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Quality Assessment of Rainwater from Rainwater Harvesting Systems in Jerdab, Kingdom of Bahrain

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Abstract— **Rainwater is considered as the purest water resource and can be purified easily by filtration and some cases by disinfection. Rainwater harvesting is a technique used to collect water as runoff from building roofs and paved areas and store it in metal or concrete tanks. The paper deals with the quality assessment of rainwater from water harvesting systems, encouraging water harvesting in Jerdab and sustainable management of water resources and optimum utilization of rainwater by building and construction of water harvesting systems to meet the requirements of the Jerdab area from domestic water supply and for agriculture. Two samples of rainwater were collected from the roof and paved way from one site located in Jerdab. The analyzed parameters are PH, conductivity, TDS, color, Salinity, Turbidity, T.Hardness, Nitrate, Nitrite, TOC, T.Nitrogen, T.coliforms, T.Fecal coliforms. The obtained results of the quality assessment were largely consistent with those reported by many other researchers including WHO standards. The obtained results indicate that, the rainwater from a rainwater harvesting system can be of consistently high quality through the selection of appropriate catchment and storage materials and the application of proper treatment by filtration and disinfection.**

Index Terms— **Water Quality, Rainwater, Water harvesting systems**

I. INTRODUCTION

Water is a very important need for all creatures on this planet; we need water to drink, to wash our hands, to shower, to cook, to water plants, to generate our power and run out our industries. With time, human population is increasing and human beings are developing, such development needs more consumption of water, and if we did not find a way to recycle and save water the whole planet will die as every creature needs water because it is the essence of life. Human being underestimates the need of water and every person must change his/her lifestyle on a way that saves water as much as possible.

The term water harvesting was probably used first by Geddes of the University of Sydney. He defined as the collection and storage of any form of water either runoff or creek flow for irrigation use. Meyer's of USDA, USA has defined it as the practice of collecting water form an area treated to increase runoff from rainfall. Recently Currier, USA has defined it as the process of collecting natural precipitation from prepared watershed for beneficial use. Now a day water harvesting has become a general term for collecting and storing runoff water or creek flow, resulting from rain in soil profile and reservoirs both over surface/ under surface. Previously this was used for arid and semiarid areas, but recently their use has been extended to sub humid and humid regions too. Every raindrop that fall from the cloud is very soft and the cleanest water sources in this world [1]. Rainwater is a part of hydrologic cycle; the never-ending exchange of water from the atmosphere to the ocean and back again as rainwater. The precipitation like hail, rain, sleet, snow and all the consequently movement of water in nature forms are from part of this cycle. Rainwater quality always exceeds the surface water and comparable to ground water because of it does not come in contact with soil and rocks where it can dissolve salts and mineral which is harmful for potable and non-portable uses. In the other hands, rainwater is valued for its purity and softness. The quality of water collected in a rain water harvesting system is affected by many factors, including:

1. Environmental conditions such as proximity to heavy industry or major roads, the presence of birds or rodents [2].
2. Meteorological conditions such as temperature, antecedent dry periods, and rainfall patterns [3].
3. Contact with a catchment material and the dirt and debris that are deposited upon it between rainfall events [4].
4. Treatment by pre-cistern treatment devices such as filtration or first-flush diversion [5].
5. Natural treatment processes taking place within the rainwater cistern [6].
6. Treatment by post-cistern treatment devices such as particle filtration, ultraviolet disinfection, chlorination, slow sand filtration or hot water systems [7].

II. WATER RESOURCES IN BAHRAIN

When considering the necessity for water conservation it is important to consider the available water resources and options for creating or accessing additional water supplies in order to facilitate demand management. In general, water resources in the geographic region are limited. In 2011, the total amount of water resources in Bahrain amounted to only 471.9 Mm3 . This amount of water supply is unable to meet the current water demand. At present, the 471.9 Mm3 of water resources are divided nearly equally between traditional and non-conventional water resources. The current distribution shows that 54.6 % of Bahrain's water resources are coming from groundwater, while only .01 % is coming from drainage. The remaining 45.3% of water resources, however, are derived from nonconventional methods: desalination at 35.6% and treated sewage effluent (TSE) at 9.7% [8].

III. BAHRAIN AVERAGE PRECIPITATION

In Bahrain there are two main seasons: a cooler season from December to February, and a hot season from April to October, within which we can distinguish a very hot period from May to mid-October. March and November are transitional months, warm but without excesses.

Due to the influence of sea, the temperature range between night and day is low, and the humidity is high, except when the winds blow from the interior of Arabia.

In winter, from December to February, temperatures are usually pleasant. The sun often shines, and the rains are scarce and sporadic. At times there can be even warm days, with peaks around 30 °C (86 °F), when the wind blows from the south, but in these months this wind is rare.

Sometimes, especially in January and February, cold air masses from the north can bring some cool and windy days, in which the daytime temperature can drop to around 15 °C (59 °F), and that of the night to around 10 °C (50 °F).

Summer in Bahrain is very hot and sunny, with highs around 38/40 °C (100/104 °F) from June to September; lows are around 29/32 °C (84/90 °F) from June to September. However, hotels, offices and restaurants are equipped with air conditioning. Moisture gradually increases over the summer, so August and September are the months with the worst combination of humidity and temperature.

Here are the average temperatures of the capital Manama.

Manama - Average temperatures

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min (°C)	14	16	18	23	27	30	31	32	29	26	22	17
Max (°C)	21	22	26	31	36	39	40	40	38	34	28	23

Table (1) Average temperatures

The prevailing wind in Bahrain is the Shamal, which is moist and blows from the north-west, more frequently in the summer months. Another wind, hot and dry, the Qaws, can blow throughout the year, but preferably in spring; it blows from the south and it's able to raise the temperature to about 30 °C (86 °F) in winter and to about 40 °C (104 °F) and above from April to October, while drastically lowering relative humidity; it is also able to raise dust and sand storms.

As mentioned, the climate in Bahrain is desert, in fact just 70 millimetres (2.8 inches) of rain fall per year; most of the rains occur in the winter months, however, they are irregular, and occasionally in winter there can be some intense rainfalls, which, being concentrated in a few hours, can cause flash floods.

Here is the average precipitation.

Manama - Average precipitation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Prec.(mm)	15	16	14	10	1	0	0	0	0	1	4	11	71
Prec.(in)	0.6	0.6	0.6	0.4	0	0	0	0	0	0	0.2	0.4	2.8
Days	2	2	2	1	0	0	0	0	0	0	1	2	10

Table (2) Average Precipitation

Precipitation in Bahrain increased to 29.46 mm in December from 3.47 mm in November of 2015. Precipitation in Bahrain averaged 6.48 mm from 1901 until 2015, reaching an all time high of 104.31 mm in January of 1969 and a record low of 0 mm in April of 2000. [9]

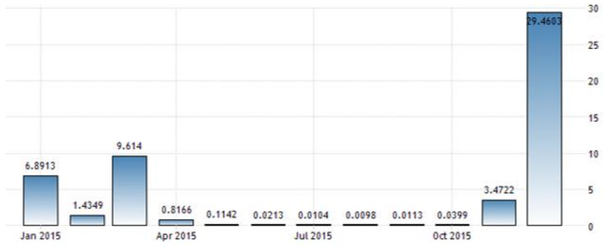

Fig. 1 Bahrain Average precipitation

Bahrain Climate	Last	Previous	Highest	Lowest	Unit	
Precipitation	29.46	3.47	104.31	0.00	mm	[+]
Temperature	18.37	24.14	37.69	12.16	Celsius	[+]

Table (3) Average precipitation and temperatures

IV. TREATMENT

The advantage of water from rainwater harvesting systems is that depending on type of application, it could be used in some cases without further treatment such as public garden irrigation and deferent exterior applications. In case of application for interior uses a filtration and prober disinfection are recommended.

To improve the quality of rainwater, a variety of treatment technologies have been developed to mitigate the contamination, which takes place following contact with a catchment surface. One treatment technique popularized in Australia is the first-flush device, which is used to divert the first 0.8–3.5 mm of rainfall from storage in the rainwater cistern [12]. The rationale for these devices is the first-flush phenomenon reported in the literature, whereby the concentration of contaminants decreases exponentially during the first few millimetres of rainfall. This trend has been observed for a range of contaminants including suspended solids, PAHs, organic compounds and trace metals [11]. Following storage in a rainwater cistern, particle filtration and UV disinfection are other means by which rainwater can be treated. A study by Kim et al. (2005) examined the performance of 5 mm and 1 mm metal membrane filters (comparable to polymeric membrane filters) and UV disinfection on roof-harvested rainwater. The Korean study observed a 50% reduction in the number of total coliforms for rainwater samples treated using a UV lamp, even at the low intensity of IUVA ¼ 5.4 W m22 [14]. Filtration was also found to reduce the number of total coliforms by rejecting them at the membrane surface. A removal efficiency of 78% and .98% was achieved with 5 mm and 1mm metal membrane filters, respectively. In addition to the rejection of biological organisms, 80% and 95% of the particles present in the rainwater were removed by the 5 mm and 1mm metal membrane filters, respectively (Kim et al. 2005). Slow sand filtration is another method shown to be effective at improving the quality of rainwater. The uncoated sand filter was shown to achieve a bacterial removal of ,21%, whereas the iron hydroxide-coated sand reduced total and fecal coliforms by 97–99%. Both turbidity and the concentration of the heavy metals zinc and lead showed improvement following slow sand filtration. The turbidity of rainwater collected from a concrete catchment surface was reduced from 8.2 to 0.5–2.4 NTU following slow sand filtration. Zinc levels dropped from 3.6 to 0.1 mg l21 and lead was reduced by 90% to 0.01 mg l21 on samples collected from a galvanized iron roofing material [10]. Storing rainwater at temperatures typical inside a residential hot water tank (50–708C) has also been shown to reduce biological contamination. A study of 27 rainwater systems at Figtree Place in Australia found that all coliform bacteria were removed after storage in the hot water tank in the 23 samples collected. This removal efficiency was achieved with rainwater of fairly poor quality. The average number of total coliforms throughout the study was 166 CFU/100 ml, with 20 CFU/100 ml fecal coliforms [7]. Another study showed a similar inactivation for Escherichia coli at sub-boiling temperatures. Spinks et al. [12] observed an almost 5 log reduction in E. coli concentrations when the water was maintained at 608C for a period of 5 minutes in a laboratory setting [13].

V. DESCRIPTION OF STUDY AREA AND RAINFULL PATTERNS

Two samples were collected from the roof and paved areas in Jerdab area in month of December, which witness the highest precipitation rainfall in the year. The average annual precipitation for Bahrain is 52.16 mm. The average daily temperature shown in Fig. 1 is of 37.690 C and average night temperature is of 12.160 C in in the winter [9]. Rainfall data shown in Fig.3 for Bahrain was recorded in the period 1969-2000.

VI. BENEFITS OF WATER HARVESTING

Rainwater harvesting systems have many advantages for users, community, government and environment as follows:

a) Rainwater harvesting systems are low cost and easy to install, operate, handle and maintain.
b) Rainwater is almost clean.
c) Rainwater can be used in potable and non-potable applications such as toilet flushing, laundries, mechanical systems, washing car, landscaping and for bathing water.
d) Rainwater harvesting has few negative environmental impacts.
e) Reducing water bills and demand on your community's drinking water supply by using rainwater for flushing toilets, washing clothes, watering the garden and washing cars.
f) Rainwater is free from pollutants, salts, minerals, and other natural and man-made contaminants.
g) Rainwater can reduce the burden for new investment to replace the ageing systems and adding the water supply infrastructures.

VII. SAMPLE COLLECTION AND LABORATORY ANALYSIS

A 300-ml glass bottle was used to collect the rainwater samples. The bottles were disinfected for 30 minutes. The following parameters were analyzed: ph, conductivity, TDS, color, Salinity, Turbidity, T. Hardness, Nitrate, Nitrite, TOC, T. Nitrogen, T. coliforms, T. Fecal coliforms.

VIII. RESULTS AND DISCUSSION

A. Chemical and physical properties:

The chemical and physical rainwater quality data for both roof's sample and paved area's sample are presented in table1 as follows:

Parameter	Unit	Roof's sample	Paved area's sample	WHO limits 1996
PH	--	7.31	7.69	7.0 - 9.2
conductivity	µS/cm	310	9190	-
TDS (mg/L)	mg/l	156	5190	500-1500
Salinity	mg/L	0.06	4.52	200
Turbidity	FNU	289	494	5-25
T.Hardness	mg/L	138	1820	100-500
Nitrate	mg/L	0.1	1.5	50
Nitrite	mg/L	0.06	11	2
TOC	mg/L	3.2	8.4	-
T.Nitrogen	mg/L	1.7	17.92	-

Table (4) Chemical and physical properties analysis of rainwater

The results presented in Tables 4, show that a number of trends are evident. The pH in both the roof's sample and the paved area's sample is within the WHO standards.

The turbidity of rainwater for both samples are above the WHO standards. The concentration of TOC in roof's sample is within the standards: however, the roof's sample has high concentration, which exceeds the standards of raw water. Total nitrogen was detected in low concentrations in the roof's sample and little bit more concentration in the paved area's sample.

B. Microbiological analysis:

The microbiological properties analysis of rainwater samples shown in table. 5, as follows:

Parameter	Unit	Paved area's sample	Who limits
Total Coliforms	CFU/100ml	64	≤10 cfu/ 100 ml
Fecal Coliforms	CFU/100ml	112	<10 cfu/ 100 ml

Table (5) Microbiological properties analysis of rainwater

The results of microbiological properties analysis show that the water sample contains little bacteria indicating beginning of the pollution of rainwater. It means that the microbiological has to be improved. In such case, disinfection may be applied. Chlorination is the most common and easily applicable practice. Chlorine is applied for the deactivation of most microorganisms and is also reasonably cheap. Chlorination is generally applied after the harvested rainwater has been removed from the storage tank, as chlorine may react with organic matter to form undesirable by-products, which can settle to the bottom of the storage tank. Chlorination should meet the level of 0.4–0.5 mg/l free chlorine [17], which is considered to be effective. This can be done by applying chlorine tablets or chlorine solution. The other solution that can be used is slow sand filtration, which is a cheap method to improve the bacteriological quality of harvested water. Slow sand filtration is a biological treatment process rather than a physical filtration process [17]. The filter is constructed carefully by using graded sand layers that have the coarsest fraction on top and finest at the base. A constant flow of water through the filter is essential for it to be effective. Effective slow sand filtration can produce water with a very low nutrient level. The main restriction of this method is that the micro-organisms can be only reduced rather than completely cleared in the treated rainwater.

IX. CONCLUSION

Harvested rainwater can play an important role in substituting and supplementing water supply from the water supply facilities. The potential of potable water savings can be substantial by using rainwater-harvesting systems. Rainwater harvesting and its treatment is affordable by individuals and will be highly useful in drought prone areas.

The results obtained showed that, chemical and physical properties of rainwater are affected by the catchment materials. The rainwater cached by surfaces made of concrete roofs is of higher quality than that made from asphalt in paved areas. The properties of asphalt caused deterioration of rainwater quality, due its ability to absorb atmospheric particles that sediment on the catchment surface between rainfall events. The pH of rainwater cached in concrete surfaces tended to be slightly acidic, whereas rainwater pH cached in asphalt surfaces was slightly basic. Although the quality of rainwater could be influenced by the environmental conditions, the rainwater cached by the rainwater harvesting systems is of high quality using appropriate materials for catchment surfaces and treatment. The obtained results also indicate that the rainwater could be treated effectively by the combination of filtration and chlorine disinfection.

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