EVALUATION OFTREATED WASTEWATER USING WATER QUALITY INDEX

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ABSTRACT

Treated wastewater provides an important contribution to the water balance in water scarce countries. However,for irrigation purposes, the quality presents both benefits and challenges. In this study,water quality wasstudied for ten water parameters monitored for 8 years. Water quality index (WQI) was estimated to describe the suitability of treated wastewater for irrigation. Yearly and monthly WQI's lied under marginal to fair. The quality of effluent combined with improper practices may harm the surrounding environment and farmers' health. Therefore, the formation of an effective strategy and involvement of farmers in decision-making is recommended and required in the long run to avoid any detrimental effects on environment and user health.

Keywords: Treated wastewater, Quality index

1 INTRODUCTION

The availability of water for irrigation in arid and semi-aridregions is a major limiting factor for crop production. Irrigation with treated wastewater (TWW) has become a common practice and vital commodity to decrease the pressure on fresh water resources. Increased regional conflicts in the Middle East have forced huge number of refugees to flee to Jordan, and as a consequence of unpredicted population growth and increased demand; the water quality is being degraded and nonrenewable water resources are depleted (Carr, 2011).

Irrigation with TWW reduces the need for freshwater and offers positive potential to environmental relief and social economic development, however, negative effects may emerge if reuse schemes were not properly planned and managed.Worldwide, Jordan has one of the lowest available water resources per capita (145$m^3cap^{-1}year^{-1}$) and this ratio is projected to decrease to 90 $m^3cap^{-1}year^{-1}$ by 2020 as a result of population growth (MWI annual report 2010). Moreover, about 60% of freshwater resources in Jordan are commonly used in irrigated agriculture (Ammary, 2007).Therefore, Jordan had to find and depend on alternative resources such as treated wastewater (TWW).

Currently, about 120 MCM of reclaimed water is produced representing 17% of the total water used for irrigation purposes. By the year 2020, it is expected that the volume of available TWW will increase to 220 $MCMyear^{-1}$.As the demand of the municipal sector and the urbanization rate is increasing constantly, the volume of generated wastewater also grows. If sufficiently treated, wastewater will be suitable for different uses depending on the level of its quality.

Developing TWW quality monitoring programs aim to help planners to protect fresh water resources. These monitoring programs could be designed on the basis of the information on the existing TWW quality, standards, and the 'use' criteria.Water quality is generally assessed by comparing existing values with average norms; however comparisons do not provide useful information on spatial and temporal variability quality in sum (Debels et al. 2005). Therefore, new techniques such as water quality indices (WQI) were developed.

WQI is a simple mathematical tool applied to provide a criteria value for large data. It is used by decision makers to decide on quality and possible uses of a given water body (Cude, 2001). In this study, the Canadian Council of Ministers of the Environment-Water Quality Index 1.0 (CCME WQI) was used. CCME is well accepted and universally applied as computer model for evaluating the water quality index (CCME, 2001).

The study aimed to examine TWW quality and identify the critical parameters affecting the quality.

2 MATERIALS & METHODS

2.1 Study area

Water quality parameters were monitored for Al-Mafraq wastewater treatment plant (MWWTP) for eight years. The site is located 3 km from Mafraq city (70 km north east the capitol Amman). The treatment facility operates under 12 stabilization ponds designed to treat 1800 and m3 d-1. Treated effluent is used to irrigate more than 100 ha mainly for forage crops (alfalfa, barley, and ryegrass).As population is increasing, the amount of wastewater and organic loads are exceeding the capacity of the treatment plant, which negatively affected the performance of the treatment plant (current efficiency < 67%).

2.2 Determination of WQI

The Canadian Council of Ministers of the Environment-1.0 water quality index (CCME WQI) was used to evaluate TWW quality. The index (WQI) is a mathematical tool that provides a comprehensive numerical value for large water quality information. Decision makers use this tool to describe the quality and possible uses of water (Cude, 2001).

Nine parameters were chosen to evaluate the WQI. Parameters were electrical conductivity in Ds m-1 (EC), pH, ammonium (NH4+), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO3), cadmium (Cd), lead (Pb), and zinc (Zn) all measured in mg L-1.

Two WQI’s were evaluated: the first is called health water quality index (HWQI) involved the use of all parameters, the second is called irrigation water quality index (IWQI) involved the use of only six parameters (metals were not included). Monthly and yearly WQI’s were estimated for treatment facility to describe the suitability of TWW for irrigation. Yearly and monthly WQI were categorized according to classification values in Table 1.

The WQI consists of three factors: (1) Scope (F1): represents the percentage of variables that do not meet their objectives (failed variables), (2) Frequency (F2): represents the percentage of tests that do not meet their objectives (failed tests), (3) Amplitude (F3): represents a descriptive value for the amount of objectives that are not met. The three factors are combined in a single number (between 0 and 100) which describes the condition of water (water quality). The objectives in this study were selected based on the Jordanian standards and the WHO Guidelines for restricted irrigation (Bataineh et al. 2002). Jordanian standards (893/2006) adopted the WHO and FAO guidelines for related TWW use (Al-Uleimat, 2008).

Calculated values are ranked according to one of the five categories (groups) which describe different environmental conditions. These values vary according to space, local conditions and issues. A minimum of four variables are needed to be used for the calculation of WQI and as follows:

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100$$

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}}\right) \times 100$$

And F3 is calculated in three steps.

(i) The frequency by which an individual test is departing from the objective and this is termed an ‘excursion’’:

$$\text{Excursion}_i = \left(\frac{\text{failed test value}_i}{\text{objective}_j}\right) - 1$$

(ii) The excursions are then summed and divided by total number of tests and this is termed as the normalized sum of excursions (nse) and as follows

$$\text{nse} = \left(\frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{No. of tests}}\right)$$

(iii) Finally, F3 is calculated by scaling the nse by asymptotic function using the following equation.

$$F_3 = \left(\frac{\text{nse}}{0.01\ \text{nse} + 0.01}\right)$$

WQI is then calculated by addition of the three factors using the following equation.

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

The divisor 1.732 is a scaling factor which normalizes the index values to a range between 0 and 100, where 0 is the poorest and 100 is the best (excellent) water quality as described in Table XXX6.

Table 1: CCME water quality index classification according to value

Excellent	Good	Fair	Marginal	Poor
95–100: Water quality is protected with a virtual absence of threat or impairment; conditions are very close to natural or pristine levels.	80–94: Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.	65-79: Water quality is usually protected, but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.	45–64: Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.	0–44: Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

3 RESULTS AND DISCUSSIONS

3.1 Average yearly and monthly HWQI’s and IWQI’s

The yearly and monthly HWQI’s and IWQI’s for studied years are presented in Figs. 1 and 2. The monthly HWQI values ranged from 54 to 90 with an average value of 73, while IWQI monthly values ranged from 51 to 86 and with average values of 66.

Moreover, the yearly HWQI values ranged from 61 to 85 with an average value of 74, while yearly IWQI values ranged from 51 to 87 and with average value of 67.

Interestingly, HWQI was consistently higher than IWQI between the years 2003 to 2011. This would indicate two things. First, the acceptability of TWW, in terms of metal content, is much better than the quality of TWW with regards to other parameters such as EC, N, TSS, and mainly BOD and COD aspects. Second, that HWQI is on the whole a weighted average of all tested parameters. It is noted that the quality of TWW quality with regards to biological demand has been stable with no improvements indicating an overloading status.

The F1 and F2 values were higher during summer months for both HWQI and IWQI. Both values (F1 and F2) reflect failed parameter and test values, respectively. It is apparent that three parameters (COD, TSS, and inflow volume) were responsible for increased these values and therefore decreased WQI as whole. Table 2 shows average, minimum, and maximum values of F1 and F2 for monthly and yearly HWQI and IWQI.

Table 2: Descriptive statistics of F1 and F2 values for monthly and yearly HWQI and IWQI.

Category		Average	Minimum	Maximum
HWQI	F1	41.6	12	75
	F2	17	9.3	22.5
IWQI	F1	55	20	80
	F2	17.3	10.5	27.5

3.2 Categories of yearly and monthly HWQI's and IWQI's

Histograms for monthly and yearly WQI's are shown in Fig.3. The yearly WQI fall under marginal category for the years 2004, 2005, 2006, 2007, and 2010, while the years 2003, 2008, and 2009 falls under fair category, and this is could be attributed to the maintenance of ponds performed in the year 2007. Regular maintenance is performed every five to seven years according to MWWTP monthly report No.7 July 2008. The monthly WQI falls under marginal category for the following months (Jan, Apr, Jun, Jul, Aug, Oct, and Dec), while the months (Feb, Mar, Sep, and Nov) fall under fair category (Fig. 4). Several factors affect the WQI such as, temperature, wind action, rainfall, solar radiation, evaporation.

The HWQI was consistently higher than IWQI fair-good category terms for both monthly and yearly WQI's. This is consistent with the average values presented in figs. 1 and 2. It is apparent that the organic loads (COD) and TSS (turbidity) were the main parameters affecting the tested quality. Although few incidents of elevated nitrogen as NO3 were observed during summer months, this is not considered as a limiting factor for irrigation water since nitrogen is required as a macro nutrient for irrigated crops.

The treatment facility is now under the process of upgrading and development through a joint venture between the Ministry of Water and Irrigation (MWI), Water Authority of Jordan (WAJ), and The United States Agency for International Development (USAID). The project works aim to increase capacity from 1800 m3 d-1 to 6550 m3 d-1. Construction works are expected to be completed soon. The Jordanian standard (JS 893/2006) for wadi discharge is adopted for effluent quality and can be used for irrigation, wadi discharge, and groundwater recharge.

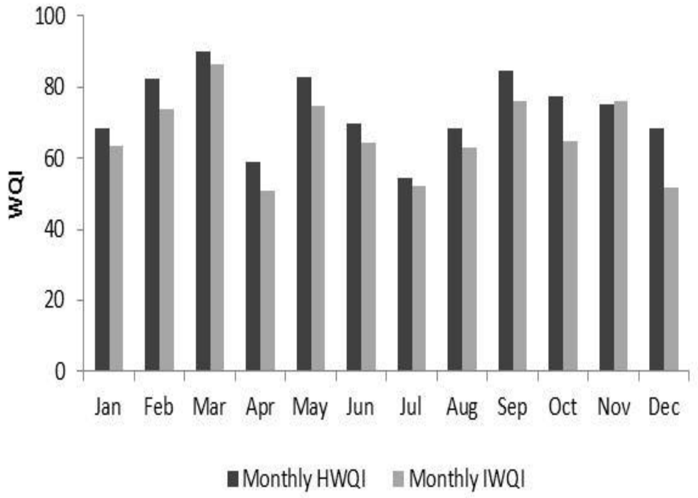

Figure 1. Average monthly health (HWQI) and irrigation water quality index (IWQI)

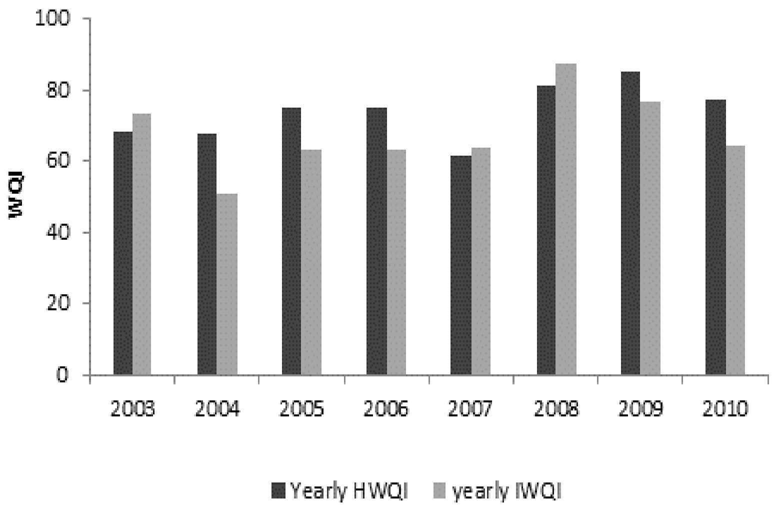

Figure 1. Average yearly health (HWQI) and irrigation water quality index (IWQI)

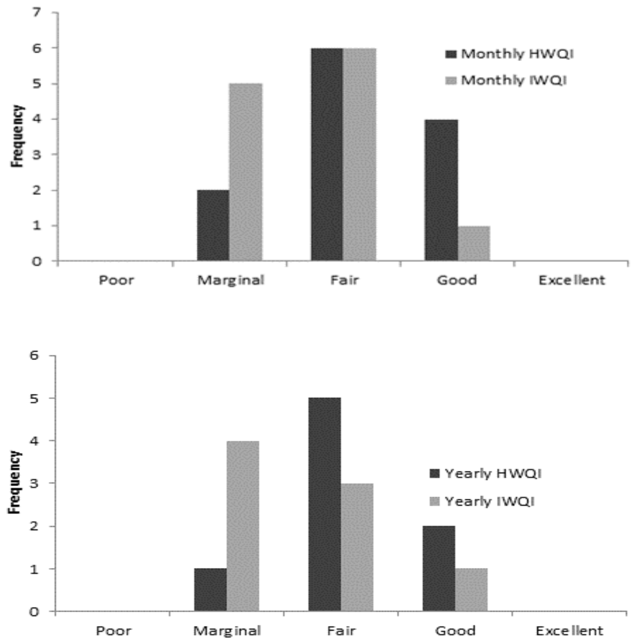

Figure 2. Frequency of monthly and yearly health (HWQI) and irrigation water quality index (IWQI)

4 CONCLUSIONS

Water qualityindex is a powerful tool that can be used effectively to monitor effluent parameters. The study revealed that the water quality lied under marginal and fair category. In terms of nitrogen content it could be postulated that the TWW is very beneficial for crop production if caution and management measured were adopted. Involvements of farmers in decision-making with regard to the TWW quality could be very helpful to attain sustainability.

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REFERENCES

Ammary, B.Y. (2007) Wastewater reuse in Jordan: present status and future plans.*Desalination*, 211, pp. 164–176.

Bordalo, A.A., Nilsumranchit, W. &Chalermwat, K. (2001) Water quality and uses of the Bangpakong River (Eastern Thailand).*Water Res*, 35(15),pp. 3635–3642.

Canadian Council of Ministers of the Environment (CCME) (2001) Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, Technical Report. *In: Canadian environmental quality guidelines, 1999. Winnipeg, Canadian Council of Ministers of the Environment.*

Carr, G. , Potter, R.B &Nortcliff, S. (2011) Water reuse for irrigation in Jordan: Perceptions of water quality among farmers. Agr Water Manage, 98, pp. 847–854.

Cude, C.G. (2001) Oregon Water Quality Index: a tool for evaluating water quality management effectiveness. Water Res Assoc, 37 (1), pp. 125–137.

Debels, P., Figueroa, R., Urrutia, R., Barra, R., &Niell, X. (2005) Evaluation of water quality in the Chilla'n River (Central Chile) using physicochemical parameters and a modified water quality index. *Environ Monit Assess*, 110, pp 301– 322.

Kannel, P.R., Lee, S., Lee, Y.S., Kanel, S.R. & Khan, S.P. (2007). Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment. Environ Monit Assess, 132, pp. 93–110.

Ministry of Water and Irrigation (MWI) Annual report (2010)Open files.