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Feasibility of Soil Aquifer Treatment for Removal Chemical Pollutants of Wastewater

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Abstract: This study evaluated Soil Aquifer Treatment (SAT) as a method applied for removal of some chemical pollutants within wastewater. This study was made on two pilot areas in Egypt, in Abu Rawash district and El Mansouria district. The study concerned with evaluating the SAT system removal efficiency by different soil types, assessing optimum soil matrix for achieving adequate SAT, evaluating the renovated water quality conjugate to various water depths and assessing the change occur in some of the wastewater constituents (zinc, iron as heavy metals and magnesium, sodium as a basic cations). The results concluded that sandy loam soil was better than clayed soil for magnesium and sodium removal through SAT and sandy soil was not recommended for Magnesium and Sodium removal. Sandy soil was better than clayed soil for zinc and Iron removal through SAT system and sandy loam soil was not recommended for zinc and iron removal.

Key words: Soil aquifer treatment, natural wastewater treatment, sandy soil, sandy loam, clay

INTRODUCTION

Soil Aquifer Treatment (SAT) are artificial recharge of groundwater through infiltration basins, a high degree of upgrading can be achieved by allowing partially-treated sewage effluent to infiltrate into the soil and move down to the groundwater. The unsaturated or vadose zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses and other microorganisms. Significant reductions in nitrogen, phosphorus and heavy metals concentrations can also be achieved. After the sewage, treated in passage through the vadose zone, the groundwater is allowed to flow some distance through the aquifer before collected. This additional movement through the aquifer can produce further purification (FAO, 2006). There are many ways for applying wastewater like direct surface, subsurface techniques and indirect techniques. Direct-surface techniques can be classified into several categories, including flooding, ditch and furrow, basins, stream channel, stream augmentation and over irrigation. Basins are the most favored method of recharging as they allow efficient use of space and require low cost and simple maintenance. They can be excavated or enclosed by levees or dikes and construction can be adapted to the terrain. Basins can be constructed either individually, such as in small drainage areas to collect urban runoff and/or in series for infiltration of stream or storm water.

Direct subsurface can be achieved when water is transported directly to the aquifer. Water can be transported to the aquifer through natural openings in the aquifer, pits or shafts, wells and drainage pipe networks. Land required for the direct sub-surface recharge structures are less than that required for surface methods and costs are high as compared to surface techniques (Rice and Bouwer, 1984; Böhlke, 2002). Indirect techniques of artificial recharge involve, pumping aquifers to induce recharge from hydraulically connected surface waters or constructing new aquifers to enhance or create groundwater reservoirs. A new technique for artificial recharge is pressurizing the unsaturated zone with compressed air, thus squeezing more water out of the unsaturated zone and hastening its system The system would work best in regions of the unsaturated zone that are below semi-permeable or other restricting layers (to prevent air from escaping back to the atmosphere (Moridis and Reddell, 1991; Bouwer, 2002).

There are many factors effecting SAT, soil clogging (which happens due to accumulation of suspended solids in the water), high hydraulic heads (due to large water depths which produce higher infiltration rates) and the groundwater table level (which must be deep enough below the infiltration system so that it does not interfere with the infiltration process). The ground water level must be at least 0.5 m below the bottom of the basin, to keep the top of the capillary fringe below the basin bottom, so that infiltration rates are not restricted by groundwater.

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Sewage effluent or other water of low quality is used for groundwater recharge by surface infiltration systems; it may be desirable to keep groundwater levels sufficiently low to create adequate unsaturated zones, below basin bottoms for aerobic processes. However, other infiltration systems operate essentially in the groundwater zone with unsaturated conditions. Thus, the issue of minimum depth to groundwater below infiltration basins for adequate quality improvement of sewage effluent or other low quality water is not yet fully resolved (Bouwer, 1990; Topper *et al*., 2004).

SAT systems are applied for groundwater recharge with polluted water (e.g., sewage effluent), the unsaturated zone and aquifer act as natural filters that reduce the concentration of various pollutants due to physical, chemical and microbiological processes. To protect high-quality native groundwater and nearby drinking water wells against encroachment by recharge water of impaired quality, the systems are designed as recharge-recovery systems where all the recharge water is taken out of the aquifer again with strategically located wells, drains, or other interceptors. Since a portion of the aquifer is then used for treatment of low-quality water, the systems are no longer called groundwater recharge systems but soil-aquifer treatment (Huisman and Olsthoorn, 1983; David *et al*., 2003).

Post-treatment can be needed if sewage water comprises 100% of the recovered water, in order to meet the quality requirements for the intended use. Technically, primary treatment alone may be sufficient as pre-treatment. In fact, the higher Total Organic Carbon (TOC) content of primary effluent may enhance the quality improvement by SAT because it increases denitrification and biodegradation. The latter is due to the co-metabolism and secondary utilization brought on by the greater availability of organic carbon. In case of using water after SAT for potable purposes, post-treatment may be necessary, to remove residual TOC and possibly pathogens those have survived. The treatment could include activated carbon filtration, reverse osmosis or other membrane filtration and disinfection (Lance *et al*., 1980; Oaksford, 1985; Metcalf and Eddy, 2003). A study program by American National Center for Sustainable Water Supply (NCSWS, 2001) was conducted for evaluating SAT. Field sites were selected for focused, study based on specific strengths and difference between sites, (such as depth to groundwater, quality of groundwater data, instrumentation and geographical consideration) was achieved. Results from field sites were compared to controlled laboratory experiments with homogeneous conditions.

Drewes *et al*. (2006) investigated the character and fate of bulk organics in reclaimed water used for groundwater recharge via soil-aquifer treatment (SAT). The study design followed a watershed-guided approach considering hydraulically corresponding samples of drinking water sources, SAT-applied wastewater effluents and subsequent post-SAT samples representing a series of different travel times in the subsurface. The current study was concerned with evaluating the removal of some pollutants (Zinc, Iron as heavy metals and Sodium, Magnesium as basic cations) by using soil aquifer treatment.

MATERIALS AND METHODS

The experimental works were carried out on soil and water samples for evaluating SAT. The collected samples were measured at the central laboratory of Kanater, Kaliobia governorate, Egypt from July 2002 to March 2003. The experimented parameters in water samples (collected from the studied locations) as well as pH were analyzed using Inductively Coupled Plasma device (ICP) according to Standard Methods for Water and Wastewater Examination (APHA, 1995).

Soil analysis was obtained and consists of:

Physical analysis:

- Clay silt and fine sand were determined using Hydrometer Methods according to Soil and Plant Analysis Council (1992).
- Medium and coarse sand were determined using dry sieves shaker.

Chemical analysis: The procedure of the chemical analysis of soil is as follows:

- The soil samples were dried to 105°C and grained.
- Soil paste was prepared from the collected samples and left for 24 h.
- The soil samples were extracted and Magnesium, Sodium, Iron and zinc contents were determined by using ICP.

RESULTS AND DISCUSSION

This study was concerned with monitoring the effect of soil aquifer treatment on removing some chemical pollutant within wastewater. These chemical pollutants were magnesium, sodium, iron and zinc. Therefore, two different areas were chosen in Abu Rawash and El

Mansouria district. The major factors involved in SAT were characteristics of applied water and soil characteristics and content. So, different sampling points were chosen for each area, sampling points 1, 2, 3 and 4 for Abu Rawash district and 5, 6, 7, 8 and 9 for El Mansouria district. Physical and chemical analysis were obtained and concluded that, Abu Rawash represents sandy light soil for all sampling points 1, 2, 3 and 4 whereas El Mansouria represents sandy loam soil at points 5 and 6 and clayed soil at points 7, 8 and 9. Table 1 and 2 represent soil classification for different points. The applied water at Abu Rawash pilot area is raw wastewater conveyed through an open wastewater conveyance channel. On the other hand, the applied water at El Mansouria pilot area is highly polluted raw wastewater discharged at several point sources on channels crossing the location and blended with it and then pumped for use in agricultural irrigation. Therefore the type of wastewater for the first location can be considered raw, whereas for the second location can be considered partially treated (due to mixing process).

Soil samples collected from the pilot areas were analyzed in order to monitor the content of soil and the effect of this content on Soil Aquifer Treatment. Applied water and renovated water samples were collected and analyzed to compare their results and evaluate the treatment process. Table 3 shows the collected soil samples from Abu Rawash area. pH, magnesium, sodium, iron and zinc content within soil layer were observed.

The soil samples analysis results at the various depths for El Mansouria district are shown in Table 4.

Table 1 and 2 show a general descending trend with depth in sodium, magnesium, iron and zinc concentration with the majority of the reaction taken place in the topsoil layer. This is quite natural given the fact that the soil particles carrying a negative charge, (that is directly proportional to pH) becomes capable of adsorbing exchangeable cations. Due to the prevailing high pH, (which ranges between 7.3 and 8.4) the high negatively charged soil particles adsorb positive charge cations, thus decreasing its concentration with depth. The concentration decreases through the first 0.5 m depth, due to the high void ratio in sandy soil especially at the topsoil layer. At a depth of 1.0 m, an increase in concentration occurs. This can be attributed to the

Table 1: Abu Rawash pilot area sampling points soil classification

Sampling point location	Percentage passing the different sieves-sieve size (mm)						Soil texture
	4.750	3.350	2.000	0.425	0.150	0.075	
1	99.95	99.95	99.84	55.69	11.45	1.650	Sand
2	100.00	100.00	99.45	45.65	12.45	1.850	Sand
3	100.00	100.00	99.35	44.85	10.98	1.760	Sand
4	100.00	100.00	99.35	53.35	13.56	2.150	Sand

Table 2: El Mansouria pilot area sampling points soil classification

Sampling point location	Sample component (%)			Soil texture
	Clay (<2 μm)	Silt (2-20 μm)	Sand (>20 μm)	
5	18.20	6.50	76.90	Sandy loam
6	22.80	1.80	75.40	Sandy loam
7	50.10	18.62	31.28	Clay
8	55.35	12.10	32.55	Clay
9	61.92	25.17	13.03	Clay

Table 3: Soil samples analysis results in Abu Rawash

Sampling point ID	Depth (m)	pH	Cations (mg L^{-1}) Mg	Na	Heavy metals (mg L^{-1}) Zn	Fe
1	0.0	8.3	49.2	230.0	0.82	0.90
	0.5	8.4	28.8	161.0	0.84	0.93
	1.0	8.1	28.8	184.0	0.82	0.86
	1.5	8.0	33.6	161.0	0.91	0.88
	2.0	8.1	26.4	121.9	0.75	0.92
2	0.0	7.7	50.4	213.9	0.99	0.96
	0.5	8.0	20.4	92.0	0.82	0.94
	1.0	8.1	20.4	85.1	0.96	0.93
	1.5	7.7	14.4	46.0	0.95	0.82
	2.0	7.8	12.0	62.1	0.86	0.84
	2.5	7.8	14.4	69.0	0.84	0.95
3	0.0	8.1	145.2	611.8	0.56	0.65
	0.5	8.2	32.4	195.5	0.82	0.56
	1.0	8.2	18.0	98.9	0.72	0.52
	1.5	8.1	26.4	75.9	0.52	0.62
	2.0	8.1	26.4	80.5	0.32	0.52
	2.5	8.2	27.6	103.5	ND*	ND*
4	0.0	8.0	398.4	351.9	0.66	1.06
	0.5	8.3	32.4	161.0	0.73	1.00
	1.0	8.2	40.8	207.0	0.78	0.86
	1.5	8.1	32.4	131.1	0.62	1.12
	2.0	8.0	39.6	338.1	0.57	0.96

*: Analysis results for these points were not determined

Table 4: Soil samples analysis results in El Mansouria

Sampling point ID	Depth (m)	pH	Cations (mg L^{-1}) Mg	Na	Heavy metals (mg L^{-1}) Zn	Fe
5	0.0	8.3	27.6	167.9	0.38	1.01
	0.5	8.2	48.0	218.5	0.34	1.21
	1.0	7.8	16.8	115.0	0.35	0.99
	1.5	7.9	19.2	80.5	0.37	1.15
6	0.0	8.1	75.6	368.0	0.36	0.88
	0.5	8.1	19.2	80.5	0.36	1.02
	1.0	8.0	18.0	80.5	0.32	0.98
	1.5	7.7	12.0	75.9	0.34	1.22
	2.0	7.8	32.4	115.0	0.44	1.11
	2.5	7.8	27.6	115.0	0.45	0.87
7	0.0	8.5	27.6	374.9	0.58	0.87
	0.5	8.6	26.4	190.9	0.42	0.76
	1.0	8.5	33.6	195.5	0.60	0.94
	1.5	8.5	28.8	167.9	0.52	0.88
	2.0	8.5	22.8	131.1	0.43	0.77
	2.5	8.4	31.2	138.0	0.55	0.97
8	0.0	8.2	32.4	200.1	0.38	1.20
	0.5	8.2	20.4	103.5	0.34	1.26
	1.0	7.8	14.4	75.9	0.37	0.86
	1.5	7.7	14.4	75.9	0.30	1.12
	2.0	7.9	21.6	115.0	0.31	1.05
	2.5	8.1	18.0	115.0	0.36	1.12
9	0.0	7.7	583.2	2530.0	0.52	1.08
	0.5	8.3	150.0	492.2	0.55	0.96
	1.0	8.6	98.4	379.5	0.62	0.88
	1.5	8.6	81.6	356.5	0.45	1.16
	2.0	8.4	106.8	473.8	0.42	1.22
	2.5	8.1	110.4	338.1	0.48	1.28

leaching of highly polluted water from the nearby watercourse. Thus, adsorption takes place where cations are adsorbed on the soil particles causing increase in their concentration. It is to be noted that, the non-uniformity in behavior in El Mansouria (which represents sandy loam to clay soil) is much more than that in Abu Rawash, (which represents sandy soil).

Irrigation of agricultural lands in the pilot areas is achieved by irrigation from watercourses. In Abu Rawash, irrigation water is generally extracted from the main channel carrying raw wastewater to Abu Rawash wastewater treatment plant, whereas in El Mansouria most watercourses used for irrigation are canals subject to severe pollution from domestic, industrial, agricultural etc., sources. Table 5 shows the analysis of the collected water samples (applied water) for the different experimented areas. The collected applied water samples sources in Abu Rawash pilot area was from El Remaly drain and in El Mansouria pilot area from El Muheit drain, Abdel Wahab branch and Omar Aref drain.

The SAT occurring in the unsaturated zone and can be evaluated by monitoring polluted water quality throughout its path in the unsaturated zone, until it reaches the interface with the groundwater aquifer, regardless to variations occurring throughout the soil profile. Table 6 represents the renovated water samples results and identification. The renovated water samples were collected at the top of the groundwater aquifer. The water samples were collected by means of production wells for Abu Rawash area and hand pumps for El Mansouria area (Table 6).

Table 7 shown the concentration of sodium and magnesium were increased in renovated water than applied water that may be due to the applied water washed out magnesium and sodium from the soil especially these soils subjected to long term pollution, in addition leaching of polluted water from El-Remaly drain until it reached the renovated water. The concentration of Zinc was decreased for points 1 and 3, not changed at point 2 and increased at point 4. Improvement for sampling points 1 and 3 may be attributed to straining through soil, adsorption to soil particles and/or to plant uptake. While for sampling point 4, deterioration in zinc concentration is may be attributed to the wash out of Zinc from the soil, in addition leaching of polluted water from El-Remaly drain. Iron concentration was decreased in sampling points 1, 2 and 4 and increased at point 3. The conclusion of that may be as mention before for zinc.

Table 5: Applied water samples analysis results at Abu Rawash and El Mansouria districts

			Cations (mg L^{-1})		Heavy metals (mg L^{-1})	
District	Sampling point ID	pH	Mg	Na	Zn	Fe
Abu Rawash	1	7.0	25.2	126.5	0.73	0.40
	2	7.2	22.8	126.5	0.72	1.13
	3	6.9	20.4	103.5	0.69	0.61
	4	7.0	19.2	138.0	0.44	0.60
El Mansouria	5	7.3	24.0	121.9	0.37	0.49
	6	7.6	31.2	115.0	0.17	0.32
	7	7.7	60.0	223.1	0.26	0.20
	8	6.9	33.6	126.5	0.23	1.05
	9	7.8	90.0	384.1	0.22	0.38

Table 6: Renovated water samples analysis results in Abu Rawash and El Mansouria districts

			Cations (mg L^{-1})		Heavy metals (mg L^{-1})	
District	Sampling point ID	pH	Mg	Na	Zn	Fe
Abu Rawash	1	7.6	48.0	190.9	0.46	0.29
	2	7.0	24.0	207.0	0.72	0.56
	3	7.4	61.2	448.5	0.62	1.22
	4	7.6	42.0	161.0	0.55	0.46
El Mansouria	5	8.1	21.6	121.9	0.47	1.09
	6	8.3	64.8	190.9	0.19	1.05
	7	7.4	141.6	1324.8	0.53	1.00
	8	7.7	56.4	213.9	0.22	0.19
	9	7.5	26.4	85.1	0.21	0.50

Table 7: Comparison and removal percentages of applied and renovated water quality in Abu Rawash and El Mansouria pilot area

Pilot area	Measured element	Sampling point	Applied water (mg L^{-1})	Renovated water (mg L^{-1})	Removal (%)
Abu Rawash	Magnesium	1	25.20	48.00	-90.48
		2	22.80	24.00	-5.26
		3	20.40	61.20	-200.00
		4	19.20	42.00	-118.75
	Sodium	1	126.50	190.90	-50.91
		2	126.50	207.00	-63.64
		3	103.50	448.50	-333.33
		4	138.00	161.00	-16.67
	Zinc	1	0.73	0.46	36.99
		2	0.72	0.72	0.00
		3	0.69	0.62	10.14
		4	0.44	0.55	-25.00
	Iron	1	0.40	0.29	27.50
		2	1.13	0.56	50.44
		3	0.61	1.22	-100.00
		4	0.60	0.46	23.33
El Mansouria	Magnesium	5	24.00	21.60	10.00
		6	31.20	64.80	-107.69
		7	60.00	141.60	-136.00
		8	33.60	56.40	-67.86
		9	90.00	26.40	70.67
	Sodium	5	121.90	121.90	0.00
		6	115.00	190.90	-66.00
		7	223.10	1324.80	-493.81
		8	126.50	213.90	-69.09
		9	384.10	85.10	77.84
	Zinc	5	0.37	0.47	-27.03
		6	0.17	0.19	-11.76
		7	0.26	0.53	-103.85
		8	0.23	0.22	4.35
		9	0.22	0.21	4.55
	Iron	5	0.49	1.09	-122.45
		6	0.32	1.05	-228.13
		7	0.20	1.00	-400.00
		8	1.05	0.19	81.90
		9	0.38	0.50	-31.58

For El Mansouria area, the concentrations of the studied cations in renovated water are bigger than the concentration in applied water (for most experimented points), that may be due to the characteristics of soil, soil condition and the suitability for percolation of water.

CONCLUSIONS

Based on the experimental results and the analysis of the laboratory results these conclusions can be achieved:

- Sandy loam soil was better than clayed soil for Magnesium and Sodium removal through SAT. Sandy soils are not recommended for Magnesium and Sodium removal.
- Sandy soil was better than clayed soil for zinc and iron removal through sat system. Sandy loam soil is not recommended for zinc and Iron Removal.
- The maximum decrease in magnesium concentration within the soil takes place at a depth of 0.5 m for sandy soil, from 1.0 to 1.5 m for sandy loam soil and from 1.5 to 2.0 m for clayed soil.
- The maximum decrease in sodium concentration within the soil takes place at a depth of 1.5 m for both sandy soil and sandy loam soil and from 1.5 to 2.0 m for clayed soil.
- The maximum decrease in zinc concentration within the soil takes place at a depth of 2.0 m for sandy soil, from 0.5 to 1.0 m for sandy loam soil and from 1.5 to 2.0 m for clayed soil.
- The maximum decrease in iron concentration within the soil takes place at a depth from 1.0 to 1.5 m for sandy soil, 2.5 m for sandy loam soil and from 0.5 to 1.0 m for clayed soil.
- Magnesium and sodium were better applied to a soil aquifer system of sandy loam nature.
- Zinc and iron are better applied to a soil aquifer treatment of sandy nature.
- Referring to above conclusions application of any of the pollutants is subject to certain conditions such as removing dead roots and litter from the soil, exchanging the topsoil layer every several years...etc., in order to improve the soil capability to accept pollutants.

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