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Groundwater Quality of Two Soil Types Irrigated With Treated Wastewater

[1]*E.M. Abd El-Lateef,* [2]*A.A. Yaseen,* [1]*M.S. Abd El-Salam,*
[1]*A.K.M. Salem,* [1]*T.A. Elewa,* [3]*Asal M. Wali and* [4]*Aml R.M. Yousef*

[1]Field Crops Res. Dept., Agric. Biol. Res. Inst.,
National Research Centre, 33 El-Buhouth St. Dokki, Cairo, Egypt
[2]Plant Nutrition Dept., Agric. Biol. Res. Inst.,
National Research Centre, 33 El-Buhouth St. Dokki, Cairo, Egypt
[3]Plant Production Dept., Arid Lands Cultivation Res. Institute
at (SRTA-City), New Borg El-Arab, Alex. 21934, Egypt
[4]Horticultural Crops Technology, Agric. Biol. Res. Inst.,
National Research Centre, 33 El-Buhouth St., Dokki, Cairo, Egypt

Abstract: In order to determine Heavy metals and Nitrate concentration of groundwater of two soil types irrigated with treated wastewater large scale field trials were carried out in the summer and winter seasons in two sites located about 20 km northeast of Cairo. The first site is located inside Gabal El Asfar farm, the soil is rich in organic matter and fertile and can be classified as loamy-sandy soil. The same area was chosen in the second site and is located inside El Berka wastewater treatment plant; the soil is gravelly sand and could be classified as sandy soil. The experimental area was divided into large experimental units according to the crop and the irrigation method. Groundwater monitoring wells included nine wells installed at Gabal El Asfar, with six to the top of the water table (mean depth 5 m) and three deeper wells paired with three of the shallower wells (mean depth 7.8 m). At El Berka, seven wells were installed around the trial area, five to the top of the water table (mean depth 15.4 m) and two deeper wells (mean depth 17.5 m). Samples of groundwater were taken from all of the monitoring wells using a submersible pump. The samples were analyzed for a range of chemical parameters. The groundwater under both sites were similar and of poor quality, the data displaying large temporal and spatial variations and would be unsuitable for potable or irrigation purposes. Long-term monitoring would be necessary to determine any effects on groundwater quality since the water table was relatively deep (5 – 8 m) and the quality of the TWW was marginally better than the groundwater. It is difficult to demonstrate from this short-term monitoring program that irrigation with treated effluent has affected groundwater quality. If there were any effects, this would be shown by the most soluble and mobile components, such as total dissolved solids and nitrate.

Key words: Irrigation · Soil types · Groundwater · NO_3 microbiology · TWW · Heavy metals

INTRODUCTION

In Egypt, the annual water demand exceeds the available fresh water by 6 billion $m^3 year^{-1}$ [1-2]). Water reuse is arising because of ambitious land reclamation programs, growing populations, increasing rural development and crop demands. However, there are attendant risks involved with reuse to the plant, soil, groundwater and health [3-6].

WRc (2001) [7] estimated that wastewater could offer about 30% of the crop requirements of N and 100% or more from crop requirements of K in sandy calcareous soil in Alexandria. However, they pointed out that in the long- term monitoring for potential toxic elements (mainly heavy metals) and nitrates in groundwater and pathogen survival in the adjacent soils exposed to agricultural activities like irrigation with treatead wastewater in such soils. Therefore, the aim of this work

Corresponding Author: Dr. E.M. Abd El-Lateef, Field Crops Res. Dept., Agric. Biol. Res. Inst., National Research Centre, 33 El-Buhouth St. Dokki, Cairo, Egypt.

is to evaluate the effect of groundwater quality of two soil types irrigated with treated wastewater. This paper addresses a wastewater reuse study for the Cairo-East Bank in Egypt.

MATERIALS AND METHODS

Large scale field trials were carried out in summer and winter seasons in two sites located about 20 km north east of Cairo. The first site is located inside Gabal El-Asfar farm, the soil is rich in organic matter and fertile and can be classified as loamy-sandy soil. The same area was chosen in the second site and located inside El-Berka wastewater treatment plant; the soil is gravelly sand and could be classified as sandy soil. The experimental area was divided into large experimental units according to the crop and the irrigation method. The design of each trial was based on 16 large plots, eight of which received wastewater only and the other eight received wastewater plus supplementary fertilizer to be adjusted for each crop according to the normal recommended rates and for each site condition. Four crops were planned to grow on each site, thus there were two replicate plots for each crop and treatment.

Table 1: Type, Number and Depth of Groundwater Monitoring Boreholes at Gabal El Asfar and El Berka Sites

Type of borehole	Gabal El Asfar (Loamy soil)	El-Berka (Sandy n soil)
Single	WG3 - 4.13 m	WB1 - 15.18 m
	WG5 - 5.05 m	WB5 - 15.24 m
	WG9 - 5.15 m	WB9 - 16.37 m
Twin	WG1 - 5.51 m	WB3 - 15.28 m
	WG2 - 8.89 m	WB4 - 17.00 m
	WG7 - 4.71 m	WB7 - 14.70 m
	WG8 - 7.45 m	WB8 - 18.02 m
	WG11 - 5.55 m	
	WG12 - 7.08 m	

Crop selection included range of food, fodder and, industrial (fiber and oil) crops according to [8]. The sampling program included treatead wastewater TWW and groundwater quality. Treated wastewaters were analyzed according to [9]. All samples were analysed according to the common standard methods. Groundwater monitoring wells (Table 1) were installed the Research Institute for Groundwater (RIGW). Nine wells were installed at Gabal El Asfar, with six to the top of the water table (mean depth 5 m) and three deeper wells paired with three of the shallower wells (mean depth 7.8 m). At El-Berka, seven wells were installed around the trial area, five to the top of the water table (mean depth 15.4 m) and two deeper wells (mean depth 17.5 m). Samples of groundwater were taken from all of the monitoring wells using a submersible pump. The samples were analyzed for a range of chemical (pH, Total NPK and heavy metals and microbiological (salmonilla and total coliform counts) parameters according to [9]. The obtained results were subjected to the proper statistical analysis using MSTAT-C program [10].

RESULTS

Treated Wastewater Quality: Final wastewater samples collected from Gabal El-Asfar and El-Berka WWTPs over the period of the trials were monthly routinely analysed for nutrients and heavy metals. The results showed that the pH of the wastewaters was within the acceptable range for reuse, normally 6.5–8.5 according to the Egyptian decree for wastewater reuse (Decree 44, 2000) [11, 12]. It is apparent that the nutrient contents of the two wastewaters were broadly similar in their suitability for reuse. The concentrations of nitrogen and phosphorus were slightly smaller in Gabal El Asfar wastewater compared with El Berka (76%) but contained more potassium (138%). Thus El Berka contained similar concentrations of N to K, but Gabal El Asfar contained about twice as much K as N. It is worthy to mention that Considerable amounts of macronutrients (NPK) were applied to the grown crops through the treated wastewater irrigation: N (19–79%), P (23–181%) and K (85–357%) of the recommended fertilizer rates according to the crop and the experimental site. The heavy metal concentrations were very small in both wastewaters and are well below the limit values for secondary wastewater reuse, usually by at least one order of magnitude where the limit values of the heavy metals according to the Egyptian decree for wastewater reuse [11] are (0.01 for Cd and Cr; 0.2 for Cu, Ni and Mn, 0.05 for Co and 5mg kg^{-1} for Fe). The numbers of faecal coliforms found in both treated wastewater were at 10^6 MPN/L, far in excess of that permitted by the guidelines of [8] and salmonella were present in all samples. Nematode ova were found in all samples of treated wastewater in excess of the limit value for reuse (mean 24 ova/L at Gabal El Asfar and 49 ova/L at El Berka). Table 1 presents the mean concentrations of treated wastewater chemistry and microbiology.

Groundwater Quality: The data showed considerable spatial and temporal variation in the groundwater at both sites and this was most marked at El Berka. There was no discernible relationship between well location and

Table 2: Mean concentrations of treated wastewater chemistry and microbiology from Gabal El Asfar and El Berka WWTPs

	Gabal El-Asfar (Loamy soil)					El-Berka (Sandy soil)				
Parameters	Mean	Min.	Max.	n	CV%	Mean	Min.	Max.	n	CV%
pH	7.83	7.69	7.98	10	1.3	7.78	7.65	7.86	9	0.8
Total N	9.7	6.5	15.1	25	23.2	12.8	7.4	18.7	25	23.9
Total P	2.6	1.1	3.6	26	28.8	3.4	1.2	5.3	26	29.3
K	19.0	11.2	32.1	27	28.3	13.8	8.3	24.1	27	23.3
Fe	0.362	0.038	0.760	13	71.7	0.577	0.064	0.980	13	54.8
Mn	0.113	0.031	0.320	11	76.3	0.115	0.010	0.320	11	67.4
Cr	0.021	0.009	0.070	11	106.3	0.027	0.006	0.087	11	120.0
Ni	0.025	0.005	0.090	11	104.7	0.039	0.007	0.082	11	68.7
Zn	0.162	0.035	0.540	11	107.4	0.094	0.011	0.180	11	67.7
Cu	0.043	0.006	0.098	11	80.7	0.049	0.014	0.093	11	56.2
Cd	<0.005	<0.005	<0.005	13	-	<0.005	<0.005	<0.005	13	-
Pb	0.069	0.014	0.190	13	70.4	0.079	0.031	0.130	13	31.7
Mo	<0.01	<0.01	<0.01	11	-	<0.01	<0.01	<0.01	11	-
Co	0.01	0.01	0.01	11	-	<0.005	<0.005	<0.005	11	-
Salmonella	1.4	1	2	26	35.8	1.8	1	2	26	26.1
F. coliforms	11	0.5	28	24	56.1	35	3	82	24	71.7
Helminth	24	4	69	25	85.6	49	5	202	25	103.1

Units: All determinants in mg/L except: *EC* (dS/m); salmonella qualitative range 0 = absent, 1 = low, 3 = high; faecal coliform bacteria 10^5 MPN/100 ml; helminth ova/L.

Table 3: Overall mean concentrations of groundwater chemistry and microbiology at Gabal El-Asfar and El-Berka

	Gabal El-Asfar (Loamy soil)			El-Berka (Sandy soil)		
		Monthly mean range			Monthly mean range	
Parameter	Means of all wells	Minimum	Maximum	Means of all wells	Minimum	Maximum
Biological oxygen demand (BOD)	6.1	3.8	8.1	4.0	2.0	6.0
Chemical oxygen demand (COD)	11.3	8.6	14.5	13.4	3.6	130.0
Total soluble solids (TSS)	25.8	22.8	30.7	26.3	21.0	31.3
Total dissolved solids (TDS)	777	461	1060	1674	1247	3063
EC	1.17	0.72	1.66	2.34	1.87	2.99
Sodium adsorption ratio (SAR)	4.5	4.3	4.6	6.7	6.4	6.9
HCO_3	10.46	10.27	10.61	5.94	4.81	7.40
Total Kjldahl nitrogen (TKN)	4.55	4.19	4.96	3.85	3.53	4.40
NH_3	1.54	1.40	1.68	1.79	1.60	1.98
NO_2	<0.2	0.20	0.20	0.04	0.04	0.04
NO_3	46.8	32.0	61.9	72.7	44.1	127.3
SO_4	91	86	96	2410	1165	3821
Cl	88	74	102	413	316	482
PO_4	4.95	0.30	8.84	1.76	0.22	8.50
K	13.05	10.22	17.33	8.72	2.30	20.00
Ca	86.4	80.9	91.8	215	161	320
Na	77.2	62.7	99.6	457	387	1045
Mg	14.3	11.6	20.0	35.9	32.9	50.1
B	0.37	0.36	0.38	2.67	1.84	3.49
Fe	0.216	0.034	0.470	0.324	0.019	0.833
Mn	0.042	0.029	0.053	0.036	0.029	0.050
Cr	<0.002	0.007	0.007	0.016	0.003	0.027
Ni	0.010	0.008	0.015	0.009	0.006	0.020
Zn	0.131	0.020	0.263	0.315	0.095	0.700
Cu	0.132	0.032	0.300	0.165	0.005	0.505
Cd	<0.005	0.001	0.001	0.013	0.006	0.015
Pb	0.058	0.005	0.090	0.037	0.006	0.099
Salmonella	6	0	22	32	0	100
F. coliforms	863	227	2101	1440	0	4158
Helminths	0.2	0.0	0.8	0.5	0	3

Units: All determinants in mg/L except: *EC* (dS/m); salmonella % positive samples; faecal coliforms MPN/100 ml; helminth eggs/L

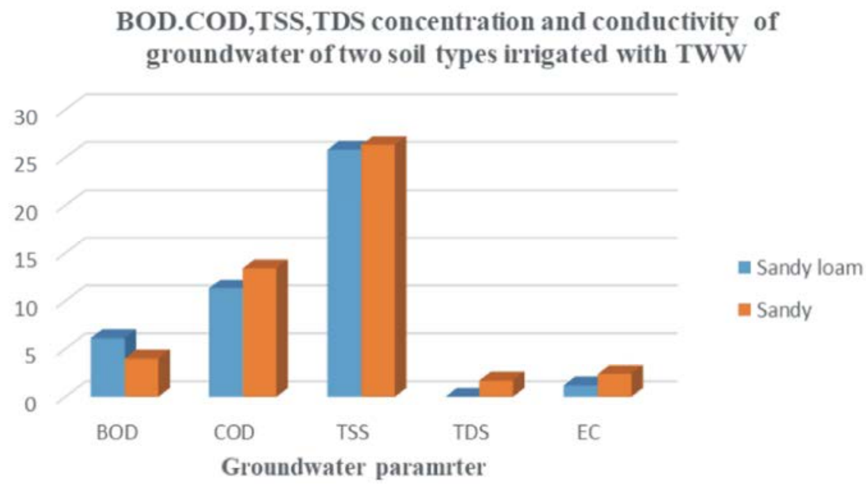

Fig. 1: Groundwater characteristics of two soil types irrigated with treated wastewater (TWW)

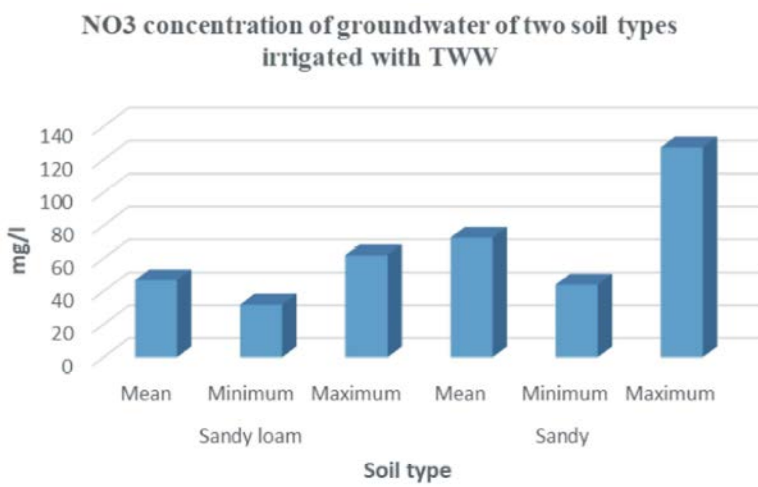

Fig. 2: Groundwater nitrate concentration of two soil types irrigated with treated wastewater (TWW)

irrigation of treated wastewater in the trials. The salinity of Gabal El-Asfar groundwater was less than half of that at El-Berka. Sodium and chloride ion concentrations were also much smaller than at El-Berka. Heavy metal concentrations in the groundwater of both sites were similar and small. The groundwater samples which have been examined for the presence of pathogenic bacteria (salmonella), faecal coliform bacteria and helminth ova indicated that the groundwater of both sites is contaminated by secondary treated wastewater irrigation. There was a seasonal effect of nitrate leaching following the peak irrigation period, with a lag phase before the nitrate reaches the groundwater. At the sandy soil, 10–57% of the samples from each well contained salmonella, whereas at the loamy soil, salmonella was not detected in five wells and the occurrence in the other four wells was only 10–20% of samples. The numbers of faecal coliforms were similar at both sites, in the range 10^2–10^3 MPN/100mL. Small numbers of parasite ova were also found in the majority of wells, with a greater number occurring at virgin soil. The groundwater under both sites was similar and of poor quality.

A comparison of the mean groundwater qualities of both sites is given in Table 3. Surprisingly, at the loamy sand soil the groundwater was notably less polluted than at the sandy soil, despite the long period of sewage irrigation on this site. There were larger concentrations of nutrients that would probably be derived form sewage irrigation, but all of the other parameters measured were similar to, or less than, those found at El Berka. The salinity of loamy sand soil groundwater was less than half of that at the sandy soil (777 mg TDS/l and 1.17 dS/m compared with 1674 mg TDS/l and 2.34 dS/m) and similar to that found in the effluent. Sodium and chloride ion concentrations were also much smaller than that at the sandy soil.

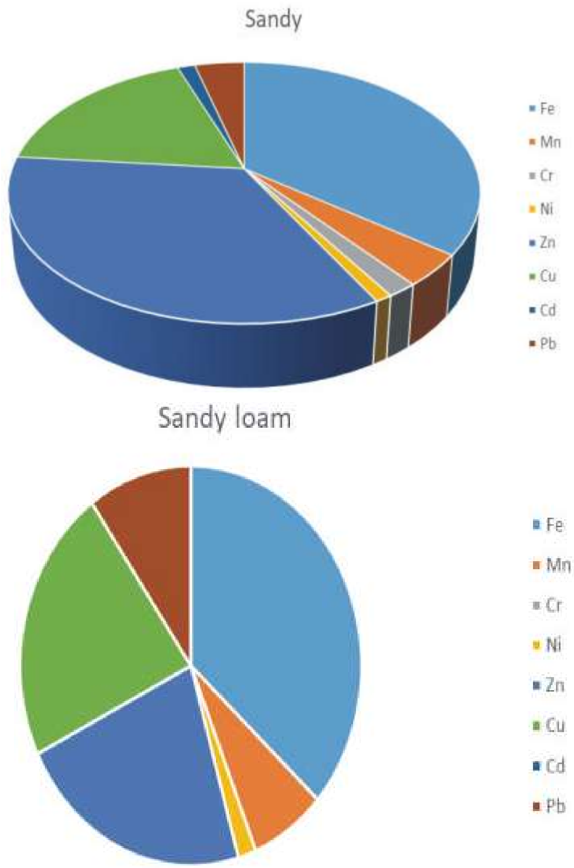

Fig. 3: Groundwater heavy metal concentration of two soil types irrigated with treatead wastewater (TWW)

It is difficult to demonstrate from this short-term monitoring programme that irrigation with treated effluent has affected groundwater quality. If there were any effects, this would be shown by the most soluble and mobile components, such as total dissolved solids and nitrate. These parameters were plotted to compare concentrations at each well over the sampling period (Figure 2 for TDS at the loamy sand soil and sandy soil, respectively and Figure 3 for nitrate, respectively).

Total dissolved solids in groundwater at Gabal El-Asfar, despite a few high values initially in Well WG12 (this is a deep reference well outside the trial area), showed a small increasing trend over the sampling period. At El-Berka, the data was initially quite variable, but there is also a small trend over time of decreasing concentrations. The fact that the reference wells at both sites were similarly affected is indicative of general water movement under both sites, rather than effluent impacting the quality directly.

It is worthy mentioning that there was a similar apparent trend may be observed for nitrate concentrations at El-Berka but at Gabal El-Asfar, the pattern that emerges is interesting in that all of the sampling wells showed declining concentrations from April but increased again from August, reaching similar levels in October to those at the start of the monitoring program. This could represent an annual rhythm of nitrate leaching following the peak irrigation period, with a lag phase before the nitrate reaches the groundwater. This follows a well recognized pattern of nitrate leaching for soil and, depending on transmission time, the nitrate currently being detected in the groundwater may have originated from sewage irrigated to this area several seasons previously.

Heavy metal concentrations in the groundwater of both sites were similar and small. This is despite the elevated concentrations of heavy metals which have accumulated in Gabal El-Asfar from long-term sewage irrigation, but this data demonstrates that heavy metals are not generally susceptible to leaching when applied to soil but are strongly bound, thus leading to accumulation in top soil Fig. 3.

DISCUSSION

The general chemistry of the treated wastewater does not impose any constraints on the types of crops that may be grown or the types of soil to which it may be applied. Beneficial additions of NPK to the grown crops were evident and in accordance with the results of [13]; they showed that these treated wastewaters would generally provide approximately 50% of N and about 70% of P requirements but about 200% of K requirement, although this varied widely according to the specific crop and whether this was calculated for a fertile or infertile soil.

However, microbial and parasitic levels indicate that chlorination at levels to achieve faecal coliform compliance does not significantly reduce viable nematode numbers. Whilst high levels of chlorination can achieve adequate nematode kill, there are other environmental considerations due to the formation of trihalomethanes. Consequently, additional treatment of this treated wastewater (such as by UV, sand filters or lagooning) would be necessary to achieve compliance. Similar conclusion was reported in similar district by WRc [14] in Alexandria.

The protection of groundwater quality is critical for sustainable agricultural production and consequently understanding the potential consequences of irrigated treated wastewater on soil is crucial to the long-term viability of treated wastewater reuse schemes. In addition to the potential treated wastewater-soil chemical interactions, there are concerns about the long-term accumulation of potentially toxic elements. The potential long-term consequences to soil quality of irrigating these treated wastewaters were modelled in other studies [13] which showed that it would take several hundred years to reach precautionary soil limit concentrations, but if crop off-take is taken into account, then heavy metal input and output would be more-or-less in balance and there would be minimal net impact on soil quality. Similar results were obtained by [15]. WRc [13] in Egypt reported that the concentrations were variable and clearly reflect minimum pollution in the short and long terms and indicate the suitability of Cairo wastewater for reuse on the agricultural land. The groundwater under both sites was similar and of poor quality, the data displaying large temporal and spatial monitoring would be necessary to determine any effects on groundwater quality since the water table was relatively deep (5–8 m) and the quality of the treated wastewater was marginally better than the groundwater. Therefore, it is difficult to demonstrate from this short-term monitoring program that irrigation with treated wastewater has affected ground water quality. If there were any effects, this would be shown by the most soluble and mobile components, such as total dissolved solids and nitrate Zedan (2006). It could be concluded from this study that irrigation with treated wastewater is favoured for some field crops due to the nutrients applied. However, signs of soil and groundwater contamination should have special concern and wastewater should be treated to higher standards to be reused and environmental monitoring should be continued.

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