Environmental Impact Assessment of Artificial Recharge of Treated Wastewater on Groundwater Aquifer System. Case study: Abu Rawash, Egypt

Zeinab El-Fakharany

Research Institute for Groundwater, NWRC
engzeinab2000@yahoo.com

Abstract: Nowadays, Egypt is suffering from shortage in available water resources due to increase of population density and food requirements. The main concern is to reuse non-conventional resource safely. One of the possible new tools in Egypt to mitigate the expected negative environmental impacts is through artificial recharge of treated wastewater which can result in additional advanced sewage treatment stage during its passage through the unsaturated zone, which is known as “Soil Aquifer Treatment (SAT)”. The main objectives of this research are to investigate and quantify the technical visibility of implementing the SAT system to renovate treated wastewater under the prevailing condition of Abu Rawash study area and application of environmental impact assessment (EIA) before and after experiment operation. The results indicated that reuse non-conventional water resources lead to improve the aquifer potentiality for low productive aquifer as in Abu Rawash area and promoting recovery of overexploited aquifer and decrease the depth to groundwater. Aquifers with deep groundwater are more suitable to achieve SAT due to large thickness of unsaturated zone. Soil plays an important role in the purification process of the recharged wastewater. BOD and COD concentrations are reduced by 50–80 % which improves the efficiency of recharge and treatment completion through soil stratification. The EIA results indicated that positive impacts increased from 15% to 64% while negative impacts decreased from 66% to 9% after experiment operation. The feasibility of artificial recharge with wastewater depends on a large extent on the quality of wastewater and the capacity of the soils in enhancing its quality. Results indicated that artificial recharge for groundwater aquifer using treated wastewater is promising technique whoever it needs more detailed study. Also a good designed monitoring system is necessary to evaluate the effect of recharge process on the groundwater quantity and quality.

[Zeinab El-Fakharany. **Environmental Impact Assessment of Artificial Recharge of Treated Wastewater on Groundwater Aquifer System Case study: Abu Rawash, Egypt .** *J Am Sci* 2013;9(2):309-315]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 41

Key words: EIA; Artificial Recharge; treated wastewater; Groundwater; SAT.

1. Introduction

Nowadays, Egypt is suffering from a shortage in available water resources due to population increase and food requirements. The Egyptian ministry of water resources and irrigation has recently developed a new water policy to enhance water availability, including safe recycling of wastewater and desalination of brackish and seawater. Wastewater reuse can be achieved through a variety of methods which can globally be grouped into two main groups, direct and indirect. Each method has its advantages and disadvantages, which are very much a function of the location of treatment plants, demand for the effluent in space and time, the quality of the effluent, the characteristics of the soils and the aquifer characteristics. In general terms, the rate of effluent discharge from treatment plants is constant over the year, while demand on water, especially for agriculture, varies greatly over the year and even over the day. Moreover, direct reuse may be faced by objections from the local users knowing its origin. These factors are the essential differences between direct and indirect reuse [1].

Research Institute for Groundwater (RIGW) [2] took over a study to gain a better understanding of artificial recharge using treated wastewater water. The main factors defining the suitability of recharge are the hydrogeological conditions and wastewater quality. The surface infiltration systems are successful techniques for recharging wastewater because they allow long paths for the wastewater through soil stratification which result into significant quality improvement as most of the treatment processes take place in the upper part of the vadose zone, where soils are finer than in the aquifer, the flow is unsaturated, and oxygen levels vary from aerobic to anaerobic [3]. One of the best methods to improve the quality of treated wastewater is the natural treatment using Soil Aquifer Treatment (SAT) techniques. This technique will also help store the treated water in aquifers [4].

The importance of environmental protection and conservation measure has been increasingly recognized during the last two decades. Egypt has implemented several executive steps towards environmental monitoring and protection and issued law number 48 for the year 1982 [5]. This law was not only to determine pollution prevention measures and control from the existing establishment, but also involved new developments and projects including expansions of the existing ones. The new establishment has dictated carrying out Environmental Impact Assessment (EIA) studies before construction or implementation of the project or the relevant expansion.

The International Commission on Irrigation and Drainage (ICID) environmental Check-list has been used to assess the scope of environmental effects of wastewater irrigation in the Gabal El Asfar farm on the groundwater quality and quantity. The study recommended the groundwater pollution control measures and other impacts related to irrigation with wastewater effluent [6]. The objectives of this research are to investigate and quantify the artificial recharge by treated wastewater by implementing the SAT system to renovate treated wastewater under the prevailing condition of Abu Rawash study area and application of environmental impact assessment (EIA) before and after experiment operation.

2. Methodology

To achieve the research objectives, the following steps are applied:

- Selecting the study area and description of components and operation of artificial recharge experiment.
- Assess the role of soil aquifer treatment system in the treatment processes.
- Investigate impact of artificial recharge using wastewater on groundwater aquifer system.
- Application of EIA before and after artificial recharge experiment operation.
- Evaluation the results of artificial recharge experiment operation and EIA.

2.1 Study area

Abu Rawash study area was selected based on the hydrogeological conditions and groundwater vulnerability to pollution. Such conditions include: (i) hydrogeological set up; (ii) depth to groundwater; (iii) hydraulic parameters; and (iv) prevailing treatment stages of the wastewater water. Another important factor was that groundwater in and near the experimental site was not a main source of drinking water. This would reduce the risks associated with possible pollution of groundwater. Other factors of importance in facilitating operations included: (i) accessibility of the site; (ii) distance to the treatment/collection facility; and (iii) distance to the laboratory. Table (1), summarizes the general conditions for Abu Rawash Study area.

Abu Rawash wastewater treatment plant (ARTP), located at the desert fringes northwest of Greater Cairo as shown in figure (1). Where, the raw wastewater from greater Cairo is collected. It provides primary treatment for industrial and domestic wastewater, It was designed to treat an average flow of 400,000 m^3/day and a peak flow of 600,000 m^3/day. Then the treated wastewater is disposed to a line canal then to Al Rahawy Drain [7]. Inlet wastewater loads indicated that ARTP requires a larger capacity as it actually receives an average flow of 950,000 m^3/day where only 400,000 m^3/day is being treated and the excess flow is by passed directly without any treatment to the nearby Alrahawy drain [8].

Table (1): General Conditions for Abu Rawash Study area.

Hydrogeological and hydraulic Criteria		Site Criteria	
Lithology of aquifer	Homogeneous	Treatment	Primary
Recharge site availability	Available	vulnerability	Medium - Low
Accessibility	Easy	Soil classification	Sand
Distance from treatment plant	200 m	Depth to water table	3.5 m
Distance from drinking water plants	Faraway	Transmissivity	300 m^2/day
Land availability	Available	Land use	Agricultural

2.2 Components and Operation of Artificial Recharge Experiment

The artificial recharge with wastewater is depending on the exchange impacts of soil on water and the impact of water on soil. Therefore soil plays an important role in purification process of the recharged wastewater [3]. Therefore, two different kinds of soil were selected to study the role of each kind of soil in wastewater treatment. Therefore, the recharge is composed of two infiltration basins and groundwater monitoring wells with varies depth distributed around and inside the recharge basin to monitor groundwater levels and collect water samples. Graded sandy soil located in recharge basin no. 1, found in the desert fringes outside the Nile Valley and Delta. Silty clay soil located in recharge basin no. 2, found inside the Nile Valley and Delta.

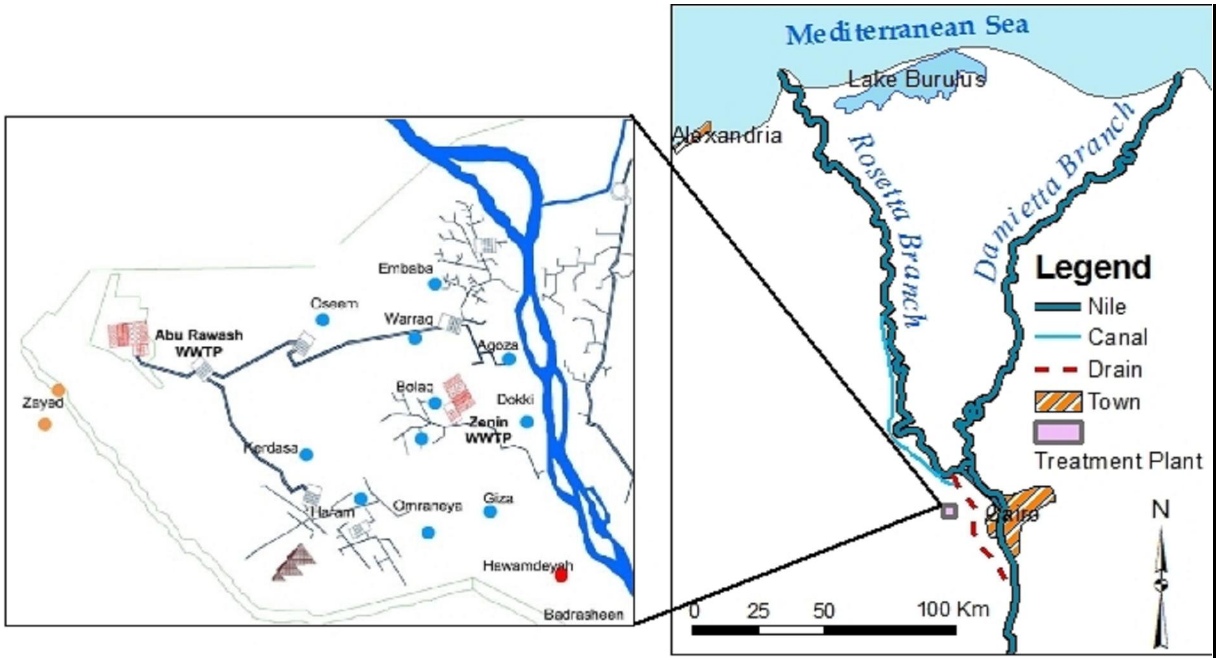


Figure (1). Layout of Abu Rawash study area.

During recharge, groundwater levels were measured at groundwater monitoring wells distributed inside and around the recharge basin. Water samples were collected from observation points inside and around the artificially recharged basins before and after treatment from the basins and from the groundwater after recharge. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) concentrations were used as indicators to assess the role of soil in achieving treatment process during the infiltration of treated wastewater through the soil profile in the unsaturated zone.

2.3 Application of ICID Check-List

The need to avoid adverse impacts and to ensure long term benefits lead to the concept of sustainability. In order to predict environmental impacts of any development and to provide an opportunity to mitigate negative impacts and enhance positive impacts, the EIA procedure was developed in the 1970s. Clearly, an EIA will not solve all problems. An important output from an EIA process should be the delineation of enabling mechanisms for such effective management. The main EIA technique used is that identified by the ICID check-list [9].

To investigate the EIA of irrigation and drainage projects the environmental check-list has been developed by Food and Agricultural Organization (FAO) to help identify possible environmental changes which such projects may bring. Application of ICID check-list can be an efficient tool in developing a decision on the most significant impacts and the shortage of data [10]. The ICID checklist consists of a very simple sheet enabling an overview of impacts to be presented clearly.

Approach of assessment of the potential impacts and identification of environmental setting has been based on the evaluation of results obtained from operation the artificial recharge experiment in Abu Rawash area. Typical EIA matrix for irrigation and drainage projects was used to qualify the base line of environmental and Hydro-geological setting and the potential impacts before and after experiment operation, which was based on a simple qualitative analysis, as shown in table 2.

3. Results and Discussion

3.1 Artificial Recharge experiment operation Results

Operation of sand Basin indicated the following results:

- Rising groundwater levels at the groundwater monitoring well in the center of the recharge basin while it decreasing outside the recharge basin, see figure 2.
- The mound formed during the recharge operation under the recharge basin disappeared later after stopping the recharge operations see figure 2.

Table 2: EIA Matrix for Qualifying Base Line and Potential of Impacts.

Group Issue	Environmental issue	Before recharge			After recharge		
		(+ve)	(0)	(-ve)	(+ve)	(0)	(-ve)
Hydrology	*1-1 Flow regime*		*		*		
	1-2 Flood regime		*			*	
	1-3 Operation of dams		*			*	
	1-4 Fall of water table		*				*
	1-5 Rise of water table		*		*		
Pollution	*2-1 Solute dispersion*			*		*	
	2-2 Toxic substances			*		*	
	2-3 Organic pollution			*		*	
	2-4 Anaerobic effects			*	*		
	2-5 Gas emissions			*	*		
Soils	*3-1 Soil salinity*			*	*		
	3-2 Soil properties	*			*		
	3-3 Saline groundwater			*	*		
	3-4 Saline drainage			*		*	
	3-5 Saline intrusion		*			*	
Sediments	*4-1 Local erosion*		*			*	
	4-2 Hinterland effect			*	*		
	4-3 River morphology		*			*	
	4-4 Channel regime		*			*	
	4-5 Sedimentation			*	*		
	4-6 Estuary erosion			*		*	
Ecology	*5-1 Project lands*	*			*		
	5-2 Water bodies	*			*		
	5-3 Surrounding areas			*	*		
	5-4 Valleys & shores			*	*		
	5-5 Wetlands & plains			*	*		
	5-6 Rare species	*				*	
	5-7 Animal migration			*		*	
	5-8 Natural industry			*	*		
Socio-economic	*6-1 Population change*	*			*		
	6-2 Income & amenity			*	*		
	6-3 Human migration	*					*
	6-4 Resettlement			*	*		
	6-5 Women's role	*			*		
	6-6 Minority groups	*				*	
	6-7 Sites of value			*	*		
	6-8 Regional effects		*		*		
	6-9 User involvement			*	*		
	6-10 Recreation			*	*		
Health	*7-1 Water & sanitation*			*	*		
	7-2 Habitation			*	*		
	7-3 Health services			*	*		
	7-4 Nutrition			*	*		
	7-5 Relocation effect			*	*		
	7-6 Disease ecology			*			*
	7-7 Disease hosts			*			*
	7-8 Disease control			*	*		
	7-9 Other hazards			*			*
Imbalances	*8-1 Pests & weeds*			*	*		
	8-2 Animal diseases			*	*		
	8-3 Aquatic weeds			*	*		
	8-4 Structural damage			*	*		
	8-5 Animal imbalances			*	*		

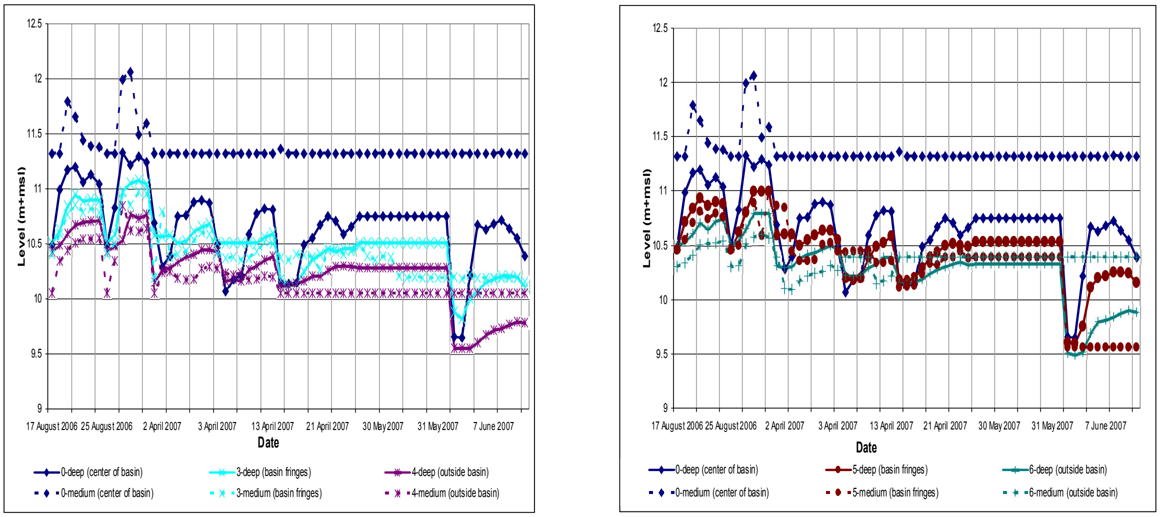


Figure 2. Groundwater levels at the groundwater monitoring well.

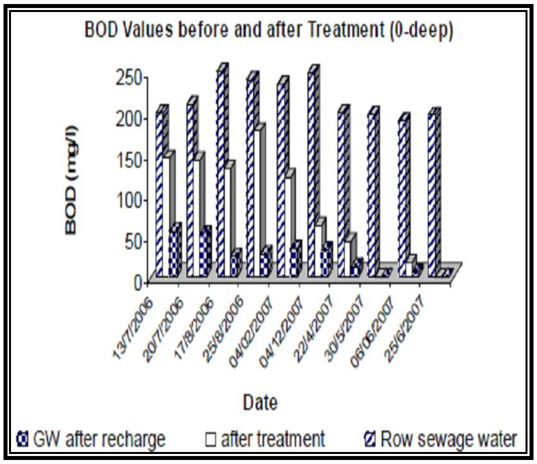
- The infiltration rate at the beginning of the experiment was 1.7cm/min and decreased gradually reaching about 0.1cm/min due to increase in soil organic matter and accumulation of heavy metals in the soil. This has dictated removal of the top layer of the basin to permit wastewater infiltration.
- Reference groundwater salinity, total dissolved solids (TDS), ranged from 2108 to 2328 mg/l and the wastewater salinity before recharge ranges from 612 to 883 mg/l. After recharge, the average shallow groundwater salinity was 757 mg/l. This indicates a reduction in the upper groundwater salinity which may be attributed to artificial recharge with low salinity treated wastewater. On the other hand salinity of the deep groundwater was 4416 mg/l.
- Concentration of heavy metals was low which may be attributed to accumulation of heavy metals in the upper 60 cm by adsorption on the surface of soil particles.
- The reference Nitrate (NO_3) concentration in groundwater ranged from 69.5 to 75.5 mg/l, being about 3.97 mg/l in wastewater before recharge. No change has been detected in the shallow groundwater while in the deep groundwater it reached 39 mg/l.
- The reference phosphate (PO_4) concentration in groundwater ranged from 1.43 to 1.61 mg/l, ranging from 8.13 to 12.03 mg/l in wastewater before recharge. No change has been detected after recharge in both the shallow and the deep groundwater. This reduction could be due to adsorption processes.
- Boron concentration in sewage effluent before recharge (0.228 - 0.3 mg/l) and reference groundwater (0.107 - 0.307 mg/l).
- The amount of zinc observed in the wastewater showed a wide variation due to a variable input of heavy metals in industrial effluent. Although observed zinc concentration in wastewater before recharge ranged from 0.041 to 0.651 mg/l, the concentration in both the shallow groundwater and the deep groundwater became 0.017 mg/l and 0.036 mg/l, respectively, which are within the same order of magnitude as the reference groundwater quality.
- Increase in both BOD and COD concentrations in shallow groundwater (30.50 mg/l for BOD and 43.50 mg/l for COD); decreasing at medium depths (10.50 mg/l for BOD and 13.00 mg/l for COD); being higher in the deep part of the groundwater (30.94 mg/l for BOD and 47.63 mg/l for COD) see figure 3.
- Analyses of microbiology parameters indicated that reference groundwater does not contain Fecal Coliform. On the other hand, it has been found in wastewater ($28x10^6$ to $200x10^6$ CFU/100ml) before treatment. After recharge, fecal coliform was detected in the shallow groundwater (up to $20x10^5$ CFU/100ml). Although this water is not used for drinking, it may impose a potential threat to the public health.

The major problem appeared in operating clay basin was the very low infiltration rate due to small porous size between clay particles and, thus, the limited amount of recharged water that can be achieved. While the results of analyses water samples indicated the following:

- Higher reduction in BOD concentration from 250 mg/l in raw sewage water to 99 mg/l after treatment and 32 mg/l in groundwater after recharge.
- Higher reduction in COD concentration from

305mg/l in raw wastewater to 183mg/l after treatment and 42 mg/l in groundwater after recharge.

- The percentage of treatment of wastewater was increased in the clay basin as a result to increase the percentage of reduction BOD to 67.67 % and COD to 77 %.



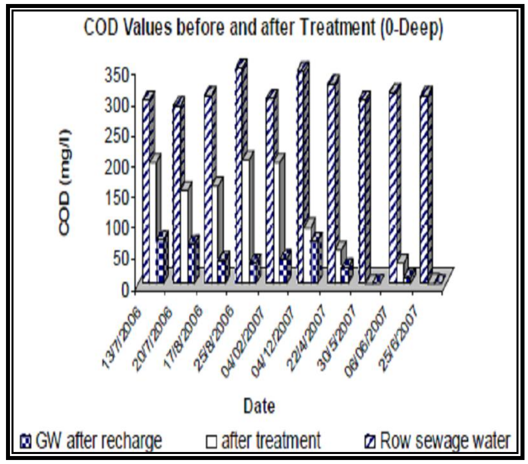


Figure 3. Comparison between BOD and COD in groundwater monitoring wells with recharge basin and raw sample.

3.2 EIA Results

Results of the Impacts EIA Matrix were developed in the form of a range using the pattern 0-100%, based on the degree of each impact and distributed among environmental issues to quantify the overall impacts. Results of application EIA matrix for irrigation and drainage projects as shown in table 3 and figures 4 and 5 indicated the following:

Table 3: EIA Matrix for Overall Impacts Qualification.

Group Issue	Before recharge				After recharge			
	(+ve)	(0)	(-ve)	Total	(+ve)	(0)	(-ve)	Total
1- Hydrology	0%	9%	0%	9%	4%	4%	2%	9%
2- Pollution	0%	0%	9%	9%	4%	6%	0%	9%
3- Soils	2%	2%	6%	9%	6%	4%	0%	9%
4- Sediments	0%	6%	6%	11%	4%	8%	0%	11%
5- Ecology	6%	0%	9%	15%	11%	4%	0%	15%
6- Socio-economic	8%	2%	9%	19%	15%	2%	2%	19%
7- Health	0%	0%	17%	17%	11%	0%	6%	17%
8- Imbalances	0%	0%	9%	9%	9%	0%	0%	9%
Total	15%	19%	66%	100%	64%	26%	9%	100%

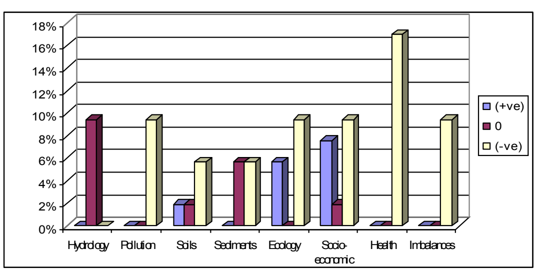


Figure 4. Percentage of negative and positive impacts before recharge.

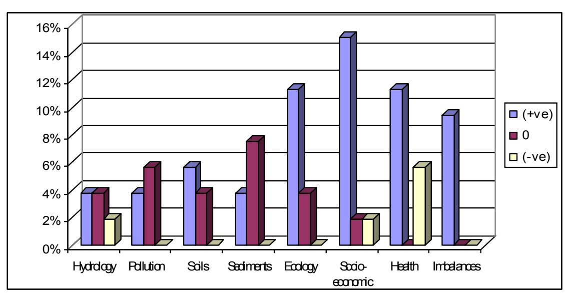


Figure 5. Percentage of negative and positive impacts after recharge.

- Reuse non-conventional water resources improve the hydrological condition of the low productive aquifers and enhance its quality.
- Treat wastewater prevent emission of harmful gases to the health and causes diseases.
- Artificial recharge of treated wastewater prevents salt accumulation in the top soil when direct use of raw wastewater for irrigation, hence lead to

improve irrigation scheme.

- Artificial recharge of treated wastewater improved water bodies' quality which may be attributed to change land features in and around wastewater treatment plants.
- Improve the social and the economic condition on the regional effect as a result of evolve new activities; more green areas; new job opportunities; higher quality of life and better services.
- The project area would be improved due to the development and additional water resources for the new reclamation lands.
- Increase the percentage of positive impacts from 15 % before experiment operation to 64 % after experiment operation.
- Decrease the percentage of negative impacts from 66 % before experiment operation to 9 % after experiment operation.

4. Conclusions and Recommendations

From the results of experiment operation and EIA application the following can be concluded:

- Reuse non-conventional water resources lead to improve the aquifer potentiality for low productive aquifer as in Abu Rawash area and promoting recovery of overexploited aquifer to enhance its quality and decrease the depth to groundwater.
- Aquifers with deep groundwater are more suitable to achieve SAT due to large thickness of unsaturated zone.
- Artificial recharge with low salinity treated wastewater lead to reduce the salinity of the shallow groundwater.
- BOD and COD concentrations are reduced by 50–80 percent which improves the efficiency of recharge and treatment completion through soil stratification.
- The organic loads cause increasing organic matter content in the soil which decrease the pores size between sand grains and decreasing the infiltration rate of the soil by time.
- The efficiency of the sand basin in the SAT was due to treatment completion through soil stratification.
- The major problem of the clay basin was the very low infiltration rate.
- The efficiency of the clay basin with respect to organic matter depletion was greater than that of the sand basin.
- Soil plays an important role in the purification process of the recharged wastewater.
- The feasibility of artificial recharge with wastewater depends on a large extent on the quality of wastewater and the capacity of the soils in enhancing its quality.
- A well designed active recovery system for the recharged pretreated wastewater considered as a protection system that prevent the contaminants from migration and extend.
- EIA is an important tool to evaluate the potential impacts before and after mitigation the existing environmental potential impacts to help decision makers in the management and protection of groundwater resource.

Thus it is recommended more detailed studies to assess the aquifer feature influences the mechanism of recharge with treated wastewater. Also a good designed monitoring system is necessary to evaluate the effect of recharge process on the groundwater quantity and quality.

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1/8/2013