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ORIGINAL ARTICLE

Rooftop level rainwater harvesting system

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Abstract Unfortunately, in Lebanon and other countries in the Middle East region, water becomes scarcer than ever before, and over the last decades the demand on domestic water has increased due to population and economic growth. Although rainwater harvesting is considered to be a safe and reliable alternative source for domestic water, the inconvenience or impracticalities related to the cost and space needed for the construction of ground or underground storage tanks makes this practice not widely common in rural areas and rarely implemented in urban cities. This paper introduces a new technique to rainwater harvesting which can be easily used in both rural and urban areas: it collects and stores rainwater directly in tanks already installed on building roofs and not necessarily in special ground or underground ones. If widely adopted in Lebanon, this technique could help in: (1) collecting around 23 MCM (70 % of the current deficit in the domestic water supply) of rainwater and thus increasing the available water per m^2 of building by 0.4 m^3 per year, (2) saving around 7 % of the amount of electric energy usually needed to pump water from an aquifer well and ground or underground tank, and (3) considerably reducing the rate of surface runoff of rainwater at the coastal zones where rainwater is not captured at all and goes directly to the sea.

Keywords Middle East · Lebanon · Rainwater harvesting · Climate change · Water shortage

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Introduction

The optimization of the use of all available water resources and the increase of the efficiency of the water distribution networks are considered to be the essential steps to follow if the water shortage problem being faced in water scarce countries is to be solved. The population increase and economic growth in the Middle East region will inevitably lead to a dramatic decrease in available water per capita per year. Climate change is also seen as another challenge that will greatly reduce natural water resources in the region (Lebanon is no exception) by affecting precipitation, temperature, evaporation, relative humidity and solar radiation. The research activities to find nonconventional water resources have noticeably increased during the last decade for its importance in a country future water budget. It is reported in Mourad et al. [1] that the reuse of grey water in toilet flushing can save up to 35 % of drinking water. The technique of rainwater harvesting, which is a technique to collect and store rainwater in a ground/underground reservoir for later domestic or agriculture use, is considered one of the most important nonconventional water resources in the world. It is widely used to alleviate problems of water shortage [2]. For example, Australians broadly collect rainwater in ground (underground) tanks due to the water shortage in rural areas. Up to 50 % of the needed water for toilet flushing, laundry, hot water, and outdoor irrigation in multi-unit residential buildings in Australia can be provided from rainwater harvesting [3]. A significant percentage of the non-potable water needs of multifamily residential buildings in New York City can be supplied with roof harvested runoff [4]. In Syria, it was found that a potential increase in water availability due to rainwater harvesting could be as much as 35 MCM [5]. A maximum of 15.5 MCM of water can be collected from

Fig. 1 Schematic diagrams for rainwater harvesting systems

roofs of residential buildings in Jordan [6]. Similar studies showed that using rainwater harvesting can give high percentage of potable water saving in Sweden, Brazil, and UK [7, 8]. There are also some rainwater harvesting techniques that can help in reducing soil erosion. In Syria, for example, large semi-circular bunds are used to reduce erosion of agricultural soil in the Badia rangeland, which is located in the eastern part of Syria with an annual rainfall less than 100 mm, by 16–53 % [9]. Rainwater harvesting can be also used to feed ponds (reservoirs) during the wet season using topographical maps and GIS [10, 11]. Figure 1 shows the designs for the mostly used techniques in rainwater harvesting system in urban and rural areas. Rainwater is collected from rooftops/paved surfaces, filtered and then charged into wells or stored in tanks situated at the ground/underground level for later consumption [12].

These methods for rainwater storage should always be accompanied with a water pressure pump (see Fig. 2) if the collected rainwater is to be consumed at a level higher than the one for rainwater storage tank, which is the case of all modern residential buildings in Lebanon and elsewhere in the region. Thus, households would not be able to benefit from the harvested water unless they have permanent access to electric energy sources whenever water is needed. However, this is not the case in Lebanon and many other countries in the Middle East where electricity is as scarce as water.

In contrast, this paper shows an unconventional technique for rainwater harvesting in which the rainwater is collected and directly stored in already existing roof tanks so that the water pressure pump would not be needed. But, before going into the details of this technique, we first study the potential of harvesting rainwater for domestic use in Lebanon.

The potential of harvesting rainwater in Lebanon

Lebanon's water resources are under stress. Available water including rivers and springs, storage dams and groundwater (estimated at 2000–2700 MCM per year) exceed projected water demand (about 1800 MCM in 2035), but widespread pollution and substandard water infrastructure restrict the Government's ability to meet water demands in the future. While the current annual expected demand is 1483 MCM, the undermining reality of all data on water resources is that Lebanon's four water establishments, combined, are currently exploiting only about 1377 MCM i.e. 106 MCM less than what is potentially needed (see Table 1). The fact that the current expected annual demand on domestic water in Lebanon is around 31 % of the total exploited water would cause around 33 MCM (31 % $\times$ 106) deficit in the volume of

Fig. 2 The plumbing diagram for a rainwater harvesting system

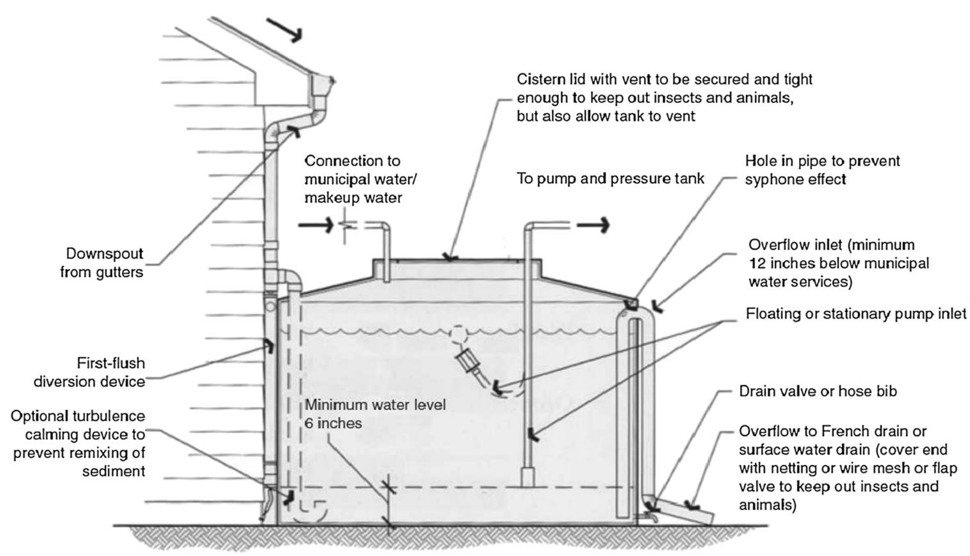

Table 1 The MCM estimated annual water demand by sector (2010–2035)

Sector	2010	2015	2020	2025	2030	2035
Domestic	505	460	427	467	512	562
Industrial	152	138	128	140	154	169
Tourism	6	8	10	13	16	21
Irrigation	810	877	935	983	1021	1050
Total	1473	1483	1500	1603	1703	1802

Source: [13]

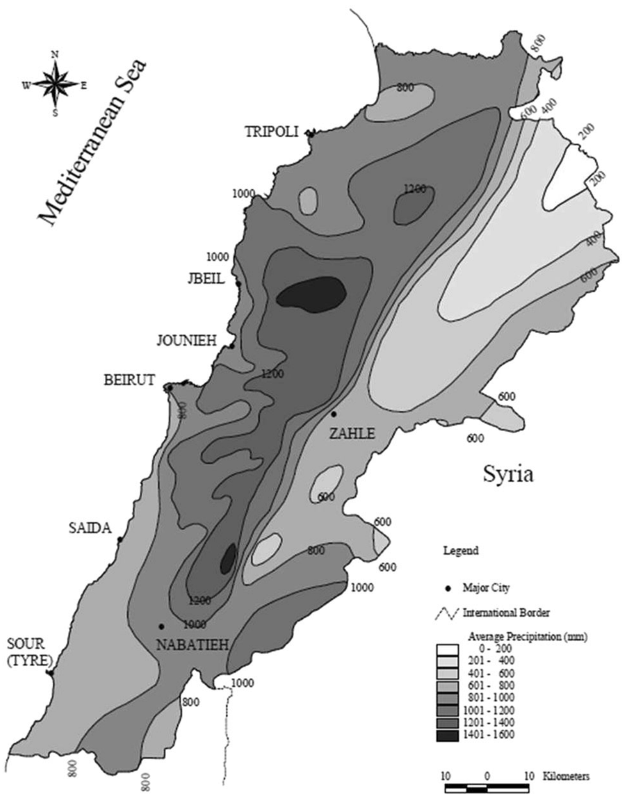

Fig. 3 Climatic zones in Lebanon

water needed for domestic use (460 MCM), and far more in the coming years if alternatives for domestic water resources were not provided [13].

Lebanon could benefit greatly from rainwater harvesting given its Mediterranean climate with an average annual rainfall of 823 mm although this varies from 700 to 1000 mm along the coast and from 1500 to 2000 mm in the mountains decreasing to 400 mm in the eastern parts and to approximately 200 mm in the northeast (see Fig. 3). Rain occurs from 80 to 90 days a year, mainly between October and April [14, 15].

To estimate the potential of rainwater harvesting in Lebanon, rainfall data, climatic areas, population, and housing type in each governorate were considered. For roof water harvesting we follow the methodology detailed in Mourad and Berndtsson [5]. That is the total roof area in each governorate is calculated based on the average area and number of typical houses. The potential rainwater harvesting volume is estimated based on the total roof area, the average annual rainfall, and the runoff coefficient. Then, the increase in domestic water availability per m^2 of building as well as the percentage of the potential volume of harvested rainwater of the current annual domestic water deficit in Lebanon are calculated.

Table 2 Average precipitation and population in the Lebanese Governorates

Governorate	Area (km^2)	Rainfall (mm/year)	Population (million)
Mount Lebanon	1985	1200	1.97702
North Lebanon	2024.8	1000	0.9644
Beqaa	4429	600	0.57864
South Lebanon & Nabatiehn	1993.4	750	0.81974
Beirut	19.8	600	0.4602
Total	10,452		4.8

Table 3 Roof runoff in Lebanon

Governorate	FA ($10^3 \times m^2$)	Rainfall (mm/year)	HW (MCM)
Mount Lebanon	26,349	1200	12.647
North Lebanon	11,030	1000	4.412
South Lebanon & Nabatieh	10,417	750	3.125
Beqaa	7353	600	1.764
Beirut	6128	600	1.470
Total	61,277		23.418

Around 60 % of the population in Lebanon live in multiple floor buildings in the costal area that receives an abundant rainfall. Table 2 presents the population as well as the area and average annual rainfall in each of Lebanon's governorates.

The potentially harvested water (HW) for each governorate is estimated by the following equation:

$$HW = R \times A \times K \quad (1)$$

where R is the average rainfall in the target governorate, A is the total roof area and K is the runoff coefficient of 80 %, which indicates a loss of 20 % of the rainwater that is discarded for roof cleaning and evaporation [6].

The harvested rainwater for each governorate was estimated by Eq. (1). According to Table 3, it is seen that the total potential of harvested water from roofs in Lebanon could reach 23 MCM if we assume that only 50 % of the

Fig. 4 Roof water tanks

rainfall is effectively harvested. Note that the floor area of residential buildings for each governorate was estimated using the Census of Buildings, Dwellings and Establishments (CBDE) performed by the Central Administration of Statistics in 2004,[1] which counts 408,515 buildings; 175,661 (43 %) in Mount Lebanon, 73,533 (18 %) in North Lebanon, 69,448 (17 %) in South Lebanon and Nabatieh, 49,022 (12 %) in Beqaa, and 40,852 (10 %) in Beirut. The floor area (FA) of each building was averaged to 150 m^2 in all governorates.

These 23 MCM of rainwater can cover around 70 % of the current deficit in the volume of water needed for domestic use (33 MCM) and increase the available water per m^2 of building by 0.4 m^3 per year in Lebanon.

System design

The design of a rainwater harvesting system must take into consideration factors such as the contributing rooftop area, the rainfall patterns, and the anticipated usage as well as the space available for storage, cost and aesthetics.

The catchment area should be calculated based on the footprint created by the roof and not by the square footage of the roof surface. It is the flat roof of residential buildings in our case. The storage tank, which is sometimes called a cistern, is the primary storage component of the system and is usually the most expensive component of the rainwater harvesting system. Material, size, and location of storage tanks are dependent upon the anticipated purposes of the collected rainwater. We use the already existing roof water tanks (see Fig. 4) for the primary storage of the collected rainwater.

The water's use defines the degrees of contaminant removal that may be required. Our rainwater harvesting system is intended for direct domestic use. Thus, a top drain cover having coarse mesh on its sides and a multi-stage water filter are used to filter out large debris, dust and bird droppings. A first flush can also be diverted by not activating the system on the first rainfall (see Fig. 5).

The conveyance in our rainwater harvesting system is not as usual as the roof drain conduit, which is usually composed of a series of gutters, downspouts and pipes that conveys precipitation from the roof through the piping and to the cistern. It is rather an ordinary water pipe to pump the accumulated rainwater into the water storage tank through a water filter. The pump used for the conveyance purpose can be as small as the 12 V, 10 W water pumps (see Fig. 6). Solar pumps of this type are available for locations without electricity.

A bypass or overflow pipe is usually necessary for an ordinary rainwater harvesting system so that continuing water flow is directed away from the full water tank to protect the area from erosion. No need for such an overflow pipe in our design as when the roof water tank has reached capacity (i.e. the tank float switch is deactivated), any additional rainwater will be drained to the street (or to a ground/underground storage tank) through the overflow of the roof drain and the pump will be off. The water pump will start pumping if and only if the water level in the storage tank is lower than its maximum and the roof rainwater gauge (the drain float switch) is activated. The outlet pipe, installed above the bottom of the storage tank, is used to supply water to the distribution system that ultimately delivers the captured rainwater to its desired location, e.g. the apartments of the residential building in our case. No need for a pump to provide adequate pressure to draw water for some applications as the gravity will do this job.

In addition to its impact on increasing available water per capita per year, the implementation of our system is simple and does not need any extra space for storage. Its cost is so comparable to buying few cisterns of water during the dry season and even far less than the ordinary rainwater harvesting systems. Next we discuss the expected savings one could achieve through the use of our system in Lebanon.

Expected savings in Lebanon

The limiting factors to instal rainwater harvesting systems in most residential buildings in Lebanon are the space available for storage, cost and aesthetics. Our technique for rainwater harvesting does not only provide a solution to cut dramatically the cost and keep the aesthetics of buildings, but rather help in reducing the electricity bills of households having access to either aquifer wells or water utility service. The savings that a multifamily residential building could reach through the use of our rainwater harvesting system are discussed using the building example below.

[1] http://www.cas.gov.lb/index.php/census-of-building-cbde-en. Accessed on: 14/11/14.

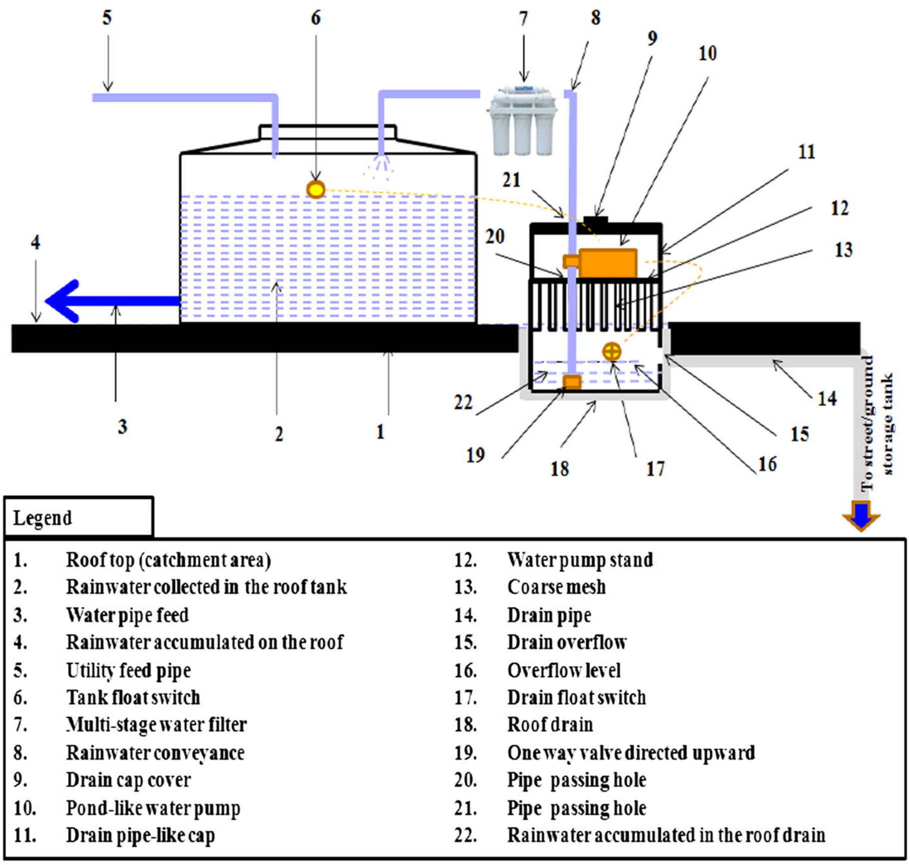

Fig. 5 Rooftop level rainwater harvesting system

Fig. 6 The water pump

First, the building is located in Beirut. Second, it has a height of 22 m and a rooftop area of 400 m^2. Third, the residents (75 persons) of this building rely only on a water well of 150 m depth for their domestic water supply. Fourth, the average monthly precipitation for Beirut in 2013 was as shown in Fig. 7. The expected amount of water that can be harvested from rainfall each wet month would be as much as shown in Table 4. Here 80 % of the rainfall is assumed to be effectively collected.

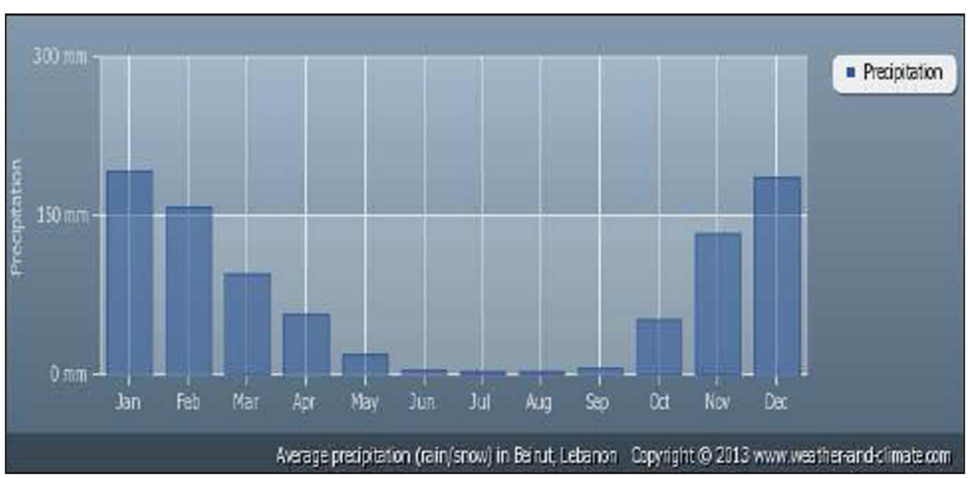

Fig. 7 Average monthly precipitation (2013)

Table 4 The average monthly rainwater collection

Governorate	Rainfall (mm/year)	HW (m^3)
January	180	46
February	155	40
March	70	18
April	40	10
May	20	5
October	30	8
November	90	23
December	180	46
Total	765	196

Table 5 The total cost for the rooftop level rainwater harvesting system

System materials (part no. in Fig. 5)	Cost (€)
1 × 10 W 12 V water pump (10)	20
2 × Float switch (6, 17)	17
1 × Water level control circuit	9
1 × Pipe-like drain cap (11)	25
1 × Multi-stage water filter (7)	38
All necessary pipe and fittings	51
Total material cost	160
Total labour cost	94
Total cost	254

This volume of water increases the availability of domestic water for the residents of this building as much as 196 m^3 a year. It serves its residents for 26 days if every resident consumes on average 100 L a day. It also reduces the rate of power consumption for water pumping of this building by around 7 % a year: the domestic water is only provided from rainwater harvesting and not from the building's aquifer well, and thus, the aquifer pump will not be operating for 26 days a year. Moneywise, this will be equivalent to 149€ and 1850€ per year, if the same volume of water was to be bought from a public water supply establishment (0.76€ per m^3) or water tankers (9.45€ per m^3), respectively. Of course, the unit price of public water supply would be far cheaper if the water establishments in Lebanon could meet the domestic water demand.

While a rainwater harvesting system usually installed at the Xeriscape Demonstration Garden in Edmond in Oklahoma, USA costs around 8500€ [12], our rooftop level rainwater harvesting system is far cheaper and costs around 254€,[2] which could be recovered in one season only. Table 5 shows the system materials and total costs for the rooftop level rainwater harvesting system.

[2] The prices of the system parts are obtained from Amazon.com.

Conclusion

Rainwater harvesting can be an important alternative to increase available domestic water and sustain groundwater. Lebanon could harvest around 23 MCM of rainwater a year and thus cover around 70 % of the current deficit in the domestic water supply estimated at 33 MCM. The proposed rainwater harvesting system is intended to collect and store rainwater in the already existing roof water tanks. It is far cheaper than the ordinary rainwater harvesting systems as it eliminates the need for a special ground or underground storage tank, submersible pump, first flush diverter and other less expensive materials. It could harvest as much as 196 m^3 a year if installed on a rooftop of 400 m^2 and receives an average yearly rainfall of 765 mm like the city of Beirut in Lebanon.

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