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# ROOFTOP RUNOFF WATER QUALITY IN UNIVERSITY BUILDINGS, CASE STUDY AT JORDAN APPLIED SCIENCE PRIVATE UNIVERSITY

RANIA S. SHATNAWI

Department of Civil Engineering, Applied Science Private University,
Amman, Jordan
E-mail: rania_sh@asu.edu.jo

## Abstract

The quality of rainwater harvested could be the key element in using the collected water. Runoff water samples collected from rooftop areas at Applied Science University campus in Amman, Jordan are analysed for some chemical and physical parameters to evaluate its quality and a simple water filter is used to enhance the runoff water quality. Results show that the pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), turbidity, alkalinity and hardness of the runoff water are within the accepted limits for limited uses such as farming. Using filters reduces most of these parameters where turbidity reduces by 77.5 % and TSS reduces by 50%.

Keywords: Jordan, Rainwater harvesting; Rooftop runoff; Water quality.

## 1. Introduction

Water is fast becoming one of the world's most prized and scarce resources, most countries are doing all they can to effectively address their current and future requirements. In arid- and semi-arid regions, like Jordan, where the per capita water consumption is relatively low (amongst the world's lowest at less than 100 $m^3$ per year), the burgeoning population adds continuously to the cost of water supply and the strain on the country's limited resources [1]. Jordan is listed as one of the world's most water-scarce countries, with an average annual rainfall of less than 50 mm in the Southeastern area and up to 650 mm in the north-west. Water availability in Jordan forms an extensive challenge for public and private institutions. The limited renewable sources are under pressure due to growing demand, which imposes the need for utilizing non-conventional sources such as Rain Water Harvesting (RWH) [2]. The runoff resulting from limited rainfall events in the arid areas is vulnerable for pollution from air precipitates during dry periods mainly in industrial and urban areas.

One answer to such water-stressed conditions is water harvesting in which, the runoff from any rainfall is collected and either filtered to potable standard or used for irrigation and other requirements [3-6]. The quality of harvested rainwater depends on factors such as the surrounding urban or industrial environment, rainfall patterns, and the extent of the dry period leading up to the first flush [7-10]. In a humid climate, for example, with intermittent dry periods, rooftop-harvested water has minimal contamination [11-14], while in places that experience long periods without rain, contaminants build up in catchment areas and pollute the first rainfall flush [9, 15-19].

Previous research has examined the definition and type of materials contaminating rooftop catchments as well as the effects of those on water quality [20-23]. In a study, Ayog et al. [11] found on nipa-thatched roofs and galvanized iron roofs, that the quality of the first flush water was recorded as being limited to quantities of Total Suspended Solids (TSS), pH balance, dissolved oxygen (DO) and a certain amount of turbidity. According to Mendez et al. [24], lower concentrations of faecal matter were found in the water harvested from roofs of steel coil coated with metal alloy (Galvalume®) compared to other roofing products and in addition, Gromaire et al. [25] explained that while a natural 'green' roof was determined to halve the runoff, however, increase the concentrations of dissolved organic matter and phosphorus compared to other materials.

In addition, Farreny et al. [26] confirmed that it is not only the fabric but also the slope and smooth or rough line of the roof that affects the quality of harvested water. Steeply sloped roofs will tend to deliver water of a superior quality than flat catchments. In their investigation into the quality of harvested rainwater in Australia, Chubaka et al. [27] found that the further the catchment is from industrial areas, the lower the general level of contaminants, although there tended to be higher levels of microorganism contaminants with minimal epidemiological impact.

In line with established physical and chemical parameters of water quality, this investigation will assess the rainwater harvested from the rooftops and parking lots at Jordan's Applied Science Private University (ASU) campus, and investigate the water treatment options that could be used to optimize its potability.

## 2. Materials and Methods

### 2.1. Study area

The Applied Science Private University campus is situated in the northern area of Jordan's capital city, Amman as shown in Fig. 1. Based on studies by Ghanem [28], the average annual rainfall in this region is 480 mm, with precipitation generally in the wet winter months between October through May, sometimes with light snow.

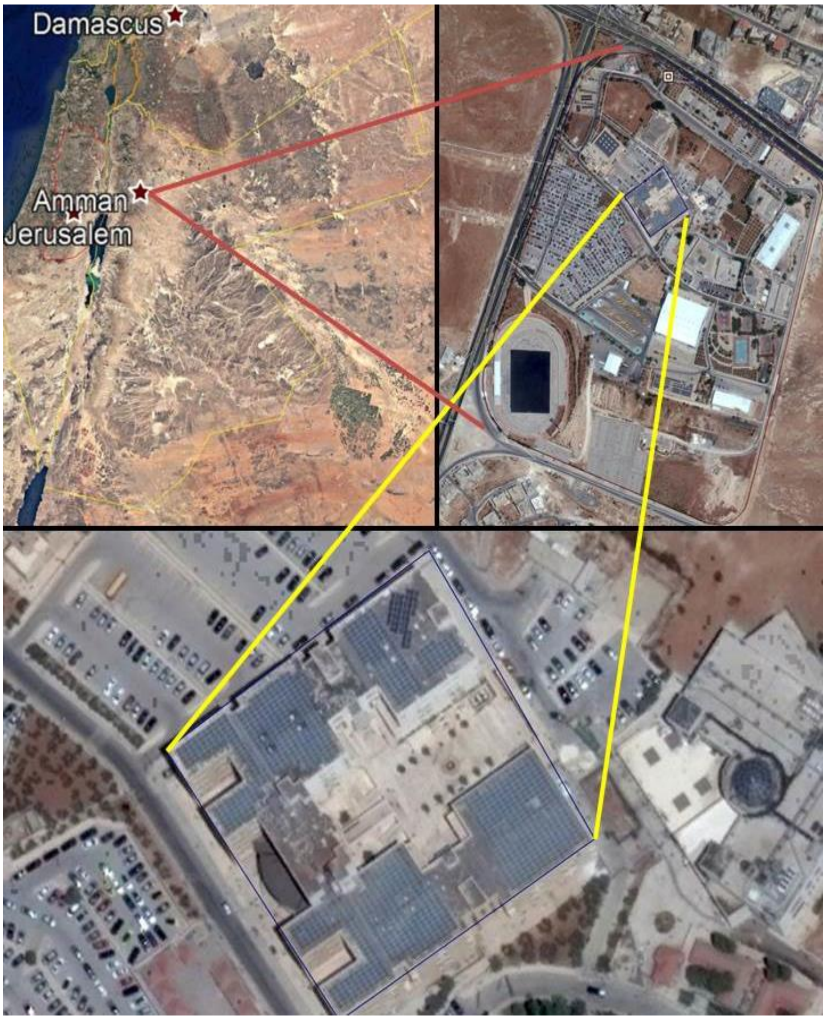


**Fig. 1. Location map of the study area.**

### 2.2. Sampling

The study incorporates three rainy seasons, namely 2007/2008, 2008/2009 and 2015/2016, during which, runoff from 19 rainfall events was recorded. Rainwater samples were harvested via the conduit on the rooftop gutter of the ASU-College of Engineering, the dates of which, collection are listed in Table 1.

**Table 1. Sampling dates for rooftop runoff.**

| Rainfall season | | |
|---|---|---|
| **2007/2008** | **2008/2009** | **2015/2016** |
| **20/12/2007** | 13/12/2008 | 1/12/2015 |
| **12/1/2008** | 29/12/2008 | 21/12/2015 |
| **18/2/2008** | 2/1/2009 | 31/12/2015 |
| **3/3/2008** | 1/3/2009 | 3/1/2016 |
| **3/4/2008** | 24/3/2009 | 11/1/2016 |
| | | 20/1/2016 |
| | | 7/2/2016 |
| | | 11/2/2016 |
| | | 18/2/2016 |

## 2.3. Quality tests

The quality of the harvested rainwater samples was assessed against setting physical and chemical water quality parameters, including turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), total and calcium hardness, total alkalinity, and pH. Standard methods were used to test for these parameters; the following Table 2 summarizes these tests [29].

**Table 2. Testing methods for water quality parameters.**

| Parameter | Testing method |
|---|---|
| **Total Suspended Solids (TSS)** | Gravimetric analysis |
| **Turbidity** | Turbidimeter |
| **pH** | pH meter |
| **Total Dissolved Solids (TDS)** | Gravimetric analysis |
| **Alkalinity** | Titration with $H_2SO_4$ as titrant |
| **Hardness** | Titration with Ethylenediaminetetraacetic acid (EDTA) as titrant |

# 3. Results and Discussion

The results of the quality analysis of the ASU rooftop runoff water are presented in Table 3.

**Table 3. Summary of physical and chemical runoff water quality.**

| | Unit | No. of samples | Min | Max | Average | Standard deviation* |
|---|---|---|---|---|---|---|
| **pH** | | 15 | 6.3 | 8 | 6.9 | 0.5 |
| **TSS** | mg/ l | 19 | 88 | 800 | 349 | 169 |
| **TDS** | mg/l | 19 | 100 | 1000 | 537 | 296 |
| **Turbidity** | NTU | 19 | 2 | 19 | 12.8 | 9.2 |
| **Alkalinity** | mg/l as $CaCO_3$ | 15 | 41 | 250 | 142 | 64 |
| **Total hardness** | mg/l as $CaCO_3$ | 13 | 97 | 275 | 167 | 59 |

*the normally known standard deviation is calculated based on the square root difference between the values and the average divided by the number of samples-1.

## 3.1. Physical quality

### 3.1.1. Total suspended solids (TSS) test

Total suspended solid concentrations in water collected during the recorded rainfall events ranged from 88 to 800 mg/l, with an average value of 349 mg/l. Dust, clay and other dry particles in the rooftop environs at the time of sampling may account for the presence of these solids. As shown in Fig. 2, there is a weak inverse relationship between the length of dry period and TSS. The expected situation is that as the dry period is longer, more solids from air accumulate on the rooftop and then carried by runoff, however, results show the opposite, this could be due to the wind, which blows away the accumulated solids during the dry period.

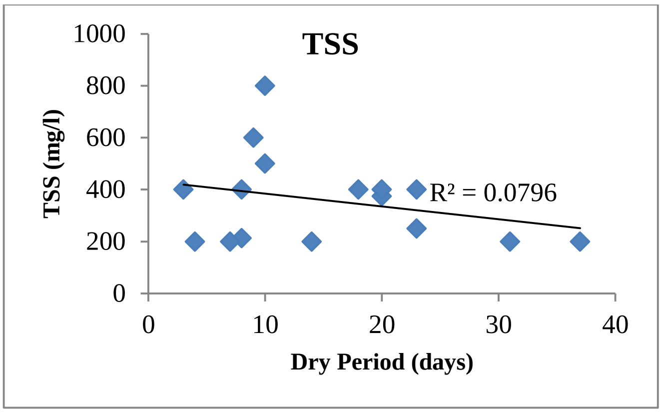


**Fig. 2. Total Suspended Solids (TSS) versus length of dry period between the rainfall events.**

### 3.1.2. Turbidity test

The turbidity levels of the samples were found to be between 2 and 19 NTU, with an average and standard deviation of 12.8 and 9.2 NTU, respectively. As can be seen in Fig. 3, the same results as for the TSS in Fig. 2 where weak inverse relationship between the length of dry period and turbidity. Since turbidity comes mostly from suspended solids, it follows the same trend as TSS.

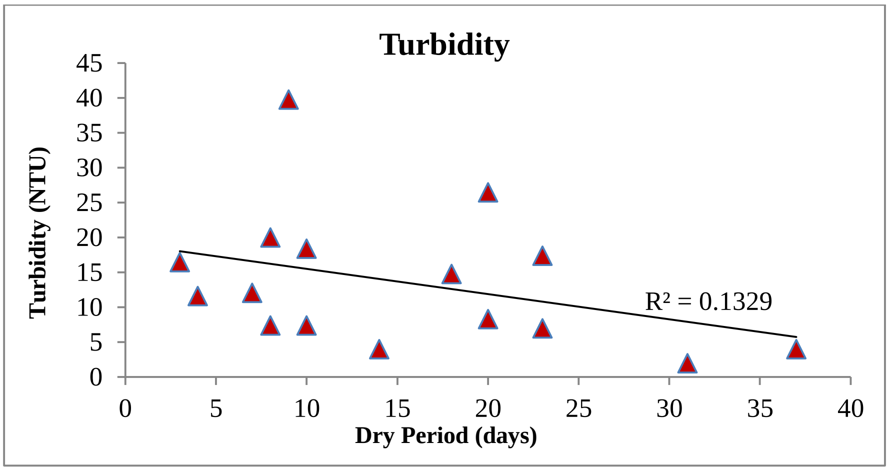


**Fig. 3. Turbidity versus length of dry period.**

## 3.2. Chemical quality

### 3.2.1. pH test

Jordanian drinking water standards (2004) require a pH to be between 6.5 and 8.5, [30]. The results presented in Table 3 confirm that the pH values for the ASU rooftop rainwater samples ranged from 6.3 to 8, with a mean value of 6.9 indicating that the water is of an acceptable pH for drinking [30]. This implies the fact that the harvested rooftop rainwater compensates to be a valuable source for drinking and domestic water uses.

### 3.2.2. Total Dissolved Solids (TDS) test

The main constituent in the chemical composition of the rooftop water samples was total dissolved solids resulting from different sources, such as, air that may contain calcium bicarbonate, nitrogen, iron phosphorous or sulphur, among other minerals. Concentrations of TDS were found to vary between 100 mg/l and 1000 mg/l, with an average of 537 mg/l that is higher than the allowable limit of Jordanian Water Standards of 500 mg/l [30] and a standard deviation of 296 mg/l. Notably as can be seen in Fig. 4, the TDS concentrations fluctuated depending on the season and event at various periods within the same season. TDS were most concentrated at the start of the wet seasons.

### 3.2.3. Alkalinity test

Bicarbonate ion (HCO-) was dominant and determined to have the greatest influence on the alkalinity of the rooftop water samples as all the measured rooftop water samples had a pH less than 8.3, in which, the measured minimum alkalinity was 41 mg/l as CaCO3, the maximum 250 mg/l as CaCO3, respectively, and the average alkalinity was 142 mg/l as CaCO3. The alkalinity average puts the mean HCO3- concentration at 173.24 mg/l. that is lower than the allowable HCO3- limit of 500 mg/l according to JWS of 2004 [30].

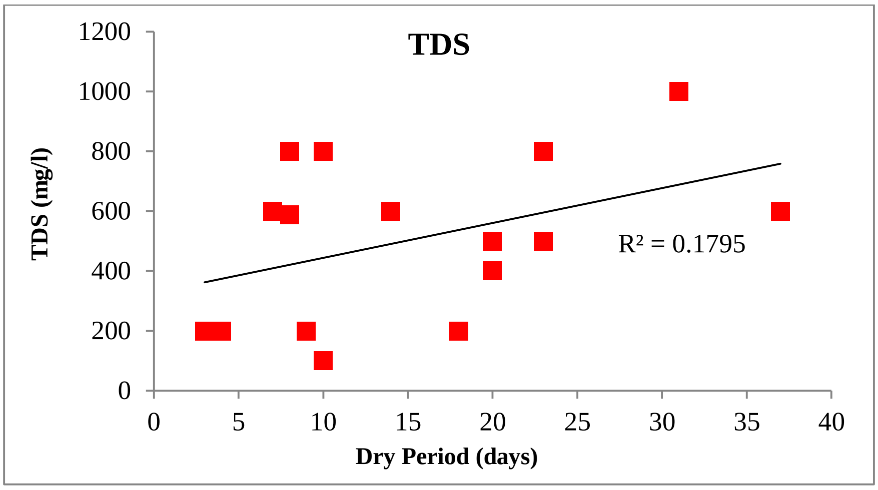


**Fig. 4. Total Dissolved Solids (TDS) versus length of dry period.**

#### 3.2.4. Hardness test

Hard water is considered to be between 150 and 300 mg/l as $CaCO_3$. The analysis results of the ASU rainwater samples to have an average total hardness of 167 mg/l as $CaCO_3$, thus, classifying the water as moderate to hard [31]. At a minimum, the water was measured at 97 mg/l as $CaCO_3$ (moderately hard) and at a maximum total hardness, it was 275 mg/l.

### 3.3. Quality enhancement

The harvested ASU rooftop rainwater was filtered to ascertain its potable suitability. The turbidity of the samples and high concentrations of solids suggest that filtration or other appropriate means of treatment are required in order to improve the quality sufficient to meet Jordanian drinking water standards. Figure 5 illustrates the on-campus design and assembly of the handmade filters, incorporating local materials like sand and gravel. These pioneering filters successfully halved the concentrations of solids in the rainwater samples. The concentrations of TSS were mitigated by the use of filtration as can be seen in Fig. 6, while turbidity was improved by an average turbidity removal of 77.5% using the handmade filters, as indicated in Fig. 7. As illustrated in the figure, the turbidity for 9 samples was measured before and after using the handmade filters at different times of the rainy season. All the filtered water samples showed turbidity of less than 5 NTU that matches the Jordanian drinking water standards [30].

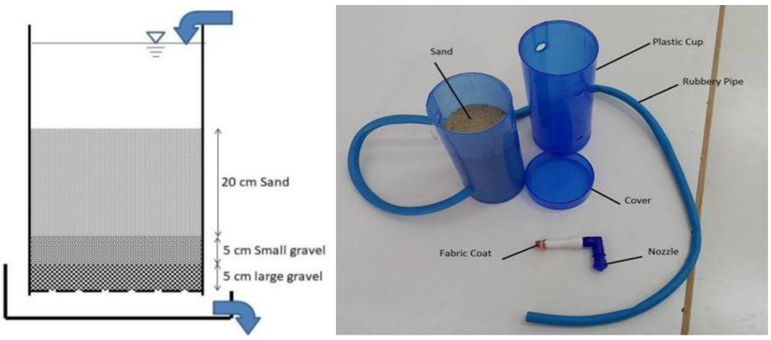


**Fig. 5. Manually designed filters used in study.**

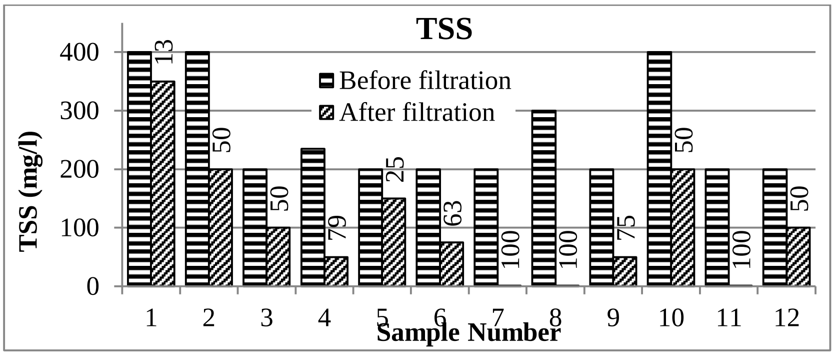


**Fig. 6. Total Suspended Solids (TSS) before and after filtration with solids' removal percentage.**

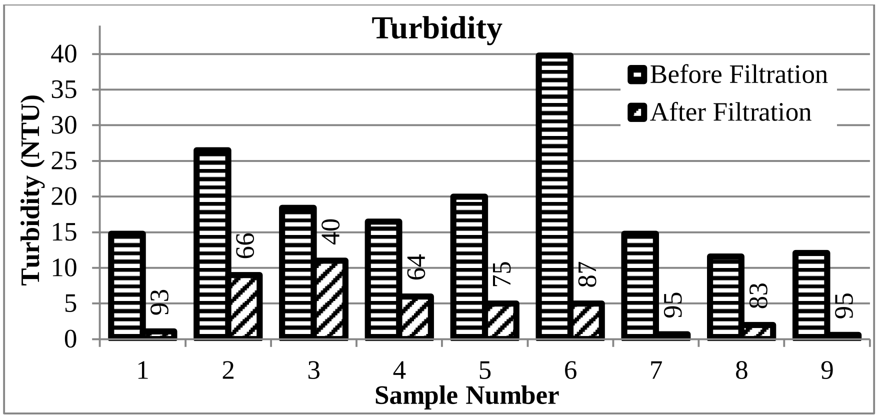


**Fig. 7. Turbidity before and after filtration with turbidity removal percentage.**

## 4. Conclusion

The water quality of rooftop runoff in urban areas is affected by human activities in the area. The ASU campus is located in an urban area with mainly residential areas. The collected runoff from the rooftop building at ASU contained limited amounts of pollutants and there is no relation between the length of the dry period before rain and runoff water quality, which indicates that there is not much of pollutant accumulation from the air between rainfall events.

The tested water quality parameters were divided into two sets physical and chemical as mentioned previously. The physical parameters included total suspended solids and turbidity. It can be concluded that the average measured concentration of suspended solids was 349 mg/ that is mainly due to the presence of clay and dust particles on the rooftop. In addition, the average turbidity was 12.8 NTU that is higher than the allowable limit of Jordanian drinking water standards (5 NTU). Whereas, the chemical water quality parameters were pH, total dissolved solids, total hardness and alkalinity. it can be concluded that the average pH of the rooftop runoff water samples was 6.9, this coincided with the finding that the samples alkalinity was mainly due to the presence of bicarbonate group ($HCO_3^-$) with an average concentration of 173.24 mg/l. It also can be concluded that the rooftop runoff water is drinkable as the measured average total hardness was 167 mg/l as CaCO3 that categorized it as hard water.

The filtration systems used showed that most of the impurities were captured by the media where the runoff water quality can be highly improved using these simple techniques, with an average percentage removal of both turbidity and suspended solids as 77.5% and 63% respectively.

## Acknowledgement

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| **Abbreviations** | |
|---|---|
| DO | Dissolved Oxygen |
| EDTA | Ethylenediaminetetraacetic acid |
| NTU | Nephelometric Turbidity Unit |
| TDS | Total Dissolved Solids |
| TSS | Total Suspended Solids |

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