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Some Biohydrological Effects of Agricultural Activities on Desert Soil and Groundwater Pollution: A Case Study

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Abstract: Large scale field trials were conducted in fertile soil and desert (virgin) soil to evaluate the effect of irrigation with secondary treated wastewater from wastewater treatment plant in Cairo on biological and chemical properties of soil and groundwater. Soil samples were taken for physical and chemical analysis after crop harvest. Groundwater monitoring wells were installed in and around the experimental soil sites. The results showed that considerable amounts of macronutrients (NPK) were applied to the grown crops during treated wastewater irrigation i.e.; N (44-79%), P (72-181%) and K (99-248%) of the recommended fertilizer rates according to the crop. Soil physical and chemical analysis showed variability in water holding capacity, organic matter, pH value, $CaCO_3$, salinity, cation exchange capacity and soil bulk density in the topsoil (0–30 cm) according to the tested cropping area Heavy metals concentrations in soil were very small and typical of sandy desert soil and the concentrations found were quite acceptable for crop production. No increases in soil concentrations were found after three seasons of effluent irrigation. The groundwater samples which examined for the presence of pathogenic bacteria (salmonella), faecal coliform bacteria and helminth ova indicated that the groundwater of both sites are contaminated by secondary treated wastewater irrigation, although it is highly unlikely that this was a direct result of irrigation to the trials considering soil type and depths to groundwater. The data showed that that all of the sampling wells showed declining concentrations from April but increasing again from August, reaching similar levels in October to those at the start of the monitoring programme which could represent an annual rhythm of nitrate leaching following the peak irrigation period, with a lag phase before the nitrate reaches the groundwater. The groundwater under such agricultural activities was of poor quality and would be unsuitable for potable or irrigation purposes.

Key words: Groundwater · Irrigation · Microbiology · Nutrients · Soils and water reuse

INTRODUCTION

In Egypt, the annual water demand exceeds the available fresh water by 6 billion $m^3 year^{-1}$ (Abou-Zeid, [1]. 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 [2-10].

Recently, WRc [11] 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), groundwater and pathogen survival is necessary to protect the environment and human health. Therefore, the aim of this work is to evaluate the effect of treated wastewater on physical and

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chemical properties soil and groundwater changes that may occur as a result of wastewater irrigation of field crops in greater Cairo. This paper addresses some biohydrological effects of agricultural activities on desert soil and groundwater pollution.

MATERIALS AND METHODS

The paper is a part of a large study entitled the "Cairo East Bank Effluent Re-use Study". The client is the Cairo Wastewater Organization (CWO) and the study is partially funded by the Kuwait Fund for Arab Economic Development (KFAED). The study was implemented by a joint venture consortium of Montgomery, Watson, Gibb International and some other Arab companies.

Large scale field trials were carried out in summer 2000 and winter of 2000–2001 seasons inside El Berka wastewater treatment plant; the soil is gravelly sand and could be classified as virgin 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 conditions. Four crops were planned to grow, thus there were two replicate plots for each crop and treatment.

Crop selection included range of food, fodder and industrial (fiber and oil) crops according to WHO [12]. For summer season 2000, soybean (Giza82 variety), maize (Single Hybrid 129 variety) and sunflower (local variety) were grown. In winter season 2000–2001, wheat (Sakha 8 variety), fababean (Giza 3 variety), lupine (Giza 1 variety) and canola (Pactol variety) were grown. Surface drip and sprinkler irrigation systems were used. Sprinkler irrigation was used for soybean and canola; drip irrigation for maize, sunflower, lupin and fababean, as well as surface irrigation for cotton and wheat.

The sampling program included wastewater, soil and groundwater quality. Treated wastewaters were analyzed according to APHA [13]. Soil samples were taken from each plot for physical and chemical analysis after the last harvest at 0–30 cm depth. All samples were analysed according to the common standard methods. Groundwater monitoring wells were installed the Research Institute for Groundwater (RIGWA). 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 APHA [13]. The obtained results were subjected to the proper statistical analysis using Cohort2 package, COSTAT program.

RESULTS

Treated Wastewater Quality: Final wastewater samples collected from 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 wastewater was within the acceptable range for reuse, normally 6.5–8.5 according to the Egyptian decree for wastewater reuse [14]. It is apparent that the nutrient contents of the wastewater were broadly suitable for reuse. The results in table ( )showed that considerable amounts of macronutrients (NPK) were applied to the grown crops during treated wastewater irrigation i.e.; N (44-79%), P (72-181%) and K (99-248%) of the recommended fertilizer rates according to the crop. The heavy metal concentrations were very small in wastewater 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 [14] 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 treated wastwater was 10^6 MPN/L, far in excess of that permitted by the guidelines of WHO [12] and salmonella were present in all samples. Nematode ova were found in all samples of treated wastwater in excess of the limit value for reuse (mean 49 ova/L). Table 1 presents the mean concentrations of treated wastewater chemistry and microbiology.

Wastewater and Chemical Additions: Irrigation quantities were accurately recorded for each plot at both sites during the summer and winter seasons. Table 2 summarises the amounts of wastewater irrigated to each crop and fertilizer treatment, as means of the plots of each treatment. Although a fixed irrigation schedule was envisaged, this had to be adapted according to crop water requirements as observed in the field. As anticipated, the irrigation requirement was much greater than the capacity of this soil and need for more leaching to control salinization of the soil surface.

Table 1: Mean concentrations of treated wastewater chemistry and microbiology from El Berka WWTP

Parameters	Mean	Min.	Max.	n	CV%
pH	7.78	7.65	7.86	9	0.8
Total N	12.8	7.4	18.7	25	23.9
Total P	3.4	1.2	5.3	26	29.3
K	13.8	8.3	24.1	27	23.3
Fe	0.577	0.064	0.980	13	54.8
Mn	0.115	0.010	0.320	11	67.4
Cr	0.027	0.006	0.087	11	120.0
Ni	0.039	0.007	0.082	11	68.7
Zn	0.094	0.011	0.180	11	67.7
Cu	0.049	0.014	0.093	11	56.2
Cd	<0.005	<0.005	<0.005	13	-
Pb	0.079	0.031	0.130	13	31.7
Mo	<0.01	<0.01	<0.01	11	-
Co	<0.005	<0.005	<0.005	11	-
Salmonella	1.8	1	2	26	26.1
F. coliforms	35	3	82	24	71.7
Helminth	49	5	202	25	103.1

Units: All determinands 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 2: Mean Quantities of Wastewater Irrigated according to Crop Type and Treatment (m^3/fd)

Crop	Irrigation method	Fertilizer: None	Fertilizer: Applied
Summer crops			
Maize	Drip	3554	3591
Cotton	Surface	10053	10564
Soya bean	Surface	2197	2831
Sunflower	Drip	2829	2884
Winter crops			
Lupin	Drip	3204	2749
Lupin	Surface	3177	2858
Wheat	Surface	3570	1959
Wheat	Sprinkler	3157	2679
Canola	Surface	3393	1972
Canola	Sprinkler	3051	2609
Faba bean	Drip	3041	2693
Faba bean	Surface	3001	2742

Fd= faddan=4200m^2

The quantities of wastewater applied are broadly in line with normal practice, with exceptions and these are related to the basic water requirement which varies between crops and the length of the growing season. For instance, cotton requires a long season to mature and consequently this had the largest amount of wastewater applied. Conversely, faba bean has a small water requirement, as indicated by the quantities irrigated in order to achieve satisfactory growth.

Table 3 lists the normally recommended application rates of inorganic fertilizer to the range of crops tested in these trials. The recommendations for some crops are different according to the fertility level of the soil and recommended rates may be greater where modern high yielding varieties are grown. Nevertheless, the wastewaters provide a significant proportion of the normal recommended fertilizer rates under infertile soil conditions. With only one exception, the amounts of nitrogen applied in wastewater were less than the recommended rates (range 44 – 79%). However, cotton received 176% of its recommended N rate, but this was an exception due to the high irrigation demand of this crop on desert soil and would not normally be grown under these conditions. These observations are important because one of the problems encountered by wastewater reuse in other countries has been the over-supply of nitrogen at normal crop irrigation duties due to the high concentrations in the wastewater. This can lead to luxurious growth at the expense of economic yield and give rise to nitrate leaching and pollution of groundwater. This is not likely to occur in Egypt as wastewaters generally have relatively low nitrogen contents.

Soil Quality: Soil physical and chemical analysis (water holding capacity (WHC), organic matter (OM), pH value, $CaCO_3$, salinity, cation exchange capacity (CEC) and soil

Table 3: Proportion of nutrients supplied by el berka wastewaters to the field trials compared with generally recommended rates of fertilizer for summer and winter crops on desert soil.

	Fertilizer recommended (kg/fd)			Addition in wastewater (kg/fd)			Nutrients supplied by wastewater as% of fertilizer		
Crop	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Summer crops									
Maize	105	15.5	24	45.8	28.0	59.4	44	181	248
Cotton	75	22.5	48	132.3	80.9	171.3	176	360	357
Soya bean	60	22.5	24	32.3	19.7	41.8	54	88	174
Sunflower	60	31	48	36.7	22.4	47.5	61	72	99
Winter crops									
Wheat	100	22.5	24	36.5	22.3	47.2	36	99	197
Faba bean	60	31	48	36.8	22.5	47.7	61	73	99
Lupin	60	31	24	38.5	23.5	49.8	64	76	208
Canola	45	22.5	24	35.4	21.6	45.8	79	96	191

Fd= faddan=4200m^2

Table 4: General physical quality of soil at El Berka (Means to 30 cm depth)

Value	Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Loam (%)	Texture class	WHC (%)	Particle Bulk density (g/cm^3)	SBD (g/cm^3)
Mean	28.9	67.2	23.2	5.6	4.0	Gravelly Sand	28.5	2.56	1.56
Min	1.7	46.9	7.0	2.0	2.0		20.8	2.36	1.41
Max	58.3	83.1	34.4	17.3	8.1		35.8	2.65	1.67
CV%	-	15.5	39.5	67.8	46.0		14.8	2.9	4.9

Table 5: General chemical quality of soil at El Berka (means to 30 cm depth)

Value	PH	EC (dS/m)	HCO_3 (meq/L)	OM (%)	CEC (meq/ 100g)	NO_3 (mg/kg)	N (mg/kg)	P (mg/kg)	K (mg/kg)
Mean	8.16	0.79	0.98	0.79	13.4	23.7	901	229	1506
Min	7.69	0.21	0.65	0.19	5.5	5.0	140	92	900
Max	8.69	2.40	1.35	1.13	25.8	125	2100	343	2350
CV%	3.1	81.1	20.3	37.9	42.8	123.5	59.8	33.2	29.4

Table 6: Heavy metal concentrations in soil at El Berka (means to 30 cm depth)

Value	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Ni (mg/kg)
Mean	1942	81.8	20.0	6.6	7.0	0.39	1.34	12.3
Min	225	37.7	7.1	4.2	3.2	0.10	0.27	5.0
Max	5391	227	55.1	17.5	14.7	0.67	3.98	18.5
CV%	71.7	58.6	74.8	51.7	38.2	54.3	95.0	33.4

Table 7: Overall mean concentrations of groundwater chemistry and mmicrobiology at El Berka

		Monthly mean range	
Parameter	Means of all wells	Minimum	Maximum
Biological oxygen demand (BOD)	4.0	2.0	6.0
Chemical oxygen demand (COD)	13.4	3.6	130.0
Total soluble solids (TSS)	26.3	21.0	31.3
Total dissolved solids (TDS)	1674	1247	3063
EC	2.34	1.87	2.99
Sodium adsorption ratio (SAR)	6.7	6.4	6.9
HCO3	5.94	4.81	7.40
Total Kjldahl nitrogen (TKN)	3.85	3.53	4.40
NH3	1.79	1.60	1.98
NO2	0.04	0.04	0.04
NO3	72.7	44.1	127.3
SO4	2410	1165	3821
Cl	413	316	482
PO4	1.76	0.22	8.50
K	8.72	2.30	20.00
Ca	215	161	320
Na	457	387	1045
Mg	35.9	32.9	50.1
B	2.67	1.84	3.49
Fe	0.324	0.019	0.833
Mn	0.036	0.029	0.050
Cr	0.016	0.003	0.027
Ni	0.009	0.006	0.020
Zn	0.315	0.095	0.700
Cu	0.165	0.005	0.505
Cd	0.013	0.006	0.015
Pb	0.037	0.006	0.099
Salmonella	32	0	100
F. coliforms	1440	0	4158
Helminths	0.5	0	3

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

bulk density (SBD) in the surface 30 cm) showed that experimental plots are quite variable, exhibiting wide ranges of values in samples taken after harvest. Tables 4 and 5 present these data. Such variability may be due to the previous land use at both sites. The nutrient content of the soil (as total NPK) at El Berka was small, as this soil had not been fertilized or irrigated previously.

Nitrate concentrations in the topsoil were also small at El Berka, 23.7 mg/kg, demonstrating the low fertility status on El Berka soil after two seasons of effluent irrigation.

Heavy metal concentrations were characterised in the topsoil (0–30 cm) at the end of the trial and the results are shown in Table 6. The concentrations were not excessive, being well within international soil quality standards and far below potential toxic thresholds.

Groundwater Quality: The data in Table (7) and Fig 1 showed considerable spatial and temporal variation in the groundwater and there was no discernible relationship between well location and irrigation of treated wastewater in the trials. The salinity of the groundwater was moderate. Sodium and chloride ion concentrations were small. It is interesting that all of the sampling wells showed declining concentrations of nitrate from April but increasing again from August, reaching similar levels in October to those at the start of the monitoring program. This could represent a seasonal effect of nitrate leaching following the peak irrigation period, with a lag phase before the nitrate reaches the groundwater. Heavy metal concentrations in the groundwater were

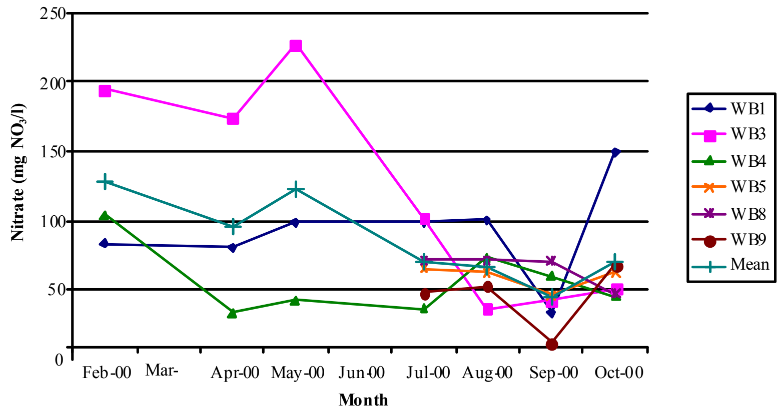

Fig. 1: Nitrate concentrations in groundwater from each monitoring well at the experimental site

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 is contaminated by secondary treated wastewater irrigation. At this virgin soil, 10-57% of the samples from each well contained salmonella. The numbers of faecal coliforms were in the range 10^2-10^3 MPN/100mL. Small numbers of parasite ova were also found in the majority of wells. The groundwater under the site condition was of poor quality.

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 WRC [11]; 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.

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 wastwater (such as by UV, sand filters or lagooning) would be necessary to achieve compliance. Similar conclusion was reported in similar district [15] in Alexandria.

The protection of soil 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 for the long-term accumulation of potentially toxic elements. The potential long-term consequences to soil quality of irrigating these treated wastewaters were modeled in other studies [11] 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 [16]. WRC [11] 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 these conditions was 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 [17].

It could be concluded from this study that irrigation with treated wastewater is favored for some field crops due to the nutrients applied. However, due to signs of soil and groundwater contamination resulted from the agricultural activities biohydrolgical effects 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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