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Full Length Research Paper

Rainwater harvesting assessment for a small size urban area in Jordan

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Jordan is currently one of the world's four poorest nations in water resources. Rainfall harvesting from rooftops, roads, and parking lots can increase the water supply for various uses and help combat the chronic water shortage in Jordan. This work aimed at evaluating the potential for potable and non-potable water savings by using rainwater at Yarmouk University and to provide recommendations for increasing water efficiency use to minimize water waste and reduce the water bill. Results showed that a maximum of 99,000 m^3/y of rainwater can be collected, 37,000 m^3/y of it from roofs of buildings and 62,000 m^3/y from open impervious areas, provided that all surfaces are used and all runoff from the surfaces are collected. The estimated potential for potable water savings is 125 to 145% of the total domestic water supply. Chemical and biological analysis of harvested water indicated the requirement of water treatment for nitrate and pathogenic organisms. The study recommends the adoption of several measures toward decreasing water consumption and eventually the water bill.

Key words: Water harvesting, Geographic Information System (GIS), satellite images, Yarmouk University, Jordan.

INTRODUCTION

Jordan is one of the four most water scarce countries in the world, with only about 150 m^3 of water available per capita per year, and it is estimated that this will drop to be about 91 m^3 per capita per year by the year 2025 if no action is taken to meet the increasing need for water (Al-Adamat et al., 2010; Ministry of Water and Irrigation, 2008; Ministry of Environment, 2006). Based on the world's bench-mark standards, a country with less than 1000 m^3 of fresh water per capita per year is considered to be a 'water scarce country' (Winpenny, 2000). The scarcity of water resources in Jordan is dictated by climate, economic and social development and population growth (Salameh and Bannayan, 1993). More than 90% of Jordan receives less than 200 mm of rainfall per year (Jordan Ministry of Environment, 2006) and approximately 92% of the rainfall falls on Jordan evaporates back to the atmosphere (Ministry of Water and Irrigation, 2008). Therefore, rainwater harvesting is crucial for meeting future demand.

Rainwater harvesting (RWH) has been adopted in many parts of the world where conventional water supply systems have failed to meet the needs of the people (Handia et al., 2003). RWH is defined as being methods for collecting and storing rainwater using techniques such as pots, tanks, cisterns, ponds or dams (Appan, 1999; Prinz, 1995; Zhu et al., 2004). Rainwater harvesting also reduces urban flooding and prevents runoff from going into sewer systems, thereby reducing loads on treatment plants.

Rainwater harvesting is practiced on large scales in cities like Delhi, where rainwater harvesting is a part of the state policy (Centre for Science and Environment, 2010). Elsewhere, countries like Germany, Japan, United States, and Singapore are also adopting rainwater harvesting. Rainwater harvesting to supply drinking water for urban areas has a long history in semi-arid areas (Abdelkhaleq and Alhaj Ahmed, 2007; Pandey et al., 2003). Building dams to tap runoff, channeling it through

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canals and storing it in reservoirs, was practiced by ancient Jordanians about 5,000 years ago to provide drinking water to the old city of Jawa, northeast of Jordan using deflection dams (Abdelkhaleq and Alhaj Ahmed, 2007) and Umm el-Jimal city in the Early Roman period (de Vries, 1997). The Nabataean civilization in south Jordan before more than 2,000 years built dams to provide their capital city of Petra and other settlements with water for drinking and irrigation (Abdelkhaleq and Alhaj Ahmed, 2007; Oleson, 1995).

Collection of rainwater and construction of recharge dams has led to an increase in groundwater level in India by 2 m (Raju et al., 2006) and in the United Arab Emirates by more than 7 m (Murad et al., 2007). Dams were also built in Saudi Arabia, Oman, Qatar and United Arab Emirates for protection from flash floods and for recharge purposes (Al-Rashed and Sherif, 2000; Murad et al., 2007).

Rainwater harvesting from roofs or impervious surfaces has widely been used to provide urban dwellers with potable water supply in many parts of the developing world (Ibrahim, 2009; Gould and Nissen-Petersen, 2003; Handia et al., 2003; Kumar, 2004; Preul, 1994; Thomas, 1998).

Harvested rainwater is a renewable source of acceptable quality that is used for different purposes including drinking, cooking, watering gardens, and indoor and outdoor cleaning. Rainwater harvesting systems may also be suitable for irrigating farms and landscapes. The greatest advantage of a rainwater harvesting system is it low maintenance costs.

Construction of rainwater harvesting cisterns has been traditionally implemented in Jordan to deal with the water scarcity. The Jordanian government developed a strategy since the early 1990s for rainwater harvesting (Abdulla and Al-Shareef, 2009), in which new homes are required to have water collection storage tanks (Abdulla and Al-Shareef, 2009).

This study aims to investigate the feasibility of an urban water harvesting system at Yarmouk University to meet its future water demands and to reduce its increasing water bill.

Yarmouk University is in Irbid city, northern Jordan. It is a major academic institution that currently hosts more than 30,000 students and about 2,500 employees. The annual water consumption for different usages was 79,517 m^3 in the year 2008 and about 68,392 m^3 for the year 2009. About 90% of this amount was used for domestic and agricultural purposes. The sources of the water supply include the public network of the Water Authority of Jordan and tanks brought in from local groundwater wells. The water bill constitutes a heavy burden on the University budget. Therefore, it is hypothesized that rainwater harvesting from rooftops and impervious open areas on campus can meet the university water needs. This study will provide recommendations for increasing water use efficiency and minimize water waste.

Description of roof rainwater harvesting system

Every RWH system consists of a preferably waterproof catchment surfaces for collecting the rainwater (for example, roof or impervious ground surfaces), delivery systems for transporting rainwater from the catchment to appropriate storage tanks (for example, gutters or surface drains) and the storage tank (Figure 1). Ideal domestic rainwater-harvesting systems also include primary screening and first flush diverters and a water treatment unit (Environment Agency, 2008). However, most of the rainwater harvesting systems around the world are composed of the roof, gutter, down pipes, and a collecting tank. Gutters and downpipes are usually made of plastic or metal, as they are the most durable (DTU, 1997).

Plastic storage tanks are widely used to store rainwater in Jordan, however, concrete is the most common material. Tanks are built above or below ground. In above-ground tanks it is easy to detect cracks and leaks, easy to drain for cleaning, and water can be extracted via gravity and/or pumps. These are usually cost less than below-ground tanks and can be raised off the ground to increase water pressure (Texas Water Development Board, 2005). On the other hand, above ground tanks take up space, are subjected to weather conditions, and require anchoring when the water level in the tank drops. Below-ground tanks can save space, but usually need a pump to extract water from it, and it is hard to detect leaks or cracks. There is a risk of contamination from groundwater or flood-waters, and they can be damaged by tree roots, if the access point is left uncovered. There is a risk of children, adults and animals drowning or contaminating the water and they usually have large excavation costs. In addition, they can sometimes crack—especially when they are constructed on clayey soil. On the other hand they are good for preventing algal growth and keep the water cool (Abdulla and Al-Shareef, 2009).

METHODOLOGY

The amount of water that can be harvested is calculated according to the equation (Gould, 1993):

$$V = Sum (R*A*RC/1000) \tag{1}$$

where V is the annual volume of rainwater that could be harvested (m^3), R is the average annual rainfall (mm/y), A is the total area used for RWH (m^2), RC is the run-off coefficient (dimensionless), and 1000 is the conversion factor from mm to m (Gould, 1993).

Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface (Table 1). The run-off coefficient accounts for water losses due to surface material texture, evaporation, losses occurring

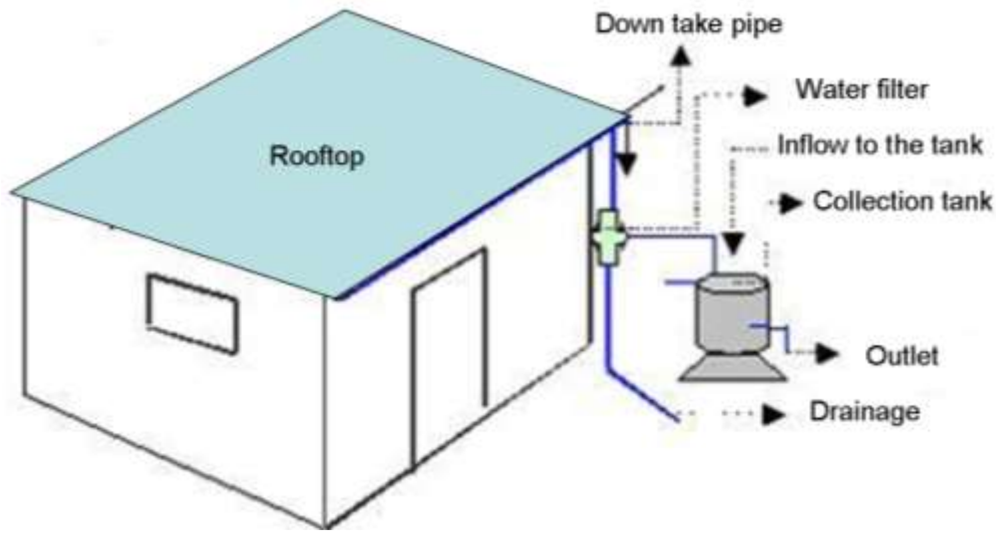

Figure 1. Typical roof water harvesting system.

Table 1. Volume of harvested rainfall and potential water saving in Yarmouk University campus.

Harvesting area	Area (m^2)	Volume (m^3)
Buildings rooftop	90,582	37,123
Open areas	151,080	61,924
Total	241,662	99,047

in gutters, spouts and storage tanks, surface cleaning and inefficiencies in the collection process. Also, wind direction and speed influence water loss from roof surfaces.

A satellite image from Google Earth (Figure 2) was digitized in ArcGIS 9.2 to obtain the areas of interest for rainwater harvesting at Yarmouk University, which are the rooftops and open areas (Figure 3). The long-term_average annual rainfall is obtained from the Irbid weather station located on campus. A runoff factor equal to 0.90 is used for this study. Then the potential saving percentage is calculated by dividing the potential volume of harvested rainfall by the annual domestic demand.

$$WS = 100\ VR / PWD \qquad (2)$$

WS is the annual potential for potable water savings (%), V is the annual volume of rainwater that could be harvested (m^3/y), and PWD is the annual potable water demand in the university (m^3/y).

Water samples were collected for quality assessment. These were taken from the main road at the northern gate of the university (#1) and from the roof of Ibn Sina building (#2), located exactly east of the north gate (Figure 4). The samples were analyzed for the following properties: nitrates, sulphates, chloride, lead, zinc, total dissolved solids, and pH. Bacteriological tests are usually based on detection of coliform bacteria which is a group of microorganisms recognized as indicators of pollution from human or animal faeces. Bacteriological analyses were performed for two types of bacteria: total coliform bacteria and the fecal indicator, Escherichia coli. Economic analysis were also investigated to estimate the costs of building underground storage tanks.

RESULTS AND DISCUSSION

Water harvesting

Using the map derived from the remote sensing data, it was possible to calculate the total roof area on campus. Table 2 shows that the potential annual average water harvested from rooftop is about 37,000 m^3, whereas that from open areas (roads and parking lots) is about 62,000 m^3/y, with approximately annual average total volume of 99,000 m^3. Results assume that all surfaces are used. The average harvested water is 0.41 m^3/m^2.

Then, to obtain potential annual water savings, water demand was compared to the volume of rainwater that could be harvested on campus. An annual average of 37,123 m^3/y of rainwater can be collected from campus roofs is equivalent to 46.69 and 54.28% of the total domestic water supply of the years 2008 and 2009, respectively (Table 2). When open areas are added, the total savings is much greater than the demand.

Water quality

The first flush of rainwater from roofs picks up most of the

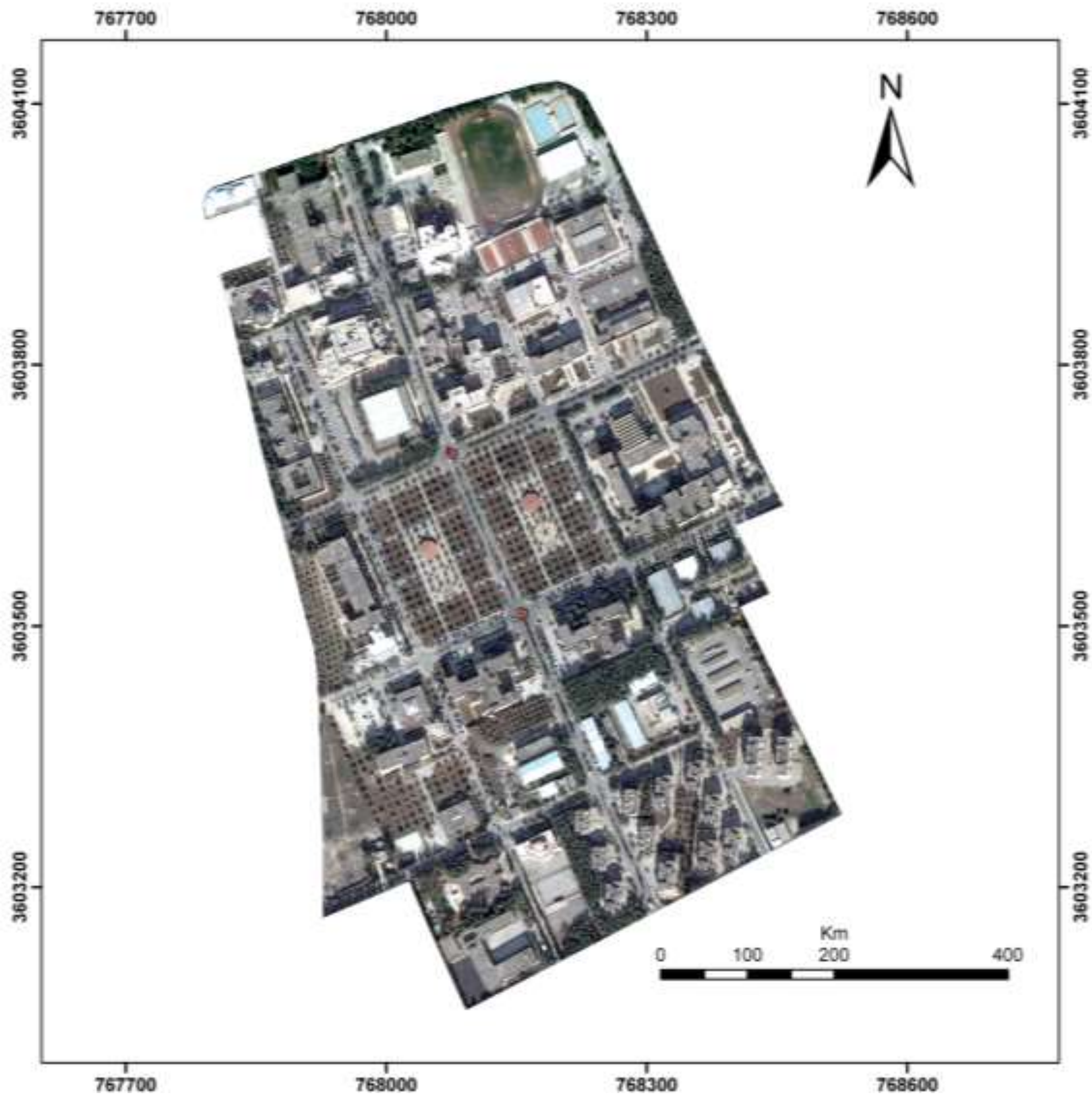

Figure 2. Satellite imagery of Yarmouk University campus from Google Earth.

contaminants during dry periods so it must be disposed. The quality of harvested rainfall is significantly controlled by the number of dry days preceding a rainfall event. Additionally, the quality of collected rainwater depends on how it is stored, therefore, storage tanks should be maintained periodically (World Health Organization, 1993, 2006).

A study by Abdulla and Al-Shareef (2009) evaluated the quality of the harvested rainwater from the roofs of the houses of Amman and Irbid cities, and showed that rainwater collected meets the WHO standards for physical and chemical parameters. The results of the biological analysis indicated that collected water does not meet WHO standards. The sources of microbiological contamination are the human and animal (mainly birds) waste present in catchment area of storage facilities. Results of analyzing harvested water from roofs and ground (Table 3) at Yarmouk University showed that water samples meet the WHO guideline except for nitrates and biological contaminants.

Economic analysis

Rainwater harvesting decrease the demand for main water supply. Rainwater harvesting systems used in housing schemes can provide water for potable and non-potable uses. The potable uses include drinking, bathing, and cooking and dish washing. Usually the rainwater used for these purposes must be treated to remove contaminants and generally the main required treatment processes are filtration and disinfection, unless the rainwater contain heavy metals, then special treatment is required. Non-potable uses of rainwater harvesting include

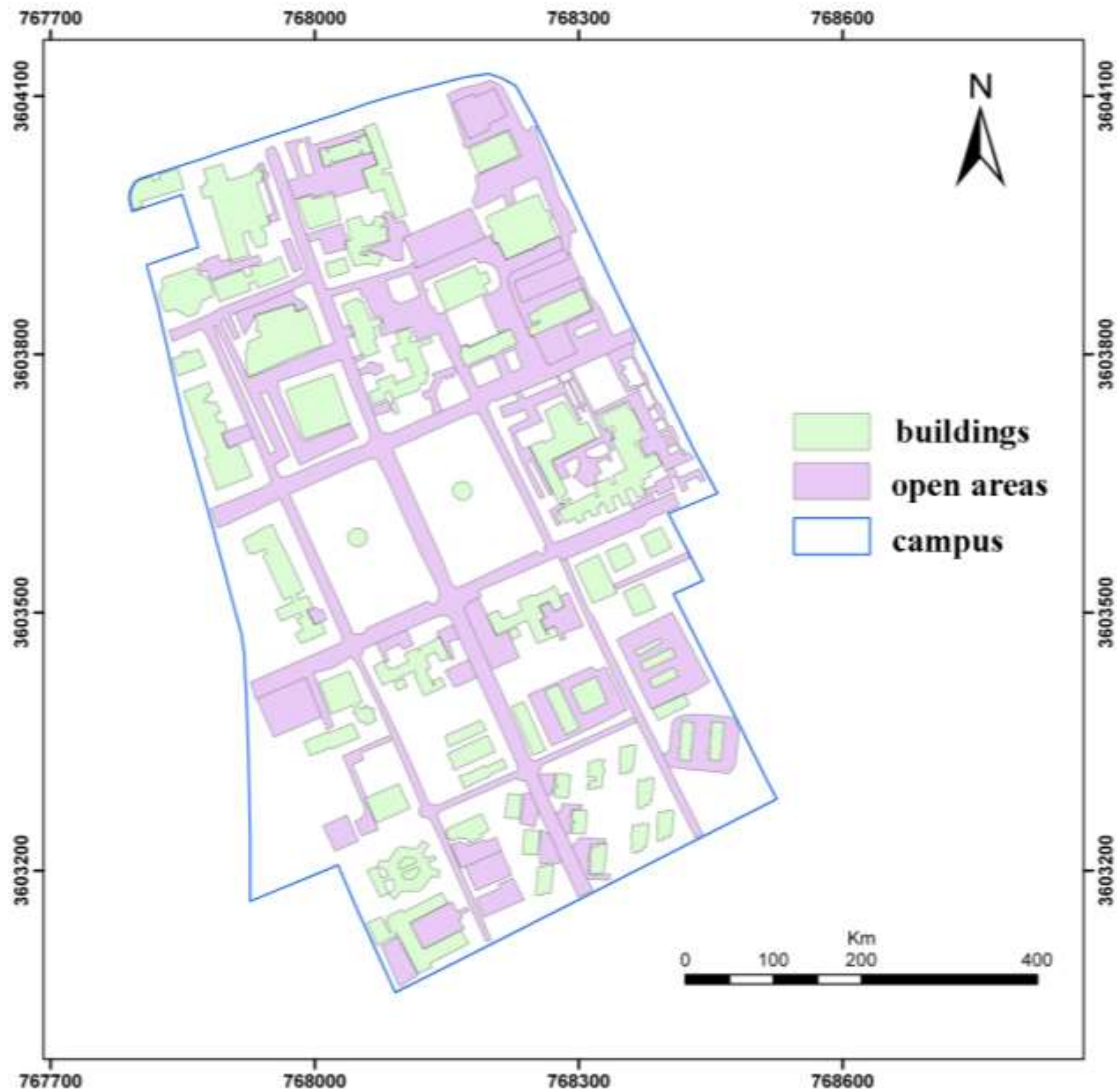

Figure 3. Buildings and open areas at Yarmouk University digitized from satellite imagery.

flushing toilets, watering gardens, and washing floors, and for such uses treatment is not required. Harvested rainwater usually does not require any kind of treatment (chemical, physical or biological) before use for most domestic purposes, which makes rainwater harvesting systems cost effective (Environment Agency, 2008).

The most expensive part of a rainwater system is usually the storage place itself. If the dry period is too long, large storage tanks are needed. Hence in arid regions, it is more feasible to use rainwater to recharge groundwater aquifers rather than for surface storage. The cost analysis that is presented in the following comprises an inquiry of the corresponding material and construction costs of a concrete reservoir.

Yarmouk University has built a concrete water tank in 2011, with 2000 m^3 capacity. The costs of this tank was about 250,000 US dollars that is, \$125/m^3 (personal communication, 2011). According to the University Engineering Department sources, it is planned to build more reservoirs when financial resources are secured.

In general, the cost of a 1500 m^3 of a concrete water tank in Jordan is around 110,000 to 120,000 US dollars based on the current market prices (Personal Communications, 2010). Although the cost of installing a rooftop or ground catchment system may be significant; the operation and maintenance costs on the long-term

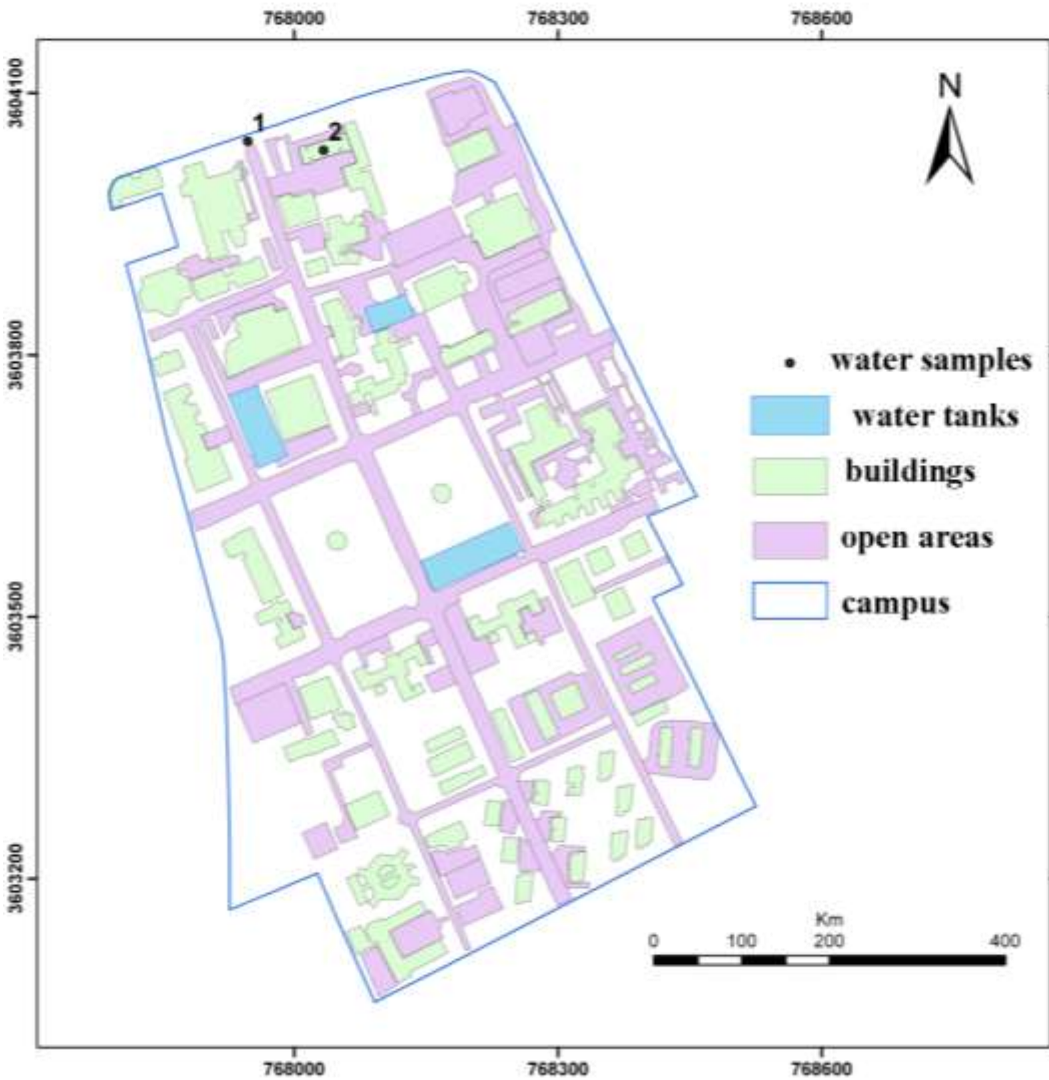

Figure 4. Buildings and open areas at Yarmouk University with proposed water storage tanks and location of water samples.

are endurable and the gains are valuable.

Taking topography into consideration, the distribution of buildings and the available open spaces, three storage tanks are suggested for installation (Figure 4).

CONCLUSIONS AND RECOMMENDATIONS

Results proved that great potential for exploitation of rainwater harvesting from rooftops and open areas is possible in Yarmouk University. A maximum of 99,047 m^3/year of rainwater can be collected from both sources (roofs and paved ground) provided that all surfaces are used and all rain falling on the surfaces is collected. This is equivalent to 125 to 145% of the total domestic water supply for the years 2008 and 2009.

It must be highlighted, though rainwater should go through proper treatment in order to be used as potable water. Water samples collected from roof and ground showed that water could be used for drinking purposes if treated for nitrates and bacteria.

Rainwater harvesting can not only provide a source of water to increase water supplies, but also can involve public organizations in water management. The results of this study should provide the needed drive for the development of a rainwater harvesting program in Yarmouk University and in Jordan in general. Water harvesting reduces the use of subsidized public water. Therefore, government support is essential in encouraging the public to install rainwater-harvesting systems. Grants would be necessary to encourage people harvesting rainwater.

Concurrent to installing water harvesting system, it is highly recommended that Yarmouk University adopt more conservative measures in water usage by using the following methods:

Table 2. Potential for potable water savings (%) from rooftop and open areas.

Harvesting area	Potential for potable water savings (%) - 2008	Potential for potable water savings (%) -2009
Rooftop	46.69	54.28
Open areas	77.88	90.54
Total	124.56	144.82

Table 3. Harvested rainwater quality at Yarmouk University, Jordan.

Parameter	Roof sample	Ground surface sample	WHO guideline (maximum value)
pH	7.16	7.5	6.5 - 8.5
Total dissolved solids (mg/l)	201	88	1000
Nitrates (as NO_3-N, mg/l)	80	66	50
Sulphates	105	71	250
Chlorides	54.45	6	250
Lead	0.07	0.04	0.05
Zinc	2.03	1.20	3
Total coliform (cfu/ml)	1930	1800	0
Fecal coliform (cfu/100 ml)	130	1100	0

cfu= colonies forming un.

1. Use low-flow and water-efficient appliances in toilets and sinks.

-placing a jar or other closed container full of water into toilet tank.
-install toilet dams.
-install low-flow sink spigots.

2. Continuous maintenance of leaks from faucets and pipes.
3. Reduce number of faucets in toilet rooms.
4. Use advanced watering techniques for example, automatic sprinkler systems with timers, if possible.
5. Train janitors on best practices of cleaning.
6. Establish a water treatment plant.
7. Continuous awareness programs for the University community to minimize water consumption.
8. Promotion of rainwater harvesting technique for domestic, landscaping, and agriculture can help to reduce the demand on water resources.

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