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ORIGINAL PAPER

Application of Huwa-San TR50 as an alternative disinfectant for municipal wastewater reuse in irrigation

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Abstract

The potential health risk related to wastewater reuse in agriculture remains a major environmental concern; although chlorine is predominantly used to treat wastewater, it leaves behind harmful disinfection by-products. Thus, in this study, a new secondary disinfectant Huwa-San (HS) has been used to reduce the harmful components in wastewater treatment plants. The effluent quality of four wastewater treatment plants and their transport lines in Riyadh, Saudi Arabia, were monitored for 8 months. The description of plants, effluent quality data, and their conformity to the standards are presented. The outcomes of this investigation proved that the mean values of disinfection by HS was more effective than chlorine in decreasing turbidity, ammonia, and *E. coli* by 2.3%, 20% and 100% in the plants and 97%, 25% and 100% in the transport lines (TL), respectively, while chlorination was more effective than HS in minimizing nitrate concentration and the sodium adsorption ratio (SAR), by 6% and 6% in the plants and in the TL, by 1% and 11%, respectively. The mean values of SAR, EC, and pH under both disinfectants were within water quality Saudi Standard. A monitoring survey at the WWTPs revealed that HS treatment met most of the quality requirements for unrestricted irrigation, whereas chlorine treatment did not achieve most of the quality requirements for restricted irrigation.

Keywords Chlorine · Huwa-San · Heavy metals · *E. coli* · Wastewater treatment plants

Introduction

The 2030 Agenda for Sustainable Development defines 17 Sustainable Development Goals (SDGs) toward ending poverty, protecting the planet, and preserving peace and prosperity (UN General Assembly 2015). The reduction of untreated wastewater and substantially increasing recycling and safe reuse globally is recommended in target 6.3 (Petousi et al. 2019).

The rapid increase in the water demand in the Middle East and North Africa (MENA) region projected to the doubling of the population over the past 30 years Moreover, these arid and semi-arid countries represent 5% of the world population; however, it contains less than 1% of the global annual renewable freshwater (Abdel-Raouf et al. 2012). In a specific aspect, The Kingdom of Saudi Arabia (KSA) faces a dire water shortage problem. The water demand exceeds sustainable conventional and non-conventional water resources. Furthermore, climate conditions, particularly worsening droughts and a growing number of dry spells, will worsen these challenges concerning the availability of sufficient amounts of water to the communities (Lange 2018).

KSA considers treated wastewater a most important water source and aims to achieve 100% use of treated wastewater by 2025. Wastewater flow in Riyadh city increased from approximately 636,000 m^3/day in 2008 to approximately 953,000 m^3/day in 2014 (Ouda 2016). According to the Gulf Cooperation Council (GCC) water statistics book, 2016,

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the total wastewater produced in the KSA was estimated at 1.6 billion m^3 per year, while the volume of treated reused wastewater was approximately 0.216 billion m^3 per year (only 13.4%). Consequently, Saudi authorities have started a countrywide initiative to develop wastewater treatment plants (WWTPs) to meet the increased demands of agricultural irrigation (Al-Jassem 2012).

Wastewater can be a great water resource, unless it poses pernicious health effects, as in the case of unrestricted irrigation water and excessive contamination of groundwater (Bouwer 2000). Urban water supply is discharged back to the environment (Council 1998). 75 or 85% of each cubic meter used is a return flow that has to be adequately treated and disposed of safely; thus, it is reasonable to consider substantial treatment or suitable reuse of these effluents in a region in which freshwater is scarce (Council 1998). The available wastewater treatment technologies can convert wastewater into renewable valuable products including irrigation water, industrial process water, biogas, heat, electricity, and nutrient-rich biosolids for soil conditioning, and even drinking water (Shevah 2016).

Chlorine is a strong oxidizing agent. Chlorination is widely used in several countries to guarantee safe drinking water or irrigation water (Hussein et al. 2013). Chlorine disinfectants are predominantly used against organisms in a water treatment system; however, it leaves residuals that exceed the acceptable limits in distributed water systems. Furthermore, the halogenated oxidation and process of disinfection give rise to disinfection by-products (DBPs) (Shubat et al. 2015). Chlorine decay occurs in different types of pipes (PVC, polyethylene) due to the interaction of chlorine with the pipe wall. It has also been proven that the decay constant of chlorine becomes high in the pipe sectors in the distribution system (Al-Jasser 2007, 2011a). Al-Jasser (2011b) proved that *fecal coliform* has exceeded the maximum allowable limit for unrestricted agricultural irrigation. After the discovery that chlorine may produce harmful DBPs, alternative disinfectants are being adopted worldwide for matching the standards required for wastewater reuse (Liberti et al. 2000). The health and environmental impacts of chlorine have impelled a worldwide search for effective toxicologically safe alternative disinfectants, a goal that remains a challenge for the scientific community (Liberti et al. 2000). The high doses of chlorine could remove biofilm; however, it is not an active method to prevent biofilm accumulation in the system due to the immoderate level of residual chlorine that requires a flushing system (Keung 2015). There are a lot of non-halogen alternatives for water treatment as hydrogen peroxide (Brown et al. 1998) or stabilized hydrogen peroxide (SHS) (Shubat et al. 2015) or the present product (Huwa-San TR 50) (Hungerbach et al. 1995).

Hydrogen peroxide (H_2O_2) is considered a strong oxidizer with an oxidation potential of 1.8 V, which is just below ozone at 2.1 V, but stronger than chlorine and chlorine dioxide with oxidation potentials of 1.5 V and 1.4 V, respectively (Lennetch 2015). HUWA-SAN™ (HS) was developed over the last 15 years. The manufacturer assumes that it is a hydrous solution of hydrogen peroxide stabilized with small amounts of silver or other stabilizing materials. It is also a wide spectrum oxidizing biocide for water treatment and decontamination from slime, bacteria, virus, molds, algae, and other water-borne pathogens typically grown in reservoirs (Huwa-San 2015). It is odorless, tasteless, colorless, biodegradable, non-toxic, with long-term effectiveness, and no build-up of resistance by microorganisms (Huwa-San 2015). Other commercial products of hydrogen peroxide and silver have been approved as water disinfectants in several countries in Europe such as Switzerland, Germany, and France (Pedahzur et al. 1995). It is highly effective, irrespective of temperature and pH variations. Huwa-San is a disinfectant for biofilm removal without the formation of byproducts (Hussein et al. 2013).

The combination of H_2O_2 and silver (Huwa-San) is approximately 100 times more powerful as a disinfectant than hydrogen peroxide alone, and it is disinfectant power increases significantly as water temperature increases (Shuval et al. 2009). It has also been proven that HS has the unique qualities of providing effective long-lasting residual disinfection in piping systems and an increase in disinfection power in hot water systems (Shuval et al. 2009). Liberti et al. (2000) suggested that the combined HS and silver disinfectant may be applied as a secondary, long-acting residual disinfectant for high-quality effluents. HS was more effective for the reduction of *E. coli* at pH 8.5 (2-log inactivation after 30 min) than sodium hypochlorite (0.6-log inactivation after 30 min) (Martin et al. 2015). The performance of the WWTPs in Riyadh was studied for 8 months from July 2018 to March 2019. The goal of this study is to compare chlorine and Huwa-San based on the standard criteria for irrigation water quality. The current ambition is to reuse the larger amount of wastewater for irrigation purposes.

Materials and methods

The municipal wastewater treatment plants scheme

The municipal wastewater was treated in three procedures as shown in Fig. 1. The primary, secondary, and tertiary treatment schemes included (1) preliminary treatment of the influent wastewater using sieving; (2) secondary treatment by an activated sludge process; (3) sedimentation tanks which receive the secondary treated wastewater to separate heavy activated sludge in the bottom of the tank while the purified treated wastewater is expelled into an outlet pipe; (4) diffused air aeration tanks that receive the

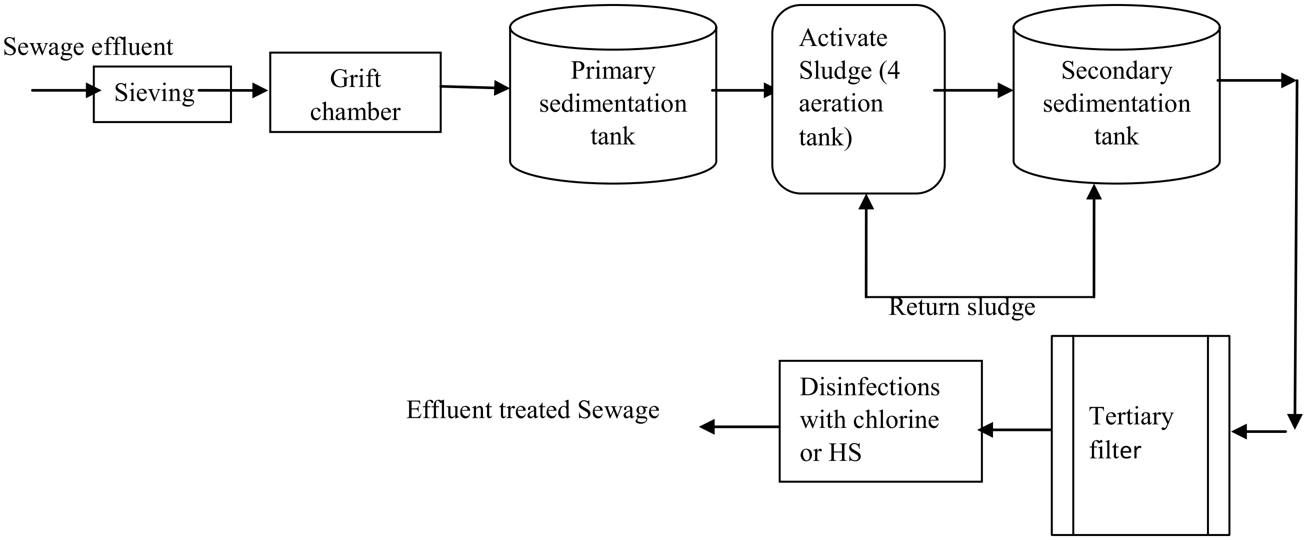


Fig. 1 Schematic diagram of the wastewater treatment plants scheme. (Adapted from Al-Hammad et al. 2014)

settled activated sludge and disposed of the excess to be treated via sludge thickeners; (5) filtration of purified water through rapid sand filters to remove the suspended matter load, turbidity, organic matter and microorganisms; and (6) disinfection using chlorine or HS to break down pathogenic bacteria (Al-Hammad et al. 2014).

Study area and plants locations

Riyadh is the capital and most populous city of Saudi Arabia. It is located at 24° 38′ N and 46° 43′ E, 612 m above sea level. The city spreads out over an area of 1798 square Km. This research included a field sampling campaign at centralized wastewater treatment plants and transport lines in Riyadh city, as shown in Fig. 2.

This current study was performed on four centralized Wastewater Treatment Plants and the Transport lines from the main plant to the substation plants serving Riyadh, as follows in Table 1:

The Northern Plant of Riyadh wastewater treatment plant (NP-RSTP) and The Southern Plant of Riyadh wastewater treatment plant (SP-RSTP) is discharged into main pumping station wastewater plant (MPS-WP) which distribute the Wastewater to HS-WP, DS-WP, and ADS-WP during its transport lines.

The preliminary, primary, secondary, and tertiary treatment schemes are the same for all the plants. Comparative disinfection with chlorine and HS is part of the treatment processes in all the treatment plants. The authorities of WWTPs collected the samples, and analyzed them in the laboratories, or sent the samples to designated laboratories for analysis. Table 1 provides a full description of these four centralized plants and their transport lines.

Materials and sampling methodology

The HS solutions used for water disinfection are owned by Roam Chemie NV of Houthalen, Belgium. The chemical structure for HS is H_2O_2 solutions (50 ppm) stabilized with minute concentrations of silver ions (26–34 ppb) or silver colloid. The silver prohibits H_2O_2 from oxidizing too quickly when it comes in contact with water (Shubat et al. 2015). The performance of the four WWTPs in Riyadh was studied by analyzing samples collected over 8 months from July 2018 to March 2019. For each plant, an average of 20 µg/L of chlorine and HS solutions were added as a part of secondary treatment, and samples were analyzed. Each composite sample consisted of five grab samples for chlorine treatments and five grab samples for HS treatments for each plant. There are 80 samples for all the plants and transport lines.

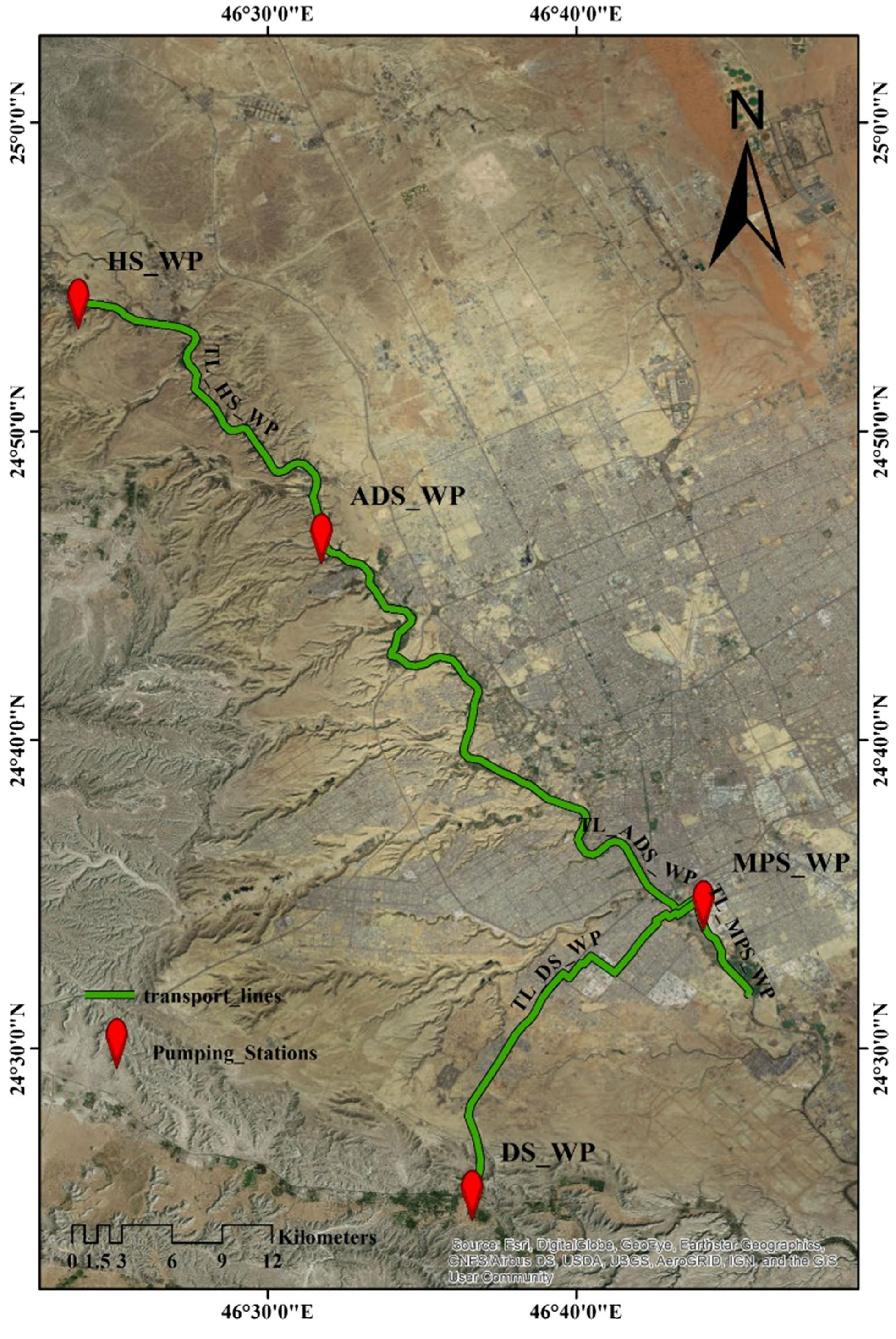
Water quality parameters

The microbiological analysis was done using the convention standard plate count method (MPN) per 100 mL as Saleem et al. (2000). The total concentrations of metal were analyzed using ICP (Perkin Elmer, Model 4300 DV). SAR was calculated based on the relation between soluble sodium, soluble calcium, and magnesium divalent cations. SAR is computed as Jiménez and Asano (2008).

$$\mathrm{SAR} = \mathrm{Na}/(\sqrt{((\mathrm{Ca}+\mathrm{Mg})/2)} \tag{1}$$

The sulfate (SO_4) concentration was determined by the turbidity method (Swift and Sparks 1996). The chloride Cl^- concentration was determined by titration with silver

Fig. 2 The centralized wastewater plants and the transport lines in Riyadh city



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nitrate ($AgNO_3$), while the HCO^3 concentration was determined by titration with sulfuric acid (H_2SO_4) (Maiti 2004). The calcium carbonate content was determined using a calcimeter, according to Swift and Sparks (1996). The soluble Na^+ and K^+ concentrations were determined using a flame photometer; the soluble Ca^{++} and Mg^{++} were determined by the versenate titration method (EDTA) (Maiti 2004). The traditional biological oxygen demand BOD_5 method measures the microorganisms' oxygen consumption over 5 days. It was determined by the dissolved oxygen device (American Public Health Association 1998). The ammonia (NH_4) was measured using Keldahel and calibrated by H_2SO_4 (Kroon 1993). The chemical oxygen demand (COD) and the nitrate (NO_3) concentration were determined by spectrophotometry (American Public Health Association 1998). Turbidity was measured using a spectrometer (Swift and Sparks 1996)

Table 1 The wastewater treatment plants and the transport lines

The wastewater treatment plants and the transport lines	The abbreviation	The lengths of transport lines
AlHyesia substation wastewater plant	HS-WP	–
Dirab substation wastewater plant	DS-WP	–
Al Diriyah substation wastewater plant	ADS-WP	–
Main pumping station wastewater plant	MPS-WP	–
Transport line for HS-WP	(TL-HS-WP)	68 km
Transport line for DS-WP	TL-DS-WP)	54 km
Transport line for ADS-WP	TL-ADS-WP	57 km
Transport line for MPS-WP	TL-MPS-WP	10 km

in the nephelometric turbidity unit (NTU). The total dissolved solid (TDS) content was measured by the gravimetric method (Hussein and Magram 2012). The EC was measured using an EC meter in units of ds m^{-1} at 25 °C. The pH was determined using a pH meter. The water quality parameters described in Table 2.

This paper reports the results obtained following the disinfection test on the treated municipal effluents. The physical, chemical, and microbiological analyses were compared with the treated wastewater standards for restricted and unrestricted irrigation in the Kingdom of Saudi Arabia (KSA), according to the standards of the Ministry of Environment, Water and Agriculture.

Results and discussion

Microbiological analysis (*E. coli*)

Disinfection by HS killed all the *E. coli* population in all the plants and transport lines, thereby accomplishing the required quality for unrestricted irrigation. Conversely, chlorination increased the *E. coli* population more than the maximum allowable contaminant for unrestricted irrigation in all the plants; however, it was suitable for restricted irrigation, except MPS-WP, as illustrated in Tables 3 and 4. Additionally, chlorination increased the *E. coli* population in all the transport lines more than the maximum allowable contaminant for unrestricted and restricted irrigation. The highest value in the chlorinated water was 2297.78 MPN/100 ml in MPS-WP, which exceeded the accepted limit for restricted irrigation, as illustrated in Tables 5 and 6. Microbiological analysis proved that HS reduced the *E. coli* population better than chlorine. These results were agreed with Keung (2015), who showed that HS was able to eliminate all traces of coliform bacteria, thus demonstrating its effectiveness at killing all the bacteria present in water. By the same token, these microbiological analysis results have been proven by Al-Hammad et al. (2014) who found that the total and *fecal coliform* counts in chlorinated water were above the allowable contamination limits. Martin et al. (2015) suggested that the increased bacterial inactivation seen in HS is caused by the addition of cations (Ag^+ in HS) that inhibit the electrostatic interactions between HS and the negatively charged bacterial cell surfaces, thus allowing HS to interact directly with the bacterial cell surface (less susceptible to inactivation by catalase).

There are two mechanisms for the enhanced toxic effect of hydrogen peroxide (HP) and silver: “chemical” and “biological” (Pedahzur et al. 1997). The chemical interactions between the two agents result in the formation of active species that are responsible for the increased toxic effect (the synergistic effect), and the biological performance, all these effects form an accumulation of cellular damages (Pedahzur et al. 1997). In a study by Davoudi et al. (2012) to find the effects of using hydrogen peroxide and silver to kill bacteria, especially *fecal coliform*, it was found that the combination effectively neutralized the bacteria’s activity after 15 min of exposure. Davoudi et al. (2012) also found that hydrogen peroxide and silver ions can be used as a powerful disinfectant agent both

Table 2 The measured water quality parameters

The water quality parameters	The unit
Microbiological presence (*Escherichia coli*)	MPN/100 mL
Heavy metals including Zn, B, Cr, Cd, Ni, Mn, Cu, Pb, and Fe	mg/L
Sodium adsorption ratio (SAR)	%
Standards water quality parameters including anions (SO_4, Cl_2, HCO_3, CO_3), cations (K^+, Na^+, Mg^{++}, Ca^{++})	meq/L
Biochemical oxygen demand (BOD_5), chemical oxygen demand (COD)	mg/L
Ammonia ($N-NH_3$) and Nitrates ($N-NO_3$)	mg/L
Turbidity analysis	NTU
Total dissolved solids (TDS) and Electrical Conductivity (Ec)	mg/L
Hydrogen ion activity (pH)	

Table 3 Effluent qualities of the HS-WP and DS-WP wastewater plants in Riyadh, Saudi Arabia

Parameters	Unit	HS-WP				DS-WP			
		HS		Chlorine		HS		Chlorine	
		Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range
E. coli	mpn/100 ml	0	0	398 ± 373.872	59–998	0	0	344.400 ± 315.977	12–688
Zn	mg/L	0.01 ± 0.01	0.003–0.015	0.024 ± 0.01	0.009–0.036	0.061 ± 0.062	0.005–0.156	2.316 ± 1.348	0.022–3.456
B	mg/L	0.28 ± 0.05	0.21–0.35	0.71 ± 0.018	0.69–0.73	0.210 ± 0.076	0.09–0.29	0.664 ± 0.027	0.62–0.69
Cr	mg/L	0.0014 ± 0.001	0.001–0.003	0.002 ± 0.001	0.001–0.003	0.0012 ± 0.0004	0.001–0.002	0.002 ± 0.001	0.001–0.003
Cd	mg/L	0.002 ± 0.001	0.001–0 .003	0.003 ± 0.002	0.001–0.006	0.0014 ± 0.001	0.001–0.003	0.002 ± 0.002	0.001–0.005
Ni	mg/L	0.018 ± 0.008	0.01–0.03	0.032 ± 0.019	0.01–0.06	0.016 ± 0.009	0.01–0.03	0.128 ± 0.070	0.01–0.19
Mn	mg/L	0.04 ± 0.035	0.01–0.09	0.128 ± 0.025	0.09–0.15	0.054 ± 0.039	0.01–0.1	0.136 ± 0.034	0.09–0.17
Cu	mg/L	0.26 ± 0.062	0.201–0.344	0.268 ± 0.067	0.215–0.377	0.231 ± 0.028	0.202–0.266	0.294 ± 0.031	0.256–0.334
Pb	mg/L	0.0026 ± 0.002	0.001–0.005	0.003 ± 0.002	0.001–0.005	0.0022 ± 0.002	0.001–0.004	0.004 ± 0.002	0.002–0.006
Fe	mg/L	3.70 ± 1.41	1.667–4.302	3.575 ± 1.402	1.552–5.102	3.621 ± 0.349	3.12–4.001	3.950 ± 0.567	3.016–4.561
SAR	%	3.21 ± 0.005	3.206–3.22	3.160 ± 0.018	3.13–3.18	3.281 ± 0.019	3.254–3.303	3.230 ± 0.027	3.19–3.26
SO4	meq/L	10.86 ± 0.152	10.6–11	10.558 ± 0.444	9.79–10.9	10.980 ± 0.045	10.9–11	11.080 ± 0.239	10.9–11.5
Cl2	meq/L	8.78 ± 0.075	8.7–8.9	9.140 ± 0.055	9.1–9.2	8.916 ± 0.085	8.8–9	8.902 ± 0.015	8.88–8.92
HCO3	meq/L	2.88 ± 0.011	2.87–2.9	2.856 ± 0.052	2.8–2.9	2.956 ± 0.061	2.88–3	2.882 ± 0.020	2.85–2.9
CO3	meq/L	0	0	0	0	0	0	0	0
K+	meq/L	0.49 ± 0.011	0.48–0.51	0.498 ± 0.017	0.48–0.52	0.49 ± 0.007	0.48–0.5	0.490 ± 0.007	0.48–0.5
Na+	meq/L	10.04 ± 0.036	10–10.1	10.028 ± 0.065	9.95–10.1	10.25 ± 0.05	10.2–10.3	10.028 ± 0.038	10–10.09
Mg++	meq/L	5.42 ± 0.045	5.35–5.45	5.420 ± 0.13	5.3–5.6	5.37 ± 0.084	5.25–5.45	5.040 ± 0.065	5–5.15
Ca++	meq/L	7.06 ± 0.089	7–7.2	7.36 ± 0.167	7.1–7.5	7.08 ± 0.084	7–7.2	7.120 ± 0.130	7–7.3
BOD5	mg/L	43.12 ± 4.022	37.4–47.8	37.9 ± 2.040	34.5–40	45.52 ± 3.420	41.2–49.7	44.620 ± 3.810	39.9–49.8
COD	mg/L	73.12 ± 0.482	72.5–73.8	58.42 ± 14.064	36.9–71.2	68.40 ± 7.163	56.6–73.5	44.620 ± 0.968	43.4–45.6
NH4	mg/L	3.74 ± 0.321	3.2–4	4.62 ± 0.239	4.3–4.9	3.52 ± 0.192	3.2–3.7	4.740 ± 0.152	4.6–4.9
NO3-N	mg/L	12.02 ± 3.144	9.5–17.3	10.46 ± 0.902	9.5–11.8	12.540 ± 1.258	10.9–14.2	10.660 ± 1.534	8.6–12.7
Turbidity	NTU	4.68 ± 0.390	4 –4.9	4.78 ± 0.75	3.9–5.8	4.50 ± 0.200	4.3–4.8	4.600 ± 0.775	4–5.9
TDS	mg/L	1412.35 ± 2.369	1409.28–1415.0	1398.912 ± 39.015	1329.28–1420	1413.504 ± 2.848	1409.92–1416.9	1414.016 ± 5.928	1408–1422.0
EC	ds m^{-1}	2.21 ± 0.004	2.202–2.211	2.186 ± 0.061	2.077–2.22	2.209 ± 0.034	2.203–2.214	2.209 ± 0.009	2.2–2.22
pH		8.29 ± 0.099	8.12–8.36	8.084 ± 0.152	7.82–8.19	8.36 ± 0.023	8.34–8.4	8.224 ± 0.047	8.19–8.3

in suspensions and on surfaces against three important human pathogens (*Escherichia coli, Proteus mirabilis, and Klebsiella pneumoniae*).

The values obtained by Al-Hammad et al. (2014) and Al-Jasser 2011b) were (71 and 84 MPN/100 mL) for NP-RSTP and SP-RSTP, respectively, were lower than those investigated in the present study which was (0 and 762,16 MPN/100 mL) for both treatment HS and chlorine, respectively. It is assumed that the plants could improve the removal of *E. coli* if HS is proposed as secondary disinfection to be used in unrestricted agricultural irrigation.

Heavy metals

As shown in Tables 3 and 4, it was found that treatment with HS in all the plants decreased the Zn, B, and Cr concentrations than chlorine. In both treatments, these elements did not exceed the permissive limit in unrestricted irrigation. Water with chlorine or HS has approximately the same effect about cadmium (Cd) in all the plants. Furthermore, the values of Ni, Mn, Cu, Pb, and Fe concentrations under HS treatment were lower, compared with those of chlorine treatment. The concentrations of these elements did not exceed the acceptable limit in unrestricted irrigation, except Fe in chlorine treatment in the MPS-WP. The results accorded with the opinion of Hussein (2014) on drinking water treatment. He demonstrated that HS was more effective than chlorine in decreasing heavy metals, except for Mn, where chlorine treatment was more effective.

The average concentrations of Ni, Pb, Mn, and Cr in HS treatment as shown in Table 7, were approximately similar to the average concentration results of Al-Hammad et al. (2014) however the concentration values of them in chlorine treatment were higher. Additionally, the mean values of Zn, B, Cr, Cu and Fe concentrations for all plants under chlorine treatment (2.215, 0.641, 0.015, 0.305 and 4.737 mg/L, respectively) were higher than those reported by Al-Turki (2010) in Buraidah, KSA. The high values of means shown in these results may be due to different operating conditions as presented in Table 7. However, the two studies (Al-Jasser

Table 4 Effluent qualities of the ADS-WP and MPS-WP wastewater plants in Riyadh, Saudi Arabia

Parameters	Unit	ADS-WP				MPS-WP			
		HS		Chlorine		HS		Chlorine	
		Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range
E. coli	mpn/100 ml	0	0	8.48 ± 4.923	2.2-13	0	0	2297.78 ± 176.995	2100.3-2444.8
Zn	mg/L	1.66 ± 1.171	0.005–3.045	2.564 ± 0.579	2.032–3.253	3.113 ± 0.195	3.002–3.456	3.959 ± 0.158	3.694–4.12
B	mg/L	0.232 ± 0.071	0.12–0.3	0.484 ± 0.098	0.41–0.65	0.342 ± 0.099	0.23–0.45	0.706 ± 0.011	0.69–0.72
Cr	mg/L	0.034 ± 0.041	0.001–0.081	0.005 ± 0.003	0.002–0.009	0.022 ± 0.010	0.012–0.034	0.051 ± 0.025	0.025–0.089
Cd	mg/L	0.001 ± 0.001	0.001–0.002	0.002 ± 0.002	0.001–0.006	0.001 ± 0.000	0.001–0.001	0.004 ± 0.003	0.002–0.008
Ni	mg/L	0.012 ± 0.004	0.01–0.02	0.064 ± 0.041	0.01–0.1	0.048 ± 0.013	0.03–0.06	0.158 ± 0.022	0.13–0.19
Mn	mg/L	0.024 ± 0.026	0.01–0.07	0.066 ± 0.029	0.03–0.1	0.042 ± 0.034	0.01–0.09	0.126 ± 0.021	0.11–0.16
Cu	mg/L	0.244 ± 0.051	0.2–0.311	0.274 ± 0.040	0.243–0.344	0.284 ± 0.013	0.266–0.299	0.384 ± 0.024	0.346–0.406
Pb	mg/L	0.002 ± 0.001	0.001–0.002	0.002 ± 0.001	0.002–0.004	0.001 ± 0.000	0.001–0.002	0.002 ± 0.003	0.001–0.007
Fe	mg/L	3.998 ± 0.076	3.889–4.102	4.749 ± 0.212	4.552–5.001	4.223 ± 0.362	3.998–4.854	6.675 ± 0.892	5.988–8.102
SAR	%	3.334 ± 0.026	3.29–3.36	3.108 ± 0.019	3.08–3.13	3.571 ± 0.512	2.66–3.85	3.17 ± 0.024	3.14–3.21
SO4	meq/L	11.44 ± 0.114	11.3–11.6	11.28 ± 0.277	11–11.6	10.28 ± 2.139	6.5–11.8	10.96 ± 0.055	10.9–11
Cl2	meq/L	8.69 ± 0.182	8.55–9	7.77 ± 0.172	7.6–8	9.474 ± 2.075	5.8–10.9	9.086 ± 0.022	9.05–9.1
HCO3	meq/L	2.96 ± 0.055	2.9–3	0.042 ± 0.000	2.7–2.8	2.92 ± 0.084	2.8–3	2.92 ± 0.084	2.8–3
CO3	meq/L	0	0	0	0	0	0	0	0
K+	meq/L	0.506 ± 0.005	0.5–0.51	0.488 ± 0.008	0.48–0.5	0.458 ± 0.116	0.25–0.52	0.604 ± 0.005	0.6–0.61
Na+	meq/L	10.172 ± 0.042	10.1–10.2	10.02 ± 0.045	10–10.1	11.428 ± 2.588	6.8–12.63	10.3 ± 0.071	10.2–10.4
Mg++	meq/L	4.102 ± 0.076	4.01–4.2	5.23 ± 0.205	5.05–5.5	4.9 ± 1.012	3.1–5.5	5.19 ± 0.065	5.1–5.25
Ca++	meq/L	7.26 ± 0.114	7.1–7.4	7.78 ± 0.217	7.5–8	7.64 ± 1.488	5–8.5	7.96 ± 0.055	7.9–8
BOD5	mg/L	45.66 ± 3.587	40.1–49.6	33.36 ± 3.765	27.9–36.8	45.22 ± 2.863	41.3–49.2	37.06 ± 2.247	33.4–39.4
COD	mg/L	71.42 ± 2.887	69.2–76.2	52.34 ± 8.528	45.6–66.5	72.26 ± 3.462	69.4–77.2	51.08 ± 1.918	49.6–54.3
NH4	mg/L	3.58 ± 0.277	3.2–3.9	4.44 ± 0.416	4.1–5.1	3.86 ± 0.404	3.4–4.3	4.66 ± 0.288	4.2–4.9
NO3-N	mg/L	9.76 ± 2.547	7.8–14.1	9.84 ± 1.757	7.2–11.6	8.84 ± 1.443	7.1–10.6	9.52 ± 1.326	7.2–10.5
Turbidity	NTU	3.98 ± 0.602	3–4.6	3.98 ± 0.835	2.8–4.9	3.58 ± 1.207	1.6–4.9	2.96 ± 1.629	1.4–5.7
TDS	mg/L	1408.26 ± 10.867	1389.44–1416.96	1263.232 ± 323.088	685.44–1416.32	1355.264 ± 287.537	865.92–1630.72	1404.416 ± 7.263	1395.84–1411.8
EC	ds m^{-1}	2.2 ± 0.017	2.171–2.214	1.974 ± 0.505	1.071–2.213	2.118 ± 0.449	1.353–2.548	2.194 ± 0.011	2.181–2.206
pH		8.128 ± 0.048	8.08–8.2	7.85 ± 0.112	7.72–7.97	7.68 ± 0.476	7.07–8.15	8.036 ± 0.083	7.91–8.12

2011b) and (Al-Hammad et al. 2014) proved that these heavy metals fall within the range stated by Saudi Standards. The average concentrations of Zn, Cr, Mn, Cu and Pb in SP-RSTP reported by Bousiakou et al. (2015) were lower than the average concentrations of the present study in both treatment (HS and Chlorine), operating the plants higher than its design capacity might be the cause for such difference in results.

On the other hand, it was established that the treatment with HS was generally more effective than chlorine at decreasing Zn, B, Cr, Cd, Ni, Mn, Cu, Pb and Fe concentration in the transport lines of the plants. Furthermore, the concentrations under HS treatment were lower, in comparison with those under chlorine treatment. The concentrations of these elements did not exceed the acceptable limit in both unrestricted and restricted irrigations, except for Fe concentration in MPS-WP. Besides, Fe concentrations under chlorine treatment did not exceed the acceptable limit in the irrigation in all the transport lines, except in TL-DS-WP, as shown in Tables 5 and 6. In general, in HS samples, the concentrations of heavy metals were very low, compared with the concentration of heavy metals in chlorine samples.

Sodium adsorption ratio (SAR)

The sodium adsorption ratio (SAR) is the most important parameter in agricultural irrigation (Chang et al. 2005) and the soil infiltration rate is affected by the sodium concentration in the water, which can cause potential infiltration problems (Al-Jasser 2011b).

The value of SAR was determined for the effluent of the four WWTPs (Tables 3 and 4), and transport lines (Tables 5 and 6). Chlorine decreased SAR in all the plants and transport lines more than HS, except in TL- HS-WP and TL-ADS-WP. All the plants and transport lines produced effluents with no irrigation use restrictions for SAR. Richards

Table 5 Effluent qualities of the TL- HS-WP and TL-DS-WP wastewater plants in Riyadh, Saudi Arabia

		TL- HS-WP				TL-DS-WP			
		HS		Chlorine		HS		Chlorine	
Parameters	Unit	Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range
E. coli	mpn/100 ml	0	0	2451.04 ± 30.125	2410.9–2488.4	0	0	2444.64 ± 20.356	2421.4–2466.8
Zn	mg/L	0.029 ± 0.028	0.003–0.062	2.154 ± 0.018	2.133–2.169	0.06 ± 0.594	0.006–1.236	2.7788 ± 0.421	2.065–3.129
B	mg/L	0.33 ± 0.091	0.2–0.42	0.71 ± 0.023	0.69–0.74	0.21 ± 0.178	0.21–0.66	0.70 ± 0.041	0.65–0.76
Cr	mg/L	0.006 ± 0.003	0.002–0.009	0.0564 ± 0.037	0.021–0.097	0	0.002–0.008	0.063 ± 0.027	0.021–0.094
Cd	mg/L	0.001 ± 0.000	0.001–0.002	0.003 ± 0.004	0.001–0.011	0.001 ± 0.000	0.001–0.001	0.004 ± 0.004	0.002–0.011
Ni	mg/L	0.016 ± 0.005	0.01–0.02	0.154 ± 0.035	0.12–0.19	0.016 ± 0.000	0.01–0.01	0.166 ± 0.019	0.14–0.19
Mn	mg/L	0.016 ± 0.009	0.01–0.03	0.106 ± 0.054	0.01–0.14	0.05 ± 0.009	0.01–0.03	0.13 ± 0.024	0.1–0.16
Cu	mg/L	0.2574 ± 0.032	0.211–0.301	0.3328 ± 0.023	0.312–0.36	0.23 ± 0.021	0.255–0.304	0.304 ± 0.004	0.299–0.309
Pb	mg/L	0.003 ± 0.003	0.001–0.007	0.0018 ± 0.001	0.001–0.004	0	0.001–0.007	0.003 ± 0.002	0.001–0.007
Fe	mg/L	4.007 ± 0.004	4.002–4.012	6.1538 ± 0.123	6.007–6.325	3.62 ± 0.175	3.701–4.122	7.017 ± 0.074	6.951–7.144
SAR	%	3.226 ± 0.024	3.206–3.267	3.243 ± 0.006	3.237–3.252	3.28 ± 0.010	3.1–3.13	3.144 ± 0.008	3.135–3.155
SO4	meq/L	11.234 ± 0.144	11–11.37	10.57 ± 0.045	10.5–10.6	10.98 ± 0.049	11.2–11.32	11.47 ± 0.067	11.4–11.55
Cl2	meq/L	8.624 ± 0.023	8.6–8.65	8.666 ± 0.085	8.6–8.8	8.92 ± 0.011	8.67–8.7	8.706 ± 0.009	8.7–8.72
HCO3	meq/L	3.120 ± 0.444	2.8–3.9	2.706 ± 0.038	2.65–2.75	2.96 ± 0.008	2.98–3	2.766 ± 0.023	2.75–2.8
CO3	meq/L	0	0	0	0	0	0	0	0
K+	meq/L	0.490 ± 0.007	0.48–0.5	0.498 ± 0.008	0.49–0.51	0.49 ± 0.007	0.49–0.51	0.492 ± 0.004	0.49–0.5
Na+	meq/L	10.036 ± 0.045	10–10.09	10.032 ± 0.019	10–10.05	10.25 ± 0.022	9.96–10.02	10.046 ± 0.036	10–10.1
Mg++	meq/L	4.400 ± 0.100	4.3–4.5	4.260 ± 0.089	4.2–4.4	5.37 ± 0.134	4.2–4.5	4.260 ± 0.074	4.15–4.35
Ca++	meq/L	7.48 ± 0.130	7.3–7.6	7.44 ± 0.089	7.3–7.5	7.08 ± 0.089	8–8.2	8.08 ± 0.084	8–8.2
BOD5	mg/L	40.92 ± 3.372	36.2–45.2	32.04 ± 2.027	29.6–35.1	45.52 ± 3.304	40.2–48.2	36.3 ± 3.313	32.7–39.8
COD	mg/L	71.56 ± 1.496	70.1–73.7	65.46 ± 1.610	63.4–66.9	68.4 ± 2.808	71–77.8	61.3 ± 9.200	45.5–66.9
NH4	mg/L	4.26 ± 0.207	4.1–4.6	5.58 ± 0.363	5.1–5.9	3.52 ± 0.303	3.1–3.9	4.82 ± 0.084	4.7–4.9
NO3-N	mg/L	8.48 ± 1.303	7.1–10.1	9.6 ± 0.800	8.6–10.6	12.54 ± 0.482	6.9–8.1	9.26 ± 0.907	7.9–10.2
Turbidity	NTU	2.34 ± 0.720	1.2–3.2	108.9 ± 7.558	101.2–120.3	4.5 ± 0.552	1.1–2.6	119.2 ± 5.167	110–122
TDS	mg/L	1421.696 ± 5.771	1416.32–1431.04	1411.2 ± 13.771	1391.36–1425.92	1413.5 ± 3.637	1415.04–1422.72	1422.98 ± 3.581	1418.88–1427.84
EC	ds m^{-1}	2.2214 ± 0.009	2.213–2.236	2.205 ± 0.022	2.174–2.228	2.21 ± 0.006	2.211–2.223	2.223 ± 0.006	2.217–2.231
pH		7.892 ± 0.086	7.82–8	7.71 ± 0.130	7.57–7.86	8.36 ± 0.074	7.81–8	7.828 ± 0.160	7.66–8.01

(1969) mentioned that SAR must be less than 4 to be safe, from 4–9 to be possibly safe, more than 9 to be hazardous. The average values of SAR in all plants were 3.27 and 3.16 for HS and chlorine treatments (safe) as shown in Table 7. The reason for this consequence due to the augmentation of electrical conductivity which, should increase the value of SAR as Al-Jasser (2011b) informed.

Anions and cations concentration

The value of sulfates SO_4 under HS treatment was lower than that of chlorine treatment in all the plants, except ADS-WP and HS-WP. Conversely, the chloride Cl^- and bicarbonate HCO_3 under HS treatment was higher, in comparison with its values under chlorine treatment in all the plants. These anions concentrations did not exceed the acceptable limit in unrestricted irrigation, as revealed in Tables 3 and 4. Generally, chlorine treatment decreased the concentration of the sulfates SO_4, chloride Cl^- and bicarbonate HCO_3, while HS has the opposite effect. Furthermore, chlorination was slightly higher than in the disinfection by HS. HS decreased potassium K^+ in all plants, except in ADS-WP. HS and chlorine had the same effect on K^+ concentration in DS-WP. Likewise, HS decreased magnesium Mg^{++} in all plants, except in the case of DS-WP. Moreover, HS decreased Ca^{++} more than the disinfection using chlorine in all the plants. Conversely, chlorination decreased Na + more than the disinfection using HS in all the plants. The maximum values of the concentrations of all the cations did not exceed the acceptable limit in unrestricted irrigation, as shown in Tables 3 and 4.

In this study, the values of anions showed that none of the effluent samples had SO_4, Cl_2, and HCO_3 concentrations that exceeded the Saudi guideline of 20 meq/L (data are shown in Table 7) according to MEWA (2006). In a similar approach, the results of cations conformed with standards,

Table 6 Effluent qualities of the TL- ADS-WP and TL-MPS-WP wastewater plants in Riyadh, Saudi Arabia

Parameters	Unit	TL-ADS-WP				TL-MPS-WP			
		Huwa-San		Chlorine		Huwa-San		Chlorine	
		Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range	Average ± standard deviation	Range
E. coli	mpn/100 ml	0.000	0.000	2283.680 ± 90.738	2211.5–2429.8	0.000	2307.300 ± 156.620	0.000	2080.2–2455.9
Zn	mg/L	2.723 ± 0.618	2.032–3.331	3.104 ± 0.924	3.081 ± 0.064	2.023–3.822	3.001–3.136	3.175 ± 0.053	3.129–3.265
B	mg/L	0.330 ± 0.092	0.21–0.45	0.640 ± 0.046	0.520 ± 0.119	0.59–0.7	0.38–0.65	0.730 ± 0.011	0.71–0.74
Cr	mg/L	0.001 ± 0.000	0.001–0.002	0.070 ± 0.034	0.002 ± 0.002	0.023–0.099	0.001–0.005	0.065 ± 0.031	0.71–0.099
Cd	mg/L	0.001 ± 0.000	0.001–0.001	0.006 ± 0.003	0.002 ± 0.001	0.001–0.008	0.001–0.003	0.005 ± 0.003	0.71–0.009
Ni	mg/L	0.010 ± 0.000	0.01–0.01	0.154 ± 0.009	0.014 ± 0.005	0.14–0.16	0.01–0.02	0.152 ± 0.008	0.71–0.16
Mn	mg/L	0.020 ± 0.119	0.01–0.04	0.036 ± 0.032	0.022 ± 0.022	0.01–0.08	0.01–0.06	0.014 ± 0.005	0.01–0.02
Cu	mg/L	0.287 ± 0.049	0.201–0.322	0.342 ± 0.031	0.263 ± 0.025	0.302–0.379	0.233–0.291	0.304 ± 0.054	0.01–0.399
Pb	mg/L	0.001 ± 0.001	0.001–0.002	0.005 ± 0.002	0.003 ± 0.002	0.002–0.007	0.002–0.007	0.003 ± 0.002	0.01–0.007
Fe	mg/L	4.028 ± 0.043	4.001–4.103	4.096 ± 0.062	3.303 ± 0.269	4.025–4.188	3.009–3.661	5.072 ± 0.085	0.01–5.203
SAR	%	3.432 ± 0.016	3.411–3.452	3.541 ± 0.006	3.273 ± 0.005	3.536–3.549	3.266–3.279	3.147 ± 0.014	3.131–3.167
SO4	meq/L	11.354 ± 0.119	11.2–11.5	11.258 ± 0.011	11.248 ± 0.004	11.25–11.27	11.24–11.25	11.394 ± 0.043	11.35–11.45
Cl2	meq/L	8.728 ± 0.019	8.7–8.75	8.742 ± 0.028	8.758 ± 0.008	8.7–8.77	8.75–8.77	8.654 ± 0.011	8.64–8.67
HCO3	meq/L	2.994 ± 0.009	2.98–3	2.996 ± 0.009	2.992 ± 0.008	2.98–3	2.98–3	2.992 ± 0.011	2.98–3
CO3	meq/L	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K+	meq/L	0.494 ± 0.005	0.49–0.5	0.494 ± 0.005	0.462 ± 0.008	0.49–0.5	0.45–0.47	0.494 ± 0.005	0.49–0.5
Na+	meq/L	10.856 ± 0.052	10.8–10.9	11.006 ± 0.019	9.970 ± 0.042	10.99–11.04	9.9–10	10.020 ± 0.039	10–10.09
Mg++	meq/L	5.452 ± 0.008	5.44–5.46	4.400 ± 0.071	4.400 ± 0.071	4.35–4.5	4.3–4.5	4.302 ± 0.071	4.2–4.4
Ca++	meq/L	7.280 ± 0.084	7.2–7.4	7.460 ± 0.055	7.080 ± 0.110	7.4–7.5	6.9–7.2	7.990 ± 0.074	7.9–8.1
BOD5	mg/L	44.380 ± 3.505	39.1–48	30.520 ± 4.523	45.420 ± 2.180	26.1–36.7	42.2–48.2	38.900 ± 5.301	34.2–44.3
COD	mg/L	73.260 ± 0.865	71.9–74.1	45.040 ± 2.899	65.500 ± 1.807	45.6–49.2	62.9–67.5	53.740 ± 3.642	45.6–59.2
NH4	mg/L	4.040 ± 0.207	3.7–4.2	5.240 ± 0.594	3.480 ± 0.383	7.3–6.2	3.2–4.1	4.780 ± 0.192	4.6–5.1
NO3-N	mg/L	7.820 ± 1.013	6.7–9.3	7.820 ± 0.415	8.640 ± 1.062	7.3–8.3	7.1–9.8	7.060 ± 1.108	6.20–9
Turbidity	NTU	1.550 ± 0.778	0.65–2.8	112.400 ± 8.204	1.620 ± 0.249	100–120	1.2–1.8	112.200 ± 8.871	101–123
TDS	mg/L	1418.240 ± 10.467	1407.36–1434.88	1415.936 ± 3.089	1410.176 ± 12.773	1410.56–1418.24	1388.16–1420.16	1403.136 ± 30.252	1349.76–1421.44
EC	ds m^{-1}	2.216 ± 0.016	2.199–2.242	2.212 ± 0.005	2.203 ± 0.020	2.204–2.216	2.169–2.219	2.192 ± 0.047	2.109–2.221
pH		8.110 ± 0.087	8.03–8.24	7.796 ± 0.138	7.800 ± 0.055	7.66–8.01	7.71–7.86	7.914 ± 0.098	7.82–8.08

falling below the maximum allowable limit. Similar findings were reported by Al-Jasser (2011b) and Aljaloud (2010), in Riyadh, KSA, who studied the quality of wastewater reuse. However, Alobaidy et al. (2010) reported higher values of SO_4 and Cl_2 (16.9 and 22.6 meq/L, respectively). On the other side, all wastewater samples contained anions below the enforcement standards (MEWA 2006).

In the transport lines Tables 5 and 6, the results differed a little from those of the plants. The value of the sulfates SO_4 under HS treatment was greater, compared with chlorine treatment in all the transport lines, except in the TL-DS-WP and TL-MPS-WP. Similarly, the value of the chloride Cl^- was higher under HS treatment, compared with chlorine treatment in transport lines, except in TL-MPS-WP. The bicarbonate HCO_3 values under HS treatment were higher, compared with chlorine treatment in TL-DS-WP and TL-ADS-WP; however, the bicarbonate HCO_3 values were the same in TL-MPS-WP and TL-ADS-WP under both treatments. It was observed that there was a close convergence between the values of ions in the HS and chlorine samples; all of them did not exceed the allowable limit for unrestricted and restricted irrigation. Hence, HS decreased the potassium K^+ in all the transport lines, except TL-ADS-WP (HS and chlorine had the same effect on K^+ concentration). Furthermore, HS decreased the magnesium Mg^{++} in all the transport lines. Besides, HS decreased the Ca^{++} concentration to a greater extent than chlorine in all the transport lines, except TL-ADS-WP. Chlorination decreased the Na^+ concentration more than the disinfection by HS in all the transport lines, except in TL-ADS-WP and TL-MPS-WP. The maximum values of the concentration of all the cations did not exceed the acceptable limits in unrestricted irrigation, as illustrated in Tables 5 and 6.

Table 7 The mean value of effluent qualities of all wastewater plants in Riyadh, Saudi Arabia

Parameters	Unit	HS (average of plants)	Chlorine (average of plants)
E. coli	mpn/100 ml	0.000	762.165
Zn	mg/L	0.576	2.215
B	mg/L	0.240	0.641
Cr	mg/L	0.012	0.015
Cd	mg/L	0.001	0.003
Ni	mg/L	0.015	0.096
Mn	mg/L	0.039	0.114
Cu	mg/L	0.244	0.305
Pb	mg/L	0.002	0.003
Fe	mg/L	3.772	4.737
SAR	%	3.276	3.167
SO4	meq/L	11.093	10.970
Cl2	meq/L	8.796	8.725
HCO3	meq/L	2.933	2.856
CO3	meq/L	0.000	0.000
K+	meq/L	0.497	0.520
Na+	meq/L	10.156	10.094
Mg++	meq/L	4.964	5.220
Ca++	meq/L	7.133	7.555
BOD5	mg/L	44.767	38.235
COD	mg/L	70.980	51.615
NH4	mg/L	3.613	4.615
NO3-N	mg/L	11.440	10.120
Turbidity	NTU	4.387	4.080
TDS	mg/L	1411.371	1370.144
EC	ds m^{-1}	2.205	2.141
pH		8.261	8.049

Biochemical demand for oxygen (BOD) and chemical demand for oxygen (COD)

Chlorine decreased BOD more than HS in all the plants. The maximum values of BOD following disinfection with HS are considered high. They do not meet the desired limit in restricted irrigation. Similarly, Chlorine decreased COD more than HS, but the maximum values of COD using HS did not exceed the acceptable limit in unrestricted irrigation as shown in Tables 3 and 4. Similarly, in the transport lines, chlorine decreased COD and BOD more than the disinfection using HS (data shown in Tables 5 and 6).

The average and maximum values of BOD are considered high. They exceeded the permissive outlines in the irrigation. Although chlorine decreased COD more than HS, the maximum values of COD following disinfection with HS did not exceed the acceptable limit for irrigation.

As presented in Table 7, the mean COD values (70.98 and 51.6 mg/L) for HS and chlorine treatments of the current study was high compared with the values obtained by Al-Jasser (2011b) who found that the COD values of the wastewater samples collected from the municipal treatment plants were 24.6 and 17 mg/L for NP-RSTP and SP-RSTP, respectively. Higher mean values (89, 122 and 212 mg/L) were shown in studies obtained by Aljaloud (2010), Abu-Rizaiza (1999) and Al-Hammad et al. (2014), respectively. On the other hand, low mean values (17.04 and 53.10 mg/L) were reported by Al-Turki (2010) and Alobaidy et al. (2010), respectively. Also, the mean values of BOD (44.76 and 38.23 mg/L) for HS and chlorine treatments of the current study were low compared with the values obtained by Al-Hammad et al. (2014) However, values shown by Al-Hammad et al. (2014) were not within the desirable limits (10 mg/L for unrestricted irrigation and 40 mg/L for restricted irrigation). The reason behind a higher concentration of COD and BOD might be due to biofilm information especially in the transport lines which increased the BOD and COD more than the limited level contamination (Fattal et al. 2018).

Ammonia and nitrates analysis

The disinfection by chlorination increased ammonia compared with HS in all plants. Therefore, HS was more effective than chlorine in reducing ammonia in all plants (data are shown in Table 3 and 4), and transport lines (data are shown in Table 5 and 6). The maximum values of ammonia are considered low, compared with the allowable contaminant levels in unrestricted irrigation. On the contrary, chlorine was more effective than HS in reducing nitrates in all plants and transport lines, except in HS-WP and DS-WP, where the values for nitrates under both treatments exceeded the acceptable limit for unrestricted irrigation.

Table 7 revealed that the mean values of ammonia NH_3–N (3.6 and 4.615 mg/L) for HS and chlorine treatments, these values differ from other reports in KSA, as Al-Hammad et al. (2014) reported the value of (2.0 mg/L) for Riyadh, and Al-Turki (2010) reported the value of (0.45 mg/L) for Buraidah, all of those values fell within the limits described by (MEWA 2006). In another indicator the mean value of nitrates NO_3^-N (11.44 and 10.12 mg/L) for HS and chlorine treatments. These results were higher than the value reported by Al-A'ama and Nakhla (1995) (8.6 mg/L) in Jubail, KSA. Also, previous reports in Riyadh showed the mean value of NO_3^-N as (9.0 and 9.67 mg/L) reported by Al-Hammad et al. (2014) and Al-Jasser (2011b), respectively. The plants have not produced effluents consistently with the permitted limits guidelines set by the Saudi Standards (shown in Table 2), this might be due to the low monitoring of the operational problems such as overloading which was necessary for improving the effluent quality.

Turbidity analysis

The water turbidity is the presence of particulate matter such as clay or silt, finely divided organic matter, plankton, or other microscopic organisms which led to a reduction in transparency (Mohammed Abdalla Hussein et al. 2013). As shown in Tables 3 and 4, treatment with HS at all the plants decreased turbidity, except for MPS-WP, whereas treatment with chlorine increased turbidity. HS and chlorine had the same effect on water in ADS-WP. The turbidity did not exceed the acceptable limit for unrestricted irrigation in all the plants, as shown in Tables 3 and 4. However, the values of turbidity under chlorine treatment in the transport lines exceeded the acceptable limit for restricted irrigation, as shown in Tables 5 and 6.

The low transparency causes light to be absorbed, rather than transmitted in straight lines through the sample (Hussein et al. 2013). The colloidal material rises the turbidity which provides adsorption sites for chemicals that may be harmful or cause undesirable tastes and odors (Hussein et al. 2013). The reason for the increased turbidity in the transport lines may be due to the biofilm information that affects the clarity and the estimated total suspended solids in water (Balkhair and Ashraf 2016). The suspended solids reduce the permeability of the soil, which in turn reduces the availability of oxygen for plants' roots (Balkhair and Ashraf 2016). Following this further, increased water temperature due to the absorption of the suspended materials by the sun leads to a reduction in the concentration of dissolved oxygen. The turbidity components provide appropriate media for the growth of pathogenic or non-pathogenic microorganisms, such as *E. coli*. Subsequently, it may cause operational problems in WWTPs, not to mention reducing the effectiveness of sterilization, as the components of turbidity act as a protective shield for pathogenic microorganisms.

Correspondingly, in the transport lines, HS was more effective in decreasing turbidity (data are shown in 5 and 6). This aligns with the results of Armon et al. (2000) who proved that the combination of hydrogen peroxide and silver ions was very effective in preventing film growth. Most disinfectants do not leave long-lasting biocidal activity in the water networks, and the water networks become susceptible to increased bacterial numbers and biofilm formation phenomena (Fattal et al. 2018). This may achieve the long-lasting residuals and biofilm control required for distribution systems as a secondary disinfectant and alternative to chloramines (similar disinfection action) (Pedahzur et al. 1995).

Total dissolved solids concentration and Electrical conductivity

Chlorine decreased the total dissolved solids (TDS) in HS-WP and ADS-WP, while HS decreased TDS in MPS-WP and DS-WP (Tables 3 and 4). Similarly, chlorine decreased the conductivity (Ec) in HS-WP and ADS-WP, while HS decreased the EC in MPS-WP and DS-WP (data shown in Tables 3 and 4). It is important to note that the maximum values of the TDS and EC concentration do not exceed the acceptable limit for unrestricted and restricted irrigation, as shown in Tables 3 and 4.

Chlorine decreased TDS in all the transport lines, except TL-DS-WP, while HS increased TDS, as shown in Tables 5 and 6. Chlorine and HS have the same effect on the conductivity (EC) in the transport lines. The maximum values of the TDS and EC concentration under chlorine and HS treatments are within the acceptable limit for unrestricted and restricted irrigation. This contrasts with the findings of Sayed and Abdel-Wareth (2017) who confirmed that HS was more effective than chlorine in a comparative study of the effects of chlorine and HS as an alternative.

Moreover, the results presented in Table 7 revealed that the wastewater samples collected from all plants had a high mean of TDS (1411.37 and 1370 mg/L) for HS and chlorine treatments, respectively still within the acceptable limits (2,500 mg/L) of the use of treated wastewater in irrigation, similar finding was reported in Baghdad, Iraq (Alobaidy et al. 2010) however, in the KSA (Jubail and Riyadh) by Al-A'ama and Nakhla (1995) and Al-Jasser (2011b) reported the mean values of TDS as 936 and 1114 mg/L, respectively. The high TDS mean values may be due to rinsing of softeners, washing of reactors and backwash of filters as Al-Hammad et al. (2014) reported. The conductivity means values for the present study lower than its value in Buraidah study by 35% (Al-Turki 2010) as shown in Table 7, but higher than its value in Riyadh study by 23% (Al-Hammad et al. 2014; Al-Jasser 2011b) as shown in Table 7.

Hydrogen ion activity (pH)

As demonstrated in Tables 3 and 4, the values of pH under chlorine treatment was lower, in comparison with that under HS treatment, except for MPS-WP. The pH values did not exceed the acceptable limit for unrestricted irrigation in all the plants under both chlorine and HS treatments. These pH concentrations did not exceed the acceptable limit for unrestricted irrigation.

The pH values under chlorine treatment were lower, compared with that under HS treatment, except in TL- MPS-WP. The pH values did not surpass the desired value for unrestricted irrigation in all the transport lines in both samples, as revealed in Tables 5 and 6.

The mean values of pH ranged between 7.2 and 7.5 as presented in Table 7. In the KSA, results were obtained by Al-Jasser (2011b) in Riyadh and Al-A'ama and Nakhla (1995) in Jubail who revealed that the range values of pH were 7.1–7.3 and 6.0–6.7, respectively. In contrast, the mean values of pH in the present study were greater little (8.12, 8.05) in HS and chlorine treatments respectively in all plants as Table 7 and (8.04, 7.8). Similar large results reported by Alobaidy et al. (2010) in Baghdad City, Iraq, their study revealed that the values of pH varied from 6.87 to 8.40 with an average value of 7.70, this suggests that the treated municipal wastewater is slightly alkaline. The pH values did not surpass the desired value in the unrestricted irrigation in all transport lines in the two disinfection treatments.

Despite the fact that the running cost of HS could be higher compared to chlorine on w/w basis, the unique properties of HS add various extra benefits to the disinfection process including the removal and destruction of biofilm, better quality, a greater yield, rinse-free, and absence of odor and taste. It has been estimated that the running cost of HS is larger than the chlorination, while the capital cost of HS is lower than the chlorination process. Additionally, the hidden costs of chlorine disinfection associated with corrosion damage, increased operating costs for aerobic digestion and severe environmental damages provide advantage of HS application over chlorination.

Conclusion

This research included a field sampling campaign at wastewater treatment plants in Riyadh for testing the efficacy of the novel alternative disinfectant, Huwa-San as sentinels of contamination. Results from the sampling campaign consistently demonstrated that HS, when used as a secondary disinfectant, can be used to maintain acceptable water quality for irrigation. The biological analysis showed that chlorinated water had the highest turbidity, ammonia and, *E. coli* response.

Building on the information provided in this paper, several recommendations for future studies in working toward this objective are provided. Although HS has been effective at wastewater treatment plants in limiting turbidity, ammonia, and *E. coli*, while maintaining acceptable water quality in Riyadh, its effectiveness has not been put to test at other wastewater plants in the kingdom. The effects of site-specific parameters such as source water composition, pipe material, biofilm effects, and network size on the efficacy of HS as a secondary disinfectant are not well defined. Interestingly, in the case study, a decrease was observed in the *E. coli* population from the point of HS addition to the plant effluent. Although these results are preliminary, it is intriguing that the presence of HS appears to be correlated with a decrease in turbidity that is formed by upstream chlorination over time. The reason for this trend was not studied in this work, but further investigation into this topic is warranted.

This research has an extreme effect on the Saudi water resources and the Saudi environment (water scarcity of Saudi Arabia and environment pollution). In the arid conditions of the Middle East, the utilization of innovative technologies to create new sources such as water reuse is a priority. The reuse of treated wastewater for agriculture has met with regulatory and cultural resistance. There is an extension experiment of this study for determining the optimum concentration for HS product. Also, the economic evaluation for this disinfectant will be considered in the future.

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