Available online at www.scientiaresearchlibrary.com

Scientia Research Library

ISSN 2348-0424
USA CODEN: JETRB4

Journal of Engineering And Techonology Research, 2014, 2 (1):25-35

(*http://www.scientiaresearchlibrary.com/arhcive.php*)

WASTEWATER REUSE THROUGH SOIL AQUIFER TREATMENT

Mahmoud A. Elsheikh[1] , Waleed K. Alhemaidi [2]

[1]*Civil & Environmental Eng. Dprt, Faculty of Engineering, Menoufiya University, Shebeen Elkom, Egypt,*

[2]*Civil & Environmental Eng. Dprt, Faculty of Engineering, University of Tabuk, Saudi Arabia,*

ABSTARCT

Groundwater resources of Saudi Arabia are depleting at a very fast rate due to the high water supply withdrawing. Natural renewable and recharging of groundwater are done through infiltration of rainwater which are not enough in Saudi Arabia. Partially treated wastewater is used as an artificial method for recharging the groundwater. A high degree of upgrading can be achieved in Soil Aquifer Treatment (SAT) system by allowing partially treated sewage to infiltrate into the soil and move down to the groundwater.

The paper uses the criteria of the existing wastewater treatment plant of Tabuk city for recharging the plant effluent into the groundwater. This study reviews many recent researches in the field of the SAT systems and their application. The reviewing of the previous study in the field of the SAT included the required wastewater characteristics, existing groundwater conditions, quality and usages of groundwater, and existing soil conditions and their suitability for a SAT system. The study investigates the existing criteria of effluent wastewater to design experimental and numerical model for the SAT based on site characteristics. This study is working for getting guidelines to build, setup and dimension of an optimum pilot plant for Soil Aquifer treatment in the site.

Keywords: Soil Aquifer treatment; Effluent wastewater characteristics; Conditions and quality of groundwater

---

INTRODUCTION

Groundwater is traditionally considered to be less risk of contamination by waterborne pathogens due to a natural filtration mechanism by soils during gravitational movement. In Saudi Arabia, most of the public water supply systems rely on groundwater. Groundwater also provides a critical water source for agricultural and industries. But as it is often the case with critical resources, groundwater is not always available when and where needed, especially in water-short areas where heavy use has depleted underground reserves. The Total actual yearly renewable freshwater resources in Saudi Arabia is estimated to be 2.4E9 m^3, meanwhile its yearly freshwater withdrawal is about 22.5E9 m^3 which is 9.4 times the renewable freshwater resources [1].

The growing competition for water around the world are leading to even greater use of the enormous water resource. As part of this trend, there has been increasable interest in the use of artificial recharge to augment groundwater supplies, especially in the countries water-short resources. Stated simply, artificial recharge is a process by which excess surface water is directed into the ground (either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration) to replenish an aquifer.

The artificial recharge using waters of impaired quality is one of many strategies that can be used, alone or in conjunction with other strategies, to increase water supplies, such as reducing water consumption, reuse of treated wastewater or creating secondary water systems that deliver certain wastewaters directly to nonpotable uses (e.g., the use of gray water for landscape irrigation). Aquifer recharge for the wastewater reuse has been considered and studied as a promising process to cope with the worldwide water scarcity [2-6]. Treated wastewater effluents from municipal wastewater treatment plants are now increasingly being considered as a reliable source of water supply [7].

Artificial groundwater recharge with reclaimed water provides one of the possibilities of a supplement of groundwater with additional advantages as follows: reduction of groundwater levels decline, protection of underground freshwater in coastal aquifers against intrusion from the ocean, and storage of reclaimed water for future reuse [8].

Soil aquifer treatment (SAT) has been found to be a low cost sustainable tertiary wastewater treatment technology, which has the ability to generate high quality effluent from secondary treated wastewater for potable and non-potable uses [4,9]. During SAT, the saturated and unsaturated zones of the natural soil and groundwater aquifer act as the medium in which physicochemical and biological reactions occur [9]. These reactions substantially reduce the levels of organic and inorganic compounds including nitrogen, phosphorus, suspended solids, pathogens and heavy metals leading to an improvement in water quality [10,11]. Mixing of the infiltrated wastewater with the groundwater and the slow movement through the aquifer increases the contact time with the aquifer material leading to further purification of the water [12,13].

The unsaturated zone has available oxygen due to ability of air flow in its porous during the drying period of the SAT treatment cycle. Availability of oxygen in the unsaturated zone is highly important in promoting aerobic biodegradation processes and nitrification. Factors influencing the efficiency of SAT include characteristics of treatment site, soil and wastewater characteristics, climate and infiltration rate [14]. Redox conditions and residence time can have a significant influence on the kinetics of dissolved organic carbon (DOC) degradation and may affect its removal efficiency[15]. Besides treatment, SAT offers the opportunity of aquifer recharge [16] thus seasonal or long-term storage of water can be achieved [4], which is especially beneficial in arid areas. Soil aquifer treatment systems are capable of supporting the removal of organic carbon, nitrogen, pathogens and many other pollutants.

MATERIALS AND METHODS

Aims of the study

The paper uses the criteria of the existing wastewater treatment plant of Tabuk city, Saudi Arabia, for recharging the plant effluent into the groundwater. This study reviews many recent researches in the field of the SAT system and its application. The reviewing of the previous SAT study included the required wastewater characteristics, existing groundwater conditions, quality and usages of groundwater, and existing soil conditions and their suitability for a SAT system. The study investigates the existing criteria of effluent wastewater to design experimental and numerical model for the SAT based on site characteristics. This study is working for getting guidelines to build, setup and dimension of an optimum pilot plant for Soil Aquifer treatment in the site.

WASTEWATER CHARACTERISTICS FOR RECHARGE THE AQUIFER

The water used for recharge the aquifer in this paper is wastewater effluent from Tabuk wastewater treatment plant in Tabuk, north of Saudi Arabia. Tabuk city is a big city in Saudi Arabia and it is the capital of the north-west (Tabuk) region which has one of the biggest aquifer in Saudi Arabia (Figure 1). The recent population of Tabuk city is about 520000 capita with average yearly increasing rate of 3.3% [17] with average daily water consumption of 280 liter per capita from the groundwater. Tabuk city produces wastewater of about 110000 m^3/day which treated in a central plant including inlet works (deceleration, screening, grit removal and scum removal chambers), biological treatment (selectors, aeration and settling tanks with return sludge), tertiary treatment (filtration units), chlorine disinfection and drying sludge (general layout of Tabuk Wastewater Treatment Plant -WWTP- is shown in Figure 2.).

Many parameters were measured to determine all characteristics of the influent and effluent wastewater of Tabuk WWTP. The parameters included biological oxygen demand "BOD", chemical oxygen demand "COD", total suspended solids "TSS", volatile suspended solids "VSS", dissolved oxygen "DO", nitrogen-nitrate "N-NO_3", nitrogen-nitrite "N-NO_2", nitrogen-amonia "N-NH_3", total kjeldahl nitrogen "TKN", total dissolved solids "TDS, sulfate "SO_4", phosphorous "P", chlorine residual "Cl_2",temprature "T", total hardness, alkalinity, chloride, pH-value, turbidity, oil and grease, fecal coliforms, etc. The removal efficiency were calculated of Tabuk WWTP from the measured parameters. Table 1 shows the characteristics of the influent and effluent wastewater and the efficiency of Tabuk WWTP. The effluent is currently discharge to a valley (WADI) after the plant of about surface area of 10 Km^2 for evaporation.

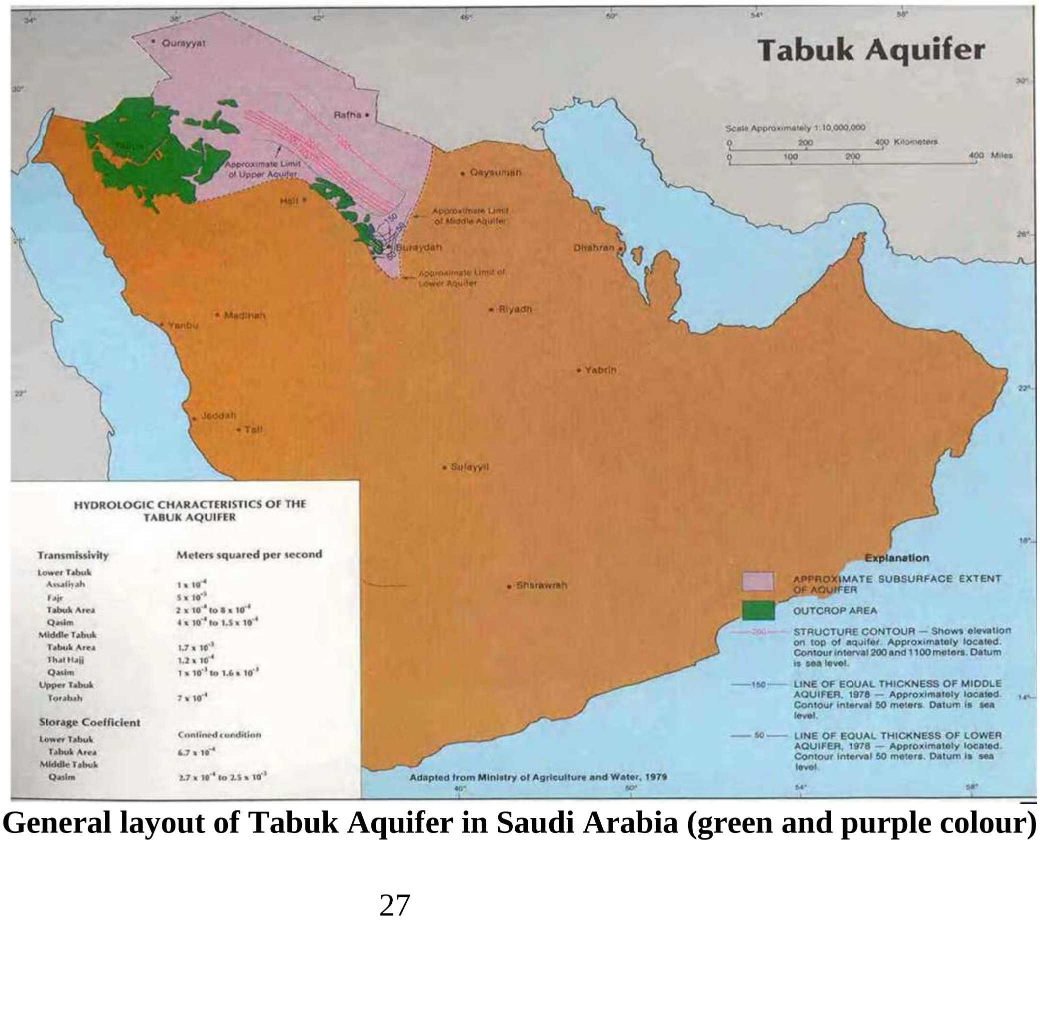

Figure 1. General layout of Tabuk Aquifer in Saudi Arabia (green and purple colour)

Figure 2. General layout of Tabuk Wastewater Treatment plant.

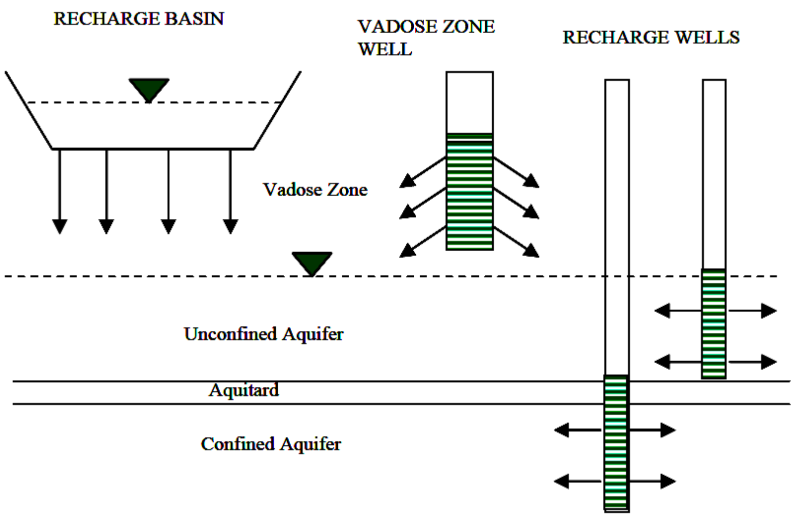

Figure 3. Major methods for aquifer recharge

Figure 4. Clogging and cleaning layer in recharge basin operated in Orange County, California, (Bouwer, et al. 2008).

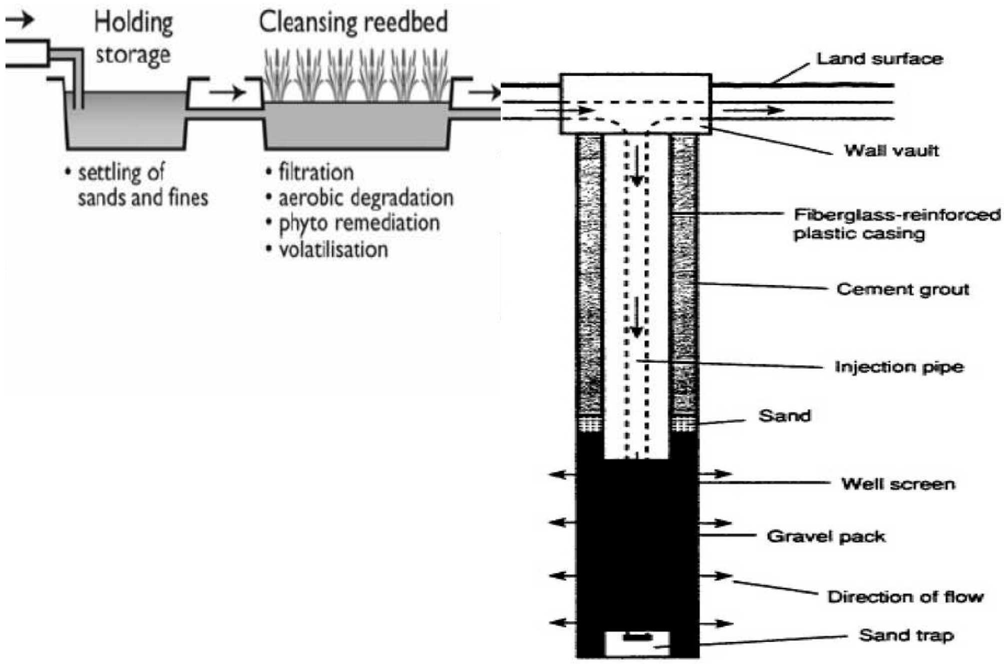

Figure 5. Constructed wetland with perforated drain in gravel layer on bottom discharged in vadose zone well for aquifer recharge.

SOIL CHARACTERISTICS SURROUNDING THE SITE OF TABUK WWTP

Many boreholes has been investigated in the site of the Tabuk WWTP. The investigation included the layers of soil in the site, soil description of each layer, depth of each layer, groundwater table, moisture contents, sieve analysis, effective size of soil, uniformity coefficients, dry density, atterberg limits, etc. Based on the geotechnical soil report, the soil profile at the site of wastewater treatment plant of Tabuk city consist of main layers:

(1) Silty sand: a top surface layer of light brown to brown, dense to very dense. The thickness of this layer is varied from 1.7 m to 2.0 m.
(2) Sandy shale (swelling shale): a layer of light gray to light brown, fine grained, highly weathered and very highly fractured sand shale below the above top layer. The thickness of this layer is extended to range of 21 m : 22 m from the ground level.
(3) Sandstone inter-bedded with shaly siltstone: a layer of brown to brown, fine grained, highly weathered and very highly fractured sand shale below the above two layers. This layer extended to the end of boreholes of 45 m.

The ground water table was not encountered within the maximum depth of boreholes of 45 m during the time of drilling. Infiltration tests were done in the boreholes in three stages; in the first layer of depth 1.5 m from the ground surface (silty sand layer), in the second layer of depth 15 m from the ground surface (sandy shale layer) and in the third layer of depth 15 m from the ground surface (sandstone layer). The boreholes were filled with water up to the ground level in the two stages and the water level in the boreholes were observed for 24 hours. The rate of infiltration was about 0.05, 0.15 and 4.5 m per day for the depth 1.5, 15 and 25 m from the ground level respectively.

SUITABILITY OF TABUK WWTP EFFLUENT FOR AQUIFER RECHARGE

The quality of the source waters used to recharge ground water has a direct bearing on operational aspects of the recharge facilities. In land application, the pollutant contents of the soil will remain at the background level and the soil's ecological and chemical integrity are preserved. When this requirement is met, the capacity of the soil to sustain any future land uses is guaranteed and the transfer of pollutants up the food chain is kept to a minimum [18]. Numerical limits, therefore, are set to prevent the pollutant concentration of the soil from rising during the course of land application.

In general, the source water characteristics that affect the operational aspects of recharge facilities include suspended solids, dissolved gases, nutrients, biochemical oxygen demand, microorganisms, and the sodium adsorption ratio (which affects soil permeability) [19]. Therefore, it is a key factor that can be controlled as part of a SAT system. One of the greatest impacts of effluent pretreatment during SAT is near the soil/water interface where high biological activity is observed. It should also be noted that the majority of oxygen demand exerted during wetting is from the oxidation of organic carbon while ammonia is removed by adsorption [20].

Earlier studies found a correlation between the organic and hydraulic loading rates and effluent quality [21]. It was observed that effluent BOD, COD, SS, TKN, NH_3 and P concentrations increased linearly with an increase in cumulative mass loading. Effluent quality with respect to these parameters was also found to deteriorate linearly with increase in cumulative hydraulic loading [21]. These results indicated that the hydraulic loading was a more important operating parameter than the organic loading in determining the effluent quality [6]. Therefore, the application guidelines based on this approach set the maximum permissible pollutant loading and provide the flexibility to develop suitable management practices for using wastewater and sewage sludge within the boundary [18].

Pretreatment requirements for groundwater recharge vary considerably depending upon the purpose of groundwater recharge, sources of reclaimed wastewater, recharge methods, location, and, more importantly, public acceptance [12]. Slow sand filter was used for pre-treatment for aquifer recharge and acts as a bio-filter, in which a large fraction of DOC is removed in the upper sand layer within the depth of 1.0–1.5 m [22,23] and the biodegradable DOC was mainly removed within 30 cm depth [22]. Also, combination of ozonation (for breakdown of the large organic molecules) and sand filtration preferentially removes soluble microbial by-product-like substances and DOC with molecular weight (MW) less than 1.0 kDa. Meanwhile, nano-filtration removes aromatic, humic acid-like and fulvic acid-like substances efficiently and specially removes DOC with MW above 1.0 kDa [24].

Water quality standards for indirect potable uses have not been formally adopted in Saudi Arabia [25]. However, there is a current effluent guideline standards for unrestricted agricultural reuse enforced by the Ministry of Agriculture and Water - Table 2 [20]. It is likely that water quality considerations will be the most stringent for direct injection, as this alternative places treated water directly into the aquifer and has the potential for the shortest residence times in the environmental buffer [26].

Guidelines for aquifer recharge are generally expected to maintain, at a minimum, a drinking water quality standard with additional treatment burdens for multiple barriers with stringent disinfection for pathogen removal. Table 3 shows the most known rigorous regulations for groundwater recharge in California, USA (adapted from [27]).

Referring to the effluent characteristics of Tabuk WWTP (Table 1), it is noted that most of the parameters are out of limits for reclaimed water standards for unrestricted irrigation in Saudi Arabia (Table 2) and California draft groundwater recharge regulations (Table 3) in spite of the existing of tertiary treatment through filtration (except the oil and grease concentrations). That could be mainly because the design capacity of the existing Tabuk WWTP units is 60000 m^3/day, meanwhile the real influent to the plant is in range of 95000-110000 m^3/day. An extension in Tabuk WWTP has executed and in going to have capacity of 120000 m^3/day. Most of the traces and heavy elements were not measured during analysis. However, it is expected to be within the allowable limits because of the low industrial activities in Tabuk and the absent of these elements in the potable water. Therefore, the existing Tabuk WWTP effluent is not ready to be used for aquifer recharge. Treatment processes are available to bring municipal wastewater effluent to levels acceptable for various recharge applications; however, even when it has been treated to a high degree.

SOIL AQUIFER WASTEWATER TREATMENT

Artificial recharge can be done using any surplus surface water. When low quality water is used for recharge, the underground formations can act as natural filters to remove many physical, biological, and chemical pollutants from the water as it moves through. Often, the quality improvement of the water is actually the main objective of recharge, and the system is operated specifically using the soil and the aquifer to provide additional treatment to the source water [19]. SAT is particularly suited to seasonally arid landscapes that feature permeable, free-draining soils [28,29]. It is common practice to operate SAT infiltration basins under a cyclic wetting and drying regime so as to restore infiltration rates and assist in the removal of nitrogen, phosphorus, organic carbon and other contaminants present in the infiltrate [23,28]. This also enables the organic-rich surficial deposits to quickly desiccate for restoration of infiltration rates in subsequent wetting cycles [30].

Figure 3 illustrates the difference in location of recharge basins, vadose zone wells, and recharge wells with respect to the saturated zone of an aquifer. Recharge basins are the most common type of surface spreading, which includes recharging water at the surface through recharge basins, ponds, pits, trenches, constructed wetlands, or other systems. Consistent with the figure, recharge wells can be used in either confined or thick, unconfined aquifers [27]. The selection of recharge method will depend on aquifer type, depth and characteristics, which impact the ability to recharge water into the storage zone and recover that water later.

The aquifer recharge has many advantages, such as groundwater resource preservation, safe water storage against evaporation and secondary contamination, water transportation, and water treatment. The significance of specific criteria and guidelines was reported for the health and regulatory aspects of aquifer recharge [12]. Soil aquifer treatment represented examples of the aquifer recharge for water reuse [31]. The contaminant removal accompanied with the aquifer recharge systems can be a result from natural physicochemical and biological reactions in the subsurface soil porous media.

A number of studies have investigated on the fate and removal of various individual or specific groups of trace pollutants to evaluate the safety of water during artificial groundwater recharge [3,19]. Under all experimental conditions investigated, the first 100 mm of the soil column was responsible for most of the removal or transformation of the wastewater parameters that occurred [6]. Many trace organic pollutants could be removed to some extent during artificial groundwater recharge depending on a number of factors, such as climate and physiochemical conditions of the aquifer [32]. Any hydrophobic compounds and disinfection byproducts present in recycled water recharged to the aquifer should be naturally degraded during aquifer passage with sufficient aquifer residence time or travel distance between recycled water injection and groundwater extraction [33]. With the bioassay based safety evaluation, the combination of soil aquifer treatment and ozonation could provide new water sources with no higher toxic than the conventional natural drinking water source [34]. DOC and trihalomethane formation potential (THMFP) can be reduced from 6.5 to 0.7 mg L^{-1} and from 267 to 52 µg L^{-1}, respectively. The very low DOC concentration of 0.6 mg L^{-1} and THMFP of 44 µg L^{-1} can be reached after the aquifer treatment [24]. Moreover, Neutral pharmaceutically active compounds (PhACs) and acidic PhACs were removed with efficiencies greater than 88% from different organic matter water matrices during batch soil passage studies of hydraulic retention time of 60 days [35].

The water quality improvements of the recycled infiltrated through a 9 m-thick calcareous vadose zone of aquifer recharge were based on changes in the chemistry and microbiology of groundwater immediately down-gradient from the infiltration gallery. Changes in the average concentrations of several constituents in the recycled water were identified with reductions of 30% for phosphorous, 66% for fluoride, 62% for iron and 51% for total organic carbon with a residence time of approximately 4 days in the vadose zone and less than 2 days in the aquifer [36]. Adsorption and precipitation are reported to be the main causes of phosphorous retention in calcareous sands and soils [37]. Sorption and biodegradation are also common mechanism for the removal of pharmaceuticals under aerobic conditions in the vadose zone [38,39]. Reductions in microbial pathogens in treated wastewater recharged to limestone aquifer over time were demonstrated using survival experiments in in-situ diffusion chambers [40]. The reductions in microbial pathogens were attributed to a combination of physical removal processes during filtration and the activity of indigenous groundwater microorganisms. The aquifer has an active treatment capacity to remove pathogens [41], but a longer period of aquifer residence may be needed to allow for more inactivation of microbial pathogens [40].

CLOGGING OF SAT SYSTEM

A major operational feature of infiltration systems for artificial recharge of ground water is soil clogging caused by accumulation of suspended solids on the bottom and banks of the infiltration facility as they settle or are strained out on the soil surface. The suspended solids can be inorganic (e.g., clays, silts, fine sands) or organic (e.g., algae, bacterial flocks, sludge particles). Also, biofilms can grow on the bottom [42]. Some mobile bacteria actually may produce mats of polymer strands, which can then strain out fine suspended particles. Thus, clogging layers may consist of a mixture of organic and inorganic products. Their thickness may range from 1 mm or less to 0.3 m or more. They have a low permeability and, hence, they reduce infiltration rates [29]. On the other hand, the controlled soil clogging accompanied with bioprocesses improves water quality as retention time increases [43]. Considering both positive and negative influence of pollutant removal [44], biological clogging in porous media must be depicted by examining a correlation between bacterial growth and hydraulic conductivity to control the aquifer recharge and improve its efficiency [45].

Clogging may also be biologically-induced. The character of DOC and its relative biodegradability are known drivers of biological clogging [46,47] causing increased production of extracellular polysaccharides in the biofilm surrounding the injection well [48]. In aquifer recharge, soil clogging by an excessive growth of bacteria is often accompanied with the aquifer recharge. Three different clogging mechanisms were suggested depending on the flow rate and substrate concentration: (1) clogging at a high flow rate can be accelerated by entrapped and accumulated biofilms, and can be easily eliminated by high shear force, (2) clogging at a low flow rate can be delayed for the time of local biofilm growths in the narrow pore necks, but the biofilm is rigid enough not to be sloughed, and (3) clogging in a solution with high substrate concentrations cannot be easily eliminated because of the growth of dense biofilms. The depicted biological clogging mechanisms will play a role in supporting studies about aquifer recharge [5].

Monitoring the effects of clogging of well is an important practice during aquifer recharge system operation. Monitored parameters include water quality (e.g., dissolved oxygen, pH, TDS) and rates of change in hydraulic head within recharge zone monitor wells. The bypass filter test can provide early warning of clogging. In addition, video analysis of the borehole and well screen is also a useful method. In recharge wells, physical maintenance practices often include backflushing or other physical agitation to loosen and remove plugging materials such as (1) compressed air jetting, (2) controlled sonic blasting, and (3) pressurized CO_2 injection. Other physical methods could include brushing or swabbing the screen. Physical maintenance in a recharge basin generally includes breakup and/or removal of the low-permeability "cake" layer. Breakup practices include disc harrows or rotary tillers, or a "dry-and-crack" technique. Several methods exist with respect to cake removal, such as scraping; however, care must be taken to minimize compaction of the basin floor [27].

DESIGN FOR SAT SYSTEMS FOR TABUK WWTP EFFLUENT

Evaluation of the viability of a SAT project and of its effectiveness requires an understanding and predictive capability of the hydraulic and chemical effects. The pre-feasibility studies and the pilot tests should be concentrated on the two topics: the unsaturated zone and the saturated zone [49]. Results from the field investigations and pilot testing is evaluated thoroughly and utilized to prepare the project description. Assessment of the depth to groundwater indicated that it is more than 45 m from the ground level. This insure potential occurrence of a vacuum condition and air entrainment which important when considering the design of recharge wells [27]. The infiltration rate in-site of the surface layer is very low (less than 0.1 m per day) and cannot be used for surface recharge. It might be there is another far location that have sufficient infiltration rate for aquifer recharge. However, the cost of pumping the effluent could be restriction for using. The second subsurface layer (up to depth of 20 m) has also a low infiltration flow (less than 0.2 m per day) and practically cannot be replaced or used for shallow vadose well for aquifer recharge [29]. Therefore, it is practically to use deep vadose well for aquifer recharge of depth more than 25 m where there is good infiltration rate of 4.5 m/day. Figure 5 shows the suggested design of the required deep vadose well for aquifer recharge of the Tabuk WWTP effluent.

However, as noted from the characteristics of the effluent water quality of Tabuk WWTP, it should have extra treatment to be suitable for aquifer recharge. There are many advanced wastewater treatment (AWWT) processes including chemical clarification, filtration, air stripping, activated carbon adsorption, microfiltration, nanofiltration, reverse osmosis, and advanced oxidation using hydrogen peroxide and UV irradiation that have been demonstrated [12]. However, all of these AWWT have high technologies that costly need extensive construction, operation and maintenance activities. Effective low-cost treatment of polluted water has led to many studies on constructed wetlands that required larger land requirement and acceptable treatment efficiency [50,51]. There is no problem in the availability of land in Tabuk because most of the land in surrounding of the plant is desert without useful uses. Therefore, the cost effective choice for aquifer recharge pre-treatment should be constructed wetland with under drainage system that collect the treated un-turbid water to be injected in the vadose well (Figure 5). The existing valley is used for pre-settling of any fine SS in Tabuk WWTP effluent.

CONCLUSION

As demand for water increases, the artificial groundwater recharge can be one option in an integrated strategy to optimize total water resource management. It believes that with pretreatment, soil-aquifer treatment, and post-treatment as appropriate for the source and site, treated wastewater can be used as a source for artificial recharge of ground water aquifers.

The effluent characteristics of existing Tabuk wastewater treatment plant is not suitable for recharging into the groundwater. The recent researches in the field of the SAT system and its application indicated that the effluent need extra treatment. Because there are huge available desert lands in the surrounding of the plant, a pre-treatment constructed wetland system was chosen due to its acceptable treatment efficiency and its effective low-cost treatment of polluted water. Also, the site soil investigation indicated that the most cost effective method for aquifer recharge is the vadose zone recharge well.

ACKNOWLEDGEMENT

This research was supported by university of Tabuk for the project number "Pj WAT S-1433-0038"…

REFERENCES

[1] K. Frenken, **2009**. Irrigation in the Middle East region in figures AQUASTAT Survey 2008. FAO Water Reports 34. Rome, 2009.

[2] J. Crook, et al. **1998**. Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water, National Research Council, ISBN: 0-309-51768-0, National Academy Press, Washington, DC (1998)

[3] D. M. Quanrud; Hafer, J., Karpiscak, M.M., Zhang, J., Lansey, K.E., Arnold, R.G., **2003**. Fate of organics during soil-aquifer treatment: sustainability of removals in the field. Water Research 37 (14), 3401-3411.

[4] P. Fox; Houston, S., Westerhoff, P., Nellor, M., Yanko, W., Baird, R. , Rincon, M., Gully, J., Carr, S., Arnold, R., Lancey, K., Quanrud, D., Ela, W., Amy, G., Reinhard, M., Drewes, J.E., **2006**. Advances in Soil Aquifer Treatment Research for Sustainable Water Reuse. AWWA Research Foundation and American Water Works Association, Denver, CO.

[5] J. W. Kim; H. Choi, Y. A. Pachepsky. **2010**. Biofilm morphology as related to the porous media clogging. Water Research 44 (2010) 1193–1201.

[6] H. M. K. Essandoh; C. Tizaoui, M.H.A. Mohamed, G. Amy, D. Brdjanovic. **2011**. Soil aquifer treatment of artificial wastewater under saturated conditions. Water Research 45 (2011) 4211- 4226.

[7] Metcalf and Eddy, Tchobanoglous G., Burton, F.L., Stensel, H.D., **2003**. Wastewater Engineering: Treatment and Reuse, fourth ed. McGraw-Hill Inc., New York.

[8] G. W. Miller, **2006**. Integrated concepts in water reuse: managing global water needs. Desalination 187, 65–75.

[9] W. Cha; Kim, J., Choi, H., **2006**. Evaluation of steel slag for organic and inorganic removals in soil aquifer treatment. Water Research 40 (5), 1034-1042.

[10] M. B. Pescod, (**1992**) Waste Water Treatment and Use in Agriculture. FAO. (Online), http://www.fao.org/docrep/T0551E/t0551e06.htm (Access date: 2012, March.20)

[11] P. Fox; R. Makam, **2009**. Surface area and travel time relationships in aquifer treatment systems. Water Environment Research 81 (11), 2337-2343.

[12] T. Asano; J. A Cotruvo. **2004**. Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. *Water Research, Volume 38, Issue 8, April 2004, 1941-1951*

[13] P. Dillon; Pavelic, P., Toze, S., Rinck-Pfeiffer, S., Martin, R., Knapton, A., Pidsley, D., **2006**. Role of aquifer storage in water reuse. Desalination 188 (1-3), 123-134.

[14] A. Tanik; Comakoglu, B., **1996**. Nutrient removal from domestic wastewater by rapid infiltration system. Journal of Arid Environments 34 (3), 379-390.

[15] S. Grunheid; Amy, G., Jekel, M., **2005**. Removal of bulk dissolved organic carbon (DOC) and trace organic compounds by bank filtration and artificial recharge. Water Research 39 (14), 3219-3228.

[16] R. L. Droste, **1997**. Theory and Practice of Water and Wastewater Treatment. John Wiley & Sons Inc., New York.

[17] Statistic year book **2010**, Saudi Central Department of Statistic and Information, Saudi Arabia 2010.

[18] A. C. Chang; G. Pan, A. L. Page, and T. Asano (**2002**).Developing Human Health-related Chemical Guidelines for Reclaimed Waster and Sewage Sludge Applications in Agriculture. World Health Organization Report, 2002.

[19] J. Andelman, et al. **1994**. “Ground Water Recharge Using Waters of Impaired Quality” US National Research Council, ISBN: 0-309-57741-1, National Academy Press, Washington, DC, (1994).

[20] US-EPA Guidelines for Water Reuse. EPA/625/R-04/108 Washington, DC, Sep. 2004

[21] P. Nema; Ojha, C.S.P., Kumar, A., Khanna, P., **2001**. Technoeconomic evaluation of soil-aquifer treatment using primary effluent at Ahmedabad, India. Water Research 35 (9), 2179-2190.

[22] P. Fox; Aboshanp, W., Alsamadi, B., **2005**. Analysis of soils to demonstrate sustained organic carbon removal during soil aquifer treatment. J. Environ. Qual. 34, 156-163.

[23] T. Rauch-Williams; Drewes, J.E., **2004**. Assessing the removal potential of soil-aquifer treatment systems for bulk organic matter. Water Sci. Technol. 50 (2),245–253.

[24] W. Linlin; Z. Xuan, Z. Meng. **2011**. Removal of dissolved organic matter in municipal effluent with ozonation, slow sand filtration and nanofiltration as high quality pre-treatment option for artificial groundwater recharge. Chemosphere 83 (2011) 693–699.

[25] WHO. **2006**. Wastewater Reuse in the Eastern Mediterranean Region. WHO, Regional Office for the Eastern Mediterranean, Regional Centre for Environmental Health Activities, CEHA, 2006.

[26] S. M. **Lacy2005**. Large Scale Systems Water Conservation, Reuse, and Recycling Workshop, National Research Council, ISBN: 0-309-54502-1, National Academy Press, Washington, DC (2005)

[27] E. J. Bouwer, et al. **2008**. Prospects for Managed Underground Storage of Recoverable Water. National Research Council, ISBN: 0-309-11439-X, National Academy Press, Washington, DC (2008).

[28] P. Fox; Narayanaswamy, K., Genz, A., Drewes, J.E., **2001**. Water quality transformations during soil aquifer treatment at the Mesa Northwest Water Reclamation Plant, USA. Water Science and Technology 43 (10), 343-350.

[29] H. Bouwer, **2002**. Artificial recharge of groundwater: hydrogeology and engineering. Hydrogeology Journal 10 (1), 121-142.

[30] P. Pavelic; P.J. Dillon, M. Mucha, T. Nakai, K.E. Barry, E. Bestland. **2011**. Laboratory assessment of factors affecting soil clogging of soil aquifer treatment systems. water research 45 (2011) 3153 -3163.

[31] G .Amy, J. Drewes, **2007**. Soil aquifer treatment (SAT) as a natural and sustainable wastewater reclamation/reuse technology: fate of wastewater effluent organic matter (EfOM) and trace organic compounds. Environmental Monitoring and Assessment 129 (1e3), 19e26.