Microbial Water Quality Assessment of WadiHanifah (Riyadh-Saudi Arabia) For Land Scape Irrigation Use: A Case-Study

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Abstract: Fresh water in the Middle East and North Africa region is becoming scarcer. The use of WadiHanfia (the valley of Hanfia) water for irrigation of landscape as a sustainable source was investigated in this paper. The microbial quality of running water in WadiHanfia was assessed at eight sampling sites. The sampling sites were selected to cover the full length of the wet part of WadiHanifa. The results showed that the bioremediation facility which is constructed on the wadi has decreased the levels of fecal and total coliform in the water. The results also indicated that high levels of fecal and total coliform have been observed after the connection between WadiHanifa and Batha channel which carries sewage water to the valley. The results of most sampling sites showed high levels of total coliform and fecal coliform during the months of April and May, particularly at the sites in the upstream of the Wadidue to the big rain events which happen during April and May in Riyadh. The results also concluded that Wadi water could be potentially a sustainable water resource for landscape irrigation after simple treatment to reduce fecal and total coliform levels.

Key words: Fecal coliform · Total coliform · Wadi Hanifa · Water quality · Sustainability.

INTRODUCTION

Many countries located in the Middle East region are arid and suffering from water shortage. The water usage for different applications, including drinking, industrial and agricultural activities, may diminish the available water resources and thus finding alternative resources is essential [1]. Treating and reusing the wastewater for non-potable purposes, such as agriculture, could contribute in resolving the problem of water scarcity and wastewater disposal. Using the treated wastewater for agricultural applications becomes common practice worldwide.

The situation of water availability in the MENA region is common to countries located in arid and semi-arid areas. In these areas, water is becoming more scarce forcing planners to consider developing non-conventional water resources including treated wastewater (TWW) reuse [2,3]. The use of treated wastewater gained increased attention since the mid-1940s, especially in arid and semi-arid areas [4] and is continuing to be considered as a reliable source of irrigation water to satisfy increasing agricultural demands. TWW reuse has been implemented in many countries to irrigate different crops and has increasingly been integrated in the planning and development of water resources in many countries such as Jordan and Tunisia [5, 6].

Additionally, using treated wastewater for irrigation is beneficial since it reduces the need for high purification levels and fertilization costs since soil and crops serve as bio-filters and wastewater contain nutrients [7]. The wastewater quality is an important factor for safe irrigation.The concentration and chemical and biological composition of dissolved constituents in water combined with the amount of water used determines its quality to be used in agriculture. Many standards have been set by different institutions to control the quality of the irrigated water [2].

Wadis (valleys) play a major role in assimilation or carrying off the municipal and industrial wastewater and run-off from agricultural land. The municipal and industrial wastewater discharge constitutes the constant polluting source, whereas, the surface run-off is a seasonal phenomenon, largely affected by climate in the basin. Seasonal variations in precipitation, surface run-off, interflow, groundwater flow and pumped in and outflows have a strong effect on wadi discharge and subsequently on the concentration of pollutants in wadi water [8].

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Pathogen loadings derive from non-point source inputs from urban or agricultural activities [9, 10], dry weather flows from storm sewers [11], wet weather loadings from combined or sanitary sewer overflows [12], or discharges from wastewater treatment plants. Climate factors are primary among drivers of source water contamination due to their influence on the transport of contaminants by precipitation-induced runoff. Runoff generated by rainfall is associated with increased levels and variability of fecal contamination in downstream surface water [13, 14].

The treatment processes of wastewater must be sustainable in terms of environmental, economic and social aspects of sustainability. The environmental sustainability is identified by some indicators including greenhouse gases, waste discharge and energy consumption. Economic sustainability involves financial, capital and operating, costs and benefits. The social sustainability is assessed according to the working conditions such as worker stress and work satisfaction. Balkema *et al*. [15] have studied these sustainability indictors to assess them for evaluation of environmental, economic and social aspects of wastewater treatment processes.

In this study, we are assessing the microbial water quality of WadiHanifa, Riyadh, Saudi Arabia, for the use of its water as sustainable water resource to irrigate landscape to persevere groundwater and desalinized water for other uses.

MATERIAL AND METHODS

Study Area of WadiHanifa: On the Najd plateau of central Saudi Arabia, WadiHanifa runs southeast for around 120 kilometers (75 mi) before losing itself on the fringes of the Rub' al-Khali, or Empty Quarter. Fed by more than 40 tributaries, this great watercourse has a catchment area covering much of the eastern Najd, more than 4500 square kilometers (1740 sq mi), across what was historically known as al-Yamamah (Fig. 1). The meandering valley (Wadi in Arabic) is dry for nearly all of the year but remains fertile, thanks to aquifers close to the surface. It has attracted human settlement for millennia.

Approximately 450,000 cubic meters of water (dry weather flow) continually flows out of Riyadh (the capital city of Saudi Arabia) each day into the WadiHanifa from various side wadis and channels. The main sources of flow into the Wadi are as follows; The North Diversion Channel (33,000 m^3/day), WadiGudwannah (6000 m^3/day), Wadi Umm Qassar (9,000 m^3/day), West Ship (19,300 m^3/day), Namar (9000 m^3/day), Sultanah (4500 m^3/day), Alshafa (4500 m^3/day) and Batha Channel, "Manfouha STP outfall" (370,000 m^3/day average and 450,000 m^3/day peak) [17, 18]. These flows are expected to increase two-fold by the year 2021. At the moment this water can be reused for irrigation, agriculture but cannot be used for potable water uses, because of water quality concerns. In attempt to treat the Wadi water, a bioremediation facility was built mid-way in the Wadi length as shown in

Fig. 1:WadiHanifa Location (Modified from [16]).

(a) Sampling Locations 1-3

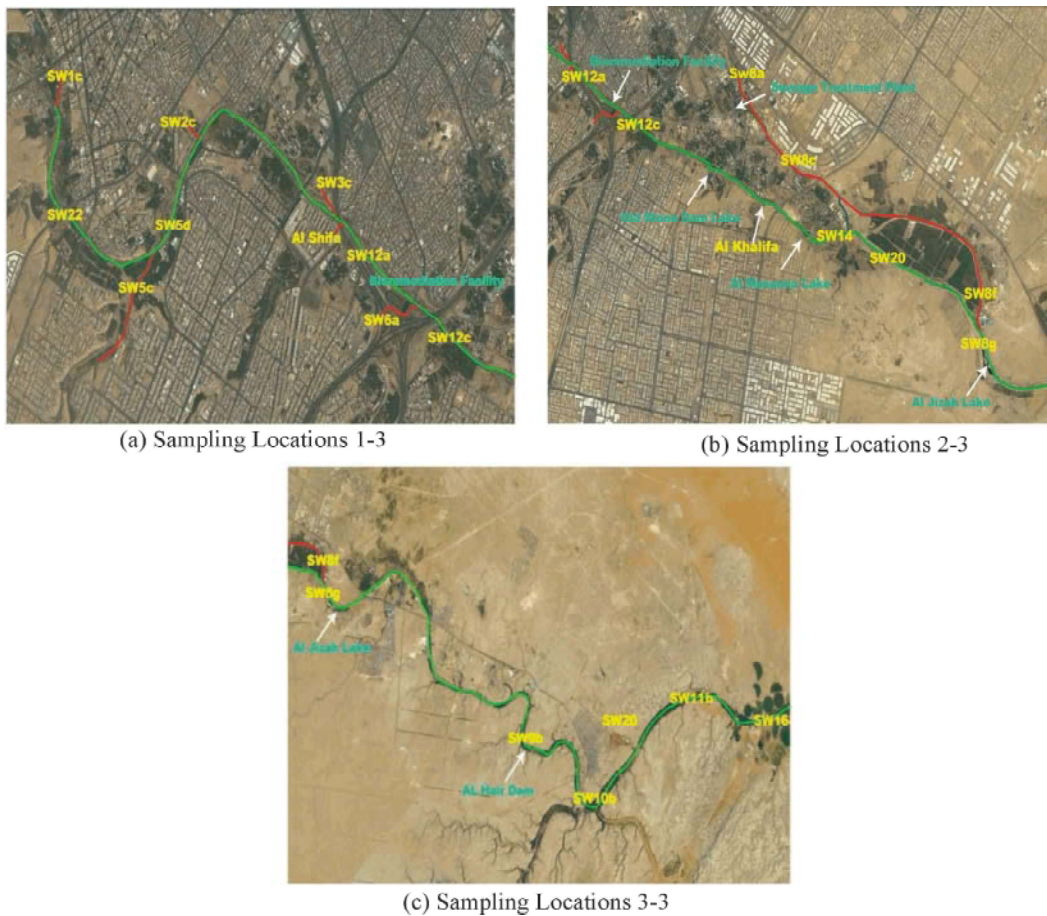
(b) Sampling Locations 2-3

(c) Sampling Locations 3-3

Fig. 2: WadiHanifa Water Quality Monitoring Sites.

Figure 1. The water quality of water after the bioremediation facility showed signs of change in the level of many parameters, however, the Wadi receives water from Al-Batha Channel which carries water from the Manfoha wastewater treatment plant and the water quality of the Wadi deteriorate after that.

Riyadh currently consumes 1.3 million cubic meters of water and this is expected to rise to 3 million cubic meters by the year 2021. Because of the continual draw-down of the water table to cope with the city's ever increasing population, Riyadh has had to find alternative sources of water. Now most of the city's (desalinated) water supply is piped in from the coast 350 km away, a very expensive and unsustainable option [17].

Monitored Parameters and Analytical Methods: In order to represent the water quality of the Wadi system accounting for stream and inputs from drains that have impact on downstream water quality, the monitoring and sampling plan was designed to cover a wide range of determinants at specific sites. Under the water-quality

monitoring plan of WadiHanfia, samples were collected each month at three points across the Wadi width at eight sites. Collecting, preservation and transportation of the water samples to the laboratory were as per standard methods [19].

The eight sites were selected to cover the full length of the wet part of WadiHanifa as shown in Fig. 2. Their names are SW3C (site 1), SW12A (site 2), SW12C (site 3), SW14 (site 4), SW20 (site 5), SW8G (site 6), SW10B (site 7) and SW16 (site 8). The sites 1 and 2 are chosen before the bioremediation facility, while sites 3, 4 and 5 are before the connection between batha channel, which carries water from Manfoha wastewater treatment plant to the Wadi and sites 6, 7 and 8 are located after batha channel.

Water temperature was measured on site using mercury thermometer. All other parameters were determined in laboratory following the standard protocols [19]. The samples were analyzed for pH, Total Colifrom (CFU/100 ml), Fecal Coliform (CFU/100 ml) and temperature (°C). The basic statistics of the data set on Wadi water quality is summarized in Table 1.

Table 1: The basic statistics of the data set on Wadi water quality

Parameters		Stations							
		SW3C	SW12A	SW12C	SW14	SW20	SW8G	SW10B	SW16
Temp (°C)	Mean	29.19833	23.53	19.96	19.4	18.85	21.3	19.32	15.7
	Std. Dev.	1.116706	23.43	22.17	21.93	21.67	22.91	21.82	18.76
pH	Mean	8.075	8.0375	8.0175	7.966667	7.973333	7.724167	7.756667	7.716667
	Std. Dev.	0.123913	0.115138	0.115454	0.08669	0.086585	0.137408	0.126515	0.136204
Total Coliform (CFU/100 ml)	Mean	23441.67	26475	18566.67	12100	16983.33	46575	35525	16125
	Std. Dev.	11678.92	10918.72	8681.886	8207.425	17490.04	14584.99	9591.011	11762.66
Fecal Coliform (CFU/100 ml)	Mean	13591.67	16691.67	9041.667	4941.667	6933.333	26258.33	20816.67	6800
	Std. Dev.	9818.393	9942.604	6316.135	3839.143	7858.792	11207.34	6570.988	5726.017

RESULTS AND DISCUSSION

Water Quality: The maximum and minimum of the total coliform for SW3, which located in the start of the wet part of the wadi, during the 12 months of sampling period, are 48700 and 5300 cfu/100 ml, respectively. Also, the average total coliform colonies in SW3 are 23441.7 with standard deviation of 11678.9. Correspondingly, the maximum and minimum fecal coliform in SW3 water sample are 37600 and 1900 cfu/100 ml, respectively and the average and standard deviation of SW3 are 13591.6 and 9818.3, respectively (Fig. 3a). Table 1 shows the average, standard deviation, maximum and minimum values for the sampling sites.

(a) Sampling location SW3C
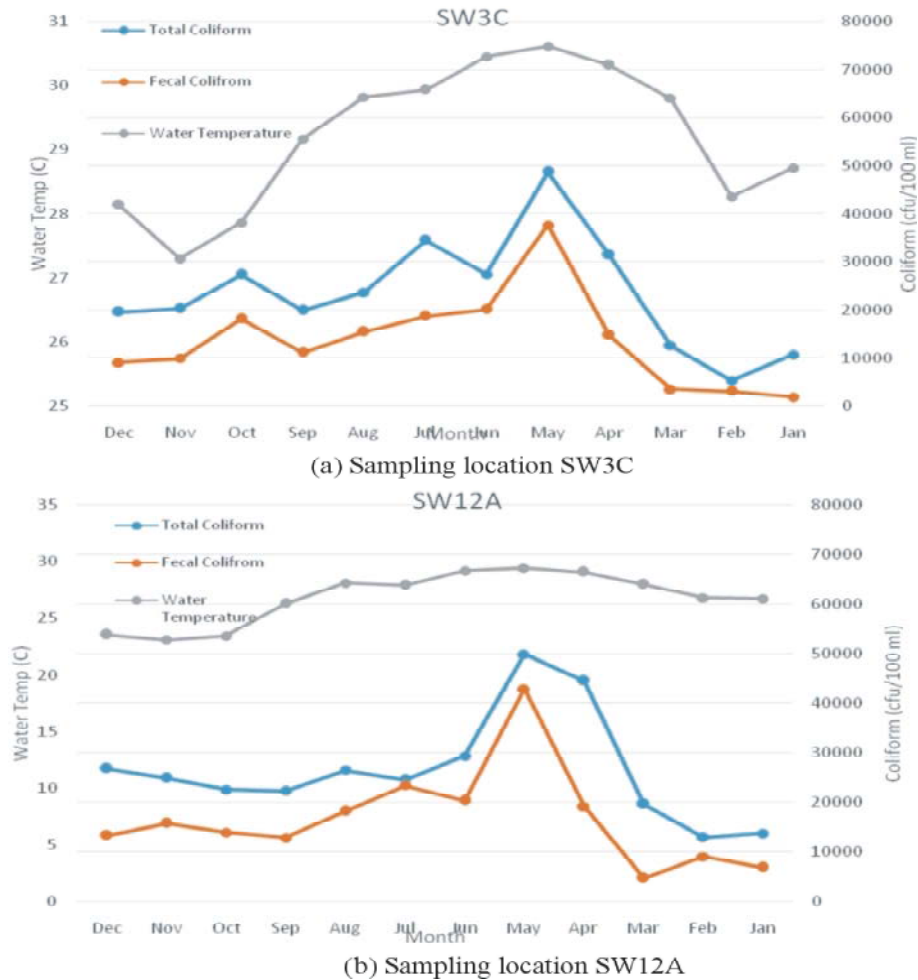

(b) Sampling location SW12A

Fig. 3: Total Coliform, fecal Coliform and water temperature for sites before the bioremediation facility.

Table 2: Total Coliform average, standard deviation, maximum and minimum values for the sampling sites.

Stations															
SW3		SW12A		SW12C		SW14		SW20		SW8G		SW10B		SW16	
TC	FC	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC
Avg.	23441.7	13591.6	26475	16691.6	18566.7	9041.6	12100	4941.6	16983.3	6933.3	46575	26258.3	35525	20816.6	16125	6800
STDEV	11678.9	9818.3	10918.7	9942.6	8681.89	6316.1	8207.42	3839.1	17490	7858.7	14585	11207.3	9591.01	6570.9	11762.7	5726.0
MAX	48700	37600	49900	42900	31300	20700	37300	15800	69300	29200	71000	42500	49100	28400	48100	18200
MIN	5300	1900	13000	4700	4600	700	6100	400	5900	700	24100	8400	23100	10500	4700	400

The maximum and minimum of the total coliform for SW12A, which located just before the bioremediation facility, during the 12 months of sampling period, are 49900 and 13000 cfu/100 ml, respectively. Furthermore, the average total coliform colonies in SW3 are26475 with standard deviation of 10918.7. Similarly, the maximum and minimum fecal coliform in SW12A water sample are 42900 and 4700 cfu/100 ml, respectively as shown in Figure 3b and the average and standard deviation of SW3 are 16691.6 and 9942.6, respectively.

SW12C, which located just after the bioremediation facility, during the 12 months of sampling period,has maximum and minimum total coliform of 37300 and 6100cfu/100 ml, respectively. Furthermore, the average total coliform colony in SW12C is 18566.7 with standard deviation of 8681.9. Likewise, the maximum and minimum fecal coliform in SW12C water sample are 20700 and 700 cfu/100 ml, respectively as shown in Figure 4a and the average and standard deviation of SW3 are 9041.6 and 6391.1, respectively.

The maximum and minimum of the total coliform for SW14 during the 12 months sampling period are 37300 and 6100 cfu/100 ml, respectively. Also, the average total coliform colonies in SW14 are 12100 with standard deviation equals to 8207.42. Consistently, the maximum and minimum fecal coliform in SW14 water sample are 15800 and 400 cfu/100 ml, respectively and the average and standard deviation of SW3 are 4941.6 and 3839.1, respectively (Fig. 4b).

SW20, which located just before the connection between batha channel and wadihanifa, during the sampling period has maximum and minimum total coliform of 69300 and 5900 cfu/100 ml, respectively. Furthermore, the average total coliform colonies in SW20 are 16983.3 with standard deviation of 17490. Likewise, the maximum and minimum fecal coliform in SW20 water sample are 29200 and 700 cfu/100 ml, respectively as shown in Figure 4c and the average and standard deviation of SW20 are 6933.3 and 7858.7, respectively.

It is noted from the results of SW12C, SW14 and SW20 that the total and fecal coliform densities are lowered drastically. The fecal coliform density for the three sampling sites have dropped below the standard set by ministry of water and electricity for the restricted irrigation, which is 1000 cfu/100 ml.

The maximum and minimum of the total coliform for SW8G, which located just after the connection between batha channel and WadiHanifa, during the 12 months sampling period are 71000 and 24100cfu/100 ml, respectively. Moreover, the average total coliform colony in SW8G is46575 with standard deviation of 14585. Similarly, the maximum and minimum fecal coliform in SW8G water sample are 42500 and 8400cfu/100 ml, respectively as shown in Fig. 5a and the average and standard deviation of SW8G are 26258.3 and 11207.3, respectively.

The results of sampling site SW8G showed increase in total and fecal coliform densities compared to the results of sites SW12C, Sw14 and SW20 because SW8G is located after the connection between batha channel and WadiHanifa, the channel carries treated municipal wastewater from Manfoha wastewater treatment plant to WadiHanifa (Fig. 6).

The maximum and minimum of the total coliform for SW10B during the 12 months sampling period are 49100 and 23100 cfu/100 ml, respectively. Also, the average total coliform colony in SW10B is 35525 with standard deviation equals to 9591.1. Consistently, the maximum and minimum fecal coliform in SW10B water sample are 28400 and 10500 cfu/100 ml, respectively and the average and standard deviation of SW3 are 20816.6 and 6570.9, respectively (Fig. 5b).

SW16, which located at the end of WadiHanifa, during the 12 months sampling period has maximum and minimum total coliform of 48100 and 4700cfu/100 ml, respectively. Furthermore, the average total coliform colonies in SW16 are16125 with standard deviation of 11762.7. Likewise, the maximum and minimum fecal coliform in SW16 water sample are 18200 and 400 cfu/100 ml, respectively as shown in Figure 4a and the average and standard deviation of SW3 are 6800 and 5726, respectively.
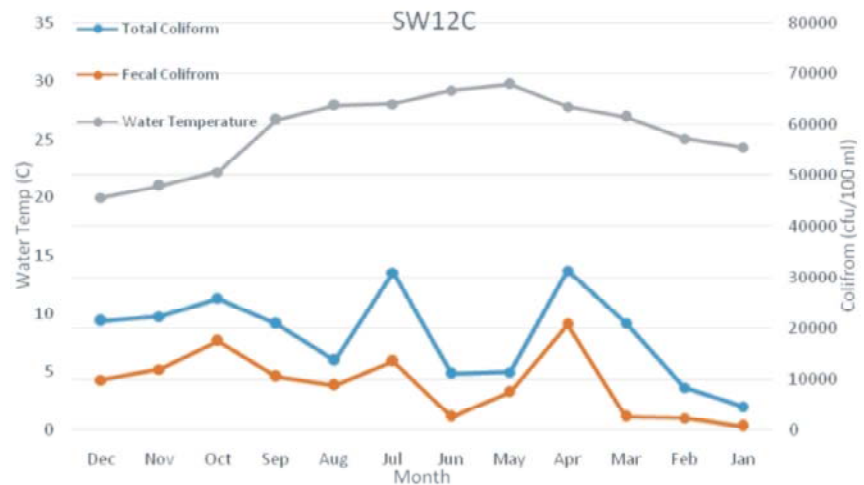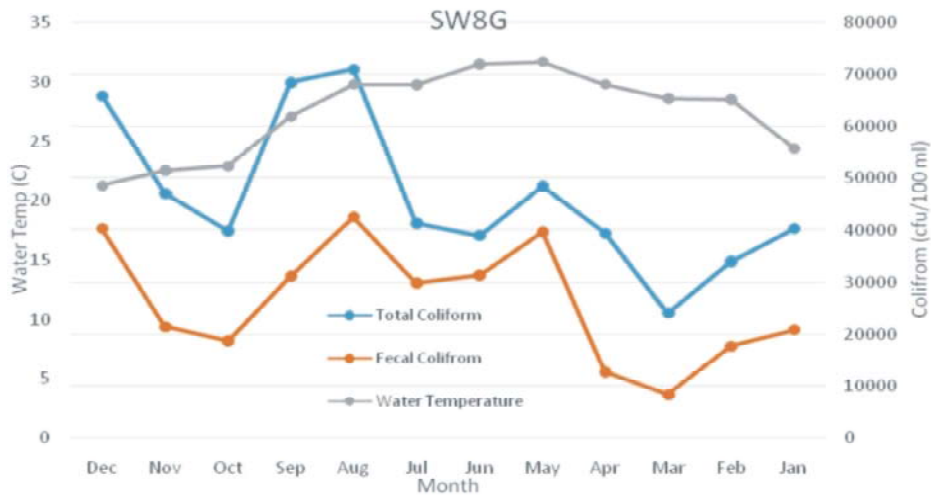
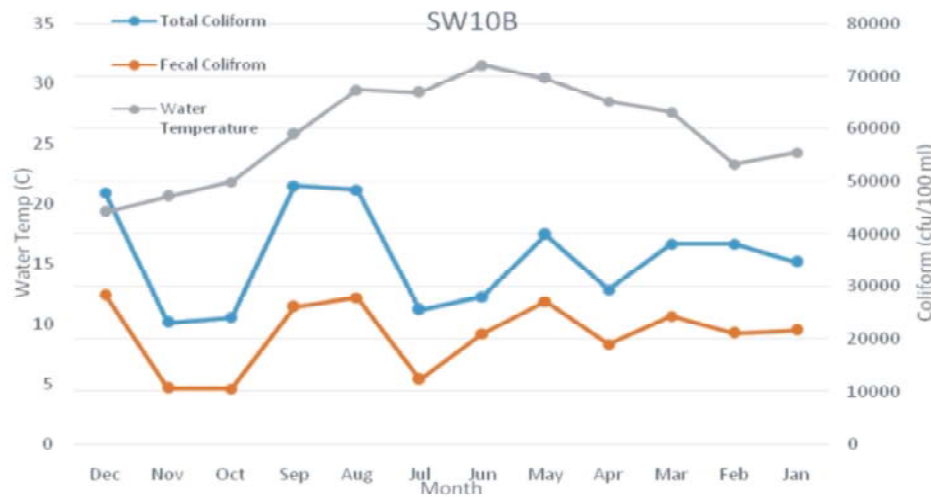(a) Sampling location SW12C
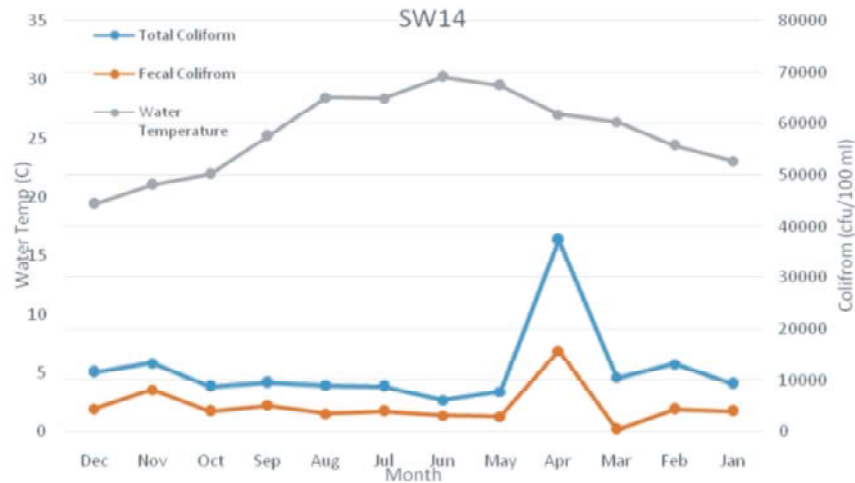
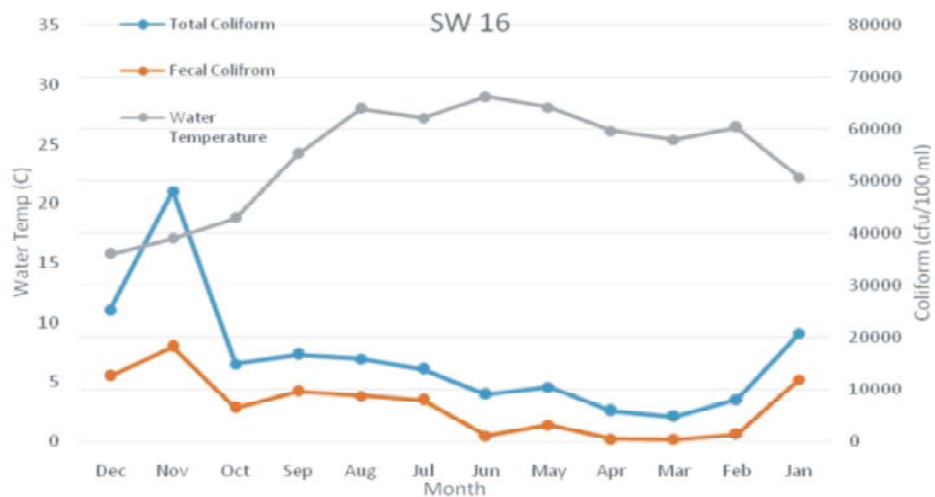(b) Sampling location SW14
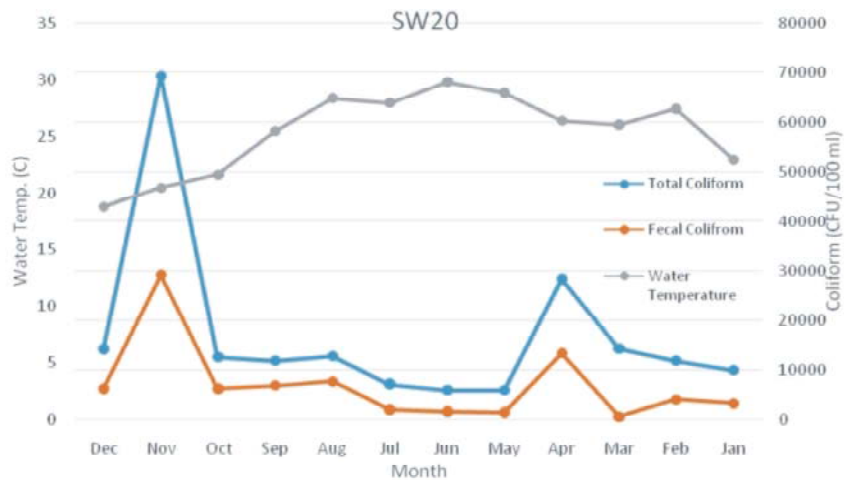
(c) Sampling location SW20

Fig. 4: Total Coliform, fecal Coliform and water temperature for sites before the connection between batha channel and wadiHanifa.

(a) Sampling location SW8G

(b) Sampling location SW10B

(c) Sampling location SW16

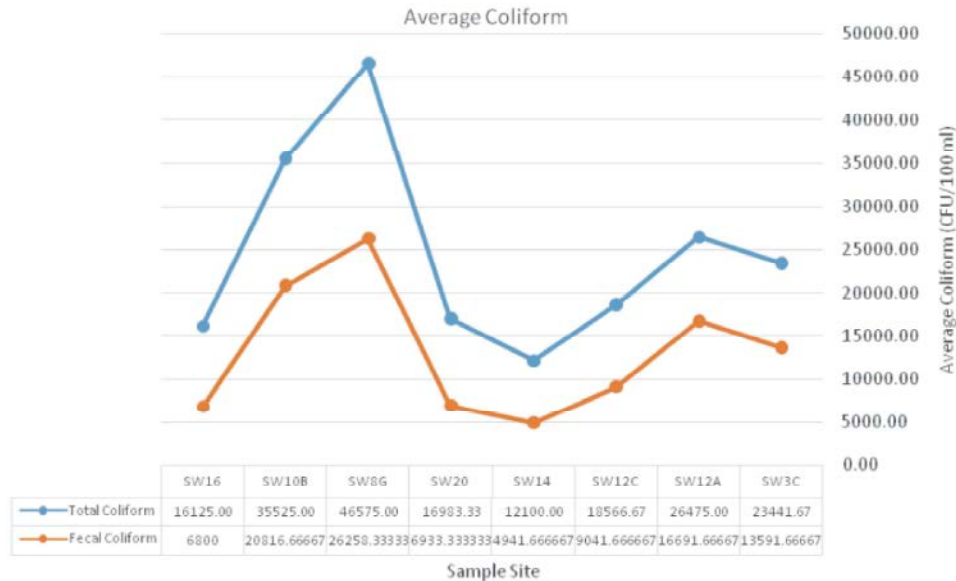Fig. 5: Total Coliform, fecal Coliform and water temperature for sites after the batha channel.

Fig. 6: Average total coliform density for all sampling sites.

The results of most of the sampling sites showed high level of total coliform and fecal coliform during the months of April and May, particularly in the sites in the upstream of the Wadi due to the big rain events which happen during April and May in Riyadh.

It is noted from the results mentioned above that the standard deviation of all the data is very high, which implicate that the rain events and climatic condition of the region affect greatly the fecal and total coliform concentrations in the Wadi water. Variability in coliform density tends to be positively related to precipitation (Cha *et al.*, 2010),therefore increases in total annual precipitation will likely elevate contamination levels.

Several standards for the reuse of wastewater for agricultural and landscape irrigation, both restricted and unrestricted, have been issued in Saudi Arabia. Initially, the Ministry of Agriculture and Water (MAW) issued several draft and tentative standards [20, 21], all of which were strict and prevented agricultural use of the treated effluent [22]. In 2003, the Ministry of Municipal and Rural Affairs (MMRA) issued new standards [23], which were replaced in 2006 by the latest standards [24], set by the Ministry of Water and Electricity (MWE) [25].

In general, samples exceed the drinking water standards. They also exceed European Union (EU) guideline microbiological standards for bathing water (500 total coliforms/100ml and 100 faecal coliforms/100ml) and also for EU maximum limits (10,000 total coliforms/100ml and 2000 faecal coliforms/100ml). Also, According to MWE (2006), the fecal coliform water quality standard for restricted irrigation is 1000 cfu/100 ml.

Statistical Analyses

Total Coliform: The t-test result for total coliform shows no significant difference between readings from stations SW12A and Sw12C. This shows that the bioremediation facility does not have a significant effect on the total Coliform amount.

	N	Mean	StDev	SE Mean
SW12A	12	26475	10919	3152
SW12C	12	18567	8682	2506

Difference = μ (SW12A) - μ (SW12C)

Estimate for difference: 7908

95% CI for difference: (-492, 16308)

T-Test of difference = 0 (vs ≠): T-Value = 1.96 P-Value = 0.064 DF = 20

However, the bioremediation facility shows seasonal changes that can be noticed in the box plot (Fig. 7). Using correlation analysis, it is concluded that the facility also breaks the correlation between readings after and before its location, but its efficiency is not enough to cause a significant change in the total coliform. The box plot shows that the readings after the station spanned a higher range of values that proves seasonal working efficiency.

The t-test result for total coliform shows significant difference between readings from stations SW20 and Sw8G. The sewage water from Batha channel, which carries water from Manfoha wastewater treatment plant, has a significant effect on the total colifrom as shown in the t-test results given below. The box plot (Fig. 8) shows a remarkable change in the total coliform values both in mean and span.
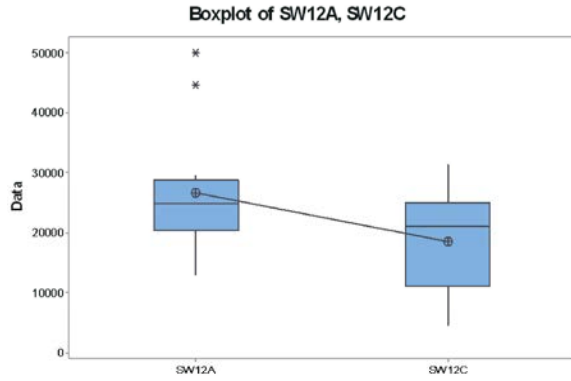
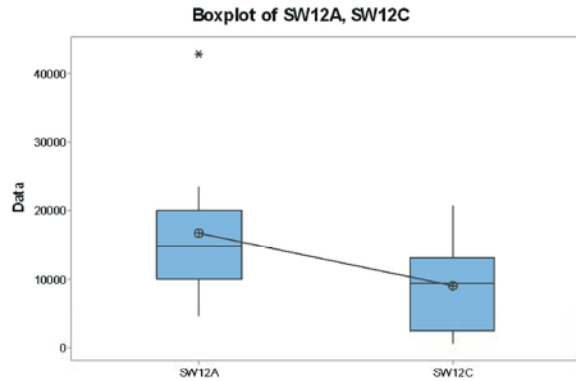Fig. 7: Boxplot for total coliform for stations SW12A and SW 12C.

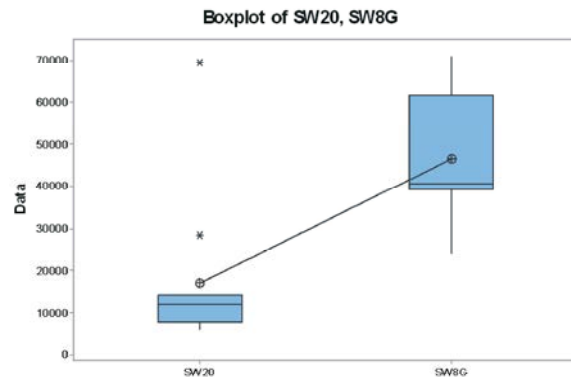Fig. 9: Boxplot for fecal coliform for stations SW12A and SW 12C

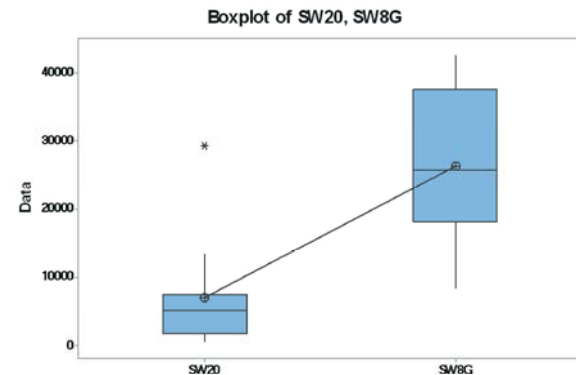Fig. 8: Boxplot for total coliform for stations SW20 and SW8G.

Fig. 10: Boxplot for fecal coliform for stations SW20 and SW8G.

	N	Mean	StDev	SE Mean
SW20	12	16983	17490	5049
SW8G	12	46575	14585	4210

Difference = μ (SW20) - μ (SW8G)

Estimate for difference: -29592

95% CI for difference: (-43263, -15920)

T-Test of difference = 0 (vs ≠): T-Value = -4.50 P-Value = 0.000 DF = 21

Fecal Coliform: The t-test shows that the bioremediation facility affects significantly the concentration of fecal coliform as there is a significant difference between readings from SW12A and SW12C. The difference is clear also in the box plot diagram (Figure 9).

N	Mean	StDev	SE Mean
SW12A 12	16692	9943	2870
SW12C 12	9042	6316	1823

Difference = μ (SW12A) - μ (SW12C)

Estimate for difference: 7650

95% CI for difference: (506, 14794)

T-Test of difference = 0 (vs ≠): T-Value = 2.25 P-Value = 0.037 DF = 18

The t-test shows that the bioremediation facility affects significantly the concentration of fecal coliform as there is a significant difference between readings from SW20 and SW8G. The sewage water from Batha channel has a significant effect on the fecal coliform as shown in the t-test results given below. The box plot (Figure 10) shows a remarkable change in the total coliform values both in mean value and span.

	N	Mean	StDev	SE Mean
SW20	12	6933	7859	2269
SW8G	12	26258	11207	3235

Difference = μ (SW20) - μ (SW8G)

Estimate for difference: -19325

95% CI for difference: (-27595, -11055)

T-Test of difference = 0 (vs ≠): T-Value = -4.89 P-Value = 0.000 DF = 19

CONCLUSIONS

The results showed that the bioremediation facility which constructed on the wadi has decreased the levels of fecal and total coliform in the water. The results also indicated that high levels of fecal and total coliform have

been observed after the connection between WadiHanifa and Batha channel. The results of most of the sampling sites showed high level of total coliform and fecal coliform during the months of April and May, particularly in the sites in the upstream of the Wadidue to the big rain events which happen during April and May in Riyadh. The results also concluded that Wadi water could be potentially a sustainable water resource for landscape irrigation after simple treatment of water to remove fecal and total coliform from water. It is noticed from the results mentioned above that the standard deviation of all the data is very high, which implicate that the rain events and climatic condition of the region affect greatly the fecal and total coliform concentrations in the Wadi water.

REFERENCES

1. Furumai, H., 2008. Rainwater and Reclaimed Wastewater for Sustainable Urban Water Use. Physics and Chemistry of the Earth, 33: 340-346.

2. Pescod, M.B., 1992. Wastewater Treatment and Use in Agriculture – FAO Irrigation and Drainage Paper 47. Food and Agriculture Organization of the United Nations, Rome, Italy, ISBN: 92-5-103135-5.

3. Hussein, I.A., T.M. Abu Sharar and A.M. Battikhi, 2005. Water resources planning and development in Jordan. In :Hamdy A. (ed.), Monti R. (ed.). Food security under water scarcity in the Middle East: Problems and solutions. Bari: CIHEAM, 2005. pp: 183-197 (Options Méditerranéennes: Série A. SéminairesMéditerranéens; n. 65)

4. Westcot, D.W., 1997. Quality Control of Wastewater for Irrigated Crop Production. Food and Agriculture Organization of the United Nations, Rome, Italy, ISBN: 92-5-103994-1.

5. Batarseh, M., A. Rawajfeh, K.K. Ioannis and K.H. Prodromos, 2011. Treated municipal wastewater irrigation impact on olive trees (Oleaeuropaea L.) at Al-Tafilah, Jordan. Earth and Environmental Science: Water, Air, & Soil Pollution 217 (1–4), 185–196. doi: 10.1007/s11270-010-0578-7

6. El Ayni, F., S. Cherif, A. Jrad and M. Trabelsi-Ayadi, 2011. Impact of treated wastewater reuse on agriculture and aquifer recharge in a coastal area: Korba case study. Earth and Environmental Science: Water Resources Management 25 (9), 2251–2265. doi: 10.1007/s11269-011-9805-2

7. Jhansi, S.C. and S.K. Mishra. 2013. Wastewater Treatment and Reuse: Sustainability Options. Consilience. The Journal of Sustainable Development Vol. 10, Iss. 1, 1 – 15 doi: 10.7916/D8JQ10Q1

8. Vega, M., R. Pardo, E. Barrado and L. Deban, 1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Water Res., 32(12): 3581- 3592

9. Petersen, T.M., H.S. Rifai, M.P. Suarez and A.R. Stein, 2005. Bacteria loads from point and nonpoint sources in an urban watershed. J. Environ. Eng., 131(10): 1414 -1425.

10. Dorner, S.M. W.B. Anderson, R.M. Slawson, N. Kouwen and P.M. Huck, 2006. Hydrologic modeling of pathogen fate and transport. Environmental Science & Technology, 40: 4746-4753.

11. Boehm, A.B., S.B. Grant, J.H. Kim, S.L. Mowbray, C.D. McGee, C.D. Clark, D.M. Foley and D.E. Wellman. 2002. Decadal and shorter period variability and surf zone water quality at Huntington Beach, California. Environmental Science and Technology, 36: 3885-3892.

12. Donovan, E., K. Unice, J.D. Roberts, M. Harris and B. Finley 2008. Risk of gastrointestinal disease associated with exposure to pathogens in the water of the Lower Passaic River. Appl Environ Microbiol 74(4):994–1003, PMID: 18156342, https://doi.org/10.1128/ AEM.00601-07.

13. Kistemann, T., T. Claen, C. Koch, F. Dangendorf, R. Fischeder, J. Gebel *et al*., 2002. Microbial load of drinking water reservoir tributaries during extreme rainfall and runoff. Applied and Environmental Microbiology, 68(5): 2188-2197.

14. Cha, S.M., S.W. Lee, Y.E. Park, K.H. Cho, S. Lee and J.H. Kim, 2010. Spatial and temporal variability of fecal indicator bacteria in an urban stream under different meteorological regimes. Water Science & Technology, 61(12): 3102-3108.

15. Balkema, A.J., H.A. Preisig, R. Otterpoh and F.J.D. Lambert, 2002. Indicators for the sustainability assessment of wastewater treatment systems. Urban Water 153-161 doi: 10.1016/S1462-0758(02)00014-6

16. Alhamid, Abdulaziz A., Saleh A. Alfayzi and Mohamed AlfatihHamadto, 2007. A Sustainable Water Resources Management Plan for WadiHanifa in Saudi Arabia. King Saud Univ., Vol. 19, Eng. Sci. (2): 209-222

17. Al-Samhouri, W. and M. Al-Naim, 2007. On Site Review Report, WadiHanifa, Riyadh, Saudi Arabia, National Built Heritage Forum. http://www.nbhf.org.sa/ pdf/br_6_WadiHanifa.pdf

18. Al-Tamimi Badr, 2012. Presentation of film about the WadiHanifah, a discussion about the Bioremediation component of the project and information about current and future portions of the project. Architecture and Design Days Conference, Riyadh, Saudi Arabia.

19. APHA, 1992. Standard Methods for the Examination of Water and Wastewater, 18th ed. APHA, Washington, DC.

20. MAW, 1986, Wastewater Regulations (Draft). Water Resources Development Department, Ministry of Agriculture and Water, Riyadh, Kingdom of Saudi Arabia.

21. MAW, 1989. Wastewater Regulations (Tentative). Water Resources Development Department, Ministry of Agriculture and Water, Riyadh, Kingdom of Saudi Arabia.

22. Abu-Rizaiza, O.S., 1999. Modification of the standards of wastewater reuse in Saudi Arabia. Water Research, 33(11): 2601-2608.

23. MMRA, 2003. Technical Guidelines for the Use of Treated Sanitary Wastewater in Irrigation for Landscaping and Agricultural Irrigation. (first ed.)Ministry of Municipal and Rural Affairs - Deputy Ministry for Technical Affairs - General Department for Infrastructure, Kingdom of Saudi Arabia.

24. MWE, 2006. Technical Guidelines for the Use of Treated Sanitary Wastewater in Irrigation for Landscaping and Agricultural Irrigation. Ministry of Water and Electricity, Kingdom of Saudi Arabia

25. Al-Jasser, A.O., 2011. Saudi wastewater reuse standards for agricultural irrigation: Riyadh treatment plants effluent compliance. Journal of King Saud University - Engineering Sciences, Volume 23, Issue 1, Pages 1-8. doi: 10.1016/j.jksues.2009.06.001