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Correlation Between Some Groundwater Chemical Parameters and Soil Texture Index of Different Soils Irrigated with Treated Domestic Wastewater

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ABSTRACT

The study was carried out to determine the correlation between soil texture index of different soils and groundwater water chemical parameters during irrigation with Treated Domestic Wastewater (TDW). Mean calcium (Ca) contents of groundwater ranged from 308-432 mg L⁻¹. The relationship between soil texture index and calcium contents of groundwater was negative ($r = -0.908$). Mean sulphate contents ranged from 755-833 mg L⁻¹ and the relationship was negative with STI (soil texture index) as indicated from the correlation coefficient (r) value of -0.939. The HCO₃ contents increased significantly with an increase in the soil texture index with R² value of 0.9516. This suggested that soil type clearly affects the HCO₃ contents of groundwater. The total alkalinity ranged from 20-30 mg L⁻¹ and is significantly affected by Soil Texture Index (STI) with a coefficient of determination value of 0.9516. Overall, correlation between STI and some ions was positive (HCO₃, total alkalinity and pH) while it was negative for Ca and SO₄ ions. The STI significantly affected the concentration of some chemical parameters of groundwater and showed high potential for more investigations on different types of soils and irrigation waters to assess groundwater contamination resulting from treated domestic wastewater irrigation.

Key words: Soil texture index, treated domestic wastewater, irrigation, correlation, groundwater

INTRODUCTION

In Saudi Arabia, water needs are increasing due to rapid growth of population (Al-Saud, 2010). Besides, agricultural activities are also increasing around the country to boost agricultural production by bringing new land under cultivation (Al-Ahmadi, 2005). Currently, main source of irrigation is the groundwater (Al-Omran *et al.*, 2005). Such factors and their interactions result in a complex groundwater quality (Hussein, 2004). Al-Othman (2009) observed that although, the Treated Domestic Wastewater (TDW) irrigation did not mainly affect the physical and chemical properties of soil under investigation but is likely to contaminate the groundwater on long term basis in Riyadh region.

Reuse of domestic treated wastewater is a potential alternate irrigation source for agricultural expansion thus restricting the use of potable water for irrigation. Because, it is considered that preservation of good quality water resources is essential for economical and ecological development of Saudi Arabia. Also, it is important to identify the best sustainable irrigation management tools with minimum possible undesirable effects on soil physical and chemical properties caused by the specific characteristics of wastewater irrigation as well as its effect on groundwater quality. Many studies have already reported the effects of irrigation with wastewater on soil agroecosystems and

Na⁺ excess is generally indicated as a major problem (Bond, 1998). With regard to the soil physical properties, the main concern is the deep percolation losses of contaminated water to groundwater. Furthermore, a significant relation between soil texture and chemical properties of groundwater would be useful to determine the main effects of this irrigation practice on the groundwater quality.

Correlation analysis is a useful statistical tool to determine the extent to which changes in the value of an attribute (such as pH) are associated with the changes in another attribute (such as soil texture index). The data for a correlation analysis consists of two input columns (independent variable and the dependent variable).

Teso *et al.* (1996) developed a logistic regression model containing independent variables related to the soil texture. The dependant variable was defined as the contamination status of soil sections and groundwater vulnerability was thus assessed through the estimation of a section's likelihood of its containing a contaminated well.

Al-Omran *et al.* (2005) investigated the groundwater quality in Riyadh region. Water samples were collected from 200 wells around Riyadh region. Based on the values of EC, these wells were divided in four groups based on water quality. The nitrate contents ranged from 0-2.55 mg L⁻¹.

Al-Omran (1987) reported that in arid area such as Saudi Arabia where irrigation water (ground water) is commonly of moderate saline category. He reported that water research studies in Saudi Arabia clearly showed sever depletion of groundwater and deterioration of ground water quality in certain area of the country, where salinity became a major problem in old agricultural oasis. Therefore, applied research program related to water saving, conservation and salinity in agriculture is essential, where agricultural activities account for more than 85% of the total water consumed. Khanfar (2008) reported that groundwater is the only source of water to meet human needs especially in arid regions like Saudi Arabia where the water resources (surface or underground) are limited, rainfall is sporadic and the potential evaporation rate is very high.

Al-Omran *et al.* (2010) showed that low quality water for irrigation can impose a major environmental constraint to crop productivity. Moreover, water quality is one of the main characteristics in the planning stages which has to be simulated and predicted. If predicted quality is not satisfying, some changes or precautionary measures must be implemented (Misaghi and Mohammadi, 2003). The main aim of this study was to use a systematic correlation and regression study among different groundwater quality parameters and the soil texture index of different soils under irrigation with treated domestic wastewater. Also to look into the potential benefits of applying different linear regression equations for predicting the groundwater quality as an approach which can be applied in any other locations.

MATERIALS AND METHODS

The linear regression approach was applied to develop a relationship between groundwater quality parameters and soil texture index of different soils irrigated with treated domestic wastewater. To achieve the study objectives, regression equations were computed taking different water quality constituents as dependent variable and the Soil Texture Index (STI) as an independent variable. A typical linear regression model was used with the expression of:

$$Y = a + bX \quad (1)$$

where, Y is the dependent variable, X is an independent variable and a, b are regression coefficients.

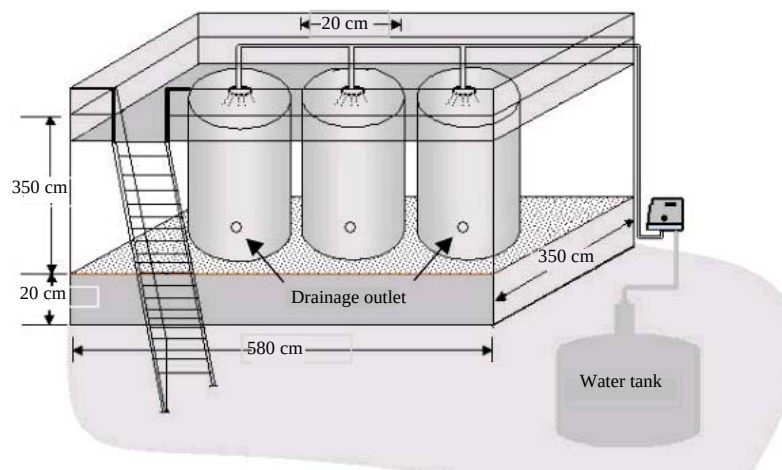


Fig. 1: Soil simulation model used in the study

Table 1: Mean physical fractions of experimental soils before and after 458 days of treated domestic wastewater (TDW) irrigation

Sand (%)		Silt (%)		Clay (%)	
I	II	I	II	I	II
80.9	86.19	5	6.00	14.1	7.81
88.4	81.85	2.5	7.00	9.1	11.15
90.9	81.52	0	6.33	9.1	12.15

I: Before irrigation, II: After 458 days of TDW irrigation

The study was carried at Riyadh using soil simulation model. The soil simulation model consisted of a soil put in concrete cylinder (Fig. 1). The diameter of concrete column was 1.58 m and packed with three different types of soils (sandy loam, loamy sand and sandy). The soil was added in successive layers, each of 20 cm height to each column over 40 cm bed of stones. The total amount of soil came to 5260 kg in each column with a total height of 3.10 m. The bulk density of soil in the column was maintained as 1.5 g cm^{-3} . Mean physical fractions of experimental soils before irrigation are given in Table 1.

The Treated Domestic Wastewater (TDW) was obtained from wastewater station of King Saud University, Riyadh. Mean chemical composition of TDW is presented in Table 2. The water was added slowly approximately over 2 days period until it started flowing from the drainage outlet (Fig. 1). Then the TDW was added in 8 periods on different dates starting from 27 March, 2006 until 16 May, 2007 (Table 3). The total quantity of applied TDW was calculated according to the rate of water evaporation per day in Riyadh area and assuming application efficiency of 65% (Al-Ghobari, 2007). The dates of water addition and the amount of rainfall during experimental duration is presented in Table 4.

However, the total quantity of applied TDW was calculated as:

$$\text{Amount of added water} = \left(\frac{\text{WE}}{\text{AE}} + \text{rainfall} \right) \frac{\text{mm}}{\text{day}} \quad (2)$$

Table 2: Mean chemical composition of treated domestic wastewater from King Saud University wastewater station

Parameter	Value
pH	7.90
Electrical conductivity	876 $\mu\text{S cm}^{-1}$
Total alkalinity	55 mg L^{-1}
Calcium	79 mg L^{-1}
Magnesium	22 mg L^{-1}
Sodium	81 mg L^{-1}
Bicarbonate	66 mg L^{-1}
Chloride	200 mg L^{-1}
Sulphate	146 mg L^{-1}
Nitrate	4.86 mg L^{-1}
Ammonium	0.10 mg L^{-1}
Phosphate	0.12 mg L^{-1}

Table 3: Amount of water evaporation in Riyadh area

Month	Water Evaporation (WE) (mm day^{-1})
January	4.88
February	7.07
March	9.48
April	12.15
May	14.76
June	17.60
July	18.39
August	17.22
September	14.66
October	11.03
November	6.56
December	5.15

Table 4: Dates of water addition and amount of rainfall during experimental period

Water added period	Date		Rainfall amount (mm day^{-1})
	Starting	Finishing	
1	27/3/2006	25/4/2006	20.6
2	5/5/2006	6/6/2006	----
3	17/6/2006	26/7/2006	-----
4	5/8/2006	8/10/2006	-----
5	18/10/2006	11/12/2006	34.54
6	21/12/2006	21/1/2007	12.4
7	31/1/2007	13/3/2007	1.26
8	23/3/2007	16/5/2007	19.0

where, WE is water evaporation per day in Riyadh area as listed in Table 3 and AE is application efficiency of water.

Oskoui and Harvey (1992) developed a formula to estimate Soil Texture Index (STI) as follows:

$$\text{STI} = \frac{\log(S_i^{C_i})}{100} \quad (3)$$

RESULTS AND DISCUSSION

pH: Mean pH ranged from 7.40-8.26. The pH is an important index of acidity or alkalinity of groundwater. A number of minerals and organic matter interact with one another to give the resultant pH of the sample (Jothivenkatachalam *et al.*, 2010). Figure 2 illustrates the variation of pH with STI with a coefficient of determination (R^2) value of 0.7522. This would mean that around 75% variability in soil pH is due to STI. It is also clear that when water passes through different soils, the final groundwater pH is affected due to solubilization of various salts present in soil. It is evident from Fig. 2 that low pH is related to low STI and might be due to silt fraction.

Total alkalinity: The total alkalinity ranged from 20-30 mg L⁻¹. Figure 3 illustrates the variation of total alkalinity with STI. The coefficient of determination (R^2) is 0.9516. This would mean that upto 95% variability in total alkalinity is due to STI i.e., if total STI is high, the total alkalinity of water will also be high. Because when the water passes through different soils, the total alkalinity of final groundwater is affected. However, the correlation was positive between total alkalinity and STI.

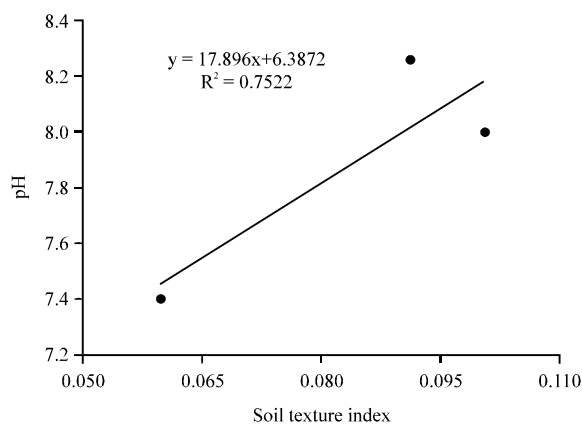


Fig. 2: Relationship between soil texture index at 133 cm soil depth and pH of groundwater

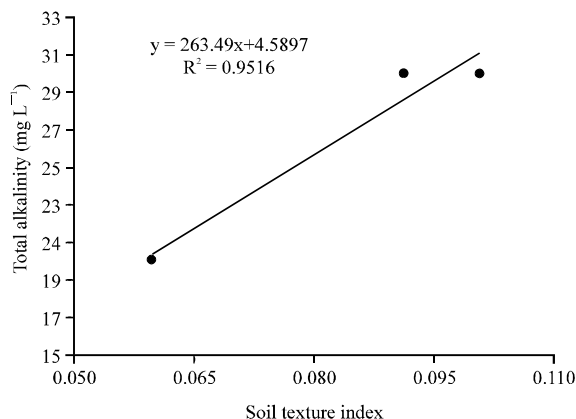


Fig. 3: Relationship between soil texture index at 133 cm depth of soil and the total alkalinity of groundwater

Calcium: Mean calcium (Ca) contents of groundwater ranged from 308-432 mg L⁻¹. The relationship between soil texture index and calcium contents of groundwater was negative ($r = -0.908$) which means that an increase in the Soil Texture Index (STI) will decrease the Ca contents of groundwater (Fig. 4). The high value of coefficient of determination (R^2) (0.8252) showed that soil fractions clearly affected the calcium concentration of groundwater which might be due to the adsorption of Ca on soil exchange complex thus resulting in low Ca contents in groundwater.

Bicarbonate: Mean bicarbonate (HCO₃) contents of groundwater ranged from 24-36 mg L⁻¹. The regression analysis between soil texture index and bicarbonate contents of groundwater showed that HCO₃ contents increased significantly with an increase in the soil texture index (Fig. 5) as evident from the R^2 value of 0.9516. This indicated that soil type clearly affects the HCO₃ contents of groundwater.

Sulphate: Mean sulphate contents ranged from 755-833 mg L⁻¹. The sulphate contents of groundwater showed negative correlation with STI with the coefficient of determination (R^2) value

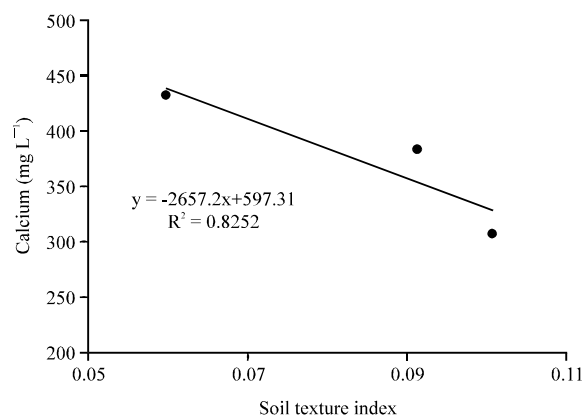


Fig. 4: Relationship between soil texture index at 133 cm soil depth and calcium contents of groundwater

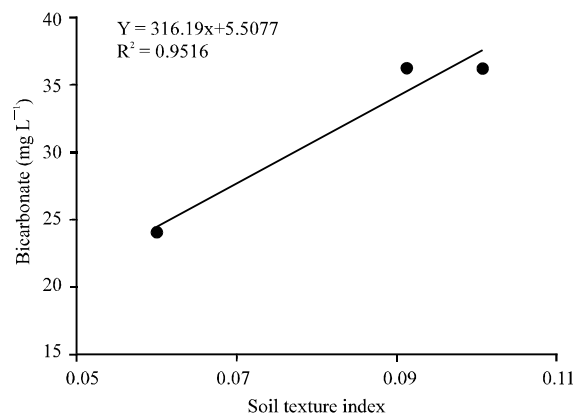


Fig. 5: Relationship between soil texture index at 133 cm soil depth and bicarbonate of groundwater

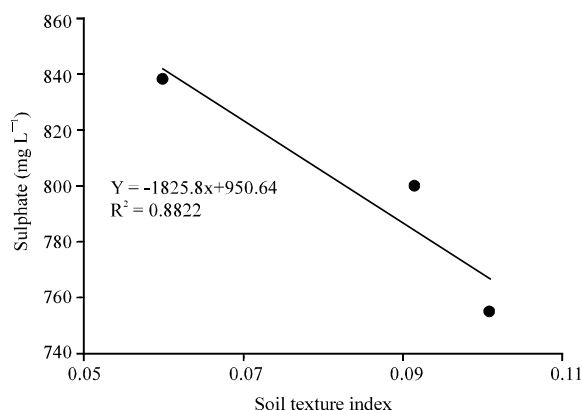


Fig. 6: Relationship between soil texture index at 133 cm soil depth and sulphate in groundwater

Table 5: Linear correlation coefficient and regression equations for some pairs of parameters which have significant value of correlation

Pair of parameters	Correlation coefficient (r)	Regression equation
pH and STI	0.8673	$Y_1 = 6.387 + 17.896x$
Total alkalinity and STI	0.9755	$Y_2 = 4.5897 + 263.49x$
Calcium and STI	-0.9084	$Y_3 = 597.3 - 2657.2x$
Bicarbonate and STI	0.9755	$Y_4 = 5.507 + 316.19x$
Sulphate and STI	-0.9393	$Y_5 = 950.64 - 1825.8x$

Y_1 : pH, Y_2 : Total alkalinity, Y_3 : Calcium, x : STI, Y_4 : Bicarbonate, Y_5 : Sulphate

of 0.8822 (Fig. 6). The negative correlation ($r = -0.939$) might be due to the adsorption of sulphate ions on soil exchange complex thus resulting low contents of sulphate in the drainage water which affected the total sulphate contents of groundwater.

The regression analysis carried out on different water quality parameters and Soil Texture Index (STI) showed high level of significance as indicated from high values of correlation coefficient (r) and coefficient of determination (R^2). The regression equations obtained from the analysis are given in Table 5. However, different dependent parameters of water quality could be calculated using the regression equation by substituting the values for the independent parameters in the equations. Similar views were reported by many researchers who stated that groundwater quality depends on a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water and inputs from sources other than water-rock interaction (Domenico, 1972; Schuh *et al.*, 1997). The study results show similarity with the findings of Gupta *et al.* (2009) who reported that quality of groundwater depends on various chemical constituents and their concentration which are mostly derived from the geological data of the particular region.

CONCLUSIONS

The main objective of this study was to map the relationship between some groundwater quality parameters and soil texture index of different soils irrigated with treated domestic wastewater using regression analysis. The results from regression analysis provided different empirical equations for pH, total alkalinity, calcium, bicarbonate and sulphate. The correlation was negative between calcium (Ca) and sulphate (SO_4) ions with STI while it was positive for total alkalinity and HCO_3 parameters with STI with high values of correlation coefficients.

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