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The Impact of Prolonged Irrigation with Treated Domestic Wastewater on Drainage Water Using A Simulation Model

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Abstract. Water is a limited resource in Saudi Arabia and considered an essential issue. This has lead to exploit treated domestic wastewater (TDW) in irrigation to reduce pressure on utilising the groundwater in Riyadh. Therefore, the aim of this study was to assess the impact of TDW on the groundwater in Riyadh area. A simulation model containing three different soil samples supplied with full irrigation system was used. The infiltered water samples were collected during the course of 458 days irrigation and analysed for general chemical (pH, total alkalinity, EC, SAR), cationic (Na+, Ca^{2+}, Mg^{2+}), anionic (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, B^{3-}, PO_4^{3-}), nitrogen compounds (NO_3^-, TNK, NH_3), oxygen demand (COD, BOD) and total organic carbon composition. The changes in the concentrations of water chemical compositions mostly showed significant differences ($p<0.000 - p<0.045$). The changes in the water chemical concentrations fall into three groups. The first group showed significant decrease in the infiltered water total alkalinity and HCO_3^-. The second group showed mostly significant increase in EC, Na+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^- and SAR. Whilst PO_4^{3-}, TNK, NH_3, COD, BOD and total organic carbon increased during irrigation then decreased after 458 days of the continuous irrigation. Chemicals in TDW that infiltered through soils A, B and C showed similar pattern of increased or decrease. The increase in the ionic concentrations of infiltered TDW could be attributed to the leach of ions from soils A, B and C. These results may be attributed to the textures of soil samples which are abundant in sand particles, Thus, high rate of water infiltration and evaporation can be considered as factors that may negatively impact on groundwater in Riyadh area which found here to contain high concentrations of salts and ions.

Introduction

The domestic wastewater in Riyadh has increased from $420x10^3$ m^3/day in 1993 to $538.5x10^3$ m^3/day in 2007, of which $396.3x10^3$ m^3/day or 94.4% of the domestic wastewater was treated in 1993. The treated domestic wastewater (TDW) increased to $536.3x10^3$ m^3/day or 99.6%, in 2007 (GDWRR, 2008). Therefore, TDW can be considered as an essential water source for reclamation and recycling applications. Indeed, 178 $x10^3$ m^3/day of TDW was used to irrigate Riyadh City's landscapes (ADA, 1990). In addition, water quality standards in Saudi Arabia encourage the reuse of wastewater at a number of locations (Abu-Rizaiza 1999). Hence, TDW can help to reduce exploiting the groundwater in Wadi Hanifa for irrigation in Riyadh. Many countries also use wastewater for irrigating agricultural fields (Hussain and Al-Saati, 1999; Domłnguez-Mariana *et al.*, 2004; Wang *et al.*, 2007).

Although wastewaters can positively contribute to soil organic and inorganic materials, they can also contribute to the risk of heavy metal, salinity of soil and groundwater and microbial contamination through prolonged irrigation (Siebe, 1995; Scott et al. 2000; Yadav *et al.*, 2002; Wang *et al.*, 2003; Heidarpour *et al.*, 2007). The nature of contamination is influenced by the chemical composition of wastewater effluents (Wang *et al.* 2003; Lucho-Constantino et al. 2005; Rattan et al., 2005). Rathan *et al.* (2005), for example, found that groundwater contained 8.6%-75% of P, K, Zn, Cu, Fe, Mn and Ni μgL^{-1} of the sewage effluents used in irrigating the same area, while S, Pb and Cd exceeded 90%. Hussain and Al-Saati, (1999) reported that wastewaters can affect the exchangeable-sodium-percentage (ESP) and soil salinity to create substantial soil and crop management problems. The intensity of irrigation is essentially related to the amount of the accumulated salts in soil. Salts, generally, can negatively impact on soil and plants by affecting the ESP, causing clay particle dispersion, and an increase of osmotic pressure, subsequently causing plant toxicity (Halliwell *et al*., 2001).

The prolonged irrigation with TDW in arid and semi-arid areas may cause further implications, particularly on groundwater in Riyadh area. This is due to the high rate of evaporation and infiltration of water. Research indicated that TDW showed little soil chemistry changes and no changes in soil texture throughout irrigation for 458 days. These results were related to the large amount of sand particles (80-91%) in the soil samples compared to the amount of mainly clay particles (Al-Othman, 2008). In an attempt to continue assessing the effect of TDW, the aim of this paper is to determine the quality of TDW after leaching through a soil column in a simulation model that was designed and constructed for this purpose. As such, this study focuses on the simulated impact of TDW on the groundwater.

Methods and Materials

Figure 1 illustrates the simulation model used in this study (open field). Each column was packed with either soil A, B or C. The three soil samples were brought from *Deraab`s* agricultural site in Riyadh District, which were characterised as sandy loam, loamy sand and sandy, respectively (Table 1). The physical and chemical characteristics of soil A, B and C are also shown in Table 1.

Soil was added in successive layers, each of about 20 cm height to each column over a bed of 40 cm high of stones. The total amount of soil in each column was 5260 kg of 3.10m height. Treated domestic wastewater (TDW) was obtained from the King Saud University wastewater station which was

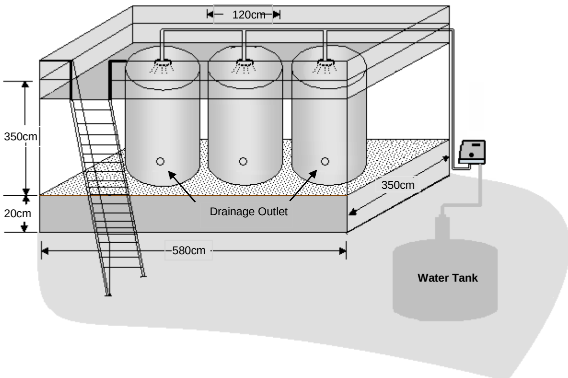


Fig. 1. A simulation model that contains three columns, each contains different soil sample. It is supplied with a complete irrigation system and drainage outlets to take sample for analysis (Open field).

Table 1. Texture, physical and chemical characteristics of soil A, B and C*.

		Soil A	SD	Soil B	SD
Sand (%)		80.90	11.21	88.42	16.39
Clay (%)		14.13	3.74	9.10	1.93
Silt (%)		5.17	1.78	2.50	1.06
Soil Texture**		Sandy Loam		Loamy Sand	
Wilting Point (cm^3 water/cm^3 soil)***		0.107	0.001	0.08	0.001
Field capacity (cm^3 water/cm^3 soil)***		0.173	0.041	0.144[1]	0.039
Saturation (cm^3 water/cm^3 soil)***		0.369	0.167	0.34	0.165
Available water (cm^3 water/cm^3 soil)***		0.066	0.015	0.04	0.004
pH		8.7	0.17	8.40	0.14
EC (ds/cm)		0.8	0.03	0.70	0.05
$CaCO_3$ (meq/L)		13.1	1.72	10.0	1.99
Na^+		3.2	0.44	2.9	0.57
Ca^{2+}	(meq/L)	2.3	0.47	2.5	0.52
Mg^{2+}		2.3	0.42	1.8	0.22
SAR		2.1	0.15	2.0	0.14
CO_3^{2-}		0.2	0.06	0.2	0.04
HCO^{2-}		0.9	0.29	0.9	0.20
Cl^-	(meq/L)	2.0	0.32	1.9	0.31
SO_4^{2-}		4.4	0.44	4.4	0.35

*Values represent means of the nine replicates of soil samples, each three taken at 50cm, 100cm and 150cm depth; **Soil texture was determined using online equation http://courses.soil.ncsu.edu/resources/physics/texture/soiltexture.swf; ***Values were calculated using the online Hydraulic Properties Calculator at http://staffweb.wilkes.edu/brian.oram/soilwatr.htm.[1] Field capacity for sandy soil should be lower than loamy sand. However, the same value for soils B and C may be due to the values of sand and clay contents and high SD.

added slowly over approximately 2 days, or until it discharged from the derange outlet (diameter = 15cm; Figure 1). Treated domestic wastewater was then added in 4 periods; 19.15L on 25 April, 319.10L on 6th June; 671.16L on 26th July and 233.98L on 8th August 2006, giving a total of 1,243.39L. The amounts of added treated domestic wastewater were calculated based on the rate of water evaporation per day in Riyadh District using the following equation:
Amount of added water/day = average of evaporated water/day x 1.5.

Water samples were collected from the drainage outlets for chemical, biochemical and microbial analysis and according to a time-scale schedule that involves taken water samples at 0, 163, 237, and 458 days.

Water samples were taken for the physico-chemical analysis in 9 periods 0, 71, 113, 163, 237, 301, 342, 393 and 458 days. However, only 0, 163, 237 and 458 days were considered in the figures and discussion unless otherwise indicated. The water samples were analysed for total alkalinity, using volumetric titration (APHA, 1995), pH by a pH meter (Thomas, 1996) while electrical conductivity (EC) was measured using an EC meter (Rhoades, 1996).

Cations including Na^+, Ca^{2+}, Mg^{2+} and anions including CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} were analysed according to standard methods (Richards, 1954; Rainwater and Thatcher, 1979). PO_4^{3-} using Ascorbic acid method and NO_3^- using chromotropic acid method (APHA, 1995) while B was measured by Sequential Plasma Spectrometer (APHA, 1995). Sodium absorption ratios (SAR) were calculated according to Richards (1954) using the following equation:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

In addition, TNK was analysed by Kjeldahl method (APHA, 1995), NH_3, BOD and COD, using standard methods (APHA, 1995). Total organic carbon analysed by Walkly and Black method (Croll, 1972).

Statistical analysis

The physico-chemical properties of treated domestic wastewater samples were analysed by mean and standard deviation. Statistical differences of different attributes were analysed by t-test to establish whether there are significant differences between 0 and 458 days, and by type of soil after 458 days of irrigation.

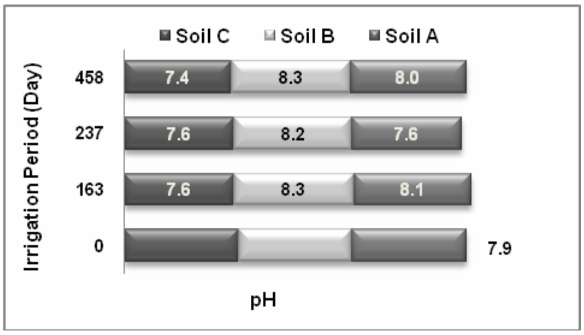


Fig. 2. pH profiles of TDW after passing through soil samples A, B and C. Standard deviation [t-test- between 0 & 458 days]: Soil A = 0.40-0.50[p< 0.474]; soil B = 0.38-0.42[p< 0.005]; and soil C = 30-0.40[p< 0.1618].

Results and Discussion

General Chemical profile of TDW

The impact of TDW on the groundwater is associated with chemical interactions between water and soil chemical and organic composition. The chemical interactions mainly represent the neutralisation or acid base reactions, which takes place on clay particles. Thus, clay particles are essential for regulating the capacity of soil to accommodate ion exchange interactions. In addition, irrigation with TDW has direct influence on the level and type of chemical exchange on the clay active site. Hence, the resulted chemical changes often impact on physical and chemical properties of irrigated soil and on the drainage water. The main question is whether the prolonged irrigation with TDW affect the groundwater chemical composition, hence raise the concern about the quality of groundwater in Riyadh area. It is important to note that due to the high percentage of sand particles and harsh climate, it is expected that the rates of water infiltration and evaporation are expected to be higher compared to soils with less sand particles. Thus, higher infiltration and evaporation may contribute to increase the diverse effect on groundwater when TDW is used as a main source for irrigation. However, the level of diverse effect on the groundwater is directly associated with the source of wastewater; i.e. domestic, industrial or mixed. Reports from the same region indicated that irrigation water is the main source of adding salts to the soil and groundwater (Hussain and Al-Saati, 1999; Heidarpour *et al*. 2007).

In order to assess the impact of TDW on the simulated groundwater, the prolonged irrigation was set up throughout a simulation model (Fig. 1). The model contains three types of soils with different physical and chemical properties (Table 1). Figure 2 shows the pH profile of water samples before and after leaching through soils A, B and C in the simulation model. Results indicated that the pH of TDW increased significantly ($p<0.005$) from 7.9 to 8.3 when infiltered through soil B. The relationship between water and soil is important for determining the availability of nutrients for plants and subsequently crop production (Cristine et al., 2003; Jiang, 2007). pH is considered as an essential facet in this relationship, particularly in term of soil chemistry which function to assist plant uptake of the essential nutrients. Thus, any increase in the acidity of groundwater would most likely to affect the quality of groundwater when is used in irrigation. Although TDW pH before and after infiltered through soil A, B and C remain in the region of moderate alkaline, over years the TDW may affect the pH of the groundwater.

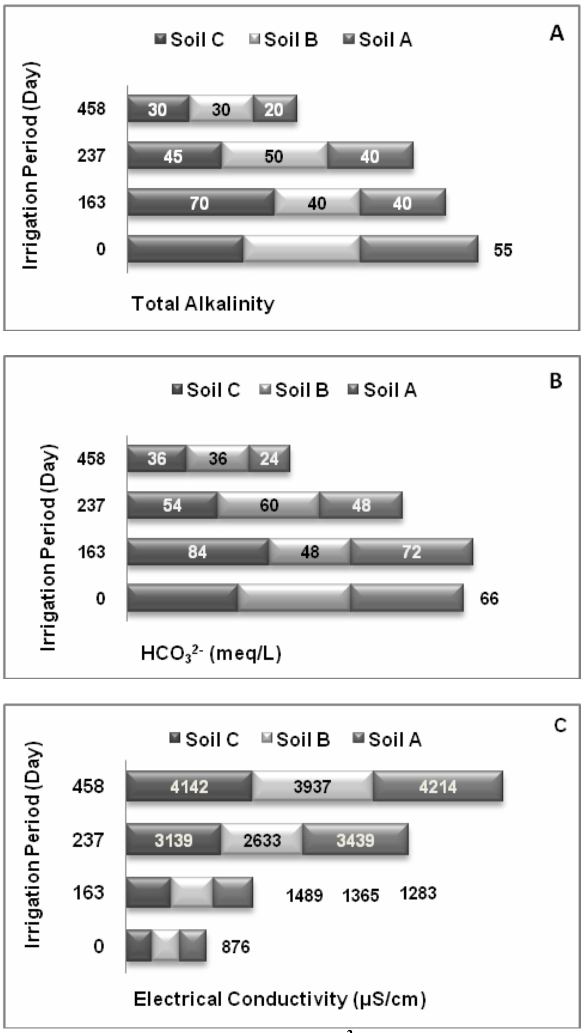


Fig. 3. Total alkalinity (A) and HCO_3^{2-} (B) and EC (C) profiles of TDW after passing through soil samples A, B and C.

Standard deviation [t-test- between 0 & 458 days]

Total Alkalinity (A)- Soil A = 5.3-14.1[p< 0.012]; soil B = 7.1-9.5[p <0.000]; and soil C = 2.5-8.0[p< 0.005].

HCO_3^{2-} (B)- soil A = 4.7-16.6[p< 0.011]; soil B = 4.7-13.8[p< 0.045]; and soil C = 4.7-15.1[p< 0.015].

EC (C)- soil A = 22.1-86.4 [p< 0. 000]; soil B = 60.5-173.1 [p< 0.000]; and soil C = 22.1-170.5 [p< 0. 000].

Figure 3A indicates that soils A, B and C decreased the total alkalinity profiles of TDW significantly ($p<0.000$-0.012) by 1.82-2.77 folds after 458 days of irrigation. Comparing the alkalinity values of TDW after 458 days of irrigation by soil type indicated that the alkalinity of the TDW infiltered through soil A was significantly lower than the corresponding alkalinity of TDW infiltered through soil B ($p<0.027$) and soil C ($p<0.032$). Total alkalinity is considered as an essential characteristic for irrigation water and soil. Normally irrigation water with higher total alkalinity causes the pH value to raise above the neutral level (pH 7.0) which is disfavour the availability of nutrients for plants (Smith *et al*., 1994). In addition, the high level of alkalinity in irrigation water may also impact on the pH of groundwater. Therefore, $CO_3^{2-}$and HCO_3^{2-} were measured (Fig. 3B). Although the composition TDW did not contain CO_3^{2-} before and after irrigation, the composition of HCO_3^{2-} (Fig. 3B) showed similar pattern to the total alkalinity of TDW before and after 458 days of irrigation (Fig. 3A). The HCO_3^{2-} concentration in TDW was decreased significantly ($p<0.011$-0.045) by 1.2-2.74 folds after 458 days of irrigation. The decrease in both alkalinity and HCO_3^{2-} could be attributed to the neutralisation reactions that took place when irrigation water is in contact with soil particles, mainly clay particles. From a chemical point view, the results in Figure 3 agree with each other. However, the complexity of soil often suggest that there are various factors, including clay composition, type of the cation that contribute to changing the values of total alkalinity and HCO_3^{2-}. It is important to note that the compositions of $CaCO_3$ in soils A, B and C did not changed significantly due to irrigation with TDW for 458 days (Al-Othman, 2008). Literature indicated that beside $CaCO_3$, bicarbonate, including $Mg(HCO_3)_2$ and $NaHCO_3$ are essentially the major contributors to the alkalinity of the soils (Bailey *et al*., 1998). In addition, these results suggest that TDWs still contain an average of approximately 45% of the original total alkalinity or HCO_3^{2-} after continuous irrigation for 458 days. Thus, the alkalinity of TDW may affect the chemical properties of the groundwater in the area.

In contrast to HCO_3^{2-} and total alkalinity profiles, EC measurements of TDW showed gradual increase by irrigation duration (Fig. 3C). The differences in EC values before and after 458 days irrigation increased significantly ($p<0.000$) by 4.5 to 4.8 folds when TDW infiltered through soil A, B and C. Generally, EC represents an essential indicator for salt concentration in soil and irrigation water. Literatures have indeed considered EC as a main parameter for salinity (Williams and Hoey, 1987).

TDW quality by salinity and cations

In order to assess the impact of the prolonged irrigation with TDW on the salinity of groundwater, the main cationic ions were analysed. These include Na^+, Ca^{2+}, Mg^{2+}, which are mainly contribute to the formation of neutral salts in soils and are represented by sodium absorption ratio (SAR). Fig. 4 shows the cationic composition of the irrigation water after leaching through soils A, B and C. The amount of Na^+ and Ca^{2+} in TDW increased significantly after 458 days irrigation by 7.8-9.7 folds ($p<0.000$-$p<0.006$) and by 2.15-2.83 folds ($p<0.000$-$p<0.003$), respectively. In addition, Mg^{2+} increased significantly ($p<0.013$) only when TDW pass through soil sample B by 1.32 fold. The calculation of SAR of TDW also showed significant increases ($p<0.002$-0.031) by 1.66-2.71 folds when infiltered through soils A, B and C after 458 days of continuous irrigation (Fig. 4). The value increases of the three cations were ranked in the order of $Na^+ > Ca^{2+} > Mg^{2+}$. The three soil samples showed no significant differences by individual cation. However, as indicates in Fig. 4, the average of Na^+ concentration in the TDW infiltered three soils A, B and C were approximately 3.33 meq/L and 6.5 folds of Ca^{2+} and Mg^{2+}, respectively. In addition, however, the SAR values between soils A, B and C showed some significant differences. SAR of TDW at 458 days irrigation of soil A was significantly higher than the corresponding SAR values of TDW infiltered through soil C ($p<0.005$). SAR value of TDW infiltered through soil B was also significantly ($p<0.015$) higher than the corresponding value for TDW infiltered through soil C.

Generally, the Kingdom of Saudi Arabia is a good example of the arid regions and need to maintain the quality of the groundwater. The groundwater in many arid and semi-arid regions is saline/sodic which can be exploited for irrigation under strict management (Chauhan *et al.* 2008). Thus, according to the above results the prolonged irrigation with TDW is most likely to contribute to increase the salinity/sodicity of groundwater in Riyadh region.

TDW quality by anions

Generally, anions form the non metals half of natural salts, in which through ionic bond formation combine with cations to form the ionic compounds. These are responsible for water and soil salinity. The

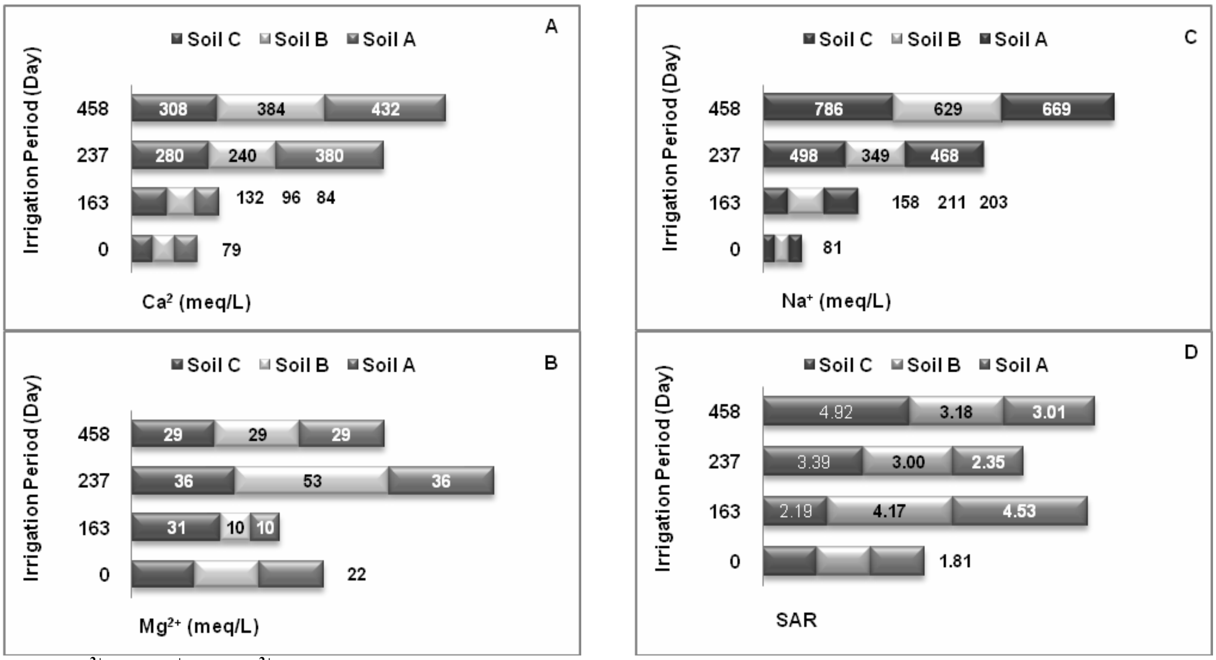


Fig. 4. Ca^{2+} (A), Na^+ (B), Mg^{2+} (C) and SAR (D) profiles of TDW after passing through soil samples A, B and C.

Standard deviation [t-test- between 0 & 458 days]

Ca^{2+} (A)- soil A = 11.5-39.4[p< 0.000]; soil B = 12.5-29.8[p< 0.003]; and soil C = 13.9-38.2[p< 0.003].

Mg^{2+} (B)- soil A = 6.2-8.0[p< 0.245]; soil B = 3.7-12.0[p< 0.013]; and soil C = 5.7-7.6[p< 0.206].

Standard deviation [t-test- between 0 & 458 days]

Na^+ (C)- soil A = 10.6-71.0 [p< 0.000]; soil B = 10.6-98.5[p< 0.006]; and soil C = 10.6-63.0[p< 0.000].

SAR (D)- soil A = 0.112-1.325[p < 0.002]; soil B = 0.112-0.625[p < 0.031]; and soil C = 0.112-0.756[p < 0.006].

most common natural salt, for example, is NaCl. Thus, anions such as Cl^- and SO_4^{2-} were measured to investigate the salinity of TDW after the prolonged irrigation. Figure 5 clearly indicates that the concentration of Cl^- and SO_4^{2-} were increased significantly by 5.52-6.23 folds ($p<0.000$-0.003) and 5.17-5.74 folds ($p<0.001$), respectively. Figure 5 also shows that the concentrations of anions (Cl^-, SO_4^{2-}) and cations (Na^+, Ca^{2+}) were closely related to each other, as anions and cations had similar pattern of increased in TDW infiltered through soils A, B and C (Figures 4 and 5). In addition, the concentration of TDW of an anion was difference by soil sample. For example, Cl^- was significantly ($p<0.043$) more in TDW infiltered through soil A than soil B. whilst, SO_4^{2-} was significantly ($p<0.039$) more in TDW infiltered through soil A than soil C. Although, it is difficult to give clear explanation to these results due to the complexity of soil/water system, it is likely to be associated with the amount of clay particles present in soil samples. In this respect, soil A contained more clay particles (14.13%) than soil B (9.10%) and C (9.12%; Table 1).

Figure 6 shows the profiles of PO_4^{3-}, NO_3^- and B in TDW after infiltered through soils A, B and C. Both NO_3^- and B increased significantly by 2.97-6.72 folds ($p<0.001$-0.017) and 1.74-2.94 folds ($p<0.022$), respectively when it was infiltered through soil A, B and C. the increased in the concentrations of PO_4^{3-}, however, was not significant.

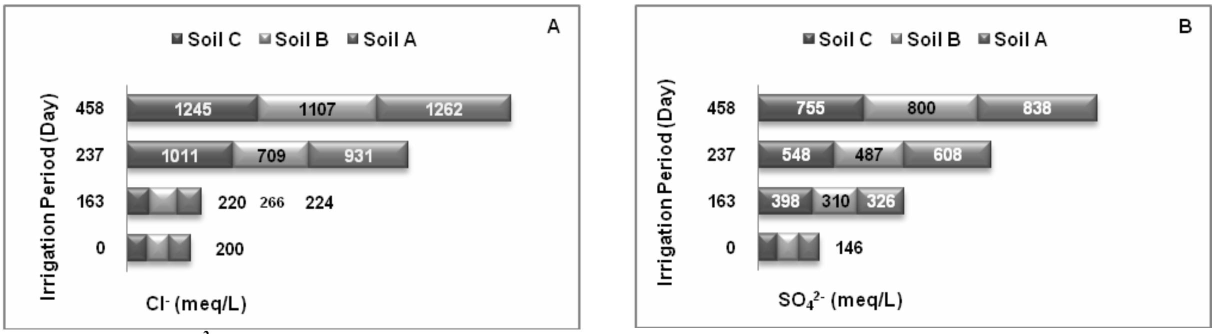


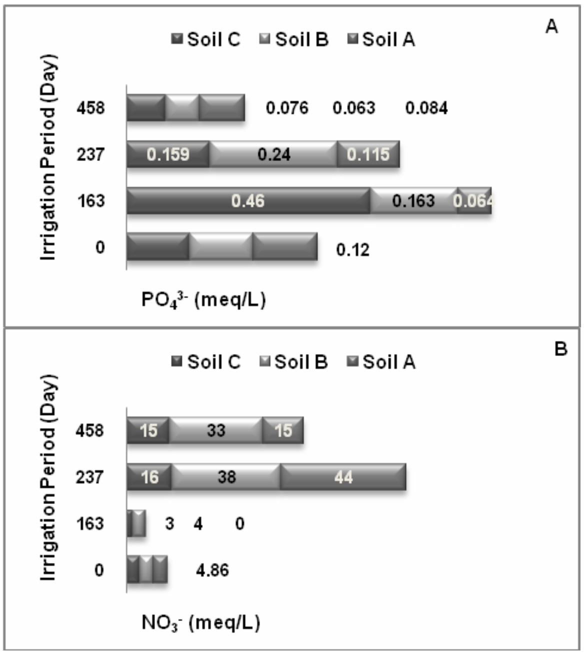
Fig. 5. Cl^- (B) and SO_4^{2-} profiles of TDW after passing through soil samples A, B and C.

Standard deviation [t-test- between 0 & 458 days]

Cl^- (A)- soil A = 28.3-78.0[p< 0.001]; soil B = 20.2-89.1 [p< 0.000]; and soil C = 28.1-102.4[p< 0.003].

Standard deviation [t-test- between 0 & 458 days]

SO_4^{2-} (B)- Soil A = 15.7-61.4[p<0.001]; soil B = 15.7-57.1 [p<0.002]; and soil C = 15.7-67.9[p< 0.001].



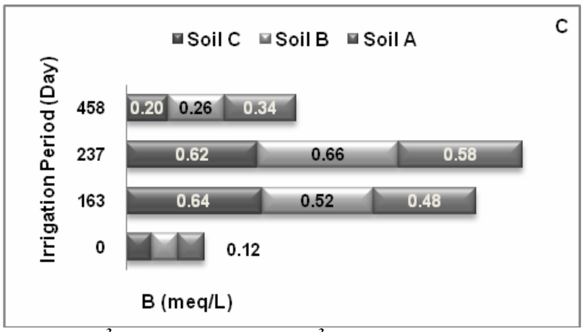


Fig. 6. PO_4^{3-} (A), NO_3^- (B), and B^{3-} (C) profiles of TDW after passing through soil samples A, B and C.

Standard deviation [t-test- between 0 & 458 days]

PO_4^{3-} (A)- soil A = 0.023-0.061[p< 0.065]; soil B = 0.032-0.081[p< 0.081]; and soil C = 0.045-0134[p< 0.186]

NO_3^- (B)- soil A = 0.121-9.093[p< 0.017]; soil B = 0.717-3.694[p< 0.002]; and soil C 0.111-1.90= [p< 0.001].

B (B)- soil A = 0.21-0.186[p< 0.023]; soil B = [p< 0.60]; and soil C = 0.021-0.102[p< 0.168].

TDW quality by nitrogen, Oxygen Demands and Carbon compounds

Figure 7 shows the effect of soil on the filtered off TDW content of the total nitrogen Kjeldahl (TNK) and NH_3 in TDW after 458 days of irrigation. The TNK represents the amount of protein measured by Kjeldahl method, which was influenced by soil sample. For example, TNK was increased significantly ($p<0.006$) by 2.27 in when TDW infiltered through soil A, while it was significantly decreased ($p<0.029$) by 1.63 fold in soil B. Soil C did not affect the concentration of irrigation TDW after 458 days. In addition, the concentration of TNK in TDW after 458 days of irrigation was significantly higher in water infiltered through soil A than the corresponding TDW that infiltered through soil B ($p<0.001$) or soil C ($p<0.002$). In addition, TNK concentration was significantly higher in TDW infiltered through soil C ($p<0.011$) than the TDW infiltered though soil B. The NH_3 concentration in TDW after irrigation for 458 days was slightly increased by 1.2-1.72 folds but only was significant when TDW infiltered through soil C ($p<0.011$). The concentration of NH_3 in TDW also showed significant differences by soils A, B and C ($p<0.028$ between A and B; $p<0.028$ between A and B) with the following rank order C> B> A.

In addition, the quality of TDW was checked by biochemical oxygen demand (CDO5), chemical oxygen demand (CDO) and total organic carbon (TOC) before, during and after irrigation for 458 days (Fig. 8). Results indicated that BOD5 in TDW either slightly increased by 1.05 fold in TDW infiltered through soil C or decreased by 1.17-1.4 fold when it infiltered through soils A and B. However, the differences between the BOD5 contents of water before or after irrigation were significantly different (Fig. 8A). In addition, soils A, B and C did not affect the BOD5 contents of TDW after infiltered through soils. The concentration of CDO in TDW increased

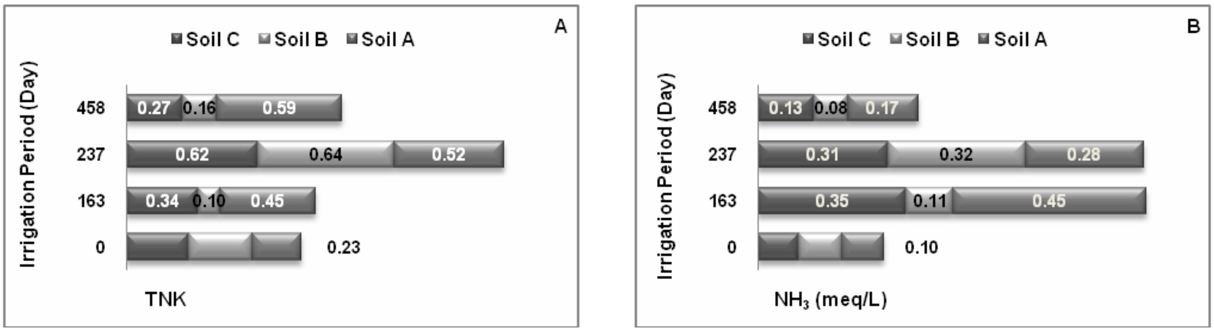


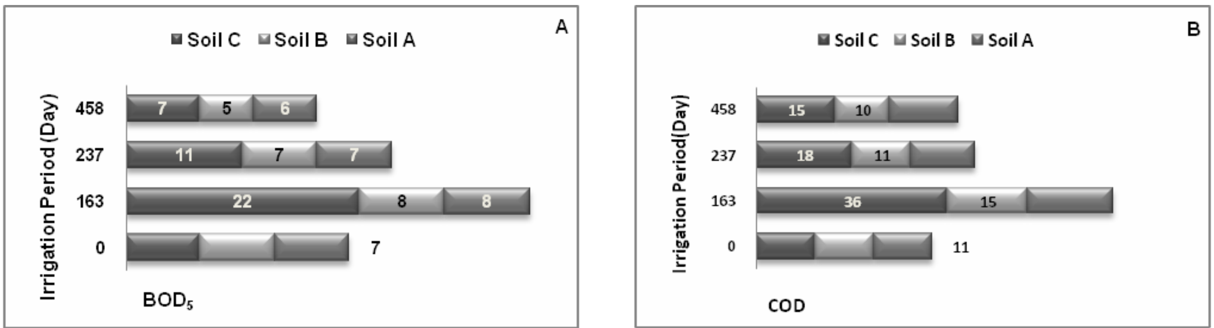
Fig. 7. TNK (A), NH_3 (B) profiles of TDW after passing through soil samples A, B and C.

Standard deviation [t-test- between 0 & 458 days]

TNK (A)- A = 0.044-0.154[p< 0.006]; soil B = 0.026-0.087[p< 0.029]; and soil C = 0.01-0.139[p< 0.135].

Standard deviation [t-test- between 0 & 458 days]

NH_3 (B)- soil A = 0.01-0.10[p< 0.070]; soil B = 0.006-0.49[p< 0.158]; and soil C = 0.01-0.05[p< 0.108].



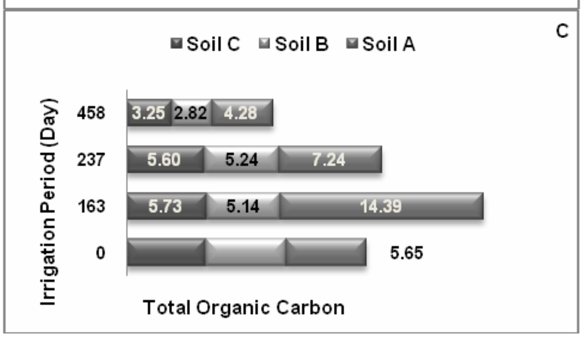


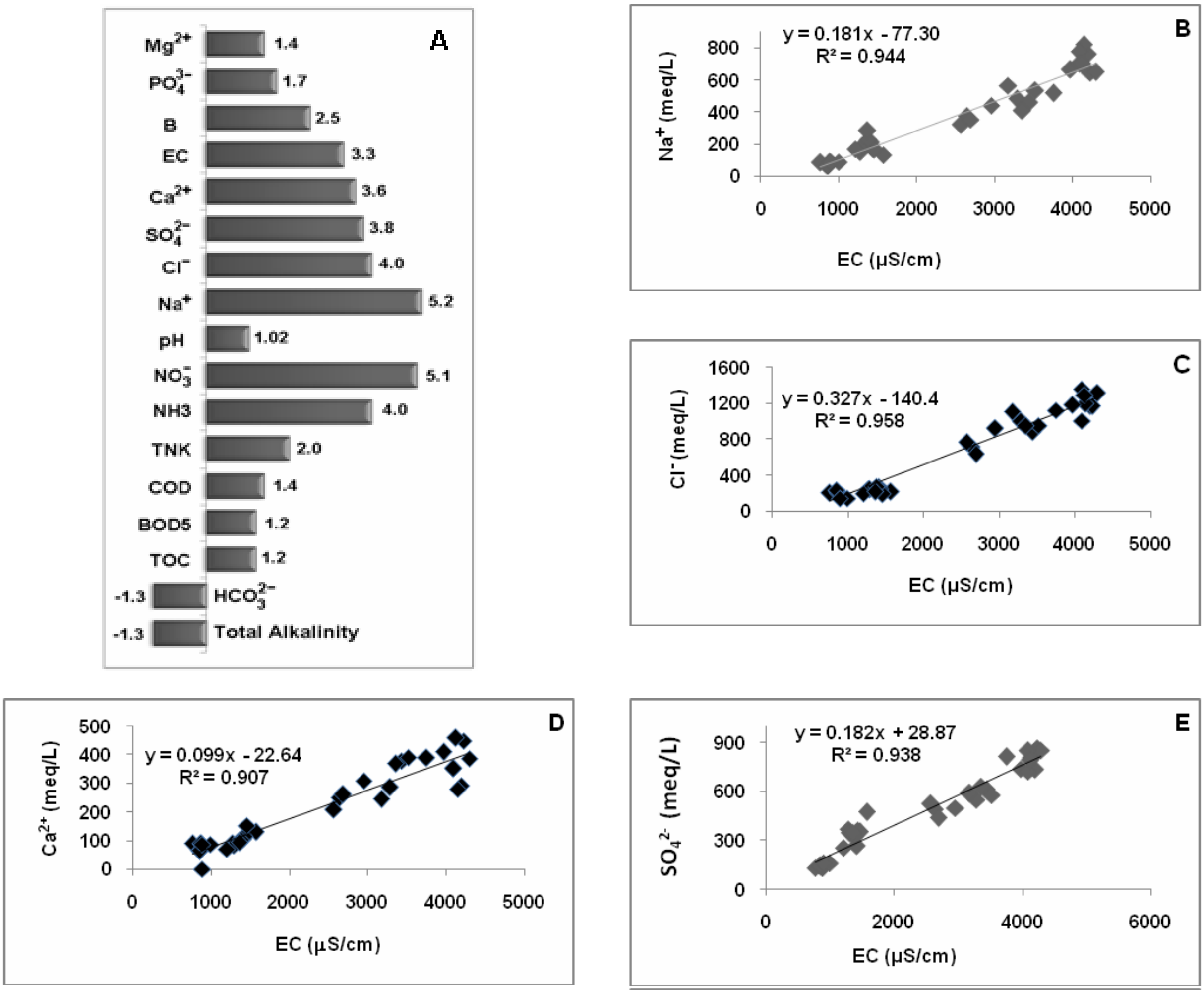
Fig. 8. COD_5 (A), COD (B), and Total organic carbon (C) profiles of TDW after passing through soil samples A, B and C.

Standard deviation [t-test- between 0 & 458 days]

BOD5 (A)- soil A = 1.0-2.0[p< 0.239]; soil B = 1.0-3.0[p< 0.239]; and soil C = 1.0-8.19[p< 0.434].

COD (B)- soil A = 1.0-2.65[p< 0.113]; soil B 1.0-5.0= [p< 0.311]; and soil C = 1.0-5.0[p< 0.010].

Total organic carbon (C)- soil A = 0.95-3.31[p< 0.115]; soil B = 0.828-2.521[p< 0.0625]; and soil C = 0.895-1.960[p< 0.088].



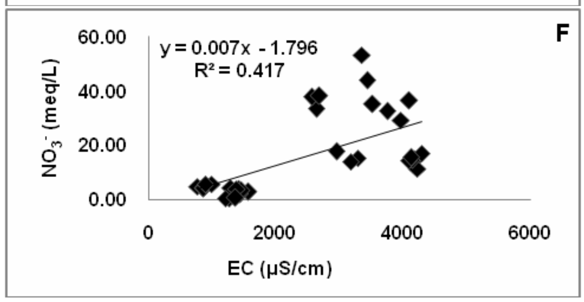


Fig. 9. (A) The concentration changes (by fold) of TDW chemicals before and after irrigation for 458 days. The correlation between EC and the following ions: Na^+ (B), Cl^- (C), Ca^{2+} (D), SO_4^{2-} (E) and NO_3 (F). Correlation Coefficient: EC and Na^+ = 0.972; EC and Cl^- = 0.979; EC and Ca^{2+} = 0.954; EC and SO_4^{2-} = 0.969; EC and NO_3^- = 0.628; Data represents the average of 27 values (each 9 represents values of a chemical that infiltered through soils A, B and C)

by 1.18 fold, when infiltered through soil A, but soil B decreased CDO values by 1.10 fold and increased significantly ($p < 0.01$) by 1.36 fold when infiltered through soil C. The effect of soil on the content of CDO of TDW indicated that TDW contained significantly ($p<0.019$) more CDO when infiltered through soil C than soil B. The contents of CDO in TDW is ranked by soil type as C>B>A. The values of total organic carbon also increased by 1.32-1.74 fold when infiltered though soil A, B and C but no significant differences occurred either between before and after irrigation or by soil type. In addition, TDW after passing through soil A, B and C did not show *E. coli* or coliforms bacteria contamination.

Appraisal the Implication of TDW on groundwater

In order to assess the implication of TDW prolonged irrigation on the quality of groundwater in Riyadh areas, data of the chemical and biochemical analyses of water samples infiltered through soil A, B

Table 2. The concentrations of chemicals for the Drainage water, TDW before and after irrigation*

	TDW (mg/L)		Ground-water (mg/L)**		TDW (mg/L)*****		Ground-water (mg/L)[2]
	before irrigation	after irrigation			before irrigation	after irrigation	
PH	7.90	7.77	7.14	Na^+	267.0	384	1245.00
Soluble salts***	561.00	1824.00	4500.00	Ca^{2+}	1583.0	5713	422.00
Hardness as$CaCO_3$****	5050.00	15835.00	31094.00	Mg^{2+}	267.0	384	200.00
Total Alkalinity	55.00	44.00	444.00	Cl^-	7013.0	26979	1877.00
NH_3	1.80	7.00	1.00	SO_4^{2-}	7012.0	26979	1156.00
TKN	0.30	0.60	12.80	HCO_3^{2-}	4027.0	3203	532.00
BOD5 days	7.00	8.30	129.22	PO_4^{3-}	3.8	6	0.37
COD	11.00	15.00	246.72	B^{3-}	8.0	21	1.52
TOC	5.65	6.90	91.05	NO_3^-	302.0	1538	21.00

* Values are average of 27 measurements (same as in figures 2-8), 9 from each TDW sample after infiltered through soil A, B or C; ** average of 36 values, 12 for each site. Samples of under groundwater were collected and analysed for their chemical/biochemical analyses between September 2005 and August 2006; *** Soluble Salts (mg/L) = EC (µS/cm) x 0.64; **** Hardness as$CaCO_3$ = (Ca^{2+} + Mg^{2+}) x 50; ***** mg/L = meq/L x Milliequivalent weight of individual ion

and C were combined and compared with the corresponding analyses for the groundwater in the same area. Results in Figure 9A indicate that the infiltered TDW though the three soils A, B and C contained more chemicals than in the original TDW contents by 1.2 to 5.2 folds. Both total alkalinity and HCO_3^{2-}, however, were down by 1.3 fold. The increase in the concentration of chemicals follows the following order: $Na^+ > NO_3^- > Cl^-/NH_3 > SO_4^{2-} > Ca^{2+} > B >$ EC > TNK > $PO_4^- > Mg^{2+}$/COD > BOD5> total organic carbon (Fig. 9A). These results may agree with the previous study on the effect of TDW prolonged irrigation on soil chemical and physical characteristics (Al-Othman, 2008). The previous data indicated that soil contents of salts (EC), Na^+, Ca^{2+}, Cl^- and SO_4^{2-} were decreased significantly after 458 days irrigation with TDW (Al-Othman, 2008). It is important to note that each soil column contained 5260 kg of soil and allowed 1243.39L of TDW to drain, hence the increase level of salts in the infiltred TDW, through soils A, B and C could be attributed to the lost of chemicals from soils. Generally, salts are more readily to leach in sandy textured soils than fine textured soils. In this respect, there is often close connection between irrigation and the ground water which is influenced by soil texture that control infiltration. Soils in Riyadh area are characterised by sandy texture, hence two factors can adversely affect groundwater; first the increase of water infiltration rate, and leaching element from soil, hence, increasing the risk of groundwater contamination. In addition, these chemicals showed different levels of positive and negative correlations (Figure 9B-F). Interestingly, EC showed strong correlation with Na^+, Cl^-, SO_4^{2-}, Ca^{2+}, NO_3^- (Figure 9B-F).

Table 2 compares the TDW, infiltered TDW through soils A, B and C and the groundwater in Riyadh area by their chemical and biochemical compositions. Generally, both types of water contained high amount of chemicals which can be classified as poor quality for irrigation and drinking. According to Cowardin classification system (Cowardin et al., 1979), water containing > 40mg/L is classified as hypersaline. Results in Table 2 clearly indicates that the soluble salts concentration has not only exceeded Cowardin classification, but also the general limits guideline for irrigation for salt sensitive (435mg/L) and moderately (870mg/L) sensitive crops (Watling, 2007). The soluble salts in groundwater was higher that infiltred TDW by 2.5 folds. In addition, water hardness and total alkalinity showed high levels in drainage and ground waters. In addition, cationic and anionic ions were at high concentrations agreeing with the measurements of soluble salts and hardness of drainage and underground waters (Table 2). Although both types of water can be classified as poor quality, the infiltered TDW can significantly increase the level of Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^{2-}, PO_4^{3-}, B and NH_3 in the groundwater. The NO_3^- concentrations in the infiltered TDW contained 1535mg/L which is higher than its concentration in the groundwater by more than 73 folds.

In conclusion, the results presented here have indicated that using treated domestic wastewater can contribute to more quality deterioration if it reach to the underground. Therefore, strict measures should be taken in using TDW.

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تأث الري   ياه الصرف الصحي ا عا ة على نوعية مياه الصرف باستخدام نظام ا اكاة

أ د بن عبدالر ن العثمان

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كلمات مفتاحية: الري- مياه الصرف الصحي- مياه جوفية- نظام المحاكاة.

ملخص البحث: تعتبر المياه من القضايا الهامة في المملكة العربية السعودية لمحدودية الموارد المائية التقليدية. وتعد مياه الصرف الصحي المعالجة مصدراً مائياً غير تقليدياً يمكن الإعتماد عليه في تلبية الاحتياجات المائية في القطاع الزراعي والصناعي حيث بدأ استغلال مياه الصرف الصحي المعالجة لأغراض ري المزارع في منطقة الرياض بشكل واسع في ظل واقع يشير إلى زيادة تلوث المياه الجوفية نتيجة لذلك.

تم اجراء هذه الدراسة باستخدام نموذج محاكاة لمقطع التربة مجهّز بأنظمة ري وصرف ومراقبة حركة المياه ومكوّن من ثلاثة أعمدة يحتوي كل منها على نوع من التربة بهدف تحديد مدى تأثير مياه الصرف الصحي المستخدمة في الزراعة على نوعية المياه الراشحة. عينات المياه المتسربة خلال الترب الثلاث تم تحليلها كيمياويا (pH، القلوية الكلية، EC، SAR) خلال فترة الري البالغة ٤٥٨ يوم. كما تم تحليل الايونات الموجبة (Na^+, Ca^{2+}, Mg^{2+})، الايونات السالبة ($CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, B^{3-}, PO_4^{3-}$)، ايونات المركبات النتروجينية (NO_3^-, TNK, NH_3)، الحاجة للأوكسجين (COD, BOD) والمحتوى الكلي العضوي. أظهرت تحليلات عينات المياه تغيرات احصائية ($p<0.000 – p<0.045$) في تركيز ومحتوى المواد الكيميائية. التغيرات في المحتوى الكيميائي لعينات المياه الراشحة (الصرف) يمكن إدراجه بثلاث حالات. أظهرت الأولى انخفاض تركيز القلوية الكلية والبيكاربونات. الحالة الثانية زيادة ملحوظة في تراكيز EC, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^- وSAR. بينما أظهرت الحالة الثالثة زيادة ثم نقصان مع اضافة مياه الري في تراكيز PO_4^{3-}, TNK, NH_3, COD, BOD والمحتوى العضوي للكربون. كما أظهرت تحليل عينات المياه الراشحة خلال الترب الثلاث A ، B، و C نمط متشابه من الزيادة أو النقصان. وقد يعزى زيادة تركيز محتوى الايونات في المياه النافذة خلال الترب الثلاث إلى إزالة تلك الأيونات من الترب A ، B، و C. كما تعزى هذه النتائج إلى قوام التربة باحتوائها على نسبة عالية من الرمل، لذا فان سرعة نفاذ المياه خلال الترب وسرعة التبخر يمكن اعتبارهما من العوامل التي قد توثر سلباً على المياه الجوفية في منطقة الرياض والتي وجدت هنا باحتوائها على تركيز عالي من الأملاح والأيونات.