International Journal of Water Resources and Arid Environments 3(1): 01-10, 2014
ISSN 2079-7079

Quantity and Quality Considerations of Rooftop Rainwater Harvesting as a Substantial Resource to Face Water Supply Shortages

Taha Mohammed Taher

Department of Civil Engineering, Faculty of Engineering, Fatih University, Istanbul, Turkey

Abstract: Yemen is facing a major challenge represented by the shortages of the renewable water resources where already water consumption and use exceeds renewable water supply. The overexploitation of groundwater for the different uses such as agriculture, domestic, touristic and industrial resulted in a deficit of more than 900 Mm^3 annually. This is resulting in a socio-economic unrest and conflicts. The capital city of Sana'a where groundwater levels drop annually by an average of 6 m is a clear example of the stress the country is facing. Rainwater harvesting systems amongst other resources such as desalination, use of treated waste water, is found as a better alternative source to increase the water supply sources. Despite the historical traditions of Yemen in water harvesting, rooftops rainwater harvesting has not received great attention even though it can help combating the dilemma of water scarcity in the country. The main objective of this paper is to prove the potentiality of rainwater harvesting for usage in the city of Sana'a to overcome the current water shortages, to reduce the overexploitation of groundwater and to minimize the costs people spent for consuming water from either local water authorities or private providers. Surface area calculation was done by building out maps out of Google Earth taking several raster data sets as a picture of the specific scene. The final surface area was calculated to be 60.3 km^2. Results show that the estimated amount of water that can be harvested annually from roof tops of Sana'a City is 11.72 Mm^3 using a runoff coefficients of 0.80, if all rooftop surfaces are used. This indicates that there will be a 20% potential annual water savings (PWS) of the total water supplied by both the Sana'a Local Water Supply and Sanitation Authority and the private providers who supply 59 Mm^3 to the city annually. However, considering the private providers supply of 27 Mm^3 to the city, a 43.4% PWS can be saved by households when utilizing Rooftop Rainwater Harvesting Systems with an estimated cost benefits of 82.0 M$. Water quality tests of collected samples from rooftops indicate safe use of rooftop rainwater when some hygiene measures are adopted including regular surface cleaning, first flush system, filtration and chlorination of stored water. The analysis in this paper can be applied in areas of similar drought condition in the region emphasizing on the local rainfall-runoff conditions.

Key words: Water shortages · Water Harvesting · Rooftops · Groundwater · Water quality · Savings · Yemen

INTRODUCTION

Many countries in the Middle East increasingly suffer from water shortages due to the unavailability of renewable water resources as a result of the rabid increase in population and low rainfall occurrence. Currently, MENA's population is growing annually at a rate of 2% (or nearly 7 million people per year), second only to sub-Saharan Africa [1]. The fastest population growth is occurring among Yemenis with annual growth rate of 3.5% and Palestinians, who are the least equipped economically and technologically to address the challenges of water.

Rooftops rainwater harvesting from rural and urban areas has not currently received great attention in Yemen. Despite the fact RTWH has the advantage to combat the chronic water shortages in the country by providing additional water supply source for domestic uses. Rainwater harvesting in Yemen is a traditional practice where in many areas you can find cisterns and bonds used to conserve rain water for domestic and animal uses.

Corresponding Author: Taha Mohammed Taher, Department of Civil Engineering, Faculty of Engineering, Fatih University, Istanbul Turkey. E-mail: tahataher@fatih.ed.tr.

Fig. 1: The main cistern [2]

Fig. 2: The flowing channels [2]

Fig. 3: View of a RTRWHS and pipes (picture taken by Taher)

The cisterns of Tawaila (rain flood harvesting), or the Tawaila Tanks are Aden's best historic sites (Figures 1 and 2). The Tawila Tanks, also known as 'Aden Tanks', the 'Cisterns', 'Queen of Sheba Tanks' or 'Solomon's Tanks', are located at the head of Tawila Valley in the southwest sector of Crater city. They are considered one of the greatest historical engineering feats in South Arabia, likely built and developed during the rules of the Ottomans and mentioned in the ancient Al- Musnad inscriptions. The systems of tanks were designed both to collect the scarce rain water and divert run off to protect the city of Crater in case of heavy rains and sweeping floods. They were excavated out of solid rock and lined with a thick coat of fine stucco, resembling marble.

Mareb dam is an example of a water harvesting technology started 2000 years B.C in Yemen to provide agricultural and domestic waters to the left and right paradise as stated in the Holy Qura'an. Yemen are utilizing rooftop rainwater harvesting as a major resource of water especially in rural areas where water supply systems are mostly absent due to lack of funds, lack of water sources or due harsh and difficult terrain mountain systems. As an example is the home of the author where the household is utilizing RTRW since 1967 (Figure 3).

Background: The central challenge facing the country in general and Sana'a Basin in particular today and in the foreseeable future is therefore how to produce more food and enhance farmer income besides meeting the other demands like drinking water and industrial needs. With a rapid increase of population, it is expected that by the year 2025, the basin population will reach 5.85 M people. The statistical year book [3] shows a population of 1,947,138 for the year 2006. Between now and then, a significant amount of additional food supply will be needed to serve the growing population which means more irrigation and consequently more water.

Sana'a Basin is experiencing a serious depletion of groundwater resources with associated water quality degradation. The water resources situation is extremely serious as abstraction exceeds recharge by more than five folds leading to water levels drop by 4-8 meters annually. Groundwater is mainly used for agricultural activities, which have expanded several times since 1980's and consume about 90% of water. Mismanagement of water resources is mainly caused by lack of data, policy and institutional framework for groundwater abstraction and use and inefficient irrigation practices. In addition, rainfall is becoming much less each year due to climatic changes. There are two rainy seasons, separated by a distinct dry interval (May-mid July). The annual rainfall generally varies between 150 and 350 mm, with some years having, higher rainfall amounts above 350 mm and lower than 150mm. The first rainy period starts in mid-March-beginning of April, the second rainy period begins mid-July-beginning of August and stops abruptly end of August. The months September through February are generally dry, although occasional thunderstorms may bring some rain during these months. Sixty-five to seventy-five percent of the rain falls during the months January-June. The number of rain days with rainfall amounts above 5 mm/day varies between 5-15 days. The average amount of rainfall per rain day is about 16-17 mm.

The potential evapotranspiration (PET) for an average year varies depending on altitude, wind exposure and latitude. The PET varies between 3-3.5 mm/day during the dry, cold period and 5-6 mm/day during the months May-June. The average total amount of evapotranspiration per year is about 1700 mm.

Objective: The main objective of this paper is to show the potentiality of rainwater harvesting for usage in the city of Sana'a to overcome the current water shortages, to reduce the overexploitation of groundwater and to minimize the costs people spent for utilizing water from either local water authorities or private providers. Therefore, this study emphasizes the importance of roof rainwater harvesting systems for domestic water supply in Sana'a.

MATERIALS AND METHODS

The accomplishment of the above objectives are pursued through assessment of the rainfall data records. Obtaining the population of the cities, evaluating their consumption rates and estimating volumes of water supplied either by local authorities or private providers are very important issues required to fulfill the above objectives. Estimation of the area of rooftops is done through ArcGIS where more accurate values have been produced. Groundwater costs and saving is also assessed. Water samples are collected from roofs, tested and results analyzed.

RESULTS AND DISCUSSIONS

Potential Rainwater Harvested for Sana'a City: The harvested rainwater volume was calculated using the rational method which constitutes of the parameters of average rainfall, surface area and roughness coefficient. A roughness coefficient of 0.80 is assumed in the calculation of the volume of rainwater harvested from roofs as suggested by [4], [5] and [6]. Such a run- off coefficient indicates a loss of 0.20% of the rainwater due to the type of the roof surface and evaporation. Thus, the rational method is probably the most popular method and preferable in storm design systems in urban areas [7]. It has been applied all over the world and many refinements of the method have been produced [6]. It has the following simple form:

Table 1: Harvested water volume guide table using run off coefficient of 0.8

Rainfall (mm)	100	150	200	250	300	350	400	450	500	600	700	800	900	1000	1500
Roof areas (m^2)	Harvested Water Volume from Roof Top (m^3)														
20	2	2	3	4	5	6	6	7	8	10	11	13	14	16	24
30	2	4	5	6	7	8	10	11	12	14	17	19	22	24	36
40	3	5	6	8	10	11	13	14	16	19	22	26	29	32	48
50	4	6	8	10	12	14	16	18	20	24	28	32	36	40	60
60	5	7	10	12	14	17	19	22	24	29	34	38	43	48	72
70	6	8	11	14	17	20	22	25	28	34	39	45	50	56	84
80	6	10	13	16	19	22	26	29	32	38	45	51	58	64	96
90	7	11	14	18	22	25	29	32	36	43	50	58	65	72	108
100	8	12	16	20	24	28	32	36	40	48	56	64	72	80	120
150	12	18	24	30	36	42	48	54	60	72	84	96	108	120	180
200	16	24	32	40	48	56	64	72	80	96	112	128	144	160	240
250	20	30	40	50	60	70	80	90	100	120	140	160	180	200	300
300	24	36	48	60	72	84	96	108	120	144	168	192	216	240	360
350	28	42	56	70	84	98	112	126	140	168	196	224	252	280	420
400	32	48	64	80	96	112	128	144	160	192	224	256	288	320	480
450	36	54	72	90	108	126	144	162	180	216	252	288	324	360	540
500	40	60	80	100	120	140	160	180	200	240	280	320	360	400	600
600	48	72	96	120	144	168	192	216	240	288	336	384	432	480	720
700	56	84	112	140	168	196	224	252	280	336	392	448	504	560	840
800	64	96	128	160	192	224	256	288	320	384	448	512	576	640	960
900	72	108	144	180	216	252	288	324	360	432	504	576	648	720	1080
1000	80	120	160	200	240	280	320	360	400	480	560	640	720	800	1200
1500	120	180	240	300	360	420	480	540	600	720	840	960	1080	1200	1800
2000	160	240	320	400	480	560	640	720	800	960	1120	1280	1440	1600	2400
2500	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	3000
3000	240	360	480	600	720	840	960	1080	1200	1440	1680	1920	2160	2400	3600
3500	280	420	560	700	840	980	1120	1260	1400	1680	1960	2240	2520	2800	4200
4000	320	480	640	800	960	1120	1280	1440	1600	1920	2240	2560	2880	3200	4800
4500	360	540	720	900	1080	1260	1440	1620	1800	2160	2520	2880	3240	3600	5400

Table 2: Rainfall data of Sana'a City (1990-2003) for 10 years

Year	1990	1991	1992	1993	1997	1998	2000	2001	2002	2003	10 years Average
Annual Average	124	111.5	350	316.5	201.5	341	330	303	124.5	227	243

$$PRWH = \frac{C \times I \times A}{1000} \quad (1)$$

PRWH is the volume of the rainwater harvested from the roofs (m^3), C runoff coefficient (dimensionless), I is the annual average rainfall (mm/year) and A is the roof area (m^2).

Simple design tables where developed applying the above equation as basic guidance to estimate the water harvested volume based on several run off coefficients of 0.60, 0.70, 0.75 and 0.80, the rainfall and the surface area [8]. Table 1 lists the water volume harvested from roof tops using rainfall average of 243 mm/year with different rooftop surface areas and run off coefficient of 0.80.

Rainfall: For water harvesting purpose we will use the average year rainfall from ten years data in the Sana'a city [9]. The average rainfall for the years (1990-2003) is taken as 243 mm/year (Table 2 and Figure 4).

A similar value of the average rainfall was found when using the Tropical Rainfall Measuring Mission (TRMM) data which is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the Japan Aerospace Exploration Agency (JAXA) NASA [8]. Almazroui [10] has confirmed the use of the TRMM data in a variety of water-related applications in Saudi Arabia when he compared the observed rainfall data to those obtained by TRMM.

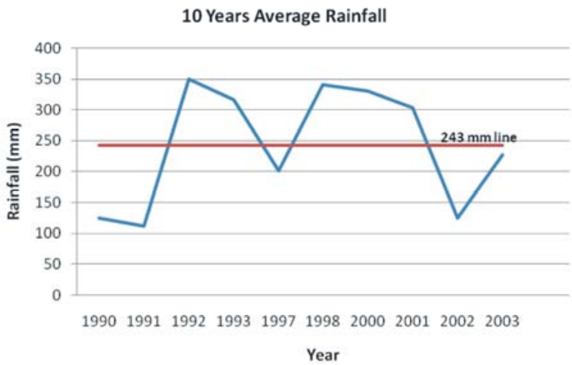

Fig. 4: Average annual rainfall for Sana'a City

He found the country's average annual rainfall obtained by the TRMM method to be 89.42 mm, whereas the measured national data is 82.29 mm. He suggested that the TRMM value of 89.42 should be multiplied by 0.93 and adding 0.04 to the result leading to a rainfall value closer to the national observed data. Zabara, *et al* [11] suggests that when there is no reliable rainfall data, TRMM data on monthly basis could be used as an alternative.

Estimation of the Area of Roof Tops of Sana'a: The total surface area of Sana'a City has been estimated using Google earth data.The maps are built out of Google Earth data. This was done by mosaicking which means taking several raster datasets as a picture of the specific scene. After preparing these scenes, the raster datasets were put together by merging all the scenes. The result is a high resolute map.

To get information about the area taken by rooftops we need to separate the rooftops from the rest of the map. This was done by a supervised classification using maximum-likelihood-estimation. For that the whole scene needs to be classified to differentiate between rooftops and other surfaces such as mountains, streets and agricultural land.

The supervised classification divides the scene in a given number of classes with a specific value, in our case the value is represented by the grey level. Before the classification can start we need to set up training areas to give the program the information about

Fig. 5: Satellite image of Sana'a city and its borders

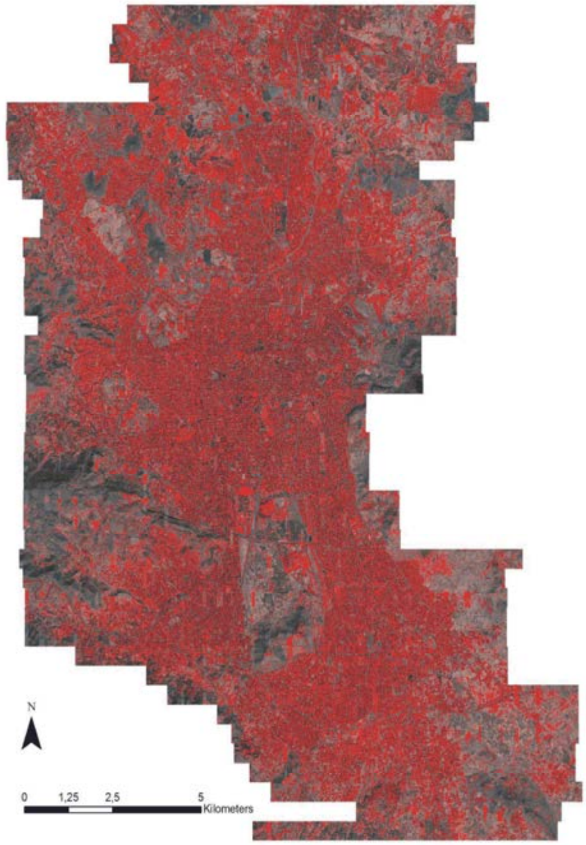

Fig. 6: Image of Sana'a city showing the rooftops areas in red

the different grey levels. The following training areas have been built: rooftops (divided in high and low reflectance), streets (divided in high and low reflectance) and vegetation, soil, rocks and shadows of buildings. After picking representative training areas the classification made new groups of grey levels. The grey levels, which seemed similar to the grey levels of the training areas, were put in the same class. The result is a new colored raster dataset, just including the defined classes. In this raster images of the rooftops are separated from the rest of the scene and can be easily measured.

The scene of Sana'a contains 614,825,954 pixels with a spatial resolution of 0.58 m^2 per pixel. The total area is about 356.6 km^2 (Figure 5). The rooftops count 116,143,796 pixel, with the same spatial resolution the area is about 67 km^2, this is 18 % of the total area of Sana'a (Figure 6). Due to errors such as misplaced of pixels during the classification and shadow occurrence since the satellite images were not 100% taken in a perpendicular angle. Therefore, a 10% error is estimated to correct these mistakes. The final roofs surface area is 60.3 km^2.

Current Water Supply: According to [12], a minimum value of 25 l/c/d is acceptable for hygiene and health care in dry regions. Hanesh, *et al*. [13] calculated the average water consumption rate for several cities in Yemen (Table 3) for the year 2006. In this table Sana'a average consumption rate in the year 2006 is 53.24 l/c/d.

Table 3: Average total water consumption – 2006 [l/c/d] [13]

Location	2006 (1st quarter)	2006 (2nd quarter)	2006 (3rd quarter)	2006 (4th quarter)	2006 Average
Ad Dis	72.5	78.2	87.4	84.3	80.6
Aden	107.8	111.9	113.4	110.3	110.9
Al Hami	62.2	69.9	73.7	74.3	70
Al Mahweet	24.3	24.9	25.5	26.2	25.2
Al Mokha	44.0	53.5	54.4	50.2	50.5
Al Reidah	55.2	57.2	56.6	55.9	55.2
Amran	52.5	61.7	57.2	57.1	57.1
Bajil	37.8	40.2	39.9	36.8	38.6
Bayt AlFaqih	38.9	44.9	47.0	40.4	42.8
Dhamar	57.9	56.4	55.3	v.m.	v.m.
Ghail	106.3	110.1	110.7	113.9	110.3
Hajjah	52.6	53.6	59.1	53.8	54.8
Hudeidah	61.1	63.9	62.3	61.7	62.6
Ibb	63.7	60.9	v.m.	v.m.	v.m.
Mansouria	35.1	39.8	40.6	36.0	37.9
Mukallah	81.9	92.0	85.3	82.2	85.4
Radaa	45.7	53.5	54.4	45.6	49.8
Sadah	54.2	55.3	57.6	49.9	54.3
Sanaa	48.3	54.1	54.5	55.7	53.6
Seiyun	54.6	64.7	69.8	61.4	62.6
Taiz	38.2	38.0	40.6	v.m.	v.m.
Yarim	34.7	33.3	28	25.0	30.3
Zabid	40.7	49.2	51.3	43.9	46.3
National Average	55.4	59.6	60.2	58.9	58.5

The Sana'a Local Water Supply and Sanitation Authority (SLWSSA) covers only 40.5% of Sana'a [13]. The estimated water demand that is being met by SLWSSA is 32 MCM in 2010 [14]. In addition, a recent survey of private water supply [15] estimated that the 189 wells recorded by the NWRA-SB 2007 survey as serving the Sana'a urban market are supplying 27 Mm^3/year. These figures suggest that the current water supply to the capital is about 59.0 Mm^3/year exceeding the natural recharge of the basin.

Potential Water Savings: The potential rainwater harvested (PRWH) is calculated using equation (1) resulting in a value of 11,722,320 m^3. Abdulla, *et al*. [5] has estimated the potential water savings by the following equation:

$$PWS = \left(\frac{PRWH}{PWD}\right) \times 100 \qquad (2)$$

PWS is the annual potential water saving in %, PRWH is the potential rainwater harvested (m^3) and PWD is the potential water demand (m^3). The obtained result is 20% annually. This implies that if collected RTRWH is completely used there will be a potential water savings from the groundwater supplies from both SLWSSA and the private providers.

Groundwater Savings: The annual utilization of harvested water in Sana'a will result in reducing pressure on groundwater. This means that there is substantial amount of water in the deep aquifers will be saved through using rooftops rainwater reducing the groundwater pumping by 11,722,320 Mm^3 annually. Referring to the 2010 consumption of 59.0 Mm^3, there will be possible annual reduction of the use of groundwater of 11.72 Mm^3 resulting to a state of equilibrium in 5 years provided that the same consumption rate is used and no increase in population. This assumed equilibrium will be when using RTRWH for domestic purposes whereas agriculture is the highest sector exploiting ground water.

Economic Analysis: The system of the rooftop rainwater harvesting consists of mainly four parts, the collection area (the roofs), a conveyance system (pipes) a storage system (tanks) and the operation and maintenance of the system. The capital cost of rainwater harvesting system is highly dependent on the type of each component. The cost of the storage component usually the highest amongst the other components of the system. A newly practiced storage tanks in Yemen is the ferro cement tanks which is very cheap material and durable. It can be built above or underground. The cost of 1 m^3 ferro cement tank constructed above ground is 61.22 US$ and the cost of 1 m^3 of underground ferro cement tank is 50.14 US$/$m^3$ [16].

Considering the low cost of the cubic meter of water supplied by the local water authority due to government subsidy and political measures, the analysis I would pursue is for the potential savings by not using private providers sources due to the following reasons: (1) the high cost per cubic meter which reaches in some areas to 10 US$ and (2) the low quality of water provided by the tankers due to the absence of control and supervision regulations.

Equation (2) is again used by fixing the the potential water demand (PWD) to 27.0 Mm^3 and the potential rainwater harvesting (PRWH) to 11, 722,320 m^3 resulting in a potential water savings of 43.4%. Simple calculation would result in an annual reduced costs for the public of 82,056,320 M US$ bearing in mind that average cost per 1 $m^3$of water is 7 US$ when assuming that the cost of 1 m^3 of water from private providers is within the range of 5-10$/$m^3$.

Assuming each household can have a 20 m^3 ferro cement type underground tank according to the maximum water volume of 16.08 m^3 which occurs in March [8] and with a cost rate of 50.14 $/ m^3, a total cost of the tank would be 1002.8 $. Piping network including first flush system and filters using PVC pipes is assumed to be 60% of the cost of tank (601.7$). This value is validated by simple calculation using local market prices of pipes including installation assuming a house that has common rooftop area of 200 m^2, height of 5 m above ground and the tank location is at a distance of 3 m from the house. The total cost per household is 1604.5 $. An amount of 5% of the total cost is set for operation and maintenance (80.24$/year) resulting in a final cost of 1684.7$/year per RTRWHS for each household. This value is spent only once for each household during implementation phase including the operation maintenance period.

The average number of people in each household is 6 persons [3]. The number of households is then calculated by dividing the city population (1,947,138) by the number of people in each household (6 persons/ household). The number of households who could benefit from the water volume saved in Sana'a city is 324,523.

Quality of RTRWH: Rainwater collection systems are commonly believed to provide safe drinking water without treatment because the collection surfaces (roofs) are

Table 4: Types of contaminants commonly found in rainwater collection systems [17]

Contaminant	Source	Risk / mitigations
Dust, ash and debris	Surrounding dirt and vegetation Volcanic activity	Moderate: Can be minimized by regular roof and down drain pipe (gutter) maintenance and use of a first-flush device and wire mesh screens.
Pathogenic Bacteria	Bird and other animal droppings on roof, attached to dust	Moderate: Bacteria may be attached to dust or in animal droppings falling on the roof. Can be minimized by use of a first-flush device and roof and tank maintenance and disinfection by chlorine.
Heavy metals	Dust, particularly in urban and industrialized areas, roof materials	Low: Unless downwind of industrial activity such as a metal smelter and/or rainfall is very acidic (this may occur in volcanic islands)
Other Inorganic Contaminants (e.g. salt from sea spray)	Sea spray, certain industrial discharges to air, use of unsuitable tank and/or roof materials	Low: Unless very close to the ocean or downwind of large-scale industrial activity
Mosquito Larvae	Mosquitoes laying eggs in guttering and/or tank	Moderate: If tank inlet is screened and there are no gaps, risks can be minimized

Table 5: Quality parameters of collected RTRWH in Sana'a

Parameter	Unit	Mean Value	Abdulla, *et al.,* 2009	NWRA	WHO
pH		6.9	7.4	6.5-9	6.5-8.5
Turbidity	NTU	4.4	-	5	5
EC	ìS/cm	105.7	402.5	450-2500	?250
TDS	mg/L	69	270.2	650-1500	200-1000
Total Hardness	mg/L	44	140.3	100-500	500
Total Alkalinity	mg/L	32	-	-	
Bicarbonate_yHCO_3_z	mg/L	42.5	-	150-500	
Carbonate _yCO_3^{-z}	mg/L	0.0		-	
Chloride_yCl_z	mg/L	1.5	-	200-600	250
Sulphate_ySO_4_z	mg/L	16.5	-	200-400	250
Fluoride_yF_z	mg/L	0.0	-	0.5-1.5	1.5
Calcium_yCa_z	mg/L	10.0	-	75-200	
Magnesium_yMg_z	mg/L	5.0		30-150	
Sodium_yNa_z	mg/L	4.0	-	200-400	50
Potassium_yK_z	mg/L	5.2	-	8-12	
Nitrateas NO_3^-	mg/L	0.0	-	10-50	50
Iron_yFe_z	mg/L	0.08	-	0.3-1	0.3
Total coliform	counts/100 ml samples	0.0	33	0	0

isolated from many of the usual sources of contamination (e.g. sanitation systems). Although roofs are higher than the ground, dust and other debris can be blown onto them, leaves can fall from trees and birds and climbing animals can defecate on them. The quality of drinking water can be much improved if these contaminants are not allowed to enter the storage tank.

The main contaminants in rainwater tanks are dusts, bacteria, inorganic materials, heavy metals and mosquito larva. Closed tanks are usually less exposed to contamination whilst open surface tanks are extremely exposed. Table 4 [17] lists the contaminants, their sources and the risks and the mitigations.

Samples of water from roofs were collected and tested in the laboratory. The results of the analysis against the WHO [12] and the Yemeni water quality standards is shown in Table 5.

From the analysis of the samples, all physical and chemical parameters are below the maximum values of both NWRA and WHO standards [12]. Turbidity results of the samples are closer to the highest limits of the standards of both NWRA and WHO [12]. The reason is mainly due to long period of dry days before collecting samples, unclean roofs, unavailability of first flush system [4] and [5] or unavailability of filtration systems. It is however advisable that household should use filters to purify water before use.

The biological quality of rainwater was tested by the common indicators of total coliform. The measured value indicates no coliform in the collected samples implying that RTRW is safe for drinking. When Aklan [4] analyzed samples collected from storage tanks, he has found total coliform exceed NWRA and WHO standards [12] which indicates that storage tanks are presenting sources of contamination if not cleaned and disinfected by chlorine regularly. Tank maintenance is recommended on a regular basis, particularly if observations and tests suggest large amount of debris entering the tank or any signs of wastes in the water.

CONCLUSIONS AND RECOMMENDATIONS

Rainwater harvesting is a potential parameter to be used both in saving the costs of groundwater supplied by the water supply utilities and private providers and preserving the precious non-renewable fossil groundwater. With acceptable accuracy, the surface area of rooftops in Sana'a city has been calculated using Google Earth data resulting in an area of 60.3 km^2 used in the calculation of the volume harvested. It is estimated that an annual potential rainwater volume of 11,722,320 m^3 can be harvested in Sana'a resulting in an annual rainwater savings of the groundwater by 20% of the total consumption from (SLWSSA + private providers). A 43.4% potential water saving can be reached when stopping the supply of the same amount of 11,722,320 m^3 from private providers. Simple calculation of the costs saved by households when using rainwater harvesting rather than the private providers supply is 82,056,320 US$/year. Water quality tests have been performed and found that RTRWH quality is within the limits of NWRA and WHO guidelines [12]. However it has been found from other studies that common indicators of total coliform and fecal coliform has higher values with samples taken directly from storage tanks than suggested by NWRA and WHO [12]. This indicates that regular cleaning and disinfection should be done. Proper installation of wire mish, first flush and filtration systems will reduce the high turbidity value found in the samples. It is recommended that households should install filters when using rainwater for drinking.

Municipalities and local authorities should develop appropriate legislation to allow residents to employ rainwater harvesting in their households. They should provide certain technical support and financial aid if needed to residents. Awareness and educational campaigns should be conducted to encourage people to use the rainwater harvesting systems. It is recommended that local governments should began using rooftop harvesting in their buildings.

Nomenclature

C	Roughness Coefficient
MENA	Middle East and North Africa
l/c/d	Litter per capita per day
LWSSA	Local Water Supply and Sanitation Authority
MoPIC	Ministry of Planning and International Cooperation
NWRA	National Water Resources Authority
NWRA-SB	National Water Resources Authority- Sana'a branch
PET	Potential Evapotranspiration
PWS	Potential Water Saving
PRWH	Potential Rainwater Harvested
PWD	Potential Water Demand
PWS	Potential Water Savings
RTRWHS	Rooftop Rainwater Harvesting System
TRMM	Tropical Rainfall Measuring Mission

REFERENCES

1. Roudi-Fahimi, F., L. Creel and R. De Souz, 2009. Finding the Balance: Population and Water Scarcity In The Middle East and North Africa, Population Reference Bureau, Washington, DC, USA, Website: www.prb.org.
2. Taher, T. and S. Saleh, 2010. Guidelines for Roof Top Rainwater Harvesting Systems in the Republic of Yemen, Draft report.
3/. CSO, Central for Statistics Organization, 2007. http://www.cso-yemen.org/ content.php?lng =arabic&id=365.
4. Aklan, M., 2011. The Potential of Rooftop Rainwater Harvesting for Sana'a Yemen, a thesis submitted for the fulfillment of the requirements of MSc degree, University of Applied Sciences- Cologne.
5. Abdulla, F.A. and A.W. Al-Shareef, 2009. Roof rainwater harvesting systems for household water supply in Jordan, Elsevier publication, Desalination, 243: 195-207.
6. Gould, J.E., 1993. Rainwater catchment systems technology: Recent development in Africa and Asia. Proc. Science and Technology in the Third World Development Conference, University of Strathcylde, Glasgow.

7., Vojdani, F., 2008. Water Harvesting and Groundwater Recharge in Arid and Semi-Arid Regions (Tehran Mega City's 2008 Water Crisis Challenges), The 3rd International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum, Ryadh, Saudi Arabia.

8. Taher, T.M. and S.A. Saleh, 2011. Rooftop Rainwater Harvesting as a Substantial Resource in Major Modern Cities Facing Droughts: a Case Study Sana'a City, International Conference on Drought Management Strategies in Arid and Semi-Arid Regions, Muscat, Oman, 11-14 December.

9. NWRA, National Water Resources Authority, 2010. Rainfall Data of Sana'a, Taiz and Ibb, Yemen.

10. Almazroui, M., 2010. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998-2009, Atmos. Res, doi: 10.1016/j.atmosres, 11.006, 2010.

11. Zabara, B., A. Babaqi, R. Soppe and D. Plinston, 2007. Technical note on rainfall in Sana'a, Water and Environment Center, WEC, Sana'a, Yemen.

12. WHO, 2008. Guidelines for Drinking-water Quality, third edition, Volume 1 Recommendations, Geneva.

13. Hanesh, A., F. Badani, R. Sofi, A. Zubairi, S. Al Koli, C. Christine Laures and B. Gerhager, 2007. Performance Indictors Information System (PIIS), Minstry of Water and Environment, Sana'a, Yemen.

14. Ward, C., S. Beddies, T. Taher, A. Sahooly, B. Gerhager and N. Al Harethi, 2009. Equity and Efficiency in Yemen's Water Reform- a sector Study and Poverty and Social Impact Analysis, Ministry of Water and Environment, Sana'a, Yemen.

15. WEC, 2010. Analysis of Private Water Providers in Urban and Pre-Urban Areas in Sana'a: Field Survey of Service Providers, Sana'a, Yemen.

16. Harteck, H., I. Karuky and S. Sharafaddin, 2008. Design and Construction of Roof Tops Rainwater Harvesting Tanks Using Ferro Cement Materials, Social Fund for Develpoment (SFD), Sana'a, Yemen.

17. Mosley, L., 2005. Water Quality of Rainwater Harvesting Systems", SOPAC Miscellaneous Report, pp: 579.