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The assessment of treated wastewater quality and the effects of mid-term irrigation on soil physical and chemical properties (case study: Bandargaz-treated wastewater)

Kami Kaboosi[1]

Abstract This study was conducted to investigate the characteristics of inflow and outflow wastewater of the Bandargaz wastewater treatment plant on the basis of the data collection of operation period and the samples taken during the study. Also the effects of mid-term use of the wastewater for irrigation (from 2005 to 2013) on soil physical and chemical characteristics were studied. For this purpose, 4 samples were taken from the inflow and outflow wastewater and 25 quality parameters were measured. Also, the four soil samples from a depth of 0–30 cm of two rice field irrigated with wastewater in the beginning and middle of the planting season and two samples from one adjacent rice field irrigated with fresh water were collected and their chemical and physical characteristics were determined. Average of electrical conductivity, total dissolved solids, sodium adsorption ratio, chemical oxygen demand and 5 days biochemical oxygen demand in treated wastewater were 1.35 dS/m, 707 ppm, 0.93, 80 ppm and 40 ppm, respectively. Results showed that although some restrictions exist about chlorine and bicarbonate, the treated wastewater is suitable for irrigation based on national and international standards and criteria. In comparison with fresh water, the mid-term use of wastewater caused a little increase of soil salinity. However, it did not lead to increase of soil salinity beyond rice salinity threshold. Also, there were no restrictions on soil in the aspect of salinity and sodium hazard on the basis of many irrigated soil classifications. In comparison with fresh water, the mid-term use of wastewater caused the increase of total N, absorbable P and absorbable K in soil due to high concentration of those elements in treated wastewater.

Keywords Bandargaz · Irrigation · Soil · Treatment · Wastewater

Introduction

Today, due to the constraint in availability of the freshwater for irrigation, wastewater especially sewage water is being used for irrigation of agriculture fields (Singh et al. 2012). Specially, in arid and semi-arid regions, irrigation water shortage turns treated wastewater into an attractive source of water for irrigated agriculture (Pescod 1992). Hamilton et al. (2007) reported that globally around 20 million ha of land were irrigated with reclaimed wastewater, and the amount would increase markedly during the next few decades as water stress intensifies (after Chen et al. 2013c). However, Chen et al. (2015a) reported in spite of poor general public's knowledge on water resources, their awareness on reclaimed water reuse was high. Moreover, some of the stakeholders had concerns about the potential risks from reclaimed wastewater reuse.

Several studies have been done to investigate the possibility of using treated wastewater for irrigation. For example, Torabian and Motallebi (2003) in addition to evaluating the wastewater quality of EKBATAN treatment plant presented the plan of wastewater reuse management. Ghasemi and Danesh (2012) studied the wastewater samples from Mashhad treatment plant and stated that according to Ayers and Westcot Guide (1985), wastewater can be used for irrigation of agricultural land. Results of Hasanli and Javan (2006) and Salehi et al. (2008) showed

✉ Kami Kaboosi
kkaboosi@yahoo.com

[1] Department of Water Engineering, Gorgan Branch, Islamic Azad University, Gorgan, Iran

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that the application of treated wastewater for irrigation of green and afforestation species is possible.

As an irrigation water resource, reclaimed water from sewage treatment plants can provide soils with the nutrients and organic matter, ameliorating health conditions (biodegradable organic matter and beneficial microorganisms), soil biological activities and thus promote soil quality and sustainability. However, reclaimed water also contains nonessential toxic elements and most noticeably salts, which may lead to soil salt levels intolerable to most landscape plants or crops, especially in heavy soil (Chen et al. 2013a, b, 2015b; Lyu and Chen 2016). Moreover, the greatest health concern in using reclaimed wastewater for irrigation is directed to pathogens (Chen et al. 2013a). Wang et al. (2013) reported that concentration of some aroma chemical components (HHCB and AHTN) can be significantly increased in reclaimed wastewater-irrigated soils, although it would take 243 and 666 years for their accumulation in soils to reach the levels that harm the ecosystem and soil biota such as germinating plants and earthworms.

Assouline and Narkis (2011) stated that treated wastewater application will differently affect different zones in the soil profile, depending on irrigation management parameters and plant uptake characteristics. Results of Singh and Agrawal (2012) showed that wastewater irrigation led to beneficial changes in physico-chemical and biological properties of the soil. Generally, wastewater application for irrigation will lead to the reduction of soil porosity and consequently decrease in water retention (Aiello et al. 2007), decrease of saturated hydraulic conductivity (Aiello et al. 2007; Assouline and Narkis 2011), reduction of soil infiltration rate (Rohani Shahraki et al. 2006; Assouline and Narkis 2011), increase the soil contamination to heavy metals (Hoseinpoor et al. 2008; Singh and Agrawal 2012; Chen et al. 2013c), increase of soil salinity (Taghvaiian et al. 2008; Hoseinpoor et al. 2008; Chen et al. 2013b; Lyu and Chen 2016), increase of soil water retention (Taghvaiian et al. 2008), decrease of soil bulk density (Rohani Shahraki et al. 2006), increasing risks of nutrient imbalances and groundwater contamination of nitrate with irrational managements of reclaimed water (Candela et al. 2007) and increase of soil surface microbial contamination and concentrations of some pathogens like viruses and Giardia (Aiello et al. 2007; Levantesi et al. 2010). However, there is no consistency as reclaimed urban wastewater impacts were dependent on the quality of reclaimed water, irrigation rate and practices, irrigation period, soil properties, influent water characteristics, treatment process, crop characteristics and local climate conditions (Pereira et al. 2012; Chen et al. 2015b).

Irrigation water scarcity in the summer season in Bandargaz region, which coincides with the peak crop water requirement period, result in farmers interest to use treated wastewater as an unconventional water resource. Since a few years, farmers in the Bandargaz region used the treated wastewater for irrigation, this study was conducted to investigate the characteristics of inflow and outflow wastewater of the Bandargaz wastewater treatment plant and the effects of mid-term use of the wastewater for irrigation on soil physical and chemical characteristics.

Materials and methods

Bandargaz City with an area exceeding 239.3 km^2 is located in the west at a distance of 40 km from the center of Golestan Province (Gorgan). The direct distance of Bandargaz wastewater treatment plant from the sea is about 1.7 km and the distance where the wastewater discharged into the sea from the Miankaleh protected area is 35 km (Fig. 1). Origin of the raw wastewater is domestic and municipal. Secondary treatment method in the Bandargaz plant is aerated lagoons. This plant with a capacity of 3,100 m^3/day was launched in 2005 (however, quality and quantity data in wastewater plant were gathered from

Fig. 1 Location of Bandargaz wastewater plant related to sea and Miankaleh protected area

Table 1 Some descriptive statistics of influent and effluent wastewater based on monthly average

Month	Parameter	BOD_{in}	BOD_{out}	COD_{in}	COD_{out}	SS_{in}	SS_{out}	Q
1	Mean	119.5	23.0	233.0	48.1	150.1	21.1	4,091.3
	SD	46.8	10.2	96.4	16.1	52.1	6.1	1,956.7
	Std. error of mean	19.1	4.1	39.4	6.6	21.3	2.5	798.8
	Minimum	45.0	15.0	57.0	25.0	55.0	15.5	600.0
	Maximum	178.4	42.0	324.7	71.7	197.3	30.3	5,999.0
	Range	133.4	27.0	267.7	46.7	142.3	14.8	5,399.0
	Variance	2,189.6	103.1	9,294.6	259.1	2,713.5	37.8	3,828,630.7
	% of total sum	7.4	8.2	7.8	8.4	7.5	10.4	9.6
2	Mean	118.1	21.6	230.5	44.8	148.7	16.1	3,733.3
	SD	40.6	9.6	86.4	15.0	43.0	3.5	1,590.8
	Std. error of mean	16.6	3.9	35.3	6.1	17.6	1.4	649.5
	Minimum	65.0	13.5	85.0	23.0	75.0	11.0	650.0
	Maximum	175.2	39.2	325.3	67.1	195.0	20.5	5,059.4
	Range	110.2	25.7	240.3	44.1	120.0	9.5	4,409.4
	Variance	1,646.1	91.8	7,468.6	225.9	1,848.8	12.4	2,530,749.2
	% of total sum	7.3	7.7	7.7	7.8	7.4	7.9	8.8
3	Mean	132.8	23.6	232.0	46.7	140.5	15.9	3,206.1
	SD	38.8	8.3	89.6	11.4	42.3	6.0	1,263.9
	Std. error of mean	15.8	3.4	36.6	4.6	17.3	2.4	516.0
	Minimum	66.0	13.8	82.0	35.0	75.0	8.5	700.0
	Maximum	173.0	37.2	326.4	64.0	185.5	25.0	4,073.3
	Range	107.0	23.4	244.4	29.0	110.5	16.5	3,373.3
	Variance	1,506.1	68.8	8,019.8	129.3	1,792.8	36.0	1,597,529.4
	% of total sum	8.2	8.4	7.8	8.1	7.0	7.9	7.5
4	Mean	138.7	20.6	238.7	43.7	151.7	20.6	2,948.6
	SD	46.1	9.9	84.4	17.8	41.3	14.7	1,145.4
	Std. error of mean	18.8	4.0	34.5	7.3	16.9	6.0	467.6
	Minimum	60.0	10.0	90.0	13.0	75.0	10.9	700.0
	Maximum	188.0	37.6	333.4	66.6	192.5	50.0	3,851.0
	Range	128.0	27.6	243.4	53.6	117.5	39.2	3,151.0
	Variance	2,122.4	97.7	7,123.2	317.5	1,707.8	217.0	1,312,043.8
	% of total sum	8.6	7.3	8.0	7.6	7.6	10.2	6.9
5	Mean	144.2	22.6	250.7	50.1	143.0	13.4	2,879.5
	SD	39.9	7.5	74.5	8.8	71.3	7.9	775.2
	Std. error of mean	16.3	3.1	30.4	3.6	29.1	3.2	316.5
	Minimum	76.5	14.4	123.5	37.6	1.1	0.0	1,626.0
	Maximum	182.6	34.4	336.4	63.9	192.7	22.0	3,747.7
	Range	106.1	20.0	212.9	26.3	191.6	22.0	2,121.7
	Variance	1,591.2	56.1	5,543.1	77.3	5,090.3	62.0	600,977.4
	% of total sum	8.9	8.0	8.4	8.7	7.1	6.6	6.8
6	Mean	145.7	24.1	245.3	49.1	141.4	14.5	2,864.4
	SD	43.4	8.1	82.6	11.1	71.6	8.5	943.4
	Std. error of mean	17.7	3.3	33.7	4.5	29.2	3.5	385.1
	Minimum	78.0	12.8	95.0	30.0	1.5	0.0	1,445.0
	Maximum	198.2	33.8	334.1	61.9	204.4	24.3	3,815.0
	Range	120.2	21.0	239.1	31.9	202.9	24.3	2,370.0
	Variance	1,886.9	64.9	6,830.6	122.5	5,126.9	71.5	889,983.2
	% of total sum	9.0	8.6	8.2	8.6	7.1	7.2	6.7

Table 1 continued

Month	Parameter	BOD$_{in}$	BOD$_{out}$	COD$_{in}$	COD$_{out}$	SS$_{in}$	SS$_{out}$	Q
7	Mean	143.6	23.6	247.5	46.2	139.4	13.5	3,169.9
	SD	52.5	9.5	90.3	14.3	73.0	8.3	1,331.6
	Std. error of mean	21.4	3.9	36.9	5.8	29.8	3.4	543.6
	Minimum	63.0	14.0	89.0	19.0	0.3	0.0	1,186.0
	Maximum	206.0	39.8	333.9	56.6	211.0	19.8	5,082.1
	Range	143.0	25.8	244.9	37.6	210.7	19.8	3,896.1
	Variance	2,751.6	90.2	8,162.1	204.5	5,335.3	68.7	1,773,072.9
	% of total sum	8.9	8.4	8.3	8.0	7.0	6.7	7.4
8	Mean	152.0	27.8	258.4	49.2	315.3	13.1	3,498.5
	SD	43.0	14.6	71.4	13.0	357.9	8.7	1,074.9
	Std. error of mean	17.6	5.9	29.2	5.3	146.1	3.5	438.8
	Minimum	80.5	11.4	136.3	26.0	135.5	0.0	2,009.0
	Maximum	204.8	46.6	335.4	64.6	1,044.0	21.0	4,787.2
	Range	124.3	35.2	199.2	38.6	908.5	21.0	2,778.2
	Variance	1,848.9	212.2	5,100.8	168.3	128,125.3	75.3	1,155,468.6
	% of total sum	9.4	9.9	8.7	8.6	15.7	6.5	8.2
9	Mean	141.7	27.3	254.8	49.7	164.5	17.9	4,107.7
	SD	30.7	12.7	63.0	6.5	27.8	3.1	1,092.9
	Std. error of mean	12.6	5.2	25.7	2.7	11.4	1.3	446.2
	Minimum	87.4	14.2	174.3	39.0	130.8	14.8	3,150.8
	Maximum	171.6	49.4	321.7	58.0	214.2	23.3	5,832.1
	Range	84.2	35.2	147.5	19.0	83.4	8.5	2,681.3
	Variance	945.3	161.9	3,968.7	42.2	773.6	9.5	1,194,324.6
	% of total sum	8.7	9.7	8.5	8.7	8.2	8.8	9.6
10	Mean	127.4	24.9	266.6	47.7	162.9	16.9	3,740.1
	SD	64.2	12.0	50.7	9.9	27.7	3.6	909.0
	Std. error of mean	26.2	4.9	20.7	4.1	11.3	1.5	371.1
	Minimum	16.0	12.6	180.6	33.8	141.0	12.9	2,432.0
	Maximum	190.8	47.2	310.3	59.6	215.2	23.0	5,137.3
	Range	174.8	34.6	129.7	25.8	74.2	10.1	2,705.3
	Variance	4,120.3	143.1	2,569.6	98.8	766.8	12.7	826,254.1
	% of total sum	7.9	8.9	8.9	8.3	8.1	8.4	8.8
11	Mean	131.4	22.4	264.7	48.6	172.5	21.0	4,002.9
	SD	36.5	12.4	42.0	8.7	27.7	8.4	1,135.0
	Std. error of mean	14.9	5.1	17.2	3.5	11.3	3.4	463.4
	Minimum	73.0	11.3	193.2	37.8	135.0	10.5	2,500.0
	Maximum	171.6	45.4	309.9	61.1	216.0	32.0	5,809.0
	Range	98.6	34.1	116.7	23.3	81.0	21.5	3,309.0
	Variance	1,329.0	154.9	1,766.3	75.0	769.0	71.1	1,288,308.8
	% of total sum	8.1	8.0	8.9	8.5	8.6	10.4	9.4
12	Mean	126.1	19.5	259.8	50.4	172.8	18.6	4,384.1
	SD	36.8	7.6	42.0	7.2	30.1	4.4	1,022.3
	Std. error of mean	15.0	3.1	17.1	3.0	12.3	1.8	417.4
	Minimum	60.3	10.7	204.3	44.4	133.5	13.2	3,483.8
	Maximum	162.0	30.3	309.3	63.1	216.7	25.0	6,271.1
	Range	101.7	19.6	105.0	18.7	83.2	11.8	2,787.3
	Variance	1,354.1	58.3	1,760.1	52.5	906.7	19.5	1,045,178.4
	% of total sum	7.8	6.9	8.7	8.8	8.6	9.2	10.3

Table 1 continued

Month	Parameter	BOD_{in}	BOD_{out}	COD_{in}	COD_{out}	SS_{in}	SS_{out}	Q
Total	Mean	135.1	23.4	248.5	47.9	166.9	16.9	3,552.2
	SD	41.8	9.9	70.1	11.4	114.4	7.6	1,238.7
	Std. error of mean	4.9	1.2	8.3	1.3	13.5	0.9	146.0
	Minimum	16.0	10.0	57.0	13.0	0.3	0.0	600.0
	Maximum	206.0	49.4	336.4	71.7	1,044.0	50.0	6,271.1
	Range	190.0	39.4	279.4	58.7	1,043.7	50.0	5,671.1
	Variance	1,750.4	97.3	4,913.8	129.1	13,076.8	57.1	1,534,365.1
	% of total sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Unit of biological oxygen demand (BOD), chemical oxygen demand (COD) and settlement solids (SS) is mg/l and discharge (Q) is m^3/day. Influent and effluent wastewaters are shown by in and out subscripts

2007). Wastewater using concrete pipe reached the natural earth channels and then emptied into the sea (Fig. 1). Within the last 9 years, farmers have removed the manhole doors and pumped the treated wastewater to agricultural lands.

In the study area, rice cultivation is dominant and irrigation season is approximately 2.5–3 months (mid-May–mid-August) along with peak of irrigation water requirement within July. In other month of year, treated wastewater is discharged to the sea.

To evaluate influent and effluent quality characteristics of wastewater, some parameters that were measured in the Bandargaz plant laboratory (from 2007 until 2012) were obtained. These parameters include biological oxygen demand (BOD_5), chemical oxygen demand (COD), settlement solids (SS) and discharge (Q). One sample in month was taken by wastewater treatment plant. Data normality was evaluated by one-sample Kolmogorov–Smirnov test (Smirnov 1948). Calculation of some descriptive statistics, data analyses of variance and means comparison (by least significant difference test at 5 % statistical level) were carried out using SPSS 16.0 package (Gomez and Gomez 1984).

Also, water samples were taken in two stages during month of July 2013 (an interval of 20 days) and 25 quality parameters including pH, total dissolved solids (TDS), electrical conductivity (EC), chloride, ammonia, nitrate, nitrite, phosphate, sulfate, total hardness (TH), total alkalinity, turbidity, potassium, calcium, magnesium, sodium, bicarbonate, carbonate, hydroxide alkalinity, BOD_5, COD, total solids, total suspended solids (TSS), total coliform and fecal coliform were measured. To assess the feasibility of usage of wastewater for irrigation, wastewater effluent quality was compared with standards for irrigation water quality. Since farmers in the area surrounding the plant from the beginning of its operation (from 2005) were using treated wastewater for irrigation, the effects of its usage on soil characteristics were evaluated. For this reason, soil

samples were collected before of summer crop season and its middle (May and July, respectively) from 0–30 cm depth. Two rice fields irrigated with wastewater and one adjacent field irrigated with fresh water were selected. Then, soil physical and chemical properties including EC, pH, calcium, magnesium, sodium, bicarbonate, carbonate, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), exchangeable sodium percentage (ESP), organic carbon, total nitrogen, phosphorus, potassium and clay, silt and sand percentage of soil (soil texture) were measured. Soil infiltration was measured using double rings methods in three replications. Total wastewater and soil properties were measured based on APHA (2012) and Klute (1986), respectively.

Results and discussion

Assessment of influent and effluent wastewater

The results showed that all parameters were normal based on one-sample Kolmogorov–Smirnov test. Some descriptive statistics of BOD_5, COD, SS and discharge (Q) of influent and effluent wastewater based on monthly and yearly average are shown in Tables 1 and 2, respectively. Based on design criteria of Bandargaz wastewater plant, BOD_5 and SS of effluent wastewater should be less than or equal to 170 and 205 mg/l, respectively. Tables 1 and 2 showed that in all months and years, means of BOD_5 and SS of effluent wastewater were less than design criteria. However, in all years and approximately in all months, wastewater discharge (Q) was greater than plant capacity (3,100 m^3/day). It was due to the entrance of surface runoff to the wastewater collection network and street washing that led to chemical dilution of wastewater.

Assessment of influent and effluent wastewater based on analysis of variance of wastewater plant data is presented

Table 2 Some descriptive statistics of influent and effluent wastewater based on yearly average

Year	Parameter	BOD_{in}	BOD_{out}	COD_{in}	COD_{out}	SS_{in}	SS_{out}	Q
2007	Mean	77.4	14.7	125.8	30.3	155.6	18.6	1,749.5
	SD	19.3	4.0	50.5	9.3	284.8	15.7	1,097.7
	Std. error of mean	5.6	1.1	14.6	2.7	82.2	4.5	316.9
	Minimum	45.0	10.0	57.0	13.0	0.3	0.0	600.0
	Maximum	114.0	25.0	204.3	44.5	1,044.0	50.0	3,991.0
	Range	69.0	15.0	147.3	31.5	1,043.7	50.0	3,391.0
	Variance	370.8	15.8	2,551.9	86.2	81,122.1	245.4	1,204,982.3
	% of total sum	9.5	10.5	8.4	10.6	15.5	18.4	8.2
2008	Mean	136.0	16.2	255.5	44.0	139.9	12.7	3,233.4
	SD	15.5	2.5	36.3	6.8	9.1	4.7	767.0
	Std. error of mean	4.5	0.7	10.5	2.0	2.6	1.4	221.4
	Minimum	110.0	12.3	203.0	34.0	124.5	4.8	1,998.0
	Maximum	152.4	20.4	294.8	54.5	151.1	19.3	4,409.0
	Range	42.4	8.2	91.8	20.5	26.6	14.6	2,411.0
	Variance	239.6	6.5	1,320.8	46.6	83.5	22.4	588,291.7
	% of total sum	16.8	11.5	17.1	15.3	14.0	12.6	15.2
2009	Mean	158.9	33.1	301.8	53.4	165.5	15.6	3,741.4
	SD	14.0	11.9	5.9	6.3	10.2	4.9	580.2
	Std. error of mean	4.0	3.4	1.7	1.8	3.0	1.4	167.5
	Minimum	123.4	18.4	293.0	44.6	152.0	8.5	2,967.0
	Maximum	172.4	49.4	310.8	63.1	185.5	24.3	4,809.4
	Range	49.0	31.0	17.8	18.5	33.5	15.8	1,842.4
	Variance	195.1	142.7	34.4	39.3	104.6	23.7	336,670.8
	% of total sum	19.6	23.5	20.2	18.6	16.5	15.4	17.6
2010	Mean	144.5	31.0	311.8	56.7	172.0	19.6	4,853.6
	SD	58.6	11.0	39.2	11.5	10.6	3.9	969.5
	Std. error of mean	16.9	3.2	11.3	3.3	3.1	1.1	279.9
	Minimum	16.0	10.7	219.2	40.0	142.1	12.9	3,558.7
	Maximum	179.4	44.2	336.4	71.7	186.5	30.3	6,271.1
	Range	163.4	33.5	117.2	31.7	44.4	17.4	2,712.4
	Variance	3,439.4	121.8	1,533.1	132.8	112.7	15.0	940,010.5
	% of total sum	17.8	22.1	20.9	19.7	17.2	19.4	22.8
2011	Mean	162.6	19.8	241.9	48.8	170.0	15.9	3,668.2
	SD	41.2	3.3	35.5	3.1	9.8	1.1	876.2
	Std. error of mean	11.9	1.0	10.2	0.9	2.8	0.3	252.9
	Minimum	86.2	14.8	182.2	45.2	164.8	14.6	2,970.4
	Maximum	206.0	26.2	297.5	57.5	196.5	18.7	5,702.3
	Range	119.8	11.4	115.3	12.4	31.7	4.1	2,731.9
	Variance	1,698.8	11.2	1,258.3	9.7	95.8	1.1	767,799.1
	% of total sum	20.1	14.1	16.2	17.0	17.0	15.7	17.2
2012	Mean	131.2	25.7	254.0	53.9	198.5	18.8	4,067.1
	SD	12.6	2.6	31.5	2.7	28.6	4.8	468.3
	Std. error of mean	3.6	0.7	9.1	0.8	8.3	1.4	135.2
	Minimum	103.6	20.4	195.8	49.7	112.9	14.9	3,478.0
	Maximum	147.0	28.8	287.3	58.0	216.7	32.0	4,998.4
	Range	43.4	8.4	91.5	8.3	103.8	17.1	1,520.4
	Variance	157.8	6.6	993.9	7.3	819.2	23.4	219,335.8
	% of total sum	16.2	18.3	17.0	18.8	19.8	18.6	19.1

Table 2 continued

Year	Parameter	BOD$_{in}$	BOD$_{out}$	COD$_{in}$	COD$_{out}$	SS$_{in}$	SS$_{out}$	Q
Total	Mean	135.1	23.4	248.5	47.9	166.9	16.9	3,552.2
	SD	41.8	9.9	70.1	11.4	114.4	7.6	1,238.7
	Std. error of mean	4.9	1.2	8.3	1.3	13.5	0.9	146.0
	Minimum	16.0	10.0	57.0	13.0	0.3	0.0	600.0
	Maximum	206.0	49.4	336.4	71.7	1,044.0	50.0	6,271.1
	Range	190.0	39.4	279.4	58.7	1,043.7	50.0	5,671.1
	Variance	1,750.4	97.3	4,913.8	129.1	13,076.8	57.1	1,534,365.1
	% of total sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Unit of biological oxygen demand (BOD), chemical oxygen demand (COD) and settlement solids (SS) is mg/l and discharge (Q) is m^3/day. Influent and effluent wastewaters are shown by in and out subscripts

Table 3 The results of analysis of variance for plant influent and effluent wastewater data

Source of variations	df	BOD$_{in}$		BOD$_{out}$		COD$_{in}$		COD$_{out}$		SS$_{in}$		SS$_{out}$		Q	
		Mean square	Sig.	Mean square	Sig.	Mean square	Sig.	Mean square	Sig.	Mean square	Sig.	Mean square	Sig.	Mean square	Sig.
Monthly															
Between	11	711	0.96	36	0.98	986	0.99	27.6	0.99	13,970	0.39	52.96	0.53	1,702,483	0.35
Within	60	1941	–	109	–	5634	–	147.8	–	12,913	–	57.80	–	1,503,543	–
Yearly															
Between	5	11,432	0.00	712	0.00	52,853	0.00	1126	0.00	4,547	0.89	82.1	0.21	12,860,000	0.00
Within	66	1017	–	51	–	1282	–	53.6	–	13,723	–	55.2	–	676,182	–

Unit of biological oxygen demand (BOD), chemical oxygen demand (COD) and settlement solids (SS) is mg/l and discharge (Q) is m^3/day. Influent and effluent wastewaters are shown by in and out subscripts

Table 4 The results of yearly means comparison for plant influent and effluent wastewater data

Year	BOD$_{in}$	BOD$_{out}$	COD$_{in}$	COD$_{out}$	SS$_{in}$	SS$_{out}$	Q
2007	77.4[d]	14.7[c]	125.8[c]	30.3[d]	155.6[a]	18.6[ab]	1,749.5[d]
2008	136.0[bc]	16.2[c]	255.5[b]	44.0[c]	139.9[a]	12.7[b]	3,233.4[c]
2009	158.9[ab]	33.1[a]	301.8[a]	53.4[ab]	165.5[a]	15.6[ab]	3,741.4[bc]
2010	144.5[abc]	31.0[ab]	311.8[a]	56.7[a]	172.0[a]	19.6[a]	4,853.6[a]
2011	162.6[a]	19.8[c]	241.9[b]	48.8[bc]	170.0[a]	15.9[ab]	3,668.2[bc]
2012	131.2[c]	25.7[b]	254.0[b]	53.9[ab]	198.5[a]	18.8[a]	4,067.1[b]

In each column, means followed by at least one letter were not significantly different at the 5 % probability level (LSD test). Unit of biological oxygen demand (BOD), chemical oxygen demand (COD) and settlement solids (SS) is mg/l and discharge (Q) is m^3/day. Influent and effluent wastewaters are shown by in and out subscripts

in Table 3. Month had significant effect on any parameters. In other words, means of all parameters had not significant differences in different months. However, year factor affected all parameters significantly, except influent and effluent SS. The results of yearly means comparison are presented in Table 4. Approximately, maximum values of all parameter were obtained in 2009–2010 and these values were increased since 2007–2010. This shows that there is

probably poor performance of plant because of some operation difficulties.

Quality parameters of four samples that were taken from the inflow and outflow wastewater are shown in Table 5. Comparing BOD$_5$ values of influent and effluent samples (Table 5) with maximum and minimum values in July (Table 1) and total years (Table 2) showed that approximately sample values were located in the range of

Table 5 Values of quality parameters of plant influent and effluent wastewater

No.	Parameter	Unit	Influent			Effluent		
			Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
1	pH	–	7.25	7.24	7.25	7.69	7.77	7.73
2	TDS	ppm	671.5	629	650	664	749	707
3	EC	μs/cm	1,304	1,527	1,416	1,289	1,405	1,347
4	Cl	ppm	770	740	755	790	880	835
5	NH_3	ppm	23	43	33.00	34.5	30	32.25
6	NO_3	ppm	0.2	1.4	0.80	2.4	2.48	2.44
7	NO_2	ppm	0.27	0.2	0.24	0.4	0.36	0.38
8	PO_4	ppm	5.6	10.5	8.05	10.5	7	8.75
9	SO_4	ppm	90	10	50	10	20	15
10	TH	ppm $CaCO_3$	200	400	300	550	420	485
11	TA	ppm $CaCO_3$	700	850	775	600	580	590
12	Turbidity	NTU	36	105	71	26	34	30
13	K	ppm	26	76.8	51.4	90	54	72.0
14	Ca	ppm	140	310	225.0	460	248	354.0
15	Mg	ppm	38.9	21.9	30.4	21.9	41.8	31.9
16	Na	ppm	85	63	74.0	71	42.1	56.6
17	CO_3	ppm	420	510	465.0	360	353.8	356.9
18	HCO_3	ppm	427	518.5	472.8	366	348	357.0
19	HA	ppm	150	300	225	300	160	230
20	COD	ppm	90	240	165	60	100	80
21	BOD_5	ppm	49	132	91	33	55	44
22	TS	ppm	676	870	773	687	589	638
23	TSS	ppm	15.6	325.2	170.4	28.4	29.6	29.0
24	Total coliform	Count in 100 mL	More than 1100	More than 1100	More than 1100	More than 1100	210	Incomputable
25	Fecal coliform	Count in 100 mL	More than 1100	More than 1100	More than 1100	More than 1100	150	Incomputable

TDS total dissolved solids, *EC* electrical conductivity, *TH* total hardness, *TA* total alkalinity, *HA* hydroxide alkalinity, *COD* chemical oxygen demand, *BOD_5* 5 days biological oxygen demand, *TS* total solids, *TSS* total suspended solids

Table 6 Assessment of effluent-treated wastewater based on Ayers and Westcot Guide (1985)

Category	Parameter	Unit	Sample 1	Sample 2	Average	Restriction
1	EC	dS/m	1.289	1.405	1.347	Low to moderate
	TDS	mg/l	664	749	706.5	Low to moderate
2	SAR	–	0.88	0.97	0.93	No limitation
3	Na (surface irrigation)	SAR	0.88	0.97	0.93	No limitation
	Na (sprinkler irrigation)	meq/l	3.09	2.74	2.92	No limitation
	Cl (surface irrigation)	meq/l	22.3	24.8	23.55	Severe
	Cl (sprinkler irrigation)	meq/l				Severe
4	$N–NO_3$	mg/l	2.4	2.48	2.44	Severe
	HCO_3	mg/l	366	348	357	Severe
	pH	–	7.69	7.77	7.73	No limitation
Conclusion		Suitable for irrigation except sensitive crops to Cl				

wastewater quality variations. However, COD values had some deviations from yearly and monthly ranges.

One of the major concerns regarding reclaimed water irrigation is on salinity (Chen et al. 2013b). Classification

of Bandargaz-treated wastewater based on United State Salinity Laboratory (USSL) (Richards 1954; Wilcox 1955) was C3S1 that represents water with high salinity and without sodium hazard. However, it was C3 based on

Richards (1954) that is suitable for salt-tolerant crop. The results showed that based on Ayers and Westcot Guide (1985), Bandargaz-treated wastewater is suitable for irrigation except for chlorine sensitive crops (Table 6).

Soil texture is moderately fine (20–30 % clay) and annually precipitation is 650 mm in Bandargaz region. Based on Table 7, Manual of Indian Council of Agricultural Research (Minhas and Gupta 1992) indicated that 2.5, 4.5 and 8 dS/m water salinity can be used for irrigation of sensitive, semi-moderate and moderate crops, respectively. Then, Bandargaz-treated wastewater is suitable for total crop irrigation.

Classification of Bandargaz-treated wastewater based on Iranian guide for Water Quality Classification (IRNCID 2002) indicated that water is low saline and its usage is possible for total crop irrigation. Also, based on similar classification presented by IRNCID (2002), Bandargaz-treated wastewater can be used in light- and medium-textured soils without limitations and provided with leaching and drainage in clay soils.

The results showed that based on handbook No. 535 Iranian Ministry of Energy (2010), almost all indices except the chlorine were located in the range of use of treated wastewater for irrigation (Table 8). However, effluent discharge into receiving surface water is not permitted due to high levels of chlorine, calcium, ammonium, phosphorus, BOD, COD and TDS. Comparing average values of BOD5 and COD of influent and effluent wastewater in July (Table 1) and their yearly averages (Table 2) with Iranian Ministry of Energy (2010) standard (Table 8) showed that raw wastewater (influent) was suitable neither irrigation nor discharging into resource

Table 7 Manual of Indian Council of Agricultural Research (1992)

Soil texture (clay %)	Maximum level of water salinity (dS/m)								
	Sensitive crops Annually rain (mm)			Semi-tolerant crops Annually rain (mm)			Tolerant crops Annually rain (mm)		
	<350	350–550	550–750	<350	350–550	550–750	<350	350–550	550–750
Fine (more than 30)	1	1	1.5	1.5	2	3	2	3	4.5
Moderately Fine (20–30)	1.5	2	2.5	2	3	4.5	4	6	8
Moderately Coarse (10–20)	2	2.5	3	4	6	8	6	8	10
Coarse (less than 10)	3	3	3	6	7.5	9	8	10	12.5

Table 8 Assessment of effluent-treated wastewater based on Iranian Ministry of Energy (2010) (✔ no have limitation, ✗ have limitation, – no limitation)

Parameter	Unit	Permissible limits		Sample			Conclusion	
		Discharge into surface receiving	Irrigation	1	2	Average	Discharge into surface receiving	Irrigation
Cl	mg/l	600	600	790	880	835	✗	✗
SO4	mg/l	400	500	10	20	15	✔	✔
Ca	mg/l	75	–	460	248	354	✗	–
Mg	mg/l	100	100	21.9	41.8	31.85	✔	✔
NH4	mg/l	2.5	–	34.5	30	32.25	✗	–
NO2	mg/l	10	–	0.4	0.36	0.38	✔	–
NO3	mg/l	50	–	2.4	2.48	2.44	✔	–
PO4	mg/l	6	–	10.5	7	8.75	✗	–
BOD5	mg/l	30	100	33	55	44	✗	✔
COD	mg/l	60	200	60	100	80	✗	✔
TSS	mg/l	40	100	28.4	29.6	29	✔	✔
pH	–	6.5–8.5	6.0–8.5	7.69	7.77	7.73	✔	✔
Turbidity	NTU	50	50	26	34	30	✔	✔
Fecal coliform	Count in 100 mL	400	400	>1100	150	Incomputable	✔	✔
Total coliform	Count in 100 mL	1000	1000	>1100	210	Incomputable	✔	✔

Table 9 Australian guideline and the results of Bandargaz-treated wastewater assessment

Parameter	Unit	Risk			Sample			Conclusion
		Low	Medium	High	1	2	Average	
BOD$_5$	mg/l	<40	40–1000	>1000	33	55	44	Low–medium
Total N	mg/l	<30	30–100	>100	34.5	30	32.25	Low
Total P	mg/l	<10	10–20	>20	10.5	7	8.75	Low
CaCO$_3$	mg/l	<200	200–500	>500	600	580	590	Medium–high
TDS	mg/l	<500	500–2000	>2000	664	749	706.5	Medium
SAR	mg/l	<3	3–9	>9	0.88	0.97	0.93	Low
Cl	mg/l	<150	150–350	>350	790	880	835	High
B	mg/l	<0.5	0.5–3	>3	–	–	–	–
pH	–	6.5–8.5			7.77	7.77	7.77	No limit

Table 10 Soil physical and chemical parameters based on saturation extract

Parameter	Unit	Wastewater-irrigated soil				Fresh water irrigated soil	
		Before seeding		Mid growth season		Before seeding	Mid growth season
		Field 1	Field 2	Field 1	Field 2		
Saturation percent	%	62.8	57.7	66	65.1	61	58
EC$_e$	dS/m	3.0	2.3	3.0	2.5	2.1	2.0
pH	–	7.7	7.8	7.6	7.5	7.36	7.8
Ca + Mg	meq/l	19.8	16.4	17.2	15.4	13.1	14.0
Na	meq/l	15.2	9.8	15.2	11.9	10.1	12.6
HCO$_3$	meq/l	7.0	8.2	6.8	8.4	5.0	6.6
CO$_3$	meq/l	0	0	0	0	0	0
SAR	(meq/l)$^{0.5}$	4.8	3.4	5.2	4.3	3.9	4.8
RSC	meq/l	0	0	0	0	0	0
ESP	%	5.5	3.6	6.0	4.8	3.4	5.4
Organic carbon	%	1.26	1.02	0.98	1.09	1.01	0.90
Total N	%	0.12	0.13	0.11	0.11	0.10	0.14
Absorbable P	mg/l	18.4	11.1	18.9	39.3	11.6	13.7
Absorbable K	mg/l	80	80	100	120	65	70
Clay	%	22	22	22	20	19	21
Silt	%	54	48	54	60	55	61
Sand	%	24	30	24	20	26	18
Soil texture	–	Silty loam					
Soil infiltration	mm/h	18.5	19.2	16.3	15.1	17.2	17.4

receiving surface water. However, based on Tables 1 and 2, effluent wastewater was suitable for irrigation purposes and discharging into surface water receiving resources.

Myers et al. (1999) presented Australian guideline for sustainable effluent-irrigated plantations. This standard and results of Bandargaz-treated wastewater assessment are given in Table 9. The results showed that almost all indices except the chlorine were located in the range of use of treated wastewater for irrigation. Based on the average value of BOD$_5$ of influent and effluent wastewater in July

(Table 1) and its yearly average (Table 2), raw (influent) and treated (effluent), wastewater had medium and low risk, respectively, for sustainable irrigated plantations (Table 9).

Assessment of effect of wastewater on soil

Soil physical and chemical parameters are shown in Table 10. The results show that the soil salinity in wastewater-irrigated area is little more than fresh water

irrigated land. Similar results were reported by Taghvaiian et al. (2008), Hoseinpoor et al. (2008) and Chen et al. (2013b). Maas and Hoffmann (1977) and Ayers and Westcot (1985) presented yield loss (%) per unit increase of soil salinity excessive from soil salinity threshold value (EC_e), where yield decrease starts (ranging from 1.5 dS/m for sensitive to 10 dS/m for salt-tolerant crops). For rice, these values are 3 dS/m and 12 %. Comparing these values with Table 10 shows that application of wastewater did not lead to increase of soil salinity beyond rice salinity threshold.

Richards (1954) divided soils into five categories on the basis of effects of soil salinity on crop yield. On the basis of Richards method (1954), soil salinity is relatively low and it has not limitations for different crops. However, yield of salt sensitive crops may be reduced in this condition.

Shainberg and Oster (1978) presented crops sensitivity to sodium hazard based on soil ESP. Crops were divided into five categories including very sensitive, sensitive, semi-tolerant, tolerant and very tolerant. Soil chemical parameters (Table 10) showed that in comparison with fresh water, the mid-term use of wastewater results in little increase of ESP but it did not cause the restrictions on soil even for sensitive crops. Chen et al. (2015b) observed a slight soil alkalization under reclaimed water irrigation that was in accordance with these findings.

Based on the criteria of Rhodes et al. (1992), the soil salinity in wastewater-irrigated area creates restrictions only for sensitive crops and there are no limitations for other plants.

Comparison of soil properties with Iranian guide for the irrigated land classification (2002) indicated that soil has any restriction in the aspect of salinity and sodium hazard.

Table 10 shows that in comparison with fresh water, the mid-term use of wastewater caused the increasing total N, absorbable P and absorbable K of soil. It was due to the high concentration of those elements in treated wastewater that were 35.07, 8.75 and 72 ppm, respectively (Table 5). Significant increase of N, P and K in soil irrigated by wastewater was reported by Meli et al. (2002), Salehi et al. (2008) and Singh and Agrawal (2012). Chen et al. (2015b) showed that soil nutrient conditions were ameliorated by reclaimed water irrigation, as indicated by the increase of soil organic matter content, total nitrogen and available phosphorus.

The results showed that the wastewater application did not reduce soil infiltration and even in some cases, it increased soil infiltration rate as well. Slight increase of soil infiltration rate was reported by Taghvaiian et al. (2008) according to this result. It happened because of increased soil organic carbon and Ca + Mg concentration.

Conclusion

Results showed that the treated wastewater is suitable for irrigation based on standards and criteria of United State Salinity Laboratory (Richards 1954; Wilcox 1955), Ayers and Westcot Guide (1985), Manual of Indian Council of Agricultural Research (1992), Australian guideline (1999), Iranian guide for Water Quality Classification (IRNCID 2002) and handbook No. 535 Iranian Ministry of Energy (2010). In comparison with fresh water, the mid-term use of wastewater did not cause the restrictions on soil in the aspect of salinity and sodium rate on the basis of Richards (1954), Shainberg and Oster (1978), Rhodes et al. (1992), and Iranian guide for the irrigated land classification (2002).

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