6.7	13.19	11	6.89	89.17	152

Table 5. Water quality based on the total hardness

Sample#	Magnesium hardness	Calcium hardness	Total hardness	Water quality class based on the total hardness
1	0	46	46	Light
2	4	64	68	Light

Table 6. Facies and type of water samples

Sample#	Concentrations of anions	Concentrations of cations	Type	Facies	Type & Facies
1	HCO3 > SO4 > Cl	Ca > Na+K > Mg	Non-carbonated	calcic	Non-carbonated and calcic
2	HCO3 > SO4 > Cl	Ca > Na+K > Mg	Non-carbonated	calcic	Non-carbonated and calcic

Table 7. Drinking water standards in human societies

Parameters	US-EPA	WHO	Ministry of Energy of Iran	Institute of Standards and Industrial Research of Iran
Nitrate	1	45	45	50
Nitrite	1	0.1	0.1	3
Flouride	4	4	6	-
Sulfate	500	450	400	400-600
Chloride	250	250	600	400
Calcium	-	100	200	250
Magnesium	-	50	150	50
Iron	0.3	0.3	1	0.3
Low hardness	-	500	500	500
Sodium	-	200	-	200
Total dissolved solids	-	1500	2000	1500
Total coliform	0	0	0	0
pH	-	6.5-8.5	-	6-9
Phosphate	-	-	0.2	-

*Chemical parameters concentration in ppm, microbial parameters concentration in MPN

Based on the Schoeller diagram, water samples harvested from reservoirs were placed in the "good category" in terms of drinking purposes (Fig. 2.).

Furthermore, there was no significant difference between the two sites in terms of effect of the asbestos cement roof on the drinking water quality; however, most of the surveyed items of the sample No (1), which were obtained only from catchments with tin surfaces, showed higher levels of physical and chemical quality, although precise decisions in this case require more samples and more frequency of occurrence.

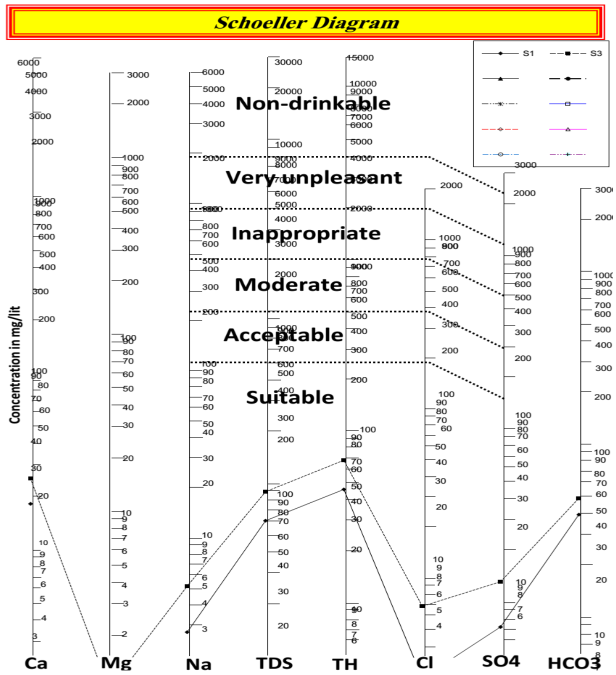

Fig. 2. Schoeller diagram of water samples

4. Discussion and Conclusion

Since there is a long history of using the rainwater flowing through the rooftops in and outside the country, over time, while gaining experience and by observing indigenous and traditional hygiene, points and technical standards have been designed and determined based on scientific standards in this field. According to this, some health considerations have been observed experimentally in the construction and maintenance of this type of system in the study area with respect to the long history, which leads to improvement in the quality of water resources. Thus, the results of analyses on the samples show a relatively high quality for drinking despite the water samples being taken over a month after the recent rainfall in the area. However, in the case of observing the complementary health and environmental considerations since the beginning of construction of the systems, there will be the possibility for the improvement in the quality and performance of the system. Furthermore, study and research into the causes of the use or non-use of these methods for water supply and release its traditional methods, on the one hand, and the gradual introduction and reorganization of the method around the world and Iran on the other hand, indicate the need for improvement in the designs with a focus on compliance with new environmental and health conditions and requirements.

5. Acknowledgments

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