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Harvested Rain Water Quality of Different Roofing Material Types in Water Harvesting System at Al al-Bayt University/Jordan

Hani Al-Amoush1)*, Saad Al-Ayyash 2) and Akram Shdeifat 3)

1) Institute of Earth and Environmental Sciences, Al al-Bayt University, Al-Mafraq, Jordan.
* Corresponding Author: E-Mail: geo_hani@yahoo.com or hani1@aabu.edu.jo
2) Faculty of Engineering, Al al-Bayt University, Al-Mafraq, Jordan. E-Mail: saad.a@aabu.edu.jo
3) Water, Environment and Arid Regions Research Center, Al al-Bayt University, Al-Mafraq, Jordan.
E-Mail: shdeifat@yahoo.com

ABSTRACT

The concentration levels of selected chemical compositions in samples of rainwater (precipitation - open atmosphere) and runoff waters from different rooftop buildings and parking lots of Al al-Bayt University premises in Jordan have been presented and analyzed.

The runoff from rooftop buildings and parking lots was compared to rainwater collected for the concentrations of the following major cations and anions: Na^{+1}, K^{+1}, Mg^{+2}, Ca^{+2}, HCO_3^{-1}, Cl^{-1}, NO_3^{-1}, SO_4^{-2}, as well as heavy metals: Al^{+3}, Pb^{+2}, Mn^{+2} and Cd^{+3}. Furthermore, pH and total dissolved solids (TDSs) were measured. Sampling procedures were basically depending on 11 rainstorms taken after rainfall events over a period of 6 months, between December 2010 and May 2011.

Average concentrations of Al^{+3}, Cl^{-1}, HCO_3^{-1}, Mg^{+2}, Na^{+1}, Mn^{+2}, SO_4^{-2} and TDSs were found to be less than or equal to those given in the Jordanian Water Standard (JWS) for drinking water, while for Ca^{+2}, the average concentration, exceeds that given in the Jordanian Water Standard (JWS) (=75 mg/l) for all roofing materials. K^{+1} concentration was found to be larger than that given in the JWS (=20 mg/l) for most of the roofing materials. Additionally, the average concentration for NO_3^{-1} was found to be larger than that given in the JWS (=50 mg/l) for seal coat. Two categories of water type were found: mixed Ca^{+2} – Mg^{+2} – Cl^- -type and Ca^{+2} - HCO_3^- type. The average concentration order of all roofing materials can be arranged as follows in terms of quality of harvested water: metal insulation < mixed concrete insulation < mixed asphalt insulation = concrete insulation < water insulation = seal coat insulation < roll asphalt insulation < thermal insulation.

KEYWORDS: Rainwater harvesting, Runoff quality, Precipitation, Rooftop, Parking lot, Jordan.

INTRODUCTION

Water resources became a big challenge to settlers at the edges of desert and in areas in which streams run in winter and which are dry most of the year. The selection of site and rainwater harvesting system is the key for success of the system (Al-Adamat el al., 2012). Simple techniques were available for people in ancient times to build water collecting systems that were sufficient to support their demands during dry months. This knowledge and management techniques were developed over time, initiating efficient water harvesting systems in arid lands. Recently, the purposes of water harvesting are expanded from making water available for direct use in drinking and farming into new purposes, such as

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ground water recharge, recreation and environmental restoration (UNEP, 2006).

Expansion of complicated human activities, such as industrial activities and use of synthesized materials in building, added the need for more knowledge on the quality of harvested water in addition to harvesting techniques (Despins et al., 2009; Kohlitz and Smith, 2015). The effect of roof material on water quality in different climates was investigated by many researchers. Studies found that roof material affects water quality and so does the location of the collecting system (Ammann et al., 2003; Forster, 1999; Farreny et al., 2011; Faller et al., 2005). Dry period and first flush runoff quality also affect water quality as shown by Gnecco et al. (2005). The runoff of paved roads and parking lots is more vulnerable to hydrocarbon pollutants. The water quality of paved surfaces showed raised concentrations of hydrocarbon compounds (Booth et al., 1999; Brattebo et al., 2003; Collins et al., 2006; Day et al., 1981; Dietz et al., 2008; Gilbert et al., 2006; Hillier et al., 1999; Legret and Colandini, 1999; Rushton, 2001).

Rooftop water harvesting in Jordan is still not utilized at a large scale even though Jordan is facing challenges to find new water supplies to meet the growing water demand. Rainwater harvesting from building rooftops and parking lots could provide a source for drinking water after proper treatment (Abdualla and Alshareef, 2009).

In this Study, rooftop runoff water samples were collected from different roofing materials and parking lots at Al al-Bayt University premises in Jordan, aiming at investigating the impact of roofing material on quality and development of water quality within the harvested water system in the study area.

STUDY AREA

Jordan with a land surface area of 89.400 km^2 has a Mediterranean climate and is classified as an arid to semi-arid region with long, hot, dry summers and short, cold, rainy winters (Kloub et al., 1995; Abu Qdais and Batayneh, 2002; Afonsoa et al., 2004; Ministry of Water and Irrigation (MWI), 2016; Al-Momani, 2008; Abdulla et al., 2009). Rainy seasons in Jordan are short with only 7% of the total surface area of Jordan receiving an annual rainfall larger than 200 mm (Kloub et al., 1995; Abu Qdais and Batayneh, 2002). The rainfall in Jordan is both spatially and temporarily erratic with a maximum of 200 mm of annual rainfall (Sewan and Al-Ansari, 2001; MWI, 2016). The average annual rainfall under normal climatic conditions is 300 mm (Jaradat et al., 1999; Al-Momani, 2008; Abdulla and Al-Shareef, 2009).

Al al-Bayt University is located in Al-Mafraq city, northeast Jordan. The area is classified as an arid-climate zone with hot summer and cold winter with average temperatures of 38°C and 14°C, respectively (Abdulla and Al-Shareef, 2009; Hadadin et al., 2010). The average annual rainfall precipitation in Al-Mafraq city is approximately 161 mm and is fairly evenly distributed throughout the winter season (Abdulla and Al-Shareef, 2009; Hadadin et al., 2010).

The sampling locations for the different roofing materials are shown in Figure 1 with Al al-Bayt University buildings covering an area of about 2.5 km^2 of the total campus area of 7.5 km^2.

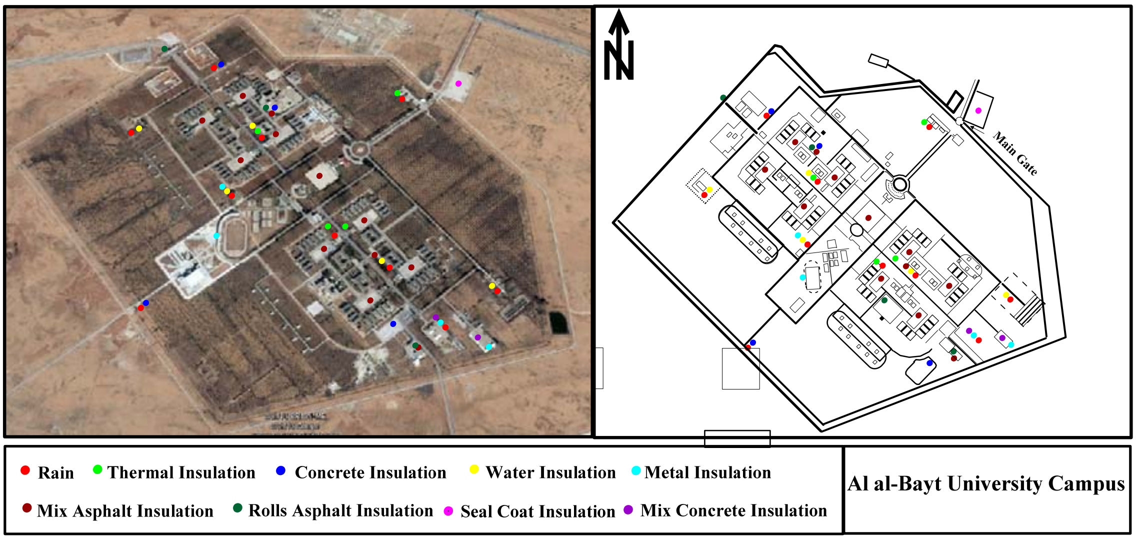

Figure (1): Location map of Al al-Bayt University campus overlain Google earth map and a sketch of university premises showing the sampling locations for different types of roofing material

METHODS

Sampling

Starting December 2010, Water Environment and Arid Regions Research Center (WEARRC), Al al-Bayt University, has been developing an experimental study in order to investigate the quality of harvested water and its evolution through the water harvesting system in Al al-Bayt University campus. The sampling system consists of 10 rainwater collectors, 15 parking-lot samplers and 20 different rooftop samplers, which have been installed in summer 2010. Forty-five wet atmospheric deposition samples from precipitation, rooftop and parking lot runoff water were collected. These samples are: 10 sample sets for rainfall, 4 thermal insulation, 3 concrete insulation, 5 water insulation, 4 metal insulation, 2 mixed concrete insulation, 12 mixed asphalt insulation, 4 roll asphalt insulation and 1 seal coat insulation. The locations of sampling sites and roofing materials are shown in Figure 1.

The building rooftop panels are made of concrete base treated with substances for thermal (aqua guard), water (asphalt, roll asphalt), concrete and metal insulation (galvanized metal roofs), while gutters and the down spout are made of cast iron and PVC. The parking lots are made of compacted base coarse treated with mixed asphalt and seal coat.

A total of 11 sampling sets were collected from 11 storm events that created runoff. These events extended over the period from December 2010 to May 2011. The total number of water samples collected are 370 samples from rainfall and runoff of different roofings and parking lots. The samples are then analyzed for chemical constituents.

Sampling Equipment

Rainfall Samplers

Rainfall samplers (rainwater collectors) were made of stainless steel with standard rainfall measuring size (20.4 cm (8 inch) inside diameter) and installed on a 0.7 to 1.0 meter tripod above ground or building roof to measure rainfall quantity (Figure 2a). Rainwater samples were collected in a smaller plastic high-density polyethylene (HDPE) container; 2-liter (2000 ml) polyethylene bottle for each rainwater storm event.

Roof Runoff Samplers

Roof runoff samplers were designed to divert a small amount of water in the gutter downspout, which has a 10.2 cm internal diameter, to a sample bottle using a 5.1cm diameter funnel (Figure 2b). The sampling equipment were fit inside and attached to the inside of the downspout using galvanized wire and pins. Roof runoff samples were collected in a smaller plastic high-density polyethylene (HDPE) 500 ml bottle.

Parking Lot Samplers

Parking lot samplers were designed to capture a small amount of the surface runoff entering a storm sewer inlet. The parking lot sampler is made of a 30 cm internal diameter PVC bucket that contains a 2-liter sampling bottle with 10.2 cm funnel. The sampling bottle is attached to a funnel and both are fixed inside the bucket using galvanized wire and pins (Figure 2c).

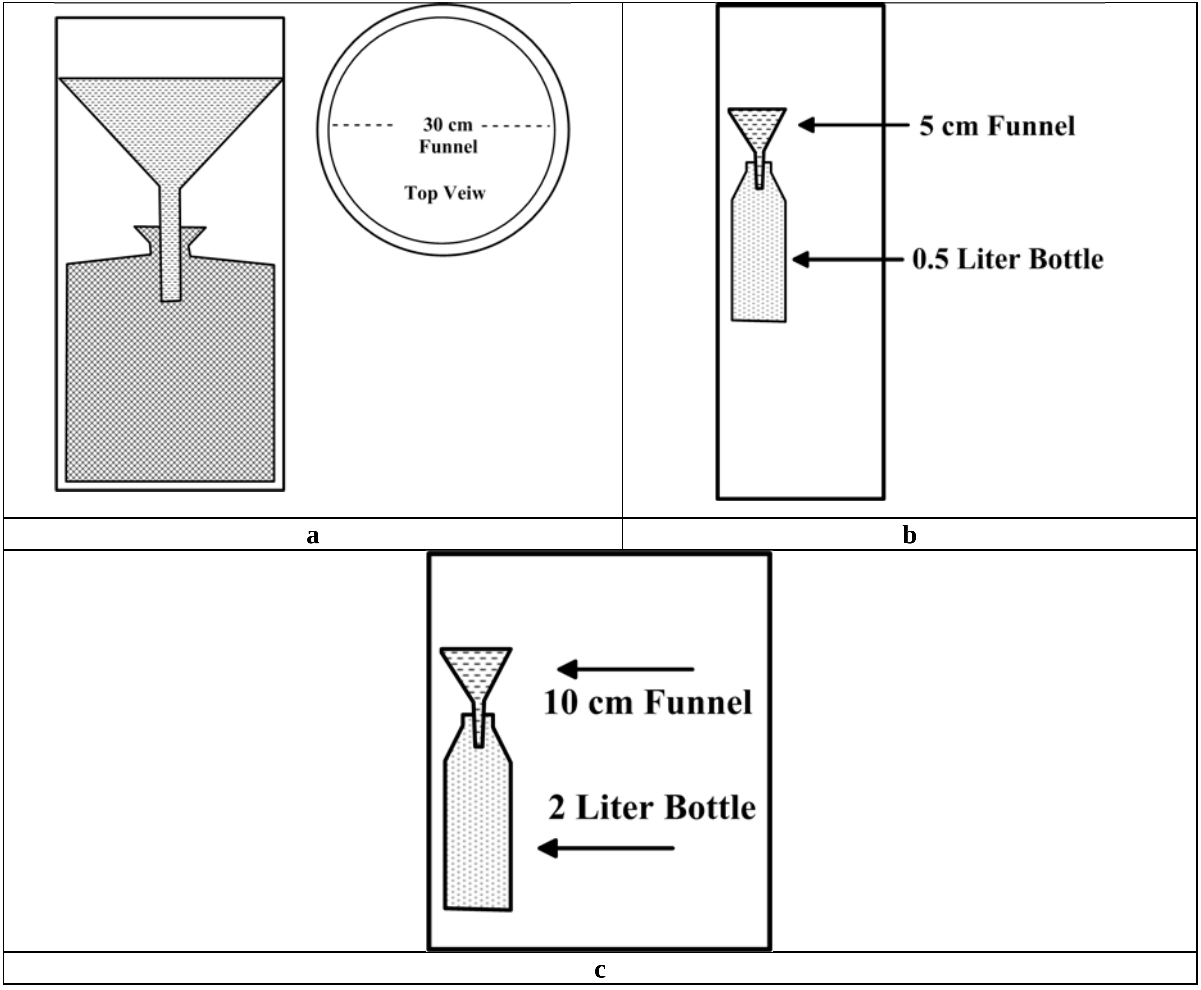

Figure (2) a: Rainfall water sampler b) Rooftop runoff water sampler c: Parking lot runoff water sampler

Analytical Methods

After each sampling, the samples are transported in an ice box to the laboratory for immediate determination of electrical conductivity (EC) and pH and then stored in a refrigerator for further chemical analysis within 48 h. For short-term storage, the storing temperature is set to 5 ± 1°C in order to avoid evaporation or freezing of the samples until subsequent analysis.

Standard procedures and methods were used to test for the water quality parameters of rainwater and runoff samples in the Water, Environment and Arid Regions Research Center (WEARRC) laboratories at Al al-Bayt University. The standard methods and equipment used are:

1) Flame photometer / Type Jen Way / Model (Clinical PFP7) to measure Na^{+1} and K^{+1} concentrations;
2) Titration methods to measure Ca^{+2}, Mg^{+2} and HCO_3^{-1} concentrations;
3) Inductively Coupled Plasma (ICP) / Perkin Elmer / Optima 2000 DV to measure heavy metal (Al^{+3}, Pb^{+2}, Mn^{+2} and Cd^{+2}) concentrations in the samples which were acidified and digested by HNO^{-3} as specified by APHA 4500 prior to the analysis of the ICP by the APHA method 3120;
4) Ion Chromatograph (IC) / Type Dion Ex/Model DX-120 to measure SO_4^{-1}, NO_3^{-1} and Cl^{-1} concentrations;
5) Type WTW/Model NO Lab Level 3 to measure pH, electrical conductance and salinity (TDS).

RESULTS

Eleven rain storm events were sampled. Dates for sampling and rainfall events and rainfall depths are shown in Table 1. The first storm event (EVENT1) tested was on December 12, 2010, while the last storm event (EVENT 11) tested was on May 1, 2011.

Table 1. Sampling dates and rainfall event dates and depths

Rainfall storm	Sampling date	Storm dates	Rainfall depth (mm)
EVENT1	12/12/2010	12/12/2010	12
EVENT2	14&15/12/2010	-------	Not Recorded
EVENT3	02&03/01/2011	29-30/01/2010	5.4
EVENT4	10/01/2011	08/01/2011	3.7
EVENT5	31/01&1/02/2011	29-31/01/2011	11.6
EVENT6	06&07/02/2011	06-07/02/2011	14.4
EVENT7	09&10/02/2011	09/02/2011	0.3
EVENT8	22/02/2011	20-21/.2/2011	3.4
EVENT9	27&28/03/2011	26/03/2011	10.4
EVENT10	07/04/2011	06/04/2011	1.6
EVENT11	02/05/2011	01/05/2011	0.5

Chemical analyses for major cations, anions and heavy metals as well as TDS and pH were performed for rainfall and different roof and parking lot runoff after each rainfall event. The cations tested for are: Na^{+1}, K^{+1}, Mg^{+2} and Ca^{+2}, while the anions tested for are: HCO_3^{-1}, Cl^{-1}, NO_3^{-1} SO_4^{-2}. The heavy meatals tested for are: Mn^{+2}, Pb^{+2}, Cd^{+2} and Al^{+3}. Descriptive statistics, including mean, maximum and minimum of the results for water quality variables have been calculated. The results for the various water quality parameters are compared to those in the Jordan Water Standard (JWS, 2004) (Table 2).

Table 2. Comparison and statistics of average ion concentrations for roofs, parking lots and rainfall with reference to Jordanian Water Standard (JWS, 2004)

Parameter	Jordanian Drinking Water Standard (JWS) (JSMO, 2004)	Rainfall at study area during study period (average for 87 samples)			Roofs and parking lots		
		Min.	Max.	Average	Min.	Max.	Average
pH	6.5-8.5	6.10	8.60	7.17	6.88	7.42	7.11
TDS	500	30.0	441.0	137.9	325.4	720.9	422.4
Al	1	0.0380	0.0600	0.0488	0.0347	0.0667	0.0550
Ca	75	11.80	197.30	81.63	86.09	147.04	114.38
Cl	200	0.14	141.7	13.12	12.43	151.93	56.44
HCO_3	500	13.67	222.87	51.94	110.76	232.46	169.68
K	20	2.85	48.00	16.58	15.88	32.6	22.46
Mg	30	0.089	74.45	12.9	13.61	20.61	16.94
Mn	1	0.025	0.11	0.0719	0.0773	0.191	0.1159
Na	200	9.42	92.31	53.64	61.38	88.69	72.27
NO_3	50	1.40	64.9	9.34	4.78	51.75	21.25
SO_4	200	4.40	163.7	30.01	31.82	152.51	76.78

Rainwater Chemistry

As shown in Table 2, the pH of the rainfall samples is found in the range from 6.1 to 8.6, with an arithmetic average of 7.17. Some values of pH are slightly below or above the limits of JWS for drinking water (6.5-8.5). TDS concentration in the rainfall water ranges from 30.0 to 441 mg/L with an average of 137.9 mg/L. These figures are within the limits of JWS for drinking water.

Concentrations of the tested anions in the rainfall water samples are as follows: for bicarbonate (HCO_3^{-1}), concentrations ranged from 13.67 mg/L to 222.87 mg/L with an average value of 51.94 mg/L; for chloride (Cl^{-1}), the results varied between 0.14mg/L and 141.7 mg/L with an average value of 13.12 mg/L. The nitrate (NO_3^{-1}) results in some samples exceeded the JWS limit (50 mg/L), varying between 1.4mg/L and 64.9 mg/L with an average value of 9.34. For sulfate (SO_4^{-2}) results, all values were below the JWS limit (200 mg/L). The SO_4^{-2} results varied between 4.4 mg/L and 163.7 mg/L with an average value of 30.01 mg/L.

Heavy metals were below detection limits in most of the rainwater samples. Lead (Pb^{+2}) and cadmium (Cd^{+2}) were below detection limits in all rainwater samples, while aluminum (Al^{+3}) and manganese (Mn^{+2}) were detected in less than 18% of the rainwater samples with values far below the JWS limits (Table 2).

The major cations were found in all the rainwater samples. The concentrations of sodium (Na^{+1}), potassium (K^{+1}), magnesium (Mg^{+2}) and calcium (Ca^{+2}) ranged from highest values of 92.31, 48.00, 74.45 and 197.3 mg/L to lowest values of 9.42, 2.85, 0.089 and 11.8 mg/L, respectively. K^{+1}, Mg^{+2} and Ca^{+2} results showed some values above the limits of JWS, while all Na^{+1} results are below the JWS limits (Table 2).

Roof and Parking Lot Runoff Chemistry

Two hundred and seventy-six runoff water samples were taken. The different roofing material types were: (thermal insulation, concrete insulation, water insulation, metal insulation, mixed concrete insulation, mixed asphalt insulation, roll asphalt insulation and seal coat insulation).

The results for runoff from rooftops and parking lots showed that the average results for all runoff water samples have pH values within the JWS. The pH average results ranged between 6.88 and 7.42 (Table 2). Lowest pH value was found to be 5.0 in samples of rooftop runoff with asphalt roll insulation and mixed asphalt insulation, while the highest value was found to be 9.4 for rooftop runoff with mixed asphalt insulation. For TDS results, the highest value was 5005 mg/L for runoff water sample with asphalt roll insulation roof, while the lowest value was 42 mg/L for metal insulation roof. The average TDS values for runoff water samples from rooftops and parking lots ranged between 325.4 mg/L and 720.9 mg/L. Some of the TDS results are above the JWS limit of 500 mg/L (Table 2).

The anion concentrations in some samples were above the JWS limits. On the other hand, as shown in Table 2, all the average values for anion results in rooftop and parking lot samples are within the JWS limits. The highest concentration for bicarbonate (HCO_3^{-1}) was found to be 1145.6 mg/L for runoff sample from mixed asphalt insulation rooftop, while the lowest value was 36.4 mg/L for runoff water from metal insulation rooftop. Chloride (Cl^{-1}) results varied between 1600 mg/L for runoff from concrete rooftop to 0.1 mg/L for metal insulation rooftop. The nitrate (NO_3^{-1}) results were found to be between 370.4 mg/L for samples from seal coat insulation parking lot to 0.11 mg/L for rooftop with water insulation. The last anion tested for is sulfate (SO_4^{-2}), where the results varied between 1243.2 mg/L and 0.2 mg/L for water insulation rooftops in both cases.

The major cation results for sodium (Na^{+1}), potassium (K^{+1}), magnesium (Mg^{+2}) and calcium (Ca^{+2}) showed that the highest value for Na^{+1} was found as 328.5 mg/L for runoff water sample from asphalt roll insulation rooftop. For K^{+1}, the highest value was recorded for sample from metal insulation rooftop to be 101.9 mg/L. For Mg^{+2}, the highest value was 89.5 mg/L for water sample from asphalt roll insulation rooftop. The last cation, Ca^{+2}, results showed that the highest value was found to be 529.9 mg/L for runoff water sample from concrete insulation rooftop. The average values for the cations tested for are within the JWS limits as shown in Table 2.

As for rainwater samples, heavy metal concentrations were below the detection limits in most of the rooftop and parking lot runoff water samples. Lead (Pb^{+2}) and cadmium (Cd^{+2}) were below the detection limits in all runoff water samples from rooftops and parking lots, while aluminum (Al^{+3}) and manganese (Mn^{+2}) were detected in 21% and 25% of the samples, respectively. The detected values for aluminum (Al^{+3}) and manganese (Mn^{+2}) were below the JWS limits.

Figures 3 through 7 summarize the average values for the various results compared to the JWS in relation with the different rooftop and parking lot insulation materials. Figure 3 shows the results for TDS, where the lowest average is 325.35 mg/L for thermal insulation rooftop, while the highest average is 720.86 mg/L for mixed asphalt insulation rooftop. Figure 4 shows the average pH values for runoff water samples from different surfaces. The lowest average is 6.88 for asphalt roll insulation rooftops, while the highest average is 7.42 for mixed concrete insulation rooftop.

Figure 5 shows the average results for the cations tested for. The lowest average for calcium (Ca^{+2}) is found for mixed concrete insulation rooftop as 86.09 mg/L, while the highest average is 147.04 mg/L for thermal insulation rooftop. For magnesium (Mg^{+2}), the lowest average is found for metal insulation rooftop as 13.61 mg/L, while the highest average is found for thermal insulation rooftop as 20.61 mg/L. For sodium (Na^{+1}), the lowest average is 61.39 mg/L for metal insulation rooftop, while the highest average is 88.69 mg/L for asphalt roll insulation rooftop. The lowest average for potassium (K^{+1}) is 15.88 mg/L for mixed concrete insulation rooftop and the highest average is 32.6 mg/L for thermal insulation rooftop.

Figure 6 shows the average results for the major anions. For bicarbonate (HCO_3^{-1}), the lowest average is 110.76 mg/L for metal insulation rooftop, while the highest average is 232.46 mg/L for thermal insulation rooftop. The lowest average for sulfate (SO_4^{-2}) is found for mixed asphalt insulation rooftop as 31.82 mg/L, while the highest average is 152.51 mg/L for asphalt roll insulation rooftop. The lowest average for chloride (Cl^{-1}) is 12.43 mg/L for thermal insulation rooftop and the highest average is 151.93 mg/L for asphalt roll insulation rooftop. For nitrate (NO_3^{-1}), the lowest average is found for thermal insulation rooftop as 4.87 mg/L, while the highest average is found for seal coat parking lot as 51.75 mg/L.

Heavy metal concentrations were below the detection limits for most of the samples. In a few samples, aluminum (Al^{+3}) and manganese (Mn^{+2}) were detected. Figure 7 shows the results for heavy metal average concentrations in runoff water samples from different rooftops and parking lots. The lowest average for aluminum (Al^{+3}) was found to be 0.0347 mg/L for thermal insulation rooftop, while the highest average concentration was found in samples from concrete insulation rooftop as 0.0667 mg/L. For manganese (Mn^{+2}), the lowest average is 0.0773 mg/L for concrete insulation rooftop and the highest is 0.191 mg/L for metal insulation rooftop.

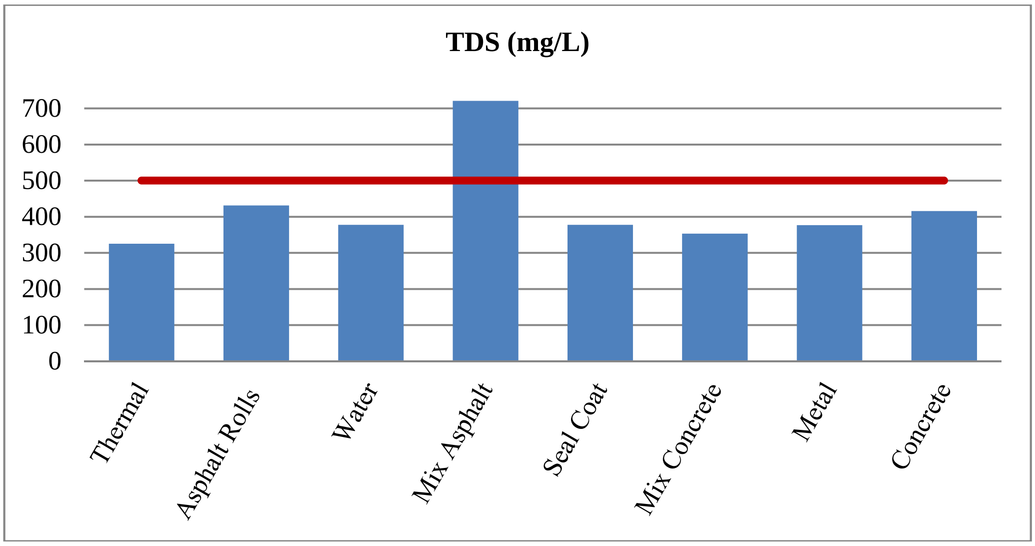

Figure (3): Average TDS in rainfall runoff from different roofing materials

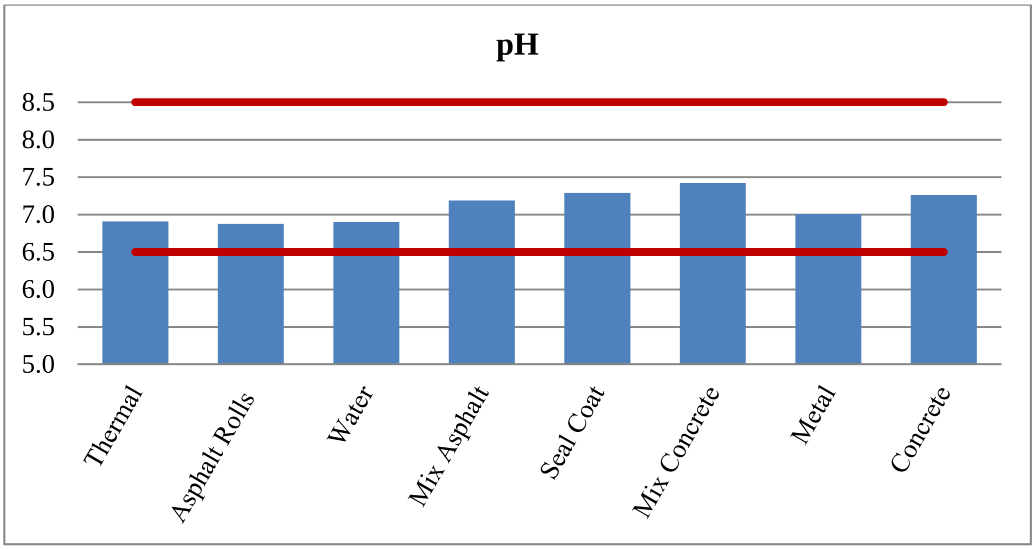

Figure (4): Average pH in rainfall runoff from different roofing materials

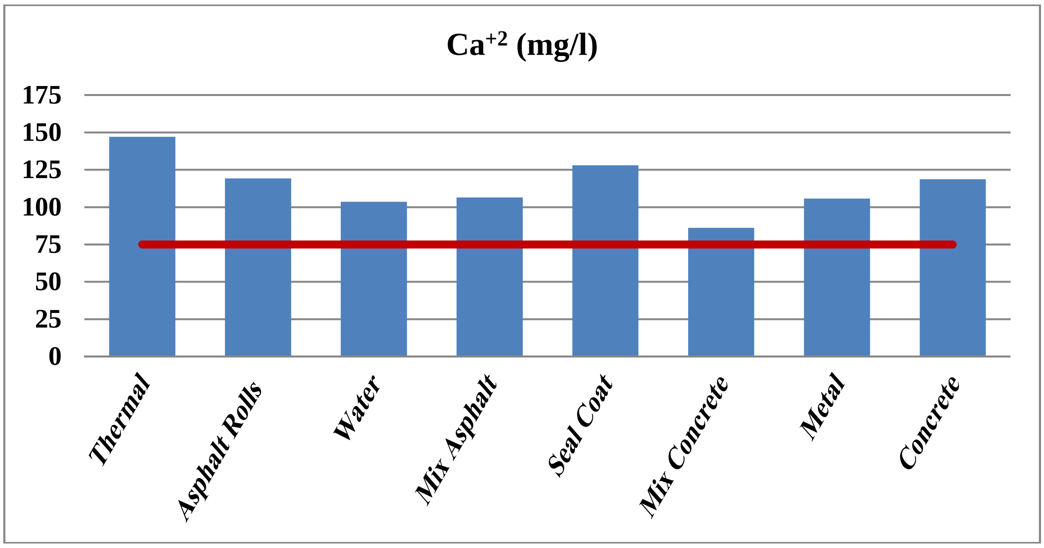

Figure (5a): Average cation concentrations in runoff from different roofing materials

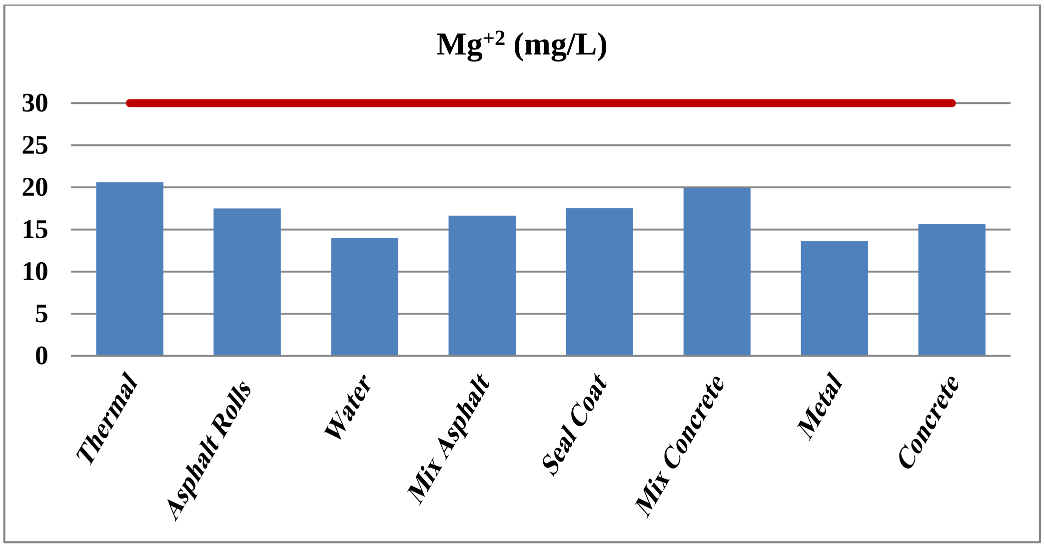

Figure (5b): Average cation concentrations in runoff from different roofing materials

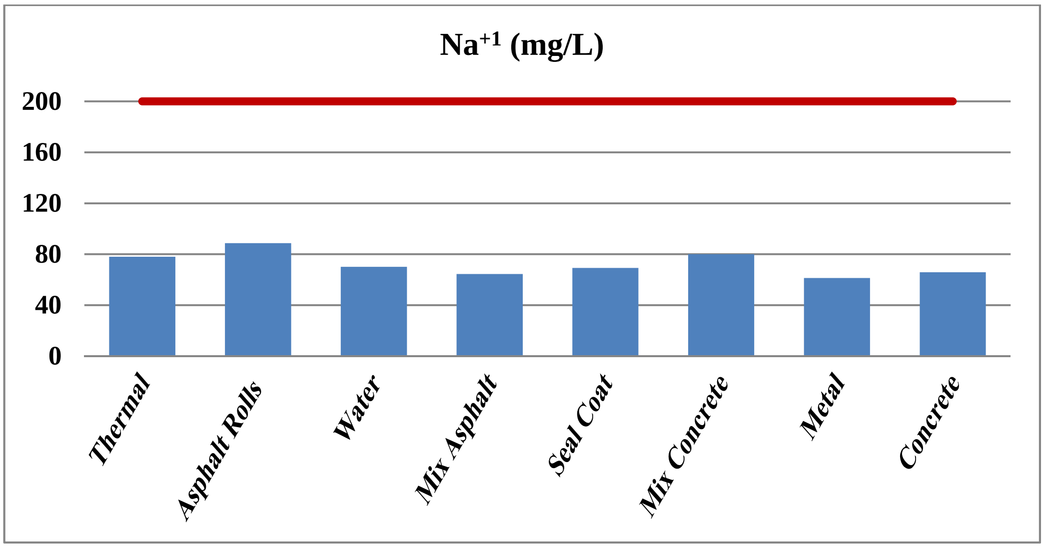

Figure (5c): Average cation concentrations in runoff from different roofing materials

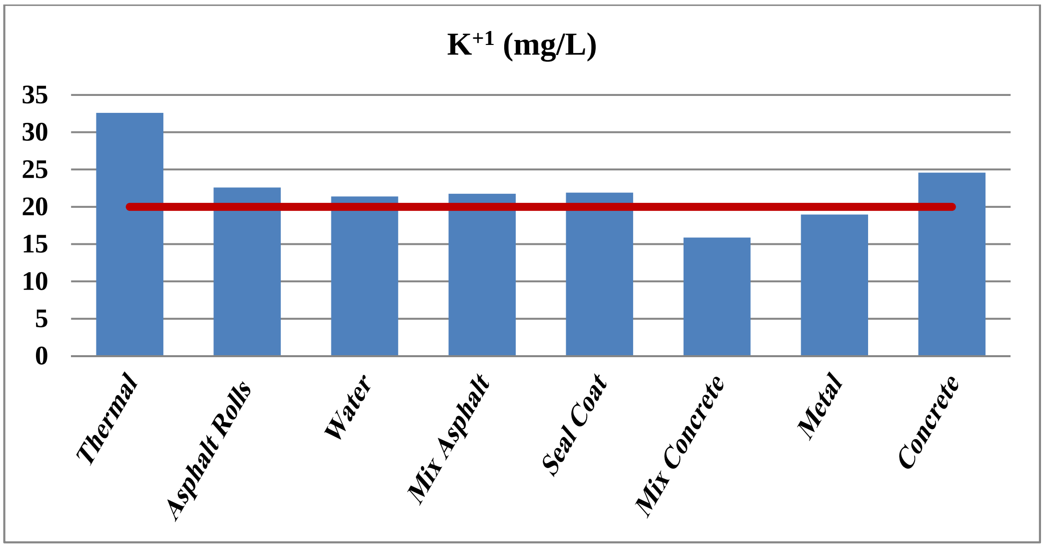

Figure (5d): Average cations concentrations in runoff from different roofing materials

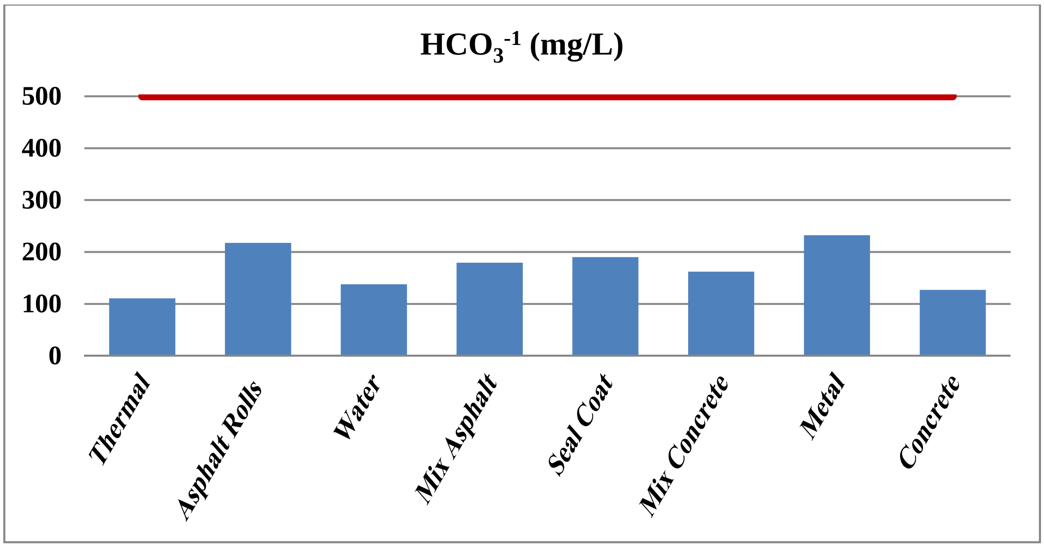

Figure (6a): Average anion concentrations in runoff from different roofing materials

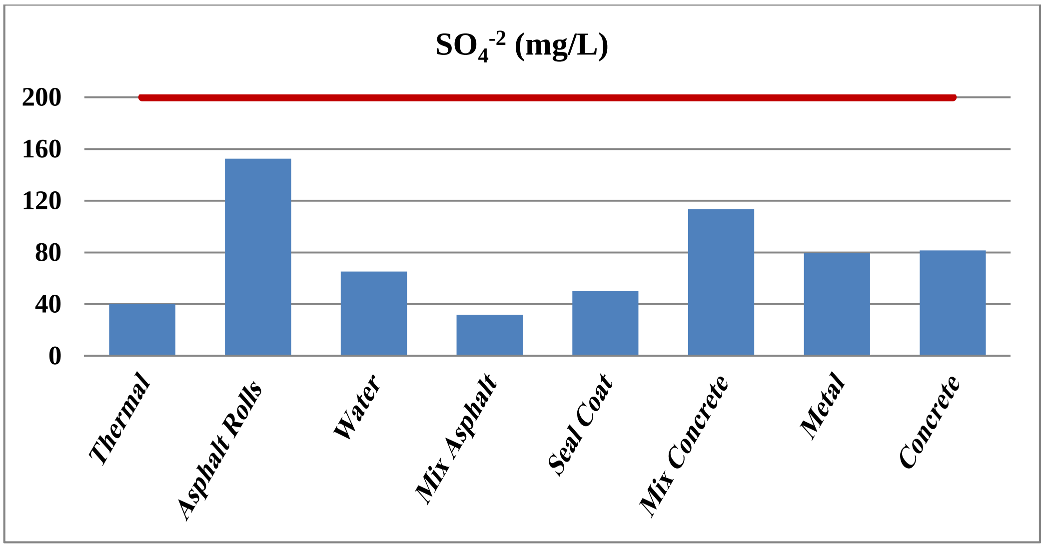

Figure (6b): Average anion concentrations in runoff from different roofing materials

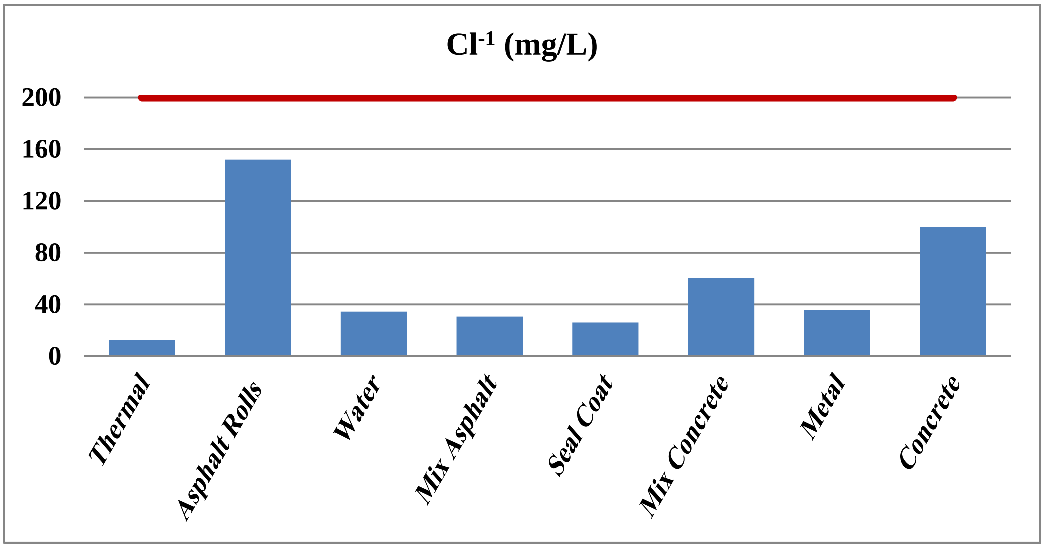

Figure (6c): Average anion concentrations in runoff from different roofing materials

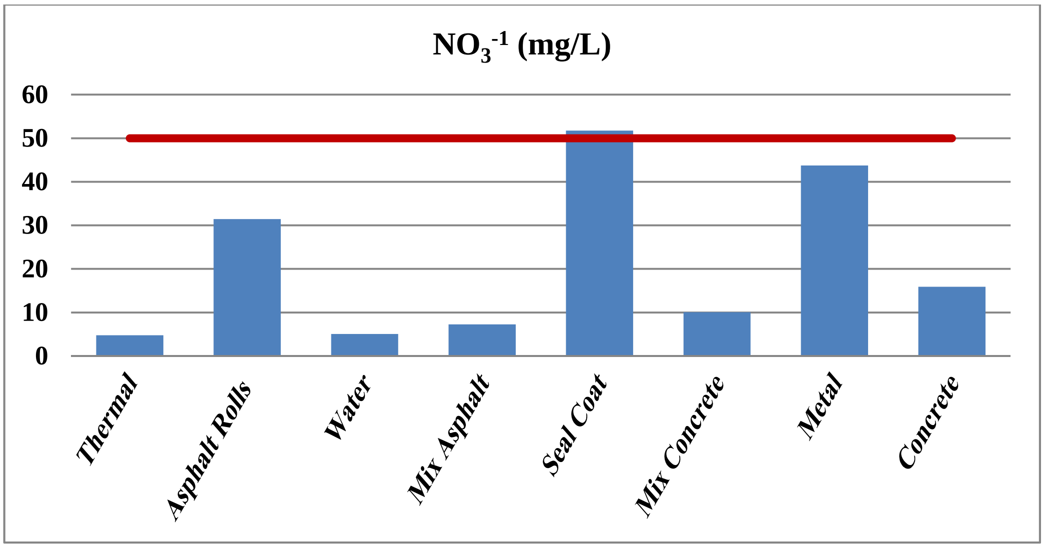

Figure (6d): Average anion concentrations in runoff from different roofing materials

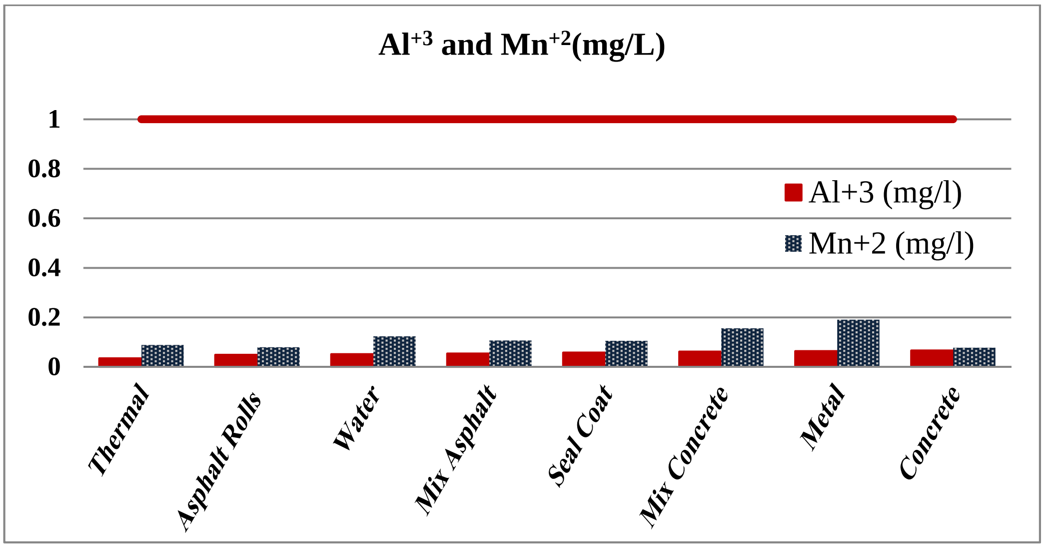

Figure (7): Average heavy metal concentrations in runoff from different roofing materials

The average concentrations of Al^{+3}, Cl^{-1}, HCO_3^{-1}, Mg^{+2}, Na^{+1}, Mn^{+2} and SO_4^{-2} were less than or equal to those given in the JWS standard for all roofing materials. The average concentration for TDS exceeds the value given in the JWS standard (=500 mg/L) for mixed asphalt insulation. The average concentrations for Ca^{+2} exceed the value given in the JWS standard (=75 mg/L) for all roofing materials, while the average concentrations for K^{+1} exceed the value given in the JWS standard (=20 mg/L) for mixed asphalt insulation, thermal insulation, seal coat insulation, water insulation, concrete insulation and roll asphalt insulation. The average concentration for NO_3^{-1} exceeds the value given in the JWS standard (=50 mg/L) for seal coat insulated parking lots (Figure 6d).

DISCUSSION

The overall water quality for runoff from different roofing materials is evaluated using the RockWare AqQA 1.5 water chemistry software (RockWare 2017). Figure 8 shows a graphical representation using Piper diagram (Piper, 1944). Classifications reveal two major types of runoff water for the different roofing materials, which are mixed $Ca^{+2} - Mg^{+2} - HCO_3^-$ and $Ca^{+2} - HCO_3^-$ types. Other methods of water chemistry evaluation are used with the RockWare AqQA 1.5 water chemistry software. Figure 9 shows the Durov representation diagram for the runoff water samples from different roofing materials and Figure 10 shows the Schoeller diagram to visualize the water composition in another way. The results show that Ca^{+2} and bicarbonate (HCO_3^{-1}) are dominant.

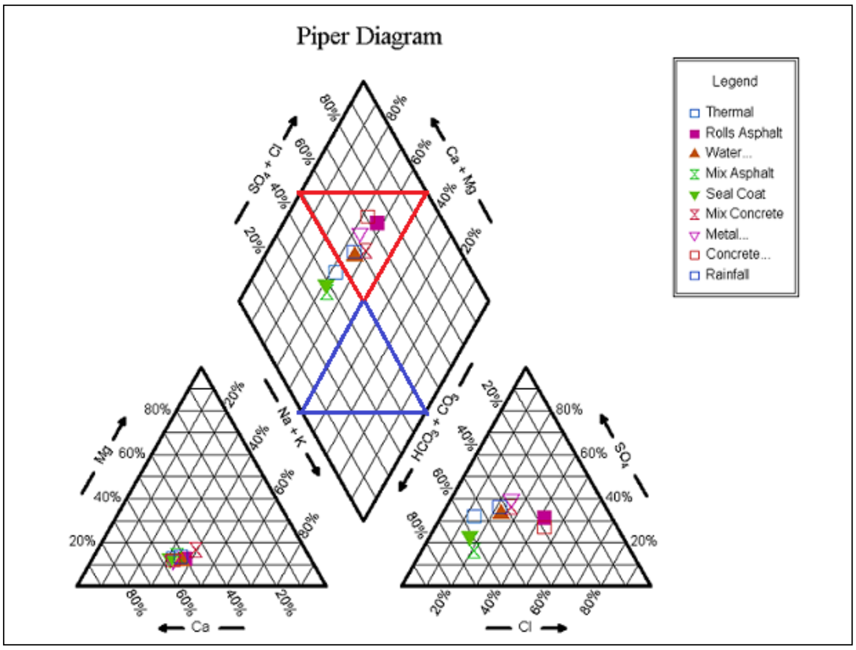

Figure (8): Piper diagram for roofing runoff water samples in the study area

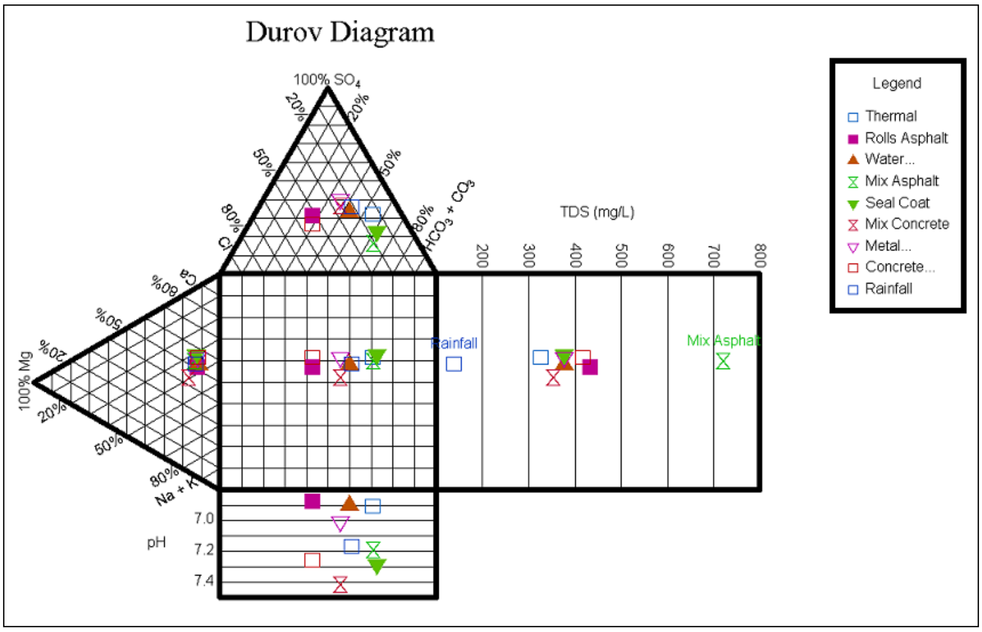

Figure (9): Durov diagram for runoff water samples from different roofing types

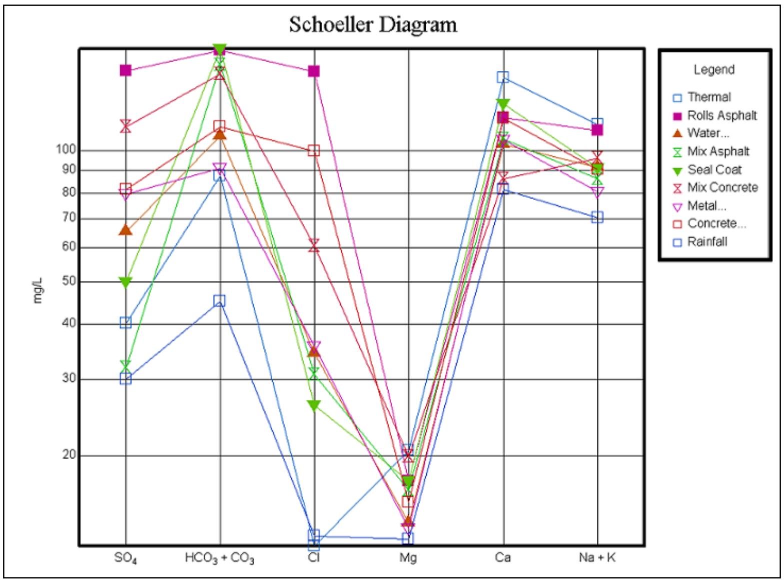

Figure (10): Scheoller plot for runoff water samples from different roofing types

It is not easy to evaluate pH values for two locations that were monitored in two different periods. However, air pollutants, such as gas emitted from boiler chimneys in the university buildings, might have impacts on precipitation acidity. On the other hand, construction activities during the research period and the effect of the mechanical wastewater treatment plant may have added alkaline pollutants, such as calcium and magnesium carbonates, as well as other soil-weathered materials to the air.

The wide range of ion concentrations may be interpreted as gas emitted from boiler chimneys. Heavy metal concentrations in rainwater and rooftop runoff probably resulted due to industrial emissions and activities in the surrounding area.

Roofs and parking lot sites are subjected to weathering when exposed to sunlight and climatic condition variations. Different materials are captured on roofs and parking lots. In addition, insulation materials are subject to weathering and decomposition due to heat energy, moisture, acid ions from rainwater and products washed off by rainwater (Mendez et al., 2011). Ions released from the roofs due to this process may change pH values, eventually influencing the runoff water quality.

The results show some correlation between the type of roofing substance and the ions washed out of them. These include substances accumulating on the surface of the roofing material, as well as substances washed out of the roofing itself.

CONCLUSIONS

The main finding of this study is that the material of the catchment surface has some effect on the chemistry of the runoff generated on that surface. Following are some of the conclusions drawn from this study.

- The average concentrations for TDS, anions (HCO_3^{-1}, Cl^{-1}, NO_4^{-1} and SO_4^{-2}), cations (Na^{+1}, K^{+1}, Ca^{+2} and Mg^{+2}) and heavy metals (Al^{+3} and Mn^{+2}) in rainwater were less than those for runoff from rooftops and parking lots. This is expected, since the runoff will wash some of the accumulated substances from the rooftop surface. TDS of rainwater increased in runoff water by 137% for thermal insulation rooftop to 422% for mixed asphalt rooftop.
- The lowest concentrations for TDS, bicarbonate ($HCO3^{-1}$), chloride (Cl^{-1}), aluminum (Al^{+3}) and nitrate $(NO_3)^{-1}$ were found in runoff samples taken from locations roofed with thermal insulation using chemical sealing materials. These materials are

designed to withstand weather conditions, mainly rising air temperature. As a result, the only added chemicals to the runoff water come from the accumulated substances from air on the rooftop. The lowest value of sulfates (SO_4^{-2}) was found for roofs covered with mixed asphalt insulation.

- Heavy metals are below the detection limits for most of the rainfall and runoff samples. Samples with detected values of Al^{+3} and Mn^{+2} have concentrations below the JWS limits. This is supported by the fact that since roofing materials do not have heavy metals, the only source will be the accumulation from air.
- The average concentrations of Al^{+3}, Cl^{-1}, HCO_3^{-1}, Mg^{+2}, Na^{+1}, Mn^{+2}, SO_4^{-2} and TDS were less than or equal to those given in the Jordanian Water Standard (JWS, 2004) for drinking water, while for Ca^{+2}, they exceed the JWS limit (=75 mg/L) for all roofing materials, but for K^{+1}, they exceed the JWS limit (=20 mg/L) for most of the roofing materials.
- For all roofing materials, the order of the average concentrations can be arranged as follows: metal insulation < mixed concrete insulation < mixed asphalt insulation = concrete insulation < water insulation = seal coat insulation < roll asphalt insulation < thermal insulation.

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