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PROCESS ENGINEERING FOR POLLUTION CONTROL AND WASTE MINIMIZATION

Suitability assessment of grey water quality treated with an upflow-downflow siliceous sand/marble waste filtration system for agricultural and industrial purposes

Safa Chaabane[1] · **Khalifa Riahi**[2,3] · **Hédi Hamrouni**[4] · **Béchir Ben Thayer**[2]

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Abstract The present study examines the suitability assessment of an upflow-downflow siliceous sand/marble waste filtration system for treatment and reuse of grey water collected from bathrooms of the student residential complex at the Higher Institute of Engineering Medjez El Bab (Tunisia). Once the optimization of grey water pre-treatment system has been determined, the filtration system was operated at different hydraulic loading rate and media filter proportions in order to assess the suitability of treated grey water for irrigational purpose according to salinity hazard, sodium hazard, magnesium hazard, permeability index, water infiltration rate, and widely used graphical methods. Suitability of the treated grey water for industrial purpose was evaluated in terms of foaming, corrosion, and scaling. Under optimal operational conditions, results reveals that treated grey water samples with an upflow-downflow siliceous sand/marble waste filtration system may be considered as a good and an excellent water quality suitable for irrigation purpose. However, treated grey water was found not appropriate for industrial purpose due to high concentrations of calcium and sodium that can generate foaming and scaling harm to boilers. These results suggest that treated grey water with an upflow-downflow siliceous sand/marble waste filtration system would support production when used as irrigation water.

Keywords Grey water · Upflow-downflow filtration · Siliceous sand · Marble waste · Grey water reuse · Irrigation · Industrial purpose · Tunisia

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✉ Safa Chaabane
chaabanesafa@ymail.com

[1] National Agronomic Institute of Tunisia, University of Carthage, Mahragène City, Tunisia

[2] Higher Institute on Rural Engineering and Equipment, University of Jendouba, Medjez El Bab City, Tunisia

[3] Laboratory LRME, Faculty of Science of Tunis, University of Tunis-El Manar, El Manar City, Tunisia

[4] Direction of Soil Resources, DGACTA, Ariana City, Tunisia

Introduction

In the Mediterranean countries, the predominant use of treated wastewater reuse (TWWR) is agricultural irrigation, and it is quickly expanding because the agriculture sector withdraws a significant share of conventional water resources over 80 % in southern and eastern Mediterranean countries (Condom et al. 2012). Tunisia, are located within arid and semi-arid areas characterized with low availability of fresh water resources. The amount of annual renewable internal fresh water resources and annual freshwater withdrawal available in Tunisia are about 402 m^3/capita and 2.9 billion m^3 (World Bank 2012). This availability of fresh water supply is low especially when compared to countries on the northern shores of the Mediterranean Sea such as Italy and Spain where internal renewable water resources exceed 2400 m^3/capita (Mizyed 2013).

As pressure on freshwater resources grows around the world, water resources are being intensively over explored and polluted and as new sources of supply become increasingly expensive, efforts are underway to identify new ways of meeting water needs. Water is becoming more scarce forcing planners to consider developing non-conventional water resources including treated grey water reuse to satisfy increasing non-potable, agricultural, and industrial applications. Treated grey water reuse offers a variety of opportunities and challenges. When treated grey water is reused either onsite or nearby, it has the potential to reduce the demand for new water supply, reduce the energy and carbon footprint of water services, and meet a wide range of social and economic needs (Allen et al. 2010).

Treated wastewater reuse for green areas and golf courses is rapidly increasing. Few regulations exist on TWWR for aquifer recharge, but it is in quick progression in countries with substantial experience and expertise in treated wastewater reuse like Spain, Israel, or Tunisia. Urban and industrial uses are localized, and there are few mentions of grey water recycling in Tunisia (Bousselmi et al. 2008). With the technical advances in grey water treatment technology, even the risks of treated grey water reuse on soil and plants (Al Hamaiedeh and Bino 2010; Rodda et al. 2011) can be satisfactorily and safely managed (Lamine et al. 2012; Merz et al. 2007). However, for various economic and social factors, the reuse of treated grey water is still limited to agricultural and industrial purposes.

Among several economic, social, and technical factors that may influence the choice of grey water reuse, grey water quality assessment appears to be a necessary and immediate task to be conducted before treated grey water reuse for agricultural and industrial purposes. Various environmental indices and parameters are now being used to ascertain water quality leading to determination of its suitability for drinking and agricultural uses (Aghazadeh and Mogaddam 2010; Rout et al. 2012; Nag and Das 2014), for industrial purpose (Haritash et al. 2014; El Tahlawi et al. 2014; Wu et al. 2015), and for potable water saving (El Hamouri et al. 2008; Mourad et al. 2011). The qualitative characterization of treated grey water is a key aspect when trying to reuse water. The present study examines the feasibility of an upflow-downflow filtration system for the treatment of bathroom grey water of the student residential complex at the Higher Institute of Engineering Medjez El Bab (ESIER-Tunisia) using available low-cost siliceous sand (SS) and marble waste (MW) media filter under different operational conditions (hydraulic loading rate and media filter proportions). Some water quality indices and widely used graphical methods (USSL and Wilcox diagram) were considered and calculated following standard equations using diagram scientific software to assess the suitability of treated grey water for irrigational purpose. Industrial suitability of the treated grey water quality was also evaluated in terms of foaming, corrosion, and scaling.

Study area

The study area is located at 5 Km in the south of Medjez El Bab city (northern Tunisia). The Higher Institute on Rural Engineering and Equipment is part of the delegation of Medjez El Bab (governorate of Beja-Tunisia) and is located on the road of Kef on a public area with agricultural vocation of the lower valley of the Medjerda. It lies from 36° 36′ 59.90″ N, 9° 32′ 44.94″ E to 36° 37′ 59.51″ N, 9° 33′ 53.74″ E (Fig. 1). The institute belongs to the Institution of Agriculture Research and Higher Education and spreads over 165 ha with net area of agricultural space about 150 ha (90.9 %). The predominant soil is calcareous soils and brown limestone soils. The institute position near the Medjerda river and Sidi Salem dam is a major asset for irrigated crops practices. The major crops grown are tomatoes, peppers, cucumbers, onions and potatoes, olive trees, and field crops.

Materials and methods

Characteristics of filter media

Marble waste (MW) generated by Utique marble cutting industry (north of Tunisia) and SS filter media derived from "Ermil-Bouarada" (north of Tunisia) with abundant amounts were used in this study as low-cost materials to investigate the performance of an upflow-downflow filtration system for bathroom grey water reuse. These mineral media were washed with distilled water and dried in an oven at 40 °C for a period to ensure a constant weight. The characteristics of filter media were investigated using a combination of characterization techniques, including N_2 adsorption-desorption, pH_{pzc}, and X-ray fluorescence. The micro-pore structure, the distribution of the pore size, pore volume, and specific surface area of siliceous sand and marble waste samples are measured by N_2 adsorption-desorption isotherms gained at liquid nitrogen temperature with a Micromeritics ASAP 2020 gas sorption analyzer. The determination of the pH_{pzc} of filter media was also performed according to the solid addition method using KNO_3 solutions (Jaouadi et al. 2013).

The results showed that the values of the pore size, pore volume, and BET specific surface area of marble waste seem to be higher than siliceous sand materials. The X-ray fluorescence analyses indicated that siliceous sand and marble waste are formed, respectively, by quartz and calcite with relatively high contents of SiO_2 and CaO (Table 1). The pH_{pzc} of siliceous sand and marble waste were determined respectively to 7.6 and 8.2. These values were also found for some iron minerals like ferrihydrite, akaganeite, and hematite. However, BET specific surface area of these iron mineral hydroxides was higher than siliceous sand and marble waste materials (Kumar et al. 2014).

Experimental set up, design, and operational conditions

The treatment process comprises an equalization unit, sedimentation unit, and an upflow-downflow filtration unit. The equalization unit regulates between raw grey water inflows

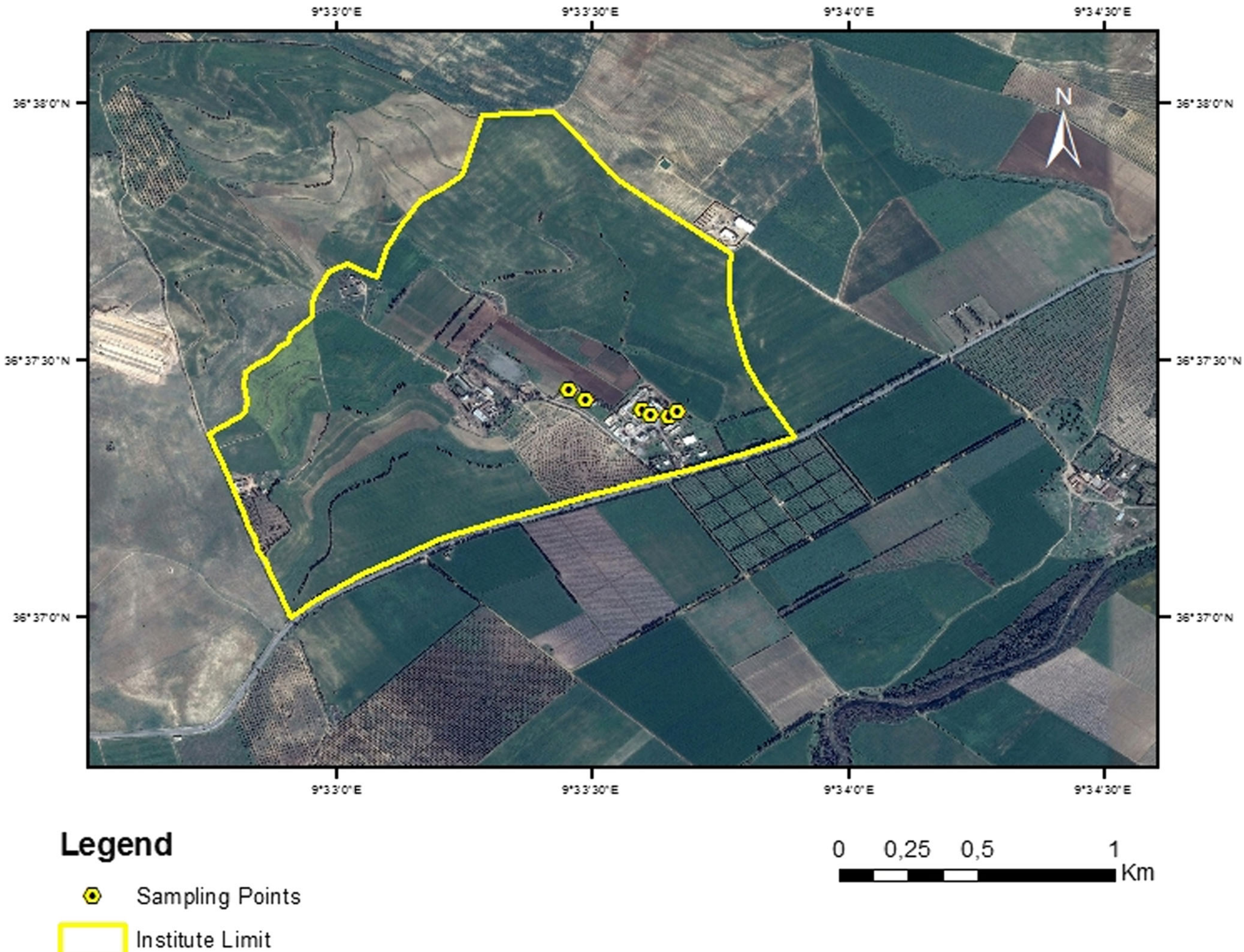


Fig. 1 Map of the study area and sampling points

Table 1 Main physicochemical characteristics of filter media

	Siliceous sand	Marble waste
Physical characteristics		
BET surface area (m^2/g)	3.027	4.192
Pore volume (cm^3/g)	0.005	0.010
Pore size (Å)	72.962	99.423
pH_{pzc}	7.6	8.2
Chemical characteristics (%)		
SiO_2	91.77	0.41
Al_2O_3	4.1	0.20
Fe_2O_3	2.20	0.09
CaO	1.82	54.11
MgO	0.02	0.15
K_2O	0.05	0.00
Na_2O	0.04	0.09
P_2O_5	0.00	0.04

(ID sample S0) and outflows to the treatment system and equalizes the quality and temperature of the raw grey water. This unit receives raw grey water directly from the bathrooms of the student housing complex at the Higher Institute of Engineering Medjez El Bab (ESIER-Tunisia). The sedimentation unit receives raw grey water from the equalization unit. In this unit, the particles are allowed to settle under gravity without the addition of coagulants. This sedimentation unit also serves as a sampling point to test for the level of contamination of the grey water. The upflow-downflow filtration unit filled with gravel acting as drain with size range from 5 to 10 mm (first bucket) and from 2 to 5 mm (second bucket) to a siliceous sand filter media with size range from 1.25 to 2 mm (third bucket) and a mixture of siliceous sand (0.4–0.63 mm) and marble waste (<0.25 mm) media filter (fourth bucket). A slope of 5 % had been provided so as to ensure sufficient flow through an upflow-downflow filtration system when in operation (Fig. 2). Two designs and operational factors: three levels of hydraulic loading rate (low rate (HLR (l) = 0.1 $m^3/m^2/h$), medium rate HLR (m) = 0.5 $m^3/m^2/h$), and high rate

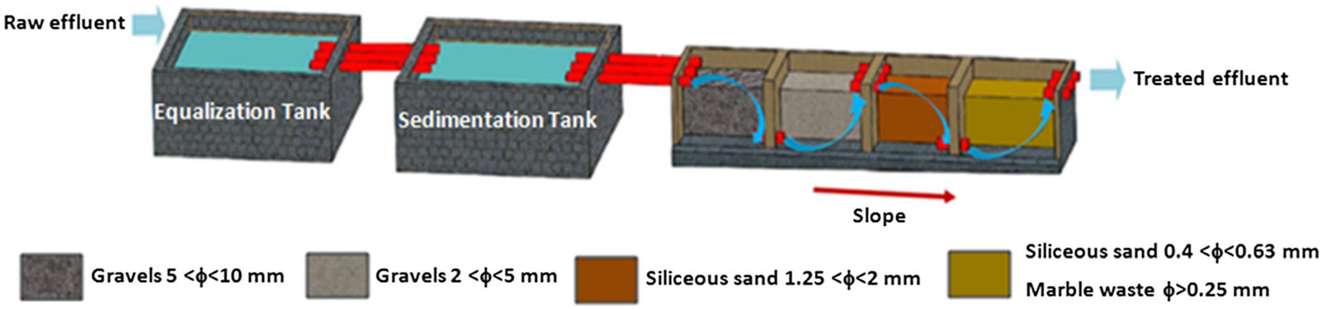


Fig. 2 Experimental set-up of an upflow-downflow siliceous sand/marble waste filtration system

HLR (h) = 1 $m^3/m^2/h$)) for three levels media filter proportions (100 % SS (MP0) (ID sample S1, S2, S3), 95 % SS + 5 % MW (MP1) (ID sample S4, S5, S6) and 90 % SS + 10 % MW (MP3) (ID sample S7, S8, S9)) were investigated in this study.

Sampling and analytical methods

A total of 43 water samples were collected from six sampling points along the student residential complex at the Higher Institute of Engineering Medjez El Bab (ESIER-Tunisia) (Fig. 1). Grey water samples were typically collected in the equalization unit using a weighted polyethylene water collector to balance flow to take into account maximum flow of grey water generated during morning hours due to bathroom use. An ID sample S10 was also collected as a reference from Medjerda river surface water (Kalaat Landalous City—north of Tunisia) used for irrigational purpose.

Grey water samples were analyzed for various chemical parameters as described by the American Public Health Association (APHA 1995). These parameters include pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), and major ions such as calcium, magnesium, sodium, and potassium as well as bicarbonates, chlorides, sulfates, and phosphates. pH and EC were measured within by using Toledo pH meter and conductivity meter, respectively. Calcium and magnesium were determined titrimetrically using the standard EDTA method, and chloride was determined by the $AgNO_3$ titration (Mohr method). Bicarbonate was estimated with hydrochloric acid, and sulfate was determined by precipitating $BaSO_4$ using $BaCl_2$. Sodium and potassium were determined using a Sherwood flame photometer. Organic matter in term of COD was determined in accordance with the closed reflux colorimetric method (oxidation with potassium dichromate at acidic pH and at 150 °C). Molybdenum blue (ascorbic acid) absorptiometry was employed for the phosphates analysis with spectroscopy UV-Visible (HACH-DR) at 690 nm. TSS was analyzed following the Wattman paper filtration method. Measurements were made in triplicates for the analysis of each monitoring parameters and data were recorded when the variations in two readings were less than 5 % ($P < 0.05$).

Suitability for irrigation purpose

The criteria of suitability assessment of water quality for agricultural and industrial purposes are different. Therefore, water which is not fit for drinking and industrial uses may be suitable for irrigation. The suitability of waters for a specific purpose depends on the types and amounts of dissolved salts (Haritash et al. 2014). However, the suitability for irrigation is assessed in terms of the presence of undesirable constituents, and only in limited situations is irrigation water assessed as a source of plant nutrients (Ayers and Westcot 1994). To assess the suitability of treated grey water for irrigation and industrial purposes, the quality parameters were computed by the following equations (Table 2).

Salinity is a common problem faced by farmers who irrigate in arid climates. The concentration of total salt content in irrigation waters, estimated in terms of EC at 25 °C and TDS, are important parameters for assessing the suitability of irrigation waters. Based on EC and TDS, waters are classified on the basis of the relationship between the electrical conductivity of waters and the electrical conductivity of saturated soil extracts (Richards 1954; USSL 1954).

The sodium hazard content in irrigation waters, estimated in terms of sodium adsorption ratio (SAR) and percent sodium (%Na), are also the major factors considered in determining the suitability of water for irrigation. SAR helps to identify the sodium hazard in relation to calcium and magnesium concentrations. SAR parameter versus EC using USSL diagram is very important in classifying irrigation water (Richards 1954).

It is important to classify the irrigation water based on the exchangeable sodium because excessive sodium affects both soil and crops, as explained earlier. In addition to SAR, %Na is also used to determine the effect of sodium. The distribution of %Na classification (Richards 1954) is used as excellent, good, permissible, doubtful, and unsuitable categories. The Wilcox diagram can also classify water based on the %Na with respect to salinity hazard that are present in water (Wilcox 1955).

Table 2 Water quality parameters computed by the following equations

Equation	Reference
$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$ (1)	Richards 1954
$\%Na = \left\{\frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^+ + K^+}\right\} \times 100$ (2)	Wilcox 1955
$SSP = \frac{Na^+ \times 100}{Ca^{2+}+Mg^{2+}+Na^+ + K^+}$ (3)	Eaton 1950
$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ (4)	Richards 1954
$MH = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100$ (5)	Szabolcs and Darab 1964
$PI = [\{Na^+ + \sqrt{HCO_3^-}\}/Ca^{2+} + Mg^{2+} + Na^+] \times 100$ (6)	Doneen 1964
$FC = 62 \times Na^+ + 78 \times K^+$ (7)	Wu et al. 2015
For acidic water:	
$CC = 1.008\ (H^+ + Al^{3+} + Fe^{2+} + Mg^{2+} - CO_3^{2-} - HCO_3^-)$ (8)	
For alkaline water:	
$CC = 1.008\ (Mg^{2+} - HCO_3^-)$ (9)	
$LSI = pH - pHs$ (10)	Haritash et al. 2014
$RSI = 2\ pHs - pH$ (11)	

All the ionic concentrations in the above equation are expressed in meq/L, and %Na and PI in percent

Water intended for agricultural use should have a lower concentration of sodium ions and higher concentrations of calcium and magnesium ions. Excessive amounts of sodium ions may cause a significant decrease in the permeability of agricultural soils receiving such irrigation water (Haritash et al. 2014). Soluble sodium percentage (SSP) is also used to evaluate sodium hazard.

Residual sodium carbonate (RSC) is an index which specifies the sodium bicarbonate hazard. In water having excess of carbonate and bicarbonate over the alkaline earth, there is a reduction in the concentration of calcium and magnesium and a relative increase in sodium. The calcium and magnesium are precipitated as carbonates, and any residual carbonate or bicarbonate is left in solution as sodium bicarbonate hazard (Richards 1954).

Generally, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in most waters. Both Ca^{2+} and Mg^{2+} ions are associated with soil aggregation and friability, but they are also essential plant nutrients. High concentration of Ca^{2+} and Mg^{2+} ions in irrigation water can increase soil pH, resulting in reducing of the availability of phosphorous (Alobaidy et al. 2010). Another indicator that can be used to specify the magnesium hazard (MH) is proposed and developed for irrigation water (Szabolcs and Darab 1964).

Permeability index is an essential factor to determine the quality of irrigation water in relation to soil for improvement in agriculture (Thivya et al. 2013). The PI in water sample measures the total concentration of Na^+ and HCO_3^- to the total cations content. The permeability index (PI) of the water was derived using major cations and HCO_3^- concentration.

Water infiltration rate into the soil is also evaluated for all water samples to assess suitability for irrigation purpose. Based on EC and SAR, waters are classified into three degrees of restriction (none, slight to moderate and severe) on agricultural use (Ayers and Westcot 1994).

In addition to the salinity, sodium and magnesium hazards, which have been the major problem, irrigation water always carries substances derived from its natural environment or from the waste products of man's domestic and industrial activities to be included in the comprehensive waste water characterization assessment prior to the development of a wastewater irrigation system. These substances may vary in a wide range, but mainly consist of pH, alkalinity, organics as COD, TSS resulting into the blockage in micro-irrigation systems.

Suitability for industrial purpose

Water used for industry is one of the important parts of urban water supply. Its requirements of water quality are very different from drinking and irrigation purposes. Each industry has its own standards for water. Generally, industrial water reuse suffers from three effects: foaming, corrosion, and scaling which are caused by adverse chemical reaction under the condition of high temperature and high pressure (Wu et al. 2015; Varol and Davraz 2014).

Water bubbled up to the surface when boiled. While bubbles cannot break open in time, thick and unstable bubbles are formed. Too many bubbles elevate the water table resulting in boilers not working (Wu et al. 2015).

Corrosive actions extremely damage the boiler, notably under high steam pressure. It eats metal through replacement reaction, even brings about explosion accidents. The corrosive coefficient is an indicator that reflects the intensity of corrosion (Wu et al. 2015).

The Langelier saturation index (LSI) is a calculated number used to predict the calcium carbonate stability of water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate. The LSI is expressed as the difference between the actual system pH and the saturation pH. The Ryznar saturation index (RSI) uses a database of scale thickness measurements in municipal water systems to predict the effect of water chemistry (Haritash et al. 2014).

Statistical analysis

Statistical analysis was performed on the physicochemical parameters and major ion concentration to detect the relationship and differences between the groundwater samples. In order to discuss the data, the values grouped with respect to the geochemical parameters. The average value of all the variables (temperature, pH, EC, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, SAR, PI, FC, CC, RSI) determined and tabulated as matrix. This matrix was analyzed with cluster analysis (hierarchical tree clustering, rescaled distance cluster combine analysis) using SPSS software. The hierarchical cluster analysis was used to group water samples into significant clusters. The dendrogram analysis was performed using the Ward Bloc method.

Results and discussion

Hydrochemical grey water quality

Piper diagram is extensively used to understand the hydrochemical regime and facies classification of water and problems concerning the geochemical evolution of water. This diagram consists of three distinct fields including two triangular fields and a diamond-shaped field. The cations expressed as percentage of total cations in meq/L as a single point on the left triangle while anions plot in the right triangle (Piper 1944). Similarities and differences among water samples can be revealed from the trilinear diagram because water of similar qualities will tend to plot together as groups.

The Piper trilinear diagram of water classification scheme revealed that most of the water samples were in the Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, HCO_3^{-}, SO_4^{2-} and Cl^{-} ionic water type. From the plot, it was observed that alkalis ($Na^{+} + K^{+}$) exceeds alkaline earth ($Ca^{2+} + Mg^{2+}$) and the strong acids ($SO_4^{2-} + Cl^{-}$) exceeds weak acids ($CO_3^{2-} + HCO_3^{-}$). Carbonate alkalinity exceeds 50 % (chemical properties are dominated by alkaline earth and weak acids) and mixed types (no cation-anion pairs) exceeds 50 % (Fig. 3). The primary carbonate salinity is attributed to the dissolution of calcite: a crystalline form of calcium carbonate, $CaCO_3$ derived from marble waste. The elevated sodium concentrations coupled to low calcium suggesting that Ca^{2+} and Na^{+} ion exchange process is an important geochemical process for the Na–Cl type of water samples (Kumar et al. 2015).

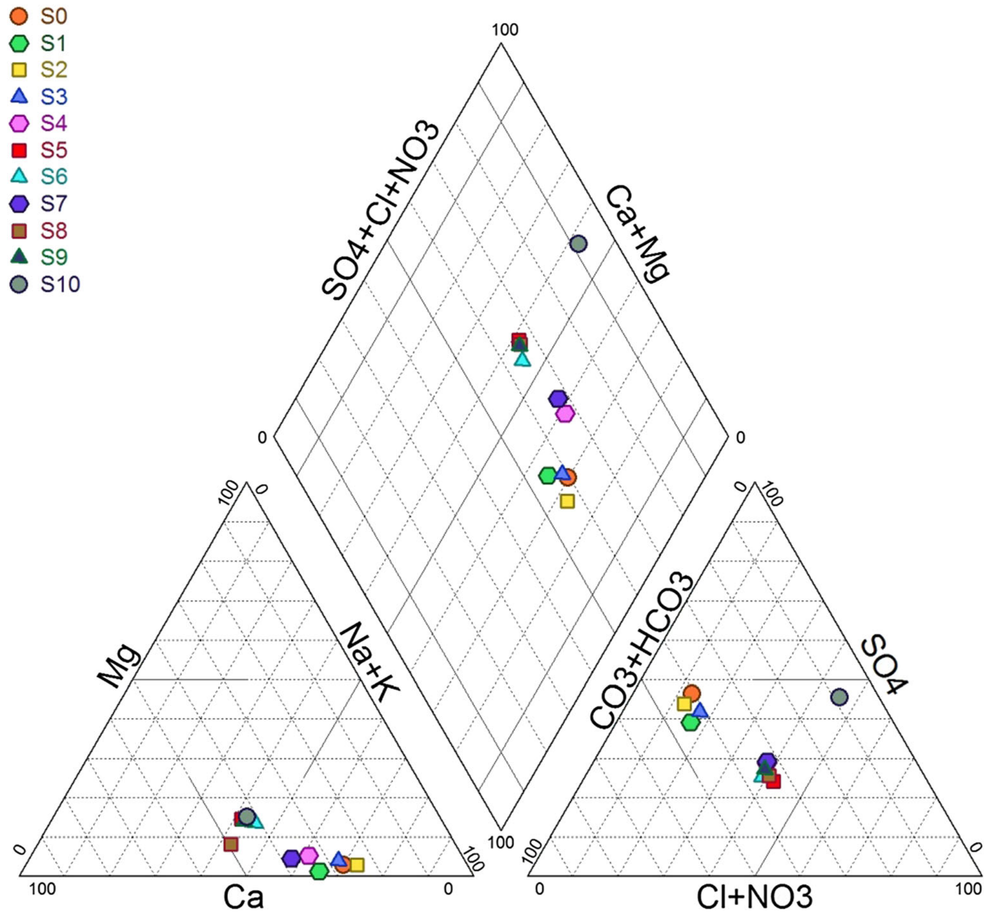
The raw and treated grey water samples were analyzed for their physical and chemical properties for determining their designated best use. The results obtained are given in Table 3. The pH values of the grey water samples were in the range of 7.35–8.82 indicating that the grey water is slightly alkaline after treatment using marble waste media filter. Electrical conductivity (EC) is directly related to the concentration of ions dissolved in the water. EC and TDS ranged respectively between 414.12–851.95 μS/cm and 265.04–545.25 mg/L. Such differences in EC and TDS can be related to the carbonates dissolution with the increase of the hydraulic loading rate. TSS and COD ranged respectively between 24–118 and 68–163.2 mg/L. Such differences in TSS and COD can be attributed to the performance of siliceous sand/marble waste media filter under variable operational conditions. The domination of cations and anions ranked according to milligram equivalent (meq/L) was in the order of $Na^{+} > Ca^{2+} > K^{+} > Mg^{2+}$ for cations and $HCO_3^{-} > Cl^{-} > SO_4^{2-}$ for anions.

Hydraulic loading rate had an influence on grey water quality: a lower filtration rate resulted in increasing the duration of the upflow-downflow filter run, and consequently, the residence time in filter system became so longer to improve grey water quality. Media filter proportions appeared to have a minor influence on performance of the upflow-downflow filter system compared with the effect of hydraulic loading rate. Our results are in good agreement with Healy et al. 2007 as they indicated that grey water influent quality and hydraulic loading rate highly influence the performance of wastewater treatment filters. Hydraulic loading rate had an influence on chemical species (phosphate, sulfate, chloride) removal efficiencies. Under higher hydraulic loading rate, dissolution of phosphate, sulfate, and chloride salts occurs which causes an increase of concentration of anions chemical species. Our observations are in good agreement with Song et al. 2002; Vohla et al. 2011 as they indicated that there is probably an optimal level for hydraulic loading rate at which chemicals and particularly the phosphate removal is the highest from analysis made on full-scale and pilot-scale treatment filter systems and column experiments.

Suitability assessment for irrigation purpose

The suitability of water for irrigation purpose is determined not only by the total amount of salt present but also by the kind of salt. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. Four problem categories (salinity, water infiltration rate, specific ion toxicity, and miscellaneous) are used for suitability assessment of water

Fig. 3 Piper trilinear diagram for major ions of water samples



for irrigation purposes (Ayers and Westcot 1994). To assess the overall irrigational water quality of the water samples, salinity hazard, sodium hazard, magnesium hazard, permeability index, water infiltration rate, and other related water quality parameters have been considered. Their corresponding values and their classification, suitability and restriction uses for irrigational purpose have been presented in Tables 4 and 5.

Table 3 Physicochemical characteristics of water samples

	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
pH	7.35	7.65	7.55	7.72	8.2	8.25	8.65	8.15	8.35	8.82	7.89
EC	682.29	414.12	434.01	619.91	458.04	489.41	758.44	491.39	497.38	851.95	2272.92
TDS	436.67	265.04	277.77	396.74	293.15	313.22	485.40	314.49	318.32	545.25	1454.67
TSS	118	24	48.80	82.60	32.71	51.61	88.50	34.55	57.30	95.77	10
COD	163.20	77.86	84.06	93.61	68.81	78.17	88.45	68	74.60	85.75	91.40
Na^+	8.66	7.43	8.28	9.48	5.63	5.85	11.54	6.06	5.81	13.98	22.77
K^+	0.20	0.21	0.20	0.25	0.14	0.14	0.16	0.15	0.12	0.17	0.24
Ca^{2+}	0.87	0.98	0.71	0.99	0.80	1.57	2.69	1.02	1.71	3.61	5.73
Mg^{2+}	0.09	0.04	0.09	0.14	0.12	0.52	0.89	0.12	0.29	1.16	2.03
HCO_3^-	5.64	5.80	5.48	5.93	3.60	3.70	4.68	4.00	3.68	4.86	4.20
SO_4^{2-}	1.61	1.27	1.37	1.51	0.79	0.66	0.83	0.90	0.69	0.96	5.60
Cl^-	1.80	2.13	1.58	2.43	4.19	4.60	5.12	4.68	4.36	5.48	22.64
PO_4^{3-}	0.03	0.01	0.01	0.02	0.01	0.00	0.02	0.01	0.00	0.02	0.01

All parameters ions are expressed in meq/L; TDS, TSS, and COD are expressed in mg/L except EC (μS/cm) and pH

Table 4 Calculated values to assess the suitability of water samples for irrigation and industrial purposes

Sample ID	Irrigation purpose						Industrial purpose			
	%Na	SAR	SSP	RSC	MH	PI	FC	CC	LSI	RSI
S0	69.89	6.27	68.32	1.82	9.31	88.43	552.77	−1.83	0.09	7.17
S1	65.35	5.22	63.52	1.75	3.66	85.69	477.11	−1.76	0.58	6.49
S2	72.71	6.56	71.03	2.30	10.87	92.67	528.57	−2.31	0.29	6.98
S3	68.30	6.31	66.57	1.42	12.22	85.15	606.79	−1.42	0.55	6.62
S4	61.05	4.15	59.61	−0.08	13.16	80.87	359.54	0.08	0.86	6.49
S5	41.76	2.86	40.80	−4.65	24.77	54.75	373.23	4.68	1.18	5.89
S6	44.97	4.31	44.37	−9.63	24.83	53.01	727.91	9.71	1.77	5.11
S7	57.62	4.01	56.20	−0.57	10.88	75.83	387.64	0.57	0.99	6.17
S8	42.54	2.90	41.70	−4.32	14.31	55.94	369.20	4.35	1.37	5.61
S9	42.58	4.53	42.06	−14.22	24.28	48.95	880.22	14.33	2.05	4.71
S10	42.56	5.78	42.12	−26.85	26.20	46.12	1430.15	27.06	1.20	5.49

Salinity hazard

The concentration of total salt content in waters, estimated in terms of EC and TDS, is an important parameter for assessing the suitability of irrigation waters. Generally, all irrigation waters with an EC of less than 2250 μS/cm and TDS value of less than 2000 mg/L are considered suitable except in some situations, e.g., very sensitive crops and highly clayey soils of poor permeability (Richards 1954; Wilcox 1955). In this study, all the water samples, except samples (S6, S9) which indicate optimized results of siliceous sand-marble waste upflow-downflow filtration under higher hydraulic loading rate and sample S10 related to Medjerda river, have an EC of less than 750 μS/cm and TDS value of less than 450 mg/L indicating good quality of irrigation water. If EC and TDS are greater than 2250 μS/cm and 2000 mg/L, respectively, then crop productivity is affected very much (Ayers and Westcot 1994). Concentration of these total salts will result in an increase in osmotic potential in the soil solution interfering with extraction of water by the plants. If total salt increases, water uptake by the plant decreases, and, hence, salt accumulates in the root zone, which may significantly affect the productivity of crop (Jain et al. 2011).

Sodium hazard

For irrigation purpose, the percent of sodium in water is a parameter computed for the suitability assessment. The classification of water samples based on %Na indicates that some water samples (S5–S10) were classified as permissible and other water samples (S0–S4) were classified as doubtful. Excess sodium in relation to calcium and magnesium concentrations causes damage to the soil structure. It reduces permeability of the soil to water and air which causes the decrease of available water for the plant and adverse effects on soil aeration (Collins and Jerkins 1996; Arveti et al. 2011). Based on Wilcox's plot, water samples were classified as excellent (S1–S8), good (S9), permissible (S0), and doubtful (S10) (Fig. 4).

The degree to which the irrigation water tends to enter into cation exchange reaction in soil can be indicated by the sodium adsorption ratio. In this study, SAR was found in the range of 2.86–6.56. All water samples (S0–S10) with SAR <10 are considered as of excellent quality (low Na water and little danger). Water samples with SAR values more than 10, problems on fine texture soil and sodium sensitive plants, especially under low leaching conditions can be founded, so soils should have good permeability (Richards 1954). Water samples were classified into three types based on the USSL diagram (Fig. 5).

US salinity hazards (USSL 1954) reveal that most water samples (S0–S5 and S7–S8) fall under C2–S1 (medium salinity hazard and low-sodium hazard) class. For medium salinity hazard, damage to salt sensitive plants may occur. Occasional flushing with low salinity water may be necessary. For low-sodium water, a little danger may occur. Some water samples that fall under C3–S1 (high-salinity hazard and low-sodium hazard) class are considered to be of moderate quality to irrigate semi-tolerant crops. For high-salinity hazard, damage to plants with low tolerance to salinity will likely occur. Plant growth and quality will be improved with excess irrigation for leaching and/ or periodic use of low salinity water and good drainage provided (Richards 1954). Medjerda river sample (S10) fell in C4–S2 (very high-salinity hazard and medium-sodium hazard) class. Very high-salinity water (C4) is not suitable for irrigation under ordinary condition. Damage to plants with high tolerance to salinity may occur. Successful use as an irrigation source requires salt tolerant plants, good soil drainage, and excess irrigation for leaching and/or periodic utilization of low salinity water (Richards 1954).

The calculated values of SSP varied from 40.80 to 68.32 % indicating two categories: no degree of restriction on the use of this wastewater in irrigation (S4–S10) and moderate to severe degree of restriction on the agriculture reuse (S0–S3). Water

Table 5 Classification of water samples for irrigation purpose

Parameter	Rate of hazard	Water class	Sample ID	Reference
Salinity hazard				
EC	<0.25	Excellent		Richards 1954
	0.25–0.75	Good	S0–S5 and S7–S8	Wilcox 1955
	0.75–2.25	Permissible	S6. S9	
	2.25–5.00	Doubtful	S10	
	>5.00	Unsuitable		
TDS	<450	Good	S0–S5 and S7–S8	
	450–2000	Permissible	S6. S9. S10	
	>2000	Unsuitable		
Sodium hazard				
%Na	<20	Excellent		Richards 1954
	20–40	Good		Wilcox 1955
	40–60	Permissible	S5–S10	
	60–80	Doubtful	S0–S4	
	>80	Unsuitable		
SAR	<10	Excellent	All samples	
	10–18	Good		
	18–26	Fair		
	>26	Poor		
SSP	<60	Suitable	S4–S10	Eaton 1950
	>60	Unsuitable	S0–S3	
RSC	<1.25	Safe	S4–S10	Richards 1954
	1.25–2.5	Permissible	S0–S3	Wilcox 1955
	>2.5	Unsuitable		
Magnesium hazard				
MH	<50	Suitable	All samples	Szabolcs and Darab 1964
	>50	Unsuitable		
Permeability index				
PI	Class I (>75 %)	Suitable	S0–S4 and S7	Doneen 1964
	Class II (25–75 %)	Acceptable	S5–S6 and S8–S10	
	Class III (<25 %)	Unsuitable		
Water infiltration rate				
WIR	SAR 0–3 EC > 0.7 SAR 3–6 EC > 1.2 SAR 6–12 > 1.9 SAR 12–20 EC > 2.9 SAR 20– 40 EC > 5.0	None	S10	Ayers and Westcot 1994
	SAR 0–3 EC 0.7–0.2 SAR 3–6 EC 1.2–0.3 SAR 6–12 EC 1.9–0.5 SAR 12–20 EC 2.9–1.3 SAR 20–40 EC 5.0–2.9	Slight to moderate	S0.S1 and S3–S9	
	SAR 0–3 EC < 0.2 SAR 3–6 EC < 0.3 SAR 6–12 EC < 0.5 SAR 12–20 EC < 1.3 SAR 20–40 EC < 2.9	Severe	S2	

EC is expressed in milliseconds per centimeter

with SSP greater than 60 % may result in Na^+ accumulations that will cause a modification on soil's physical properties by displacing Mg^{2+} and Ca^{2+} ions. This exchange process in soil reduces the permeability and eventually results in soil with poor internal drainage (Ayers and Westcot 1994). Continued uses of alkaline waters for irrigation in a closed system may

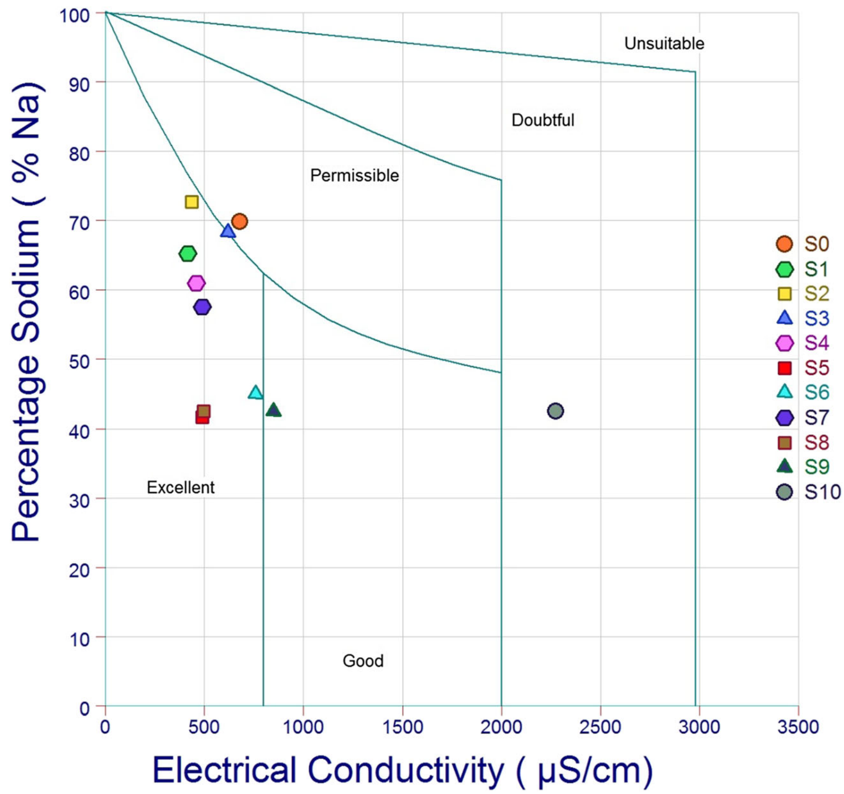


Fig. 4 Suitability of water samples for irrigation according to the Wilcox diagram

have adverse effects on soil physical properties (Halliwell et al. 2001), deteriorate the soil and water resources of the region, and affect the sustainability of crop production in the long run (Alobaidy et al. 2010).

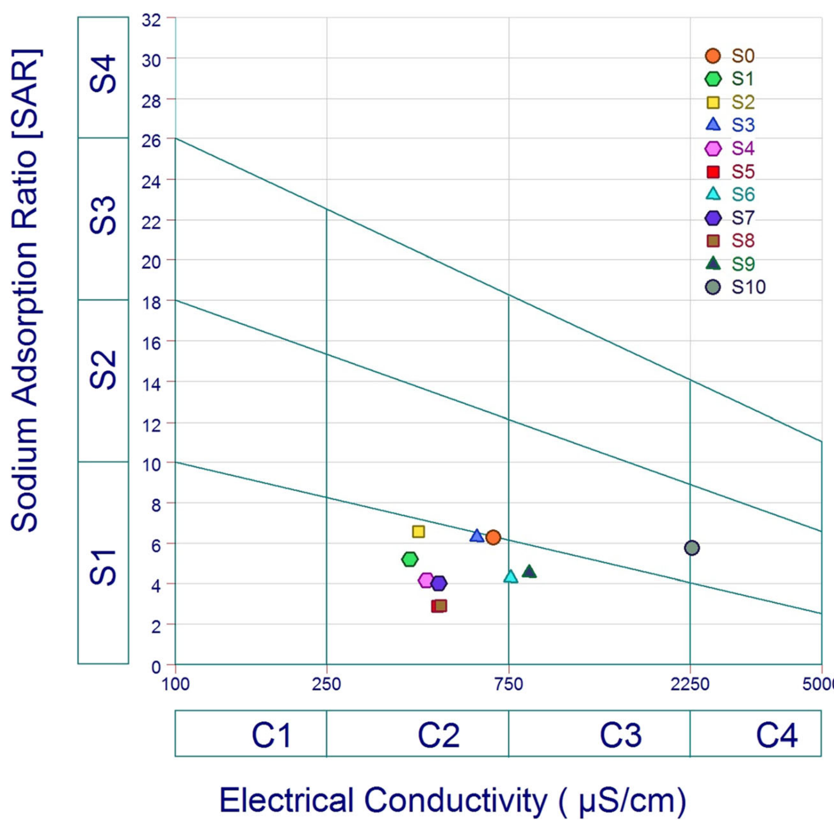


Fig. 5 Suitability of water samples for irrigation according to USSL diagram

Residual sodium carbonate values were calculated to determine the hazardous effect of sodium bicarbonate on the water quality for agricultural purpose. According to Richards (1954), residual sodium carbonate is classified into three categories which are safe, permissible, and unsuitable (Table 5). Water samples having RSC values greater than 2.5 meq/L has been considered harmful to the growth of plants and unsuitable for irrigation purpose. Water samples (S0–S3) with RSC values between 1.25 and 2.5 meq/L are considered permissible for irrigation purpose. Water samples (S4–S10) with RSC values less than 1.25 meq/L are considered safe for irrigation purpose. A high value of RSC in water value leads to an increase in the adsorption of sodium on soil. The excess of carbonate in solution will enhance the precipitation of $CaCO_3$ in the soil which in turn will increase sodium in solution, and it also affects the uptake of nutrients by plants. The dominance of alkaline earth influences the suitability of water for irrigation purpose (Thivya et al. 2013).

Magnesium hazard

Irrigation water samples having magnesium hazard values greater than 50 are considered harmful and unsuitable for irrigation purposes. For this study, all water samples having the magnesium hazard values less than 50 are considered safe for irrigation purpose. A high level of magnesium usually promotes a higher development of exchangeable sodium in irrigated soils (Ayers and Westcot 1994). Excess of magnesium deteriorates soil structure particularly where waters are sodium dominated and highly salinized which is the cause of poor yield of crops (Nagaraju et al. 2006).

Permeability index

The permeability of soil is influenced by sodium, calcium, magnesium, and bicarbonate contents in soil which also influences the quality of irrigation water on long-term use. Doneen evolved a criterion for assessing the suitability of water for irrigation based on a permeability index (PI) and waters can be classified as class I, class II, and class III (Doneen 1964). Class I and class II waters are categorized as acceptable to good for irrigation with 25–75 % or more of maximum permeability. Class III water is unsuitable with 25 % of maximum permeability. In the present study, the PI of water samples ranged from 46.12 to 92.67 % (Table 5). It is observed that all the water samples fall in class I and class II category of Doneen's chart. Therefore, the water samples were acceptable to good for use in irrigation.

Water infiltration rate

Water infiltration rate of water was evaluated using EC and SAR together. In this study, the most water samples fall in slight to moderate degree of restriction on use in irrigation. For severe degree of restriction on use in irrigation, an infiltration problem related to water quality in most cases may occur in the surface few centimeters of soil and is linked to the structural stability of this surface soil. When a soil is irrigated with high sodium water, a high sodium surface soil develops which weakens soil structure. The surface soil aggregates then disperses to much smaller particles which clog soil pores (Ayers and Westcot 1994).

Other related water quality parameters

The general parameters are those that are analyzed to assess the effectiveness of the wastewater treatment process and to evaluate variability in the quality of the wastewater prior to its release to the environment. They also represent water quality values that, if exceeded, can often restrict treated wastewater sources from being considered for irrigation purposes. The measured values of pH were found to range from 7.35 to 8.82. The pH of all water samples was less than the prescribed maximum limit of 8.4 (Ayers and Westcot 1994; WHO 1989) for irrigation purposes except for samples S6 and S9. This alkalinity controlled by carbon dioxide, carbonate, and bicarbonate equilibrium may be related to the effect of alkaline material present in the water (marbles waste) under higher hydraulic loading rate (Hem 1985). Calcium and magnesium ions become insoluble due to high carbonates and bicarbonates thereby leaving sodium as the dominant ion in solution (Tak et al. 2012). Total suspended solids (TSS) typically ranged from 10 to 118 mg/L for water samples. Chemical oxygen demand (COD) typically ranged from 68 to 163 mg/L for water samples. Except sample S0, all water samples have values below 100 mg/L for TSS and values below 150 mg/L for COD, indicating no restriction to irrigation use (Alberta Environment 2000).

Suitability assessment for industrial purpose

Water for industrial use refers to applications such as cooling water, boiler feed water, and in manufacturing processes. Its requirements of water quality are very different from drinking and irrigation purposes, even altered in various industries (Wang and Jin 2012). Each industry has its own standards for water. Generally, they suffer from three effects of incrustation, foaming, and corrosion which are caused by adverse chemical reaction under the condition of high temperature and high pressure (Wu et al. 2015). To assess the overall industrial water quality of the water samples, four computed water quality parameters have been considered, namely foaming coefficient (FC), corrosion coefficient (CC), Langelier saturation index (LSI), and Ryznar saturation index (RSI). Their

Table 6 Classification of water samples for industrial purpose

Parameter	Rate of hazard		Water risks	Sample ID	Reference
Foaming risk					
FC	FC < 60		No foaming		Wu et al. 2015
	60 < FC < 200		Marginal		
	FC > 200		Foaming	All samples	
Corrosion-scaling risks					
CC	CC > 0		Corrosive	S10	Wu et al. 2015
	CC < 0	CC + 0.0503 Ca^{2+} < 0	No corrosive	S0–S3	
		CC + 0.0503 Ca^{2+} > 0	Mildly corrosive	S4–S9	
LSI	LSI ≥ 0		No corrosive	All samples	Haritash et al. 2014
	LSI < 0		Corrosive		
RSI	<5.5		Heavy scale	S6 and S9–S10	Ryznar 1944
	5.5–6.2		Scale	S5 and S7–S8	
	6.2–6.8		No difficulties	S1 and S3–S4	
	6.8–8.5		Corrosive	S0.S2	
	>8.5		Very corrosive		

corresponding values and their classification for industrial purposes have been presented in Tables 4 and 6.

Foaming risk

Foam is generally a dispersion of gas bubbles in a liquid. Stable foams play an important role in different industries, either as nuisance or as intended product. The water of no foaming action is FC < 60, and that of foaming action is FC > 200. While FC is in the range of 60–200, the water is marginal. As per the data of water samples, the values of FC range from 359.54 to 1430.15, which all belong to foaming action range. It means that water boiler needs to be refreshed. Foaming action is a result of the saponification reaction related to sodium (Na), potassium (K), grease, and TSS (Wu et al. 2015). It is also suggested that increased surfactant loads (surfactants in waste water as detergents from households) are able to intensively produce foam (Hug 2006).

Corrosion-scaling risks

The corrosiveness-scaling of water can be estimated by the calculation of one or more indices. CC, LSI, and RSI were used to estimate corrosiveness-scaling risks of water samples to be

Table 7 Pearson's correlation matrix (r^2) of physicochemical parameters and major ions of water samples

	Temp	pH	EC	Na	K	Ca	Mg	HCO_3	SO_4	Cl	SAR	PI	FC	CC	RSI
Temp	1														
pH	0.08	1													
EC	−0.28	0.01	1												
Na	−0.47	0.08	0.95**	1											
K	−0.53	−0.62*	0.45	0.55	1										
Ca	−0.26	0.38	0.91**	0.92**	0.22	1									
Mg	−0.29	0.39	0.90**	0.92**	0.21	0.99**	1								
HCO_3	−0.60*	−0.58	−0.12	0.09	0.76**	−0.23	−0.25	1							
SO_4	−0.20	−0.30	0.94**	0.86**	0.62*	0.73**	0.73*	0.04	1						
Cl	−0.02	0.11	0.96**	0.85**	0.27	0.89**	0.89**	−0.35	0.90**	1					
SAR	−0.59	−0.71*	0.26	0.38	0.87**	−0.00	−0.00	0.81**	0.45	0.05	1				
PI	0.01	−0.76**	−0.54	−0.52	0.31	−0.80**	−0.80**	0.57	−0.26	−0.61*	0.56	1			
FC	−0.48	0.07	0.95**	1.00**	0.56	0.92**	0.91**	0.10	0.86**	0.85**	0.39	−0.51	1		
CC	−0.07	0.52	0.82**	0.77**	−0.06	0.94**	0.95**	−0.54	0.62*	0.88**	−0.26	−0.88**	0.77**	1	
RSI	0.06	−0.89**	−0.38	−0.46	0.30	−0.72*	−0.71*	0.44	−0.08	−0.44	0.52	0.92**	−0.45	−0.76**	1

*Correlation significant at 0.05 level

**Correlation significant at 0.01 level

used for industrial purposes. As per the data, according to corrosiveness-scaling values, generally most of the water samples are alkaline water and have no to mildly corrosive, but they can generate scaling harm to boilers. Excessive corrosion is a serious economic and potential health problem. Corrosive actions are influenced by many factors, such as temperature, dissolved oxygen, total dissolved solids, pH, alkalinity, H_2S, CO_2, and organic matters (Wu et al. 2015; Barringer et al. 1993). Other chemical compounds, which are not routinely analyzed in most water samples, can be involved in the corrosion process. Dissolved carbon dioxide, forming carbonic acid at low pH, may dissolve protective calcium carbonate or hydrated iron oxide films (Singley et al. 1985).

Water containing excessive amounts of bicarbonates and carbonates has a tendency to deposit minerals on the pipe surface. This mineral deposition reduces the internal volume of the pipe and thus reduces the flow capacity; sometimes this leads to total blockage. It is formed by precipitation of calcium salt ($CaCO_3$,

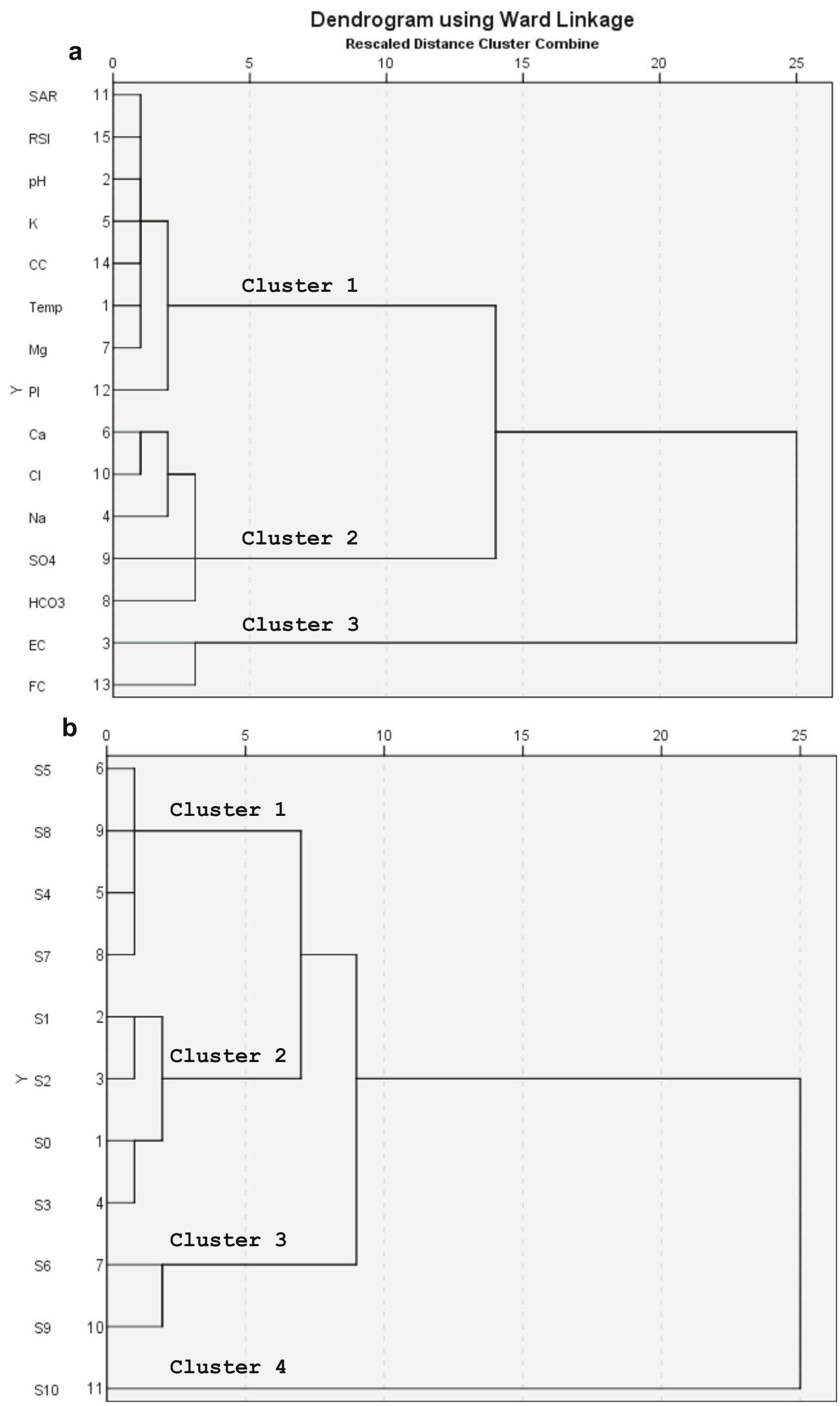


Fig. 6 Dendrogram for the water samples grouping. **a** With respect to their physicochemical parameters and **b** based on water samples

CaO, $CaSO_4$, $CaSiO_3$), magnesium salt ($Mg(OH)_2$, $MgSiO_3$), and suspended solids dissolved in water (Ryznar 1944).

An assessment undertaken to identify and to characterize potential hazards and their risks (assessing the source water quality and characterizing what water quality parameters pose a risk to the environment, human health or product specifications) is needed. Verification monitoring and testing programs should be developed based on the risk assessment. It is important to identify what parameters and characteristics need to be monitored, at what point in the process, and how often they need to be monitored.

Statistical analysis

Statistical analysis using SPSS software was performed on some physicochemical water quality parameters and major ion concentration of water samples to detect the relationship and differences. Pearson's matrix correlation coefficients have been calculated to examine the possible relationships among the measured and calculated parameters (Table 7).

The results of correlation matrix revealed that the very strong positively correlated values were found between Cl^- and EC (0.960), Na^+ and EC (0.947), SO_4^{2-} and EC (0.941), Ca^{2+} and EC (0.906), Mg^{2+} and EC (0.903) in water samples, which indicates their contribution to water mineralization and salinity hazards. Very strong positively correlated values were found between Na^+ and FC (1.000), EC and FC (0.946), Ca^{2+} and FC (0.917), and Mg^{2+} and FC (0.913) in water samples, which indicates that these ions may be related to the foaming action. High to strong positively correlated values were found particularly between Cl^- and CC (0.885), EC and CC (0.824), Na^+ and CC (0.771), and SO_4^{2-} and CC (0.622) in water samples, which indicates that chloride, sodium, and sulfate probably increases corrosion rates by increasing the conductivity of the water. These ions may inhibit the formation of protective films by ion-pairing with calcium and magnesium (Schock and Neff 1982). Very strong positively and strong negatively correlated values were also found respectively between RSI and PI (0.925) and between RSI and others parameters (pH (−0.889), Ca^{2+} (−0.724), and Mg^{2+} (−0.712)) in water samples, indicating that the permeability of soil may be influenced by calcium, magnesium content, and hydrogen ion activity. Very strong positive correlation was found between Ca^{2+}/Mg^{2+} (0.992), Ca^{2+}/Na^+ (0.920), and Na^+/Mg^{2+} (0.916) in water samples, suggesting that the common source of these ions is carbonate dissolution ($CaCO_3$, $MgCO_3$, and $NaCO_3$). Strong positive correlation that was found between Ca^{2+}/SO_4^{2-} (0.735), Mg^{2+}/SO_4^{2-} (0.726), and Na^+/SO_4^{2-} (0.863) in water samples may probably be related to dissolution of sulfate salt ($CaSO_4$, $MgSO_4$, and $NaSO_4$), while strong positively correlation was found between Ca^{2+}/Cl^- (0.891), Mg^{2+}/Cl^- (0.889), and Na^+/Cl^- (0.854) in water samples could be related to dissolution of chloride salts ($CaCl_2$, $MgCl_2$, and NaCl).

A classification scheme using Euclidean distance for similarity measurement, together with Ward's method for linkage, was used in this analysis to produce the most distinctive groups. The dendrogram analysis was performed and the results are shown three groups with respect to their physicochemical parameter and four groups based on water samples (Fig. 6). Three spatial water types were distinguished from the dendrogram based on their physicochemical parameter (Fig. 6a). The first group represents SAR, RSI, pH, K, CC, Temp, Mg, and PI which indicate correlation between irrigational and industrial parameters. Group 2 consists of five ions (Ca^{2+}, Cl^-, Na^+, SO_4^{2-}, HCO_3^-) which, demonstrate their contribution to mineralization. Group 3 is made up of foaming coefficient influenced by EC. Four spatial water types were distinguished from the dendrogram based on water samples (Fig. 6b). The first group represents four samples (S4–S5 and S7–S8) which indicate optimized results of siliceous sand/marble waste upflow-downflow filtration system for low and mildly hydraulic loading rate. Group 2 consists of four samples (S0–S1 and S2–S3) which demonstrate raw grey water samples and optimized results of sand upflow-downflow filtration. Group 3 is made up of two samples (S6, S9) which indicate optimized results of sand-marble waste upflow-downflow filtration under higher hydraulic loading rate. Finally, group 4 represents only water sample S10 related to water samples of Medjerda river. Hydrochemical characteristic of water samples from Medjerda river is different in comparison to raw and treated grey water samples because there are different wastewater treatment plants operational since 1994 collecting mainly the waste from the exciting towns on the Medjedra river basin and from the rural areas (UNEP, 2016).

Conclusion

In the present study, the suitability assessment of an upflow-downflow siliceous sand/marble waste filtration system of grey water collected from bathrooms of the student residential complex at the Higher Institute of Engineering Medjez El Bab (Tunisia) for agricultural and industrial purposes has been evaluated by the standard guidelines. Under optimal operational conditions (hydraulic loading rate and media filter proportions), results reveals that treated grey water samples with siliceous sand/marble waste may be considered as a good to an excellent water quality suitable for irrigation purpose (medium salinity hazard and low-sodium hazard class). However, treated grey water was found not appropriate for industrial purpose due to high concentrations of calcium and sodium that can generate foaming and scaling harm to boilers. The suitability of treated grey water with an upflow-downflow siliceous sand/marble waste filtration system for irrigation purpose judged on the potential severity of problems that can be expected to develop during long-term use according to salinity hazard, sodium hazard, magnesium hazard, permeability index, water infiltration rate, and other related water quality parameters showed that treated grey water would support production when used as irrigation water indicating the potential of grey water treatment and reuse system for sustainable water management.

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