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ADVANCED HIGHLY POLLUTED RAINWATER TREATMENT PROCESS

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Abstract: A new PVC-filter filled with recycled glass and crushed foam glass has been investigated the removal of major pollutants in rainwater to enhance the physical properties and enrich the matrix of this potential source of water with essential minerals. The physical properties of 10 pre-filtered and 10 post-filtered specimens of rainwater are tested. Then, all samples are analysed to assess the chemistry of rainwater. The ions found in pre-filtered rainwater follows the order: $HCO_3^- > SO_4^{2-} > NO_3^- > Cl^- > F^-$ for anions and $Ca^{2+} > Mg^{2+} > Na^+ > NH_4^+ > Sr^{2+} > K^+$ for cations. The relative abundance of heavy metals in pre-filtered rainwater follows the descending order: Cu^{2+}, Fe^{2+}, Zn^{2+}, Se^{4+}, Pb^{2+}, Mn^{2+}, As^{5+}, Ni^{2+}, Cd^{2+}. On the other hand, the high concentrations of SO_4^{2-}, NO_3^-, and the heavy metals found in this study can be signs of that Damascus rainwater is mainly of anthropogenic origin. After filtration, the analyses in rainwater becomes in conformity with the World Health Organization for drinkability. The performance of this filter is compared with Eugene Water & Electric Board. This comparison proves that this filter is greener and eco-friendly option to conventional rainwater purification practices. Results of this research prove the capability of this filter to shift polluted raindrops into a freshwater.

Keywords: Heavy metals; Anthropogenic; Eco-friendly; Ecological footprint; Toxic

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INTRODUCTION

Filtration is the most effective form of water treatment and purification which considers more efficient than sterilisation in some applications (Ray *et al.*, 2011). Filtration is able to selectively remove large amounts of drinking water contaminants. Water filters can remove little but dangerous chemicals and trace elements and secure much healthier source of drinking water. Indeed, there are many types of water filters available in the market as: (i) weave wire filter which is made up of SS (stainless steel, grade 316) and of rigid PVC (Dickenson, 1997), (ii) cloth filter that is just a piece of fine cloth i.e. PP (polypropylene, $(C_3H_6)_n$), polyester (PE, $(C_{10}H_8O_4)_n$), nylon, cotton and is especially used to remove most cholera bacteria and some other pathogens (Huq *et al.*, 2010). Despite, the two types can filter TSS (total suspended solids) coming with runoff, but fail to filter any bacteriological contaminants if present in water. In addition, the degree of filtration and the capacity of the two filters lie in the range of 3.94–7.87 thou (1 inch = 1000 thou) and 1320–11888 gal/h, respectively (Huq *et al*., 2010). Therefore, these filters could only be used in systems where rainwater is harvested for non-potable purposes, (iii) Pop up nylon sieve filter (2.36 inch OD) developed by Shivakumar (2005) has just two advantages: (A) when the filter gets clogged, it comes out of the casing, and (B) the filter maintenance is handy, (iv) Eugene Water & Electric Board (EWEB) filter is constructed from 100% PE fibre and filled with gravel and sand (EWEB, 2004). This filter is used to remove accumulated sediments and other debris (Morgenstern *et al.*, 2011), (v) Dewas filter was designed on May 28, 1999 by Mohan Rao from India, manufactured from PVC (polyvinyl chloride, $(C_2H_3Cl)_n$) pipe (5.5 inch OD and 4.0 ft long) (ENVIS Newsletter Parisara, 2012; Mamta *et al.*, 2012). Despite all of these numerous water filters sold in market, there are no standards and regulations existed on the global level regarding the installation and use of water filters, where people are end up buying one that is completely useless for the type of water problem they are having. For example, different filters may reduce chemicals, minerals, and parasites present in water. Some types get rid of heavy metals, while others are better for non–volatile chemicals, bacteria or sediment.

Few attempts have been made to investigate rainwater quality in Damascus which is one of the most polluted cities in the world (Kattan, 1997). However, none of these studies has prescribed an environmental solution for Damascus polluted rainwater which can save the deserved rights of farmers (Aljerf, 2018a). The reason attributes to the following factors: (i) fluctuation of the annual average rainfall, (ii) instability of the manufacturing conditions on the industrial sector (Aljerf, 2018b), and (iii) the varied agricultural practices that are taken place inside and/or around the city (Aljerf, 2018a). Samples were collected from five locations in Damascus city in March 5, 2015. After that, they filtered to decontaminate this source of water by using a PVC-local made filter filled with inexpensive filtering media.

MATERIALS AND METHODS

This section explains data collection, specifies the optimised analytical methods, and proposes a new filter design. **Table 1** presents the methods used in this study.

Sample collection

Sample collection was performed in accordance with EPA. Rain water samples (n = 500) were collected chronically in 5 urban sites: Dummar (DU) (north-west), Barzeh (BH) (north-east), Almaza (MA) (south-west), Midan (MI) (south-east), Al-Salihiyah (SA) (centre) in Damascus city in March 5, 2015 (52 °F, humidity: 36%, average rainfall: 1.2 inch, wind NE AT 32.8 ft/h).

The duration of sample collection was taking place from 2 to 10 min in heavy to moderate showers and from 20 to 40 min at light rainfall intensity. The samples were gathered manually on an event basis, using only wet collector for each sample. The collector is an HDPE plastic bucket fitted with a polyethylene funnel (10.2 inch OD), has been installed at top building (around 40 ft above the ground level and 3.3 ft from the floor of the roof) along with the progress of the rain shower. Before collecting rainwater samples, each bucket had previously been soaked in 20% HNO_3 for 1-d then rinsed several times with DI (deionised water) (Milli-Q Ultrapure water specifications: 18.2 MΩ/cm @ 77 °F, TOC ≤ 5 ppb, Bacteria ≤ 1 CFU/mL). Then after sampling, the buckets were sealed with clean plastic lids to avoid contamination during transport to laboratory.

In laboratory, the quantity of each rainwater sample taken from a bucket was divided into two bottles; the first part was used for the measurement of the analyses without filtration, while, the second part was filtered. The bottles were kept in a refrigerator at 39.2 °F until measurements. The contents of the two parts were used for subsequent physical and chemical analyses within couple days. Glassware used in this study for sample collection, filtration, and storage were rinsed copiously with DI water to remove salts. Then, they were heated at 842 °F in a muffle furnace for a minimum of 4 h to get rid of organics prior to reuse. Also, the funnels were rinsed with DI water, stored in clean plastic bags, brought out, and mounted on the stand (8.2 ft height) for next use. Moreover, the receiving bottles were rinsed several times by DI water and dried before reuse.

Filter

The filter presented in **Fig. 1** was designed in this study to realise two subjects: (i) to receive rainfall which is sprinkled from the top of the filter, and (ii) to reduce the exceedingly high ecological footprint by minimising the use of chemicals and radiation sources.

Table 1. The adopted analytical techniques and instrumentations

Analyte	Instrument	Methods
Acidity	-	ASTM D1067
Al	Acid extractable by the preliminary treatment, novAA 400 P (Analytik Jena AG, Jena, Germany)	ASTM D857
Alkalinity	-	ASTM D1067
B^{3+}	LaMotte 2000-01 SMART Spectrophotometer	ASTM D3082
BOD_5	BODTrak II Respirometric BOD Apparatus (Hach, Colorado, USA)	ASTM WK28466
COD	-	ASTM D6697
Colour	DR 1900 (Hach, Colorado, USA)	APHA
EC	MP-4 Portable Meter (Hach, Colorado, USA)	ASTM D1125
DO	DR 1900 (Hach, Colorado, USA)	ASTM D888-I
FC	m-FC & Microscope Compound 10X (Hach, Colorado, USA)	9222 D-1997
H^+	-	4500- H^+ B-2011
HCO_3^-	-	APHA
Hg^{2+}	novAA 400 P (Analytik Jena AG, Jena, Germany)	ASTM D3223
NH_4^+	IntelliCAL ISENH3181 Ammonia-Selective Electrode (Hach, Colorado, USA)	ASTM D1426
pH	CP-411 pH-Meter (Analyiso GmbH, Greifswald, Germany)	ASTM D1293
Na^+, K^+	FLAPHO 4 spectrophotometer (Carl Zeiss Jena, Jena, Germany)	ASTM D1428
Ca^{2+}, Mg^{2+}, Sr^{2+}	novAA 400 P (Analytik Jena AG, Jena, Germany)	ASTM D3920, (Aljerf & Mashlah, 2017
Cl^-, F^-, NO_3^-, $SO4^{2-}$	Dionex ICS-900 (Thermo Scientific, FL, USA)	ASTM D4327
Cd^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Ni^{2+}, Pb^{2+}, Zn^{2+}, Al^{3+}, Se^{4+}, Cr^{6+}	novAA 400 P (Analytik Jena AG, Jena, Germany)	ASTM D3919
TDS	MP-4 Portable Meter (Hach, Colorado, USA)	ASTM D5907
TOC	Shimadzu TOC-VCSH	ASTM D7573
TC	LT and BGB (Microscope Compound 10X, Hach, Colorado, USA)	APHA
TH	-	ASTM D1126
TP	Spectron CA72TP (Endress+Hauser AG, Reinach BL, Switzerland)	ASTM D515
TSS	DR 1900 (Hach, Colorado, USA)	ASTM D5907
Turbidity	2100Q IS (Hach, Colorado, USA)	ASTM D1889

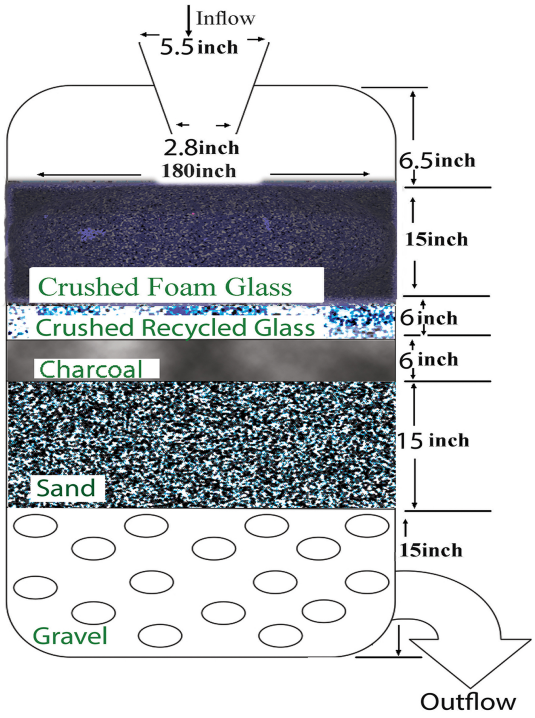

Fig. 1 Devised sediment filter.

This is a type of granular settlement filter, utilises waste products to remove suspended pollutants from collected rainwater, therefore encouraging industrial ecology practices (Aljerf, 2018b). In addition, this filter involves in its design a single phase with two homogeneous layers of CRG (crushed recycled glass) and FG (crushed foam glass), both suitable for long-term storage and disposal.

The filter can be employed to effectively remove turbidity (suspended particles as silt and clay), colour, heavy metals, and microorganisms. In addition, it may enhance the quality of this possible new source of drinking water. A filter unit of 5283 gal PVC-made chamber (1–inch thickness and 0.02 lbs/inch) filled with inexpensive and easily available filtering media (0.2 inch fine mesh) such as gravel, sand-charcoal GL-70 (Auro Carbon & Chemicals, Gujarat, India) with 25429 yd^2/oz (750 m^2/g) granules, and CRG layer (0.2 inch fine mesh, specific gravity: 2.283 analysed according to ASTM D854, and porosity: 0.52 measured in agreement with ASTM C949-80 to remove debris and dirt from rainwater collected before the flux goes at the bottom through a 0.007 inch mesh of SS (304 grade) screen. The volume of the filter is suitable to let water passing through, so that, particles tend to be trapped in pore spaces or adhere to sand particles.

The FG (0.25 inch diameter, pH = 9.8, organic content = 0, and of vitreous nature) brought from JSC Gomeglass (Gomel, Belarus), was used due to the high efficiency of this coarse-grained form to absorb over 200% its weight in water. Air forms small voids during foam production. This product has high water

absorption and low bulk density (9.3 lb_m/ft^3) measured both in accordance with ASTM C373 and high porosity (0.9) according to ASTM C949-80. These properties make this medium possible to remove some risk contents from rainwater but increases other pollutants that came from the melting process during FG manufacturing like Ag^+ (silver), Ba^{2+} (barium), Cd^{2+} (cadmium), Hg^{2+} (mercury), Pb^{2+} (lead), Se^{4+} (selenium), As^{5+} (arsenic), and Cr^{6+} (chromium) (Arulrajah *et al.*, 2015).

The sand and gravel are scrubbed and dried to remove all clay, shale, inorganic impurities, and any other foreign matter, then dried and sized using PLC controller for consistency. Considering that the space between sand particles is typically larger than the smallest suspended particles in rainwater.

Charcoal crushed in small pits is primarily used to improve taste and remove odour, colour, Cl_2 (chlorine), sediments, and organics such as: THMs (trihalomethanes, CHX_3), pesticides, industrial solvents (i.e. halogenated hydrocarbons), PCBs (polychlorinated biphenyls, $C_{12}H_{10-x}Cl_x$), and PAHs (polycyclic aromatic hydrocarbons), if they exist in rainwater. So, there are many potentially harmful contaminants can be disposed from rainwater when using charcoal. This carbon layer can be generated up to 10 frequency filtration times. The CRG is processed from collected soda-lime glass bottles, which is then heat treated to remove contaminants and residuals before application and enrich the medium of filtered rainwater with alkali minerals. CRG consists in general from alkaline oxides and some other oxides i.e. Al_2O_3 (aluminium oxide) and SiO_2 (silica) (Nassar & Soroushian, 2013; Aljerf, 2015a). In addition, CRG has a range of other organic pollutants that are below the limits for inert waste classification (Nassar & Soroushian, 2013).

The filter's engineering design is compatible for the outflow that enters the storage tank or recharge structure. This system can filter 2500 gal of rainwater (enough for 10 persons to live for a year) per day. According to the U.S. Geological Survey and the design of the devised filter, we need to distribute 4.24 million filters to harvest all the annual quantity of rainfall for New York State.

Consequently, the system of this filter considers two points: (1) the needs for the effective implementations of recycling and reusing materials which satisfies the principal of "Polluter Cleans Polluters (PoClPos)" (Aljerf, 2018b), and (2) industry encouragement to efficiently participate in waste recovery markets. Upon usage, this filter needs a regular cleaning to avoid bacteria build-up. Besides, the average annual maintenance cost of the filter is estimated by around £2 and the cost of this filter attains £409 which is 31% less than the cost of the filter manufactured by EA Water PVT Ltd (Sultanpur, India) (Available at: http://www.eawater.com/about-us.html).

RESULTS AND DISCUSSION

Physical properties

Upon arrival at the laboratory, the volumes and weights of 10 samples with 2 lots were taken from each bottle with five replicates (n = 5). Each sample is attributed to a bucket that represents one administrative region in Damascus. The measurements of the volumes and weights were immediately indicated. Then, half volume of each sample with 5 replicates (n = 5) has been passed through the sediment filter (**Fig. 1**) and the physical properties were tested for each half (**Table 2**).

The average temperature has decreased after filtration a potential increase in DO of the post-filtration samples. In addition, the density, surface tension, and viscosity were slightly decreased after filtration. Moreover, the odour and taste improvement after filtration refer to possible disposal of organic, biological, and heavy metals contents in rainwater.

Chemical properties

After assessment of the physical properties of rainwater pre- and post- filtration, the chemical study was started by executing the analysis of two SRM samples. The observed values of SRM-1643c and SRM-2694, in the laboratory had been compared with the corresponding true values of the analyses given by the National Institute of Standards and Technology (Gaithersburg, USA).

The average of five replicates and SD (standard deviation) of the observed values were recorded then the recovery, S (R), and PRD (Relative percent difference) had been tabulated (**Table 3**).

Table 2. Physical properties of ten inflow specimens and ten outflow specimens (2 samples were taken from the same administrative region)

Physical property	Inflow [a]	Outflow	Method
Average temperature, °F	57.2	55.4	-
Average density ± SD, lb/ft^3	64.4 ± 8.3	63.3 ± 7.9	Gravimetric
Average surface tension ± SD, dyn/cm	0.0144 ± 0.0018	0.0142 ± 0.0018	Capillary Rise Method
Odour	Very slight	Unobjectionable	ASTM D1292
Taste	Bitter metallic and corrosion	Agreeable	Sensory evaluation
Viscosity ± SD, lb/ft^2 s	186.1 ± 23.3	183.9 ± 23.0	ASTM D445

[a] Five replicates (n = 5) for each measurement.

Table 3. Target values of SRM-2694 and SRM-1643c rainwater samples

Analyte	True value ($\times 10^3$) [b]	Observed value [b]		Recovery (%)
		Mean ($\times 10^3$) [f]	SD ($\times 10^3$)	
Al^{3+}	8.068 [d]	7.507	0.1193	93.04
As^{5+}	5.753 [d]	5.332	0.4420	92.68
B^{3+}	8.349 [d]	7.717	0.4350	92.44
Ca^{2+}	3.508 [e]	3.578	0.0210	102
Cd^{2+}	0.842 [d]	0.772	0.0351	91.67
Cl^-	70.2 [e]	70.9	1.2	101
EC	21889 [e]	21720	286	99.23
Cr^{6+}	1.333 [d]	1.263	0.0140	94.74
Cu^{2+}	1.543 [d]	1.473	0.0281	95.45
F^-	7.016 [e]	6.461	0.0351	92.1
Fe^{2+}	7.507 [d]	6.91	0.0281	92.06
K^+	7.016 [e]	6.609	0.0281	94.2
Mg^{2+}	3.508 [e]	3.557	0.0210	101.4
Mn^{2+}	2.455 [d]	2.315	0.0421	94.29
Na^+	28.063 [e]	26.372	0.1263	93.98
NH_4^+	70.157 [e]	64.622	3.2	92.11
Ni^{2+}	4.28 [d]	4.062	0.0491	94.85
NO_3^-	491.098 [d]	490.642	4.4	99.91
Pb^{2+}	2.455 [b]	2.266	0.1193	92.29
pH[C]	3.6 [e]	3.5	0.08	97.22
SO_4^{2-}	771.726 [e]	743.663	3.4	96.36
Sr^{2+}	18.521 [d]	17.609	0.8138	95.08
Zn^{2+}	5.192 [d]	4.911	0.1123	94.59

S (R): Standard deviation of percent recovery.
RPD: Relative percent difference.
[b] Average concentration and standard deviation were measured by (grain/gal [U.K.]) that expressed as value ($\times 10^3$), except EC at 77 °F which measured by (µS/inch) and was not associated by value ($\times 10^3$).
[c] pH measured without ($\times 10^3$).
[d] SRM-1643c.
[e] SRM-2694.
[f] Mean of 5 replicates.

The recovery values of the measured analyses lied in the range [91-102] and the S (R) and RPD values were found acceptable (**Table 3**). After checking the feasibility of the optimised methods through the last step of calculated recoveries for two SRM samples, the chemistry of rainwater samples has been defined. The corresponding parameters (bacteriological, inorganic ions, organic nutrient and demand, physical, and toxic metals) were measured with 5 replicates (n = 5) for the measurements of pre- and post- filtration samples according to the international standard methods and some other valuable methods accredited on the international level (**Table 1**).

Table 4 shows a comparative data of the water quality of inflow and outflow parameters. The DL (detection limits) calculated by taking, three SD of ten replicate (n = 10) blank level measurements, variances, skewness values, and the MCL (maximum contaminant levels) listed by one of the following references: CPCB, EPA's HRL, ISI, and USEPA.

Please Insert **Table 4**

The variance values give an accurate description about the distribution of concentrations. This statistical probability of the volatility of the measurements for rainwater samples before filtration is presented in the following descending sequence: alkalinity, conductivity, TDS, TSS, HCO_3^-, TH, SO_4^{2-}, COD, Ca^{2+}, DO, TC, BOD_5, S (R), RPD, NH_4^+, turbidity, NO_3^-. Therefore, the variance values assured that the rainwater of collected samples at the same time have not the same matrix and the matrices differ according to the location of rainfall, orographic, topographic sites, meteorological conditions, macro- and micro- climate conditions (i.e. altitude, ambient nutritional occurrence, temperature, humidity, and light), behaviour of elements, anthropogenic impacts and the distance from the sources of contamination.

All measurements, the skewness factors ranged from -1 to +1 indicating in all cases data have approached Gaussian distribution (Aljerf & Mashlah, 2017). Consequently, no additional transformations were required for this type of data analysis. In general, the small rainfall is expected to generate higher concentrations of chemical species (i.e. heavy metals, biological pollutants) due to the reduction in the removal of suspended particles by wet deposition.

Therefore, respect to the measured concentrations of pre-filtration rainwater, the distributions of analytes varied and some parameters in some locations in Damascus city overlapped the *EPA's MCL* values (**Table 4**). The colour, FC (10.9–13.0% of TC) and TC were prevailed in all rainwater samples at risk limits. BOD_5 values skyrocketed over the relative *EPA's MCL* in BH, MA, MI, and SA locations. The TP values overlaid the *EPA's MCL* in all samples except in MI rainwater. The variations of heavy metals in rainwater can be explained by the scavenging factors of pollutants and source of pollutant emissions. The relative abundance of heavy metals in rainwater was mentioned in the following descending order: Cu^{2+}, Fe^{2+}, Zn^{2+}, Mn^{2+}, Pb^{2+}, Se^{4+}, As^{5+}, Ni^{2+}, Cd^{2+}, which may reflect the dependence of availabilities upon their evaporation and their absolute solubility values. Iron was observed in higher concentrations to the *EPA's MCL* for all samples except DU rainwater. Lead and copper concentrations of MA, MI, and SA samples were over the *EPA's MCL* values. Arsenic was found at critical values in MA and SA samples. Fluoride fraction was extended over the corresponding *EPA's MCL* in BH and DU rainwater samples. Aluminium was found above the safe limit for drinking water in 60% of SA samples and all MI samples (N = 100). MI samples had the highest contents of Nickel and Zinc with lowest pH values (*Median* = 6.4). The later parameter may refer to neutralisation effect and the oxidation of organic matter (Kempe, 1984).

In general, rainwater falls at equilibrium level with atmospheric CO_2. Its pH value normally attains "5.6" in clean atmosphere due to the dissolution of CO_2 in rain droplets (Bayraktar & Turalioglu, 2005). However, the pH values of samples collected from other sites other than MI show strong inputs of alkaline species to rainwater samples in these regions. The higher loadings

Table 4. Comparison between the chemical measurements of pre- and post- filtration rainwater samples[g]

Water quality parameter	Inflow [h]			Outflow [h]		DL (×10⁴)	Var. (×10⁴)	Skew	MCL [n] (×10⁴)
	Min (×10⁴)	Max (×10⁴)	SD (×10⁴)	Max (×10⁴)	SD (×10⁴)				
Acidity	9541	10103	63	3648	21	21.05	4	0.35	NIL [j]
Al^{3+}	7	70	7	21	0.00	2.1	0.05	-0.06	6.1
Alkalinity	25958	91906	7647	108743	9050	2526	59811	0.12	140314
As^{5+}	0.00	35	7	0.00	0.00	1.4	0.02	0.03	7
B^{3+}	0.00	112	14	147	21	5.6	0.26	-0.43	NIL [j], 2105 [k]
BOD_5	2666	7928	575	351	28	192	331	0.06	3500
Ca^{2+}	15715	23362	772	31009	1052	267.3	642	-0.17	52618
Cd^{2+}	≤ DL	≤ DL	-	≤ DL	-	0.00	0.00	0.23	1.4
Cl^-	1684	2455	84	2666	91.2	28.8	7	-0.27	2806
COD	4209	12488	905	≤ DL	-	302	823	0.03	NIL [j]
Colour	8	12	0.50	≤ DL	-	0.166	142	0.58	5.0
EC	38.6	74.8	3.8	90.6	4.6	1.3	361	-0.66	787 [l]
Cr^{6+}	≤ DL	≤ DL	-	≤ DL	-	7	-	-	35.1
Cu^{2+}	772	1333	56	91	7	18.2	3	0.48	912
DO	2947	8910	660	9682	702	220	435	0.70	9822
F^-	1052	1614	56	596	21	18.2	3	-0.18	1403
Fe^{2+}	196	1473	161	154	14	54	26	0.32	210
FC	227	318	10.9	≤ DL	-	2.7	1189	-0.89	0.000
H^+	0.5	1.8	0.1	0.4	0.09	0.02	8.4	0.32	NIL [j]
HCO_3^-	12402	18466	645	19952	702	530	1010	-0.17	NIL [j]
Hg^{2+}	≤ DL	≤ DL	-	≤ DL	-	0.000	-	-	1.4
K^+	393	582	21	4069	140	7	0.4	-0.18	NIL [j]
Mg^{2+}	3438	5051	175	19644	681	58	31	-0.20	21047
Mn^{2+}	≤ DL	42	7	≤ DL	-	1.4	0.03	0.52	35
Na^+	1894	2806	98	13821	474	32	9	-0.17	NIL [j]
NH_4^+	281	3508	337	≤ DL	-	112	113	-0.18	NIL [j]
Ni^{2+}	7	14	0.8	≤ DL	-	0.7	0.00	0.31	14
NO_3^-	4560	6805	232	2947	98	78	55	-0.17	31571 [m]
Pb^{2+}	8	49	7	≤ DL	-	2.1	0.03	0.38	10.5
pH	6.4	6.9	0.06	7.1	0.06	0.100	0.04	-0.23	[6.5-8.5]
Se^{4+}	14	28	0.12	7	0.03	0.7	0.00	0.08	35
SO_4^{2-}	20135	29957	1052	6454	225	342	1058	-0.17	175392
Sr^{2+}	1263	2385	119	2666	133	84	14	0.05	NIL [j], 2947 [k]
TDS	18935	36797	1854	44593	2267	639	17693	-0.18	350784
TC	2091	2455	39	≤ DL	-	3.9	15332	0.22	4.5
TH	31571	46304	1543	53460	1754	502	2277	-0.23	350784
TP	21	42	3.8	14	0.00	0.7	0.00	-0.20	[7-21]
TSS	43217	64334	2175	13751	463	702	4877	-0.17	NIL [j]
Turbidity	4209	7016	302	70	8.3	56	90	-0.18	7016 [m]
Zn^{2+}	14	70	7	63	7	2.1	0.03	0.34	84.2

[g] The concentrations and the standard deviations expressed as value (× 10^3), except the following parameters: colour, EC, FC, H^+, pH that had not associated by value (× 10^3).

[h] Concentrations in (grain/gal [U.K.]) except EC at 77 °F, acidity, alkalinity, colour, FC, H^+, TC, and turbidity which measured by µS/inch, grain/gal [U.K.] $CaCO_3$, grain/gal [U.K.] $CaCO_3$, Hazen units, CFU/gal [U.K.], µeq/gal [U.K.], CFU/gal [U.K.], and NTU, respectively. Considering that: 1 grain/gal [U.K.] = 14.3 mg/L.

[i] Note: At pH = 7, $[H^+]$ = 0.1 µeq/L = 0.4 µeq/gal [U.K.]

[j] NIL: Nonexistence by USEPA.

[k] HRL provided by EPA.

[l] Provided by CPCB.

[m] Provided by ISI.

[n] MCL: Maximum Contaminant Level.

of alkaline elements in the form of carbonate dust particles of rainwater produce an increasing in pH values. This refers to probable consumption of dissolved CO_2 gas by existed organisms (i.e. coliform) in rainwater (Dermine, 1985). Manganese was only found in MA samples over the relative EPA's MCL. Damascus rainwater was found of high EC probably due to the following reasons: (1) high contents of dust and TDS, (2) elevated ion-adsorption capacity of carbonate, and (3) adsorption-desorption process taking place between solid and liquid phases (Wang & Liu, 2015; Aljerf, 2018b). Chloride fraction came off the Saharan dust storms from the south during the past winter and spring seasons. Calcium and magnesium contributions in Damascus rainwater generally result from both of sea salt and dust particles (or particulate matters). In frequent, the latter two elements participate in the neutralisation reactions that take place in atmospheric precipitation (Al-Taani *et al.*, 2015). The origins of sodium and potassium cations are mainly: (1) dust sea salts and the aerosols of the Mediterranean Sea, and (2) polar depressions that affect Syria during the rainy seasons (Sciare *et al.*, 2003). The observed ratio of Cl^-/Na^+ (0.9) is much lower than of seawater (1.8) suggesting either a fractionation of Cl^- or enrichment of Na^+ (Mouli *et al.*, 2005). The main potential sources of nitrate in Damascus rainwater are: airborne fertiliser particles, motor vehicle emissions, and the intense thunderstorms (Al-Momani *et al.*, 1995). Ammonia found in Damascus atmospheric wet deposition could be a result of several sources including the volatilisation of animals' and pets' residues, human excrements, natural loss by plants, and biomass burning. When ammonia incorporates the rain structure, NH_4^+ neutralises the rain acidity (Al-Momani *et al.*, 1995). The observed alkalinity of rainwater is mostly due to the high loading of particulate matters present in the local atmosphere of the study area. The suspended particulate matters are rich in carbonate/bicarbonate of calcium which buffer the acidity of rainwater (Özsoy & Örnektekin, 2009). Rainwater acidity is mainly due to H_2SO_4 and HNO_3, while, HCl, HF, and organic acids could be neglected (Shukla & Sharma, 2010). The relative contribution of SO_4^{2-} to rainwater acidity was calculated using the equivalent ratio: $[NO_3^-]/[NO_3^-]+[SO_4^{2-}]$. This ratio showed that the contribution of nitrate in the acidity of rain was 18% that means that the acidity of Damascus rainwater was mainly due to SO_4^{2-} with 82%. The reason for the presence of nitrate and sulphate in high quantity might be due to the common anthropogenic sources, i.e. fuel combustion, cars and trucks emissions from the intensive traffic. However, the accumulation of SO_4^{2-} and NO_3^- in the upper atmosphere is being washed out during the rainy season. Furthermore, the analysis of major ions showed that the net concentration of anions is lower than that of cations ($\frac{\sum (anions)}{\sum (cations)} = 0.87$), presumably because NO_2^-, $HCOO^-$, and CH_3COO^- ions were not measured. At last, the data measured in **Table 4** highlight the real nature of Damascus rainwater that mainly contains high concentrations of calcite minerals and carbonate compounds.

After filtration, the distributions of analyses in rainwater have been regulated (**Fig. 2**). The amount of NH_4^+, Cd^{2+}, Ni^{2+}, Pb^{2+}, As^{5+}, COD, colour, FC, and TC were totally found under DL. Others reached the safer levels for drinking water i.e. F^-, Cu^{2+}, Fe^{2+}, Al^{3+}, TP, BOD_5, turbidity. The matrices of the filtered rainwater samples have basically been enriched with K^+, Na^+, and Mg^{2+} (**Fig. 2**). EC and TDS were increased by 17.4% and 17.5%, respectively, which reflects the rich content of the post-filtered rainwater with univalent ions such as Na^+, K^+, and Cl^-.

The range of pH rainwater was found [6.4-6.9] that shows low acidity. This is primarily a function of the carbonate system that composes of CO_2, H_2CO_3 (carbonic acid), HCO_3^-, and CO_3^{2-} (AWWA, 1990). After filtration, a slight increase of the maximum pH was noticed. This could be due to a possible reaction of the HCO_3^- of rainwater with both H^+ and OH^- (hydroxyl) ions in the filter. Actually, this obviously increases the buffering capacity (alkalinity) of the outflow water and as a result neutralises its pH value. The pH of the outflows belongs to a range [6.5–9.0] which is likely preferred for the majority of aquatic creatures (EPA, 1986).

The change of chemistry for rainwater after filtration was presented in **Fig. 3**. The percentage of cations (**Fig. 3A**) and anions (**Fig. 3B**) of filtered wet precipitation showed dominant alkaline cations in the following descending order: Ca^{2+}, Mg^{2+}, Na^+. The anionic species were also recognised in this sequence: HCO_3^-, SO_4^{2-}, NO_3^-, Cl^-. These distributions typically attribute to the arid and semiarid urban environments (Domingo *et al.*, 2011), and the filtered water exactly conforms to the World Health Organization (WHO) for drinkability.

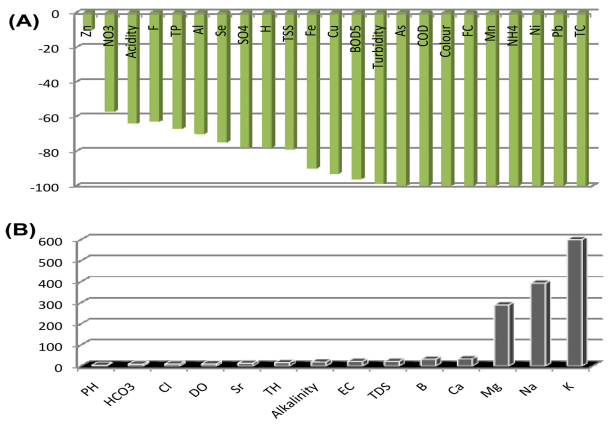

Fig. 2 (A) gain and (B) loss of components in rainwater after filtration.

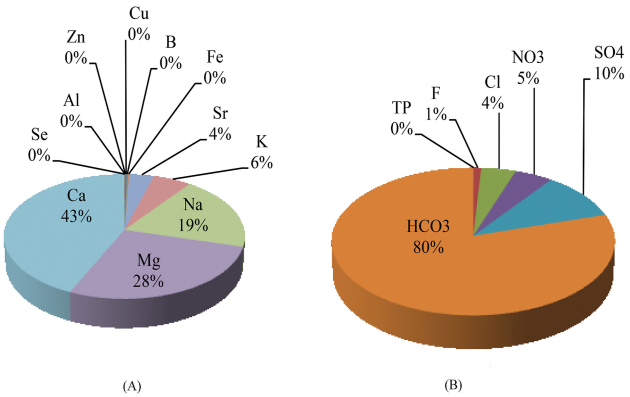

Fig. 3 Post-filtration rainwater ions: (A) major cations, and (B) major anions.

Filter performance assessment

There is exactly just one study the author can compare the competitivity of his devised filter and this provides extra novelty points for the current study. This filter is EWEB that constructed from 100% PE fibre and filled with gravel and sand (Morgenstern et al., 2011).

Many concluding points through the comparison of the efficiency of the sediment filter presented in this study with EWEB filter were observed and listed as follows:

- TSS reduction efficiency in water for the two filters is similar (> 79%).
- The current filter is better in reducing maximum turbidity (99%) that attained 87% when EWEB filter used.
- EWEB filter increases the maximum EC (29%) than the sediment filter presented in this study that realised 21%.
- The major difference between the two efficiencies is that the current filter increases TH by 15% while EWEB decreases this essential parameter by 25%. This means that the innovative filter in the current study is not suitable for hard water treatment.
- The devised filter shows a growing of the maximum pH [6.9-7.1], while EWEB shifted more this value (0.5) from 7.3 to 7.8.

CONCLUSIONS

The results of the chemical analysis of pre-filtered rainwater samples could be used as a base to evaluate the composition of atmospheric deposition and estimate Damascus' air quality. These data can also be used to develop the implementation procedures of preventive measures in controlling atmospheric emissions in Damascus. Furthermore, this study creates an opportunity to the enhancement of the sustainable waste management in the contemporary life expectancy by using rainwater filter fillings from raw materials available everywhere in nature such as: carbon, sand, gravel, and glass. Also, the recycle then reuse of tiny fractures of glass and foam glass in the fillings have reduced the fraction of pollutants in rainwater without using chemical-based cleaning products, which finally recover high-quality pure water. Relative reductions of pollutants in rainwater are simply considered to share other green practices as green nanotechnology (Aljerf & Nadra, 2019) in combating global climate change and contributes to the cuts necessary for stabilising greenhouse gas emissions at the agreed levels. As concluded, the filtered water is exactly a renewable source; the overall benefit could be considerable. In this case, the combined impact of the filtered rainwater by this system and energy savings might lead to substantial monetary reserves, alongside other benefits of risk water and resource use management. For instance, it is highly recommended to use this filtration system of rainwater in the tourism and hospitability industry that use comparatively energy intensive (Aljerf, 2015b). The filter converts rainwater to a new source of water that meets both the US EPA standards for potable water and the Polluter Cleans Polluters (PoClPos) principal (Aljerf, 2018b). Consequently, it is high time; this research opens the door for a new global rainwater sediment filter, which seems a greener and eco-friendly option to the conventional rainwater purification practices.

We should all want the earth to be as beautiful for us today as it can, and to be as beautiful for many generations to come. Here, the author of this work recommends researchers and all who concern in hydrology, chemistry, ecology, and green building engineering to work on further developments of the fillings used in this work in order to extend the range of applicability of this filter.

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