https://dx.doi.org/10.22161/ijreh.2.5.4 ISSN: 2456-8678

The Reuse of Treated Wastewater via Groundwater Recharge for the Development of Sustainable Water Resources

Saeid Eslamian[1], Elahe Hedayat[1], Saleh Tarkesh Esfahani[1], Kaveh Ostad-Ali-Askari[2*], Vijay P. Singh[3], Nicolas R. Dalezios[4], Mohammed Matouq[5]

[1]Department of Water Engineering, Isfahan University of Technology, Isfahan, Iran.
[2*]Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran. **Corresponding Author Email:** koa.askari@khuisf.ac.ir
[3]Department of Biological and Agricultural Engineering &Zachry Department of Civil Engineering, Texas A and M University, 321 Scoates Hall, 2117 TAMU, College Station, Texas 77843-2117, U.S.A.
[4]Laboratory of Hydrology, Department of Civil Engineering, University of Thessaly, Volos, Greece & Department of Natural Resources Development and Agricultural Engineering, Agricultural University of Athens, Athens, Greece.
[5]Al-Balqa Applied University, Chemical Engineering Department, President of Jordan Japan Academic Society, JJAS, P.O. Box 4486, Amman 11131- Jordan.
***Corresponding Author:Dr. KavehOstad-Ali-Askari**, Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran.
Emails: koa.askari@khuisf.ac.ir , kaveh.oaa2000@gmail.com

Abstract— *Due to the reduction of groundwater resources, the artificial recharge of these resources through the reuse of treated wastewater (modified water) is an efficient way to tackle the problem. Some of the most important goals to be achieved regarding such a situation are the development of underground resources, building barriers to help avoid the penetration of the saline water to the underground water table in the coastal areas, creating additional levels of water treatment by soil and controlling the soil settlement. The modified water helps to compensate for the underground water. Asthe additional stage of the purification of the modified water offers assurance on the sewage management system, this natural water treatment created underground eliminates the need for costly wastewater treatment processes. Moreover, the groundwater aquifers provide a natural mechanism for the subsurface transfer of the modified water and eliminate the need for the surface storage facilities and associated problems, such as evaporation and the growth of algae, which degrade the water quality. One of the most commonly used methods is the aquifer storage and recovery (ASR) technology, which helps overcome the seasonal imbalance associated with the retrieval systems in the world. In the present paper, the methods used to realize this solution, including among others flood spreading, the soil aquifer treatment (SAT) systems, injection in unsaturated areas, and direct injection are examined. Furthermore, the advantages and disadvantages of using the modified water and the required hydraulic analyzes for designing direct injection wells and injection in unsaturated areas will also be investigated.*
Keywords— Aquifer, ASR, SAT Systems, Penetration.

I. INTRODUCTION

Surface flooding, flooding irrigation, the improvement of water flow channels, hill filtration and the use of surface infiltration ponds are some of the flood spreading techniques. These systems depend on many factors such as the type of soil and its porosity, the groundwater depth, the topography of the area as well as the quantity and quality of the modified water. (1 & 2)

In an exact study entitled 'an investigation of soil aquifer treatment for sustainable water reuse',the utilization of different SAT systems in locations with different characteristics and the pre-treated fluid in an aim to achieve sustainable principles led to significant results. (3) In all the studied systems, the amount of water quality improvement is similar to that byBouwer in 1984, signifying that when the transfer time in the saturated or saturated area is sufficient, the water quality will be highly improved. (4)

Many of the specific criteria for the quality of the modified water (for the underground water) and the organics in the groundwater aquifers should be examined before the establishment and implementation of the operation. These criteria include the possible chemical interactions between the modified water and the underground water, iron deposition, ionic reactions,

https://dx.doi.org/10.22161/ijreh.2.5.4 ISSN: 2456-8678

biochemical changes, temperature variations as well as viscosity variations. (5)

The results of the study conducted by the AWWARF in 2001 entitled 'an investigation of soil aquifer treatment for sustainable water reuse'indicated that the cleaning potentiality ofa SAT system ismost significantly noticeable where the duration of water transport through the infiltration interface, including its recovery, was six months or more. The presence of microbes accelerates the mineralization of organic compounds. However, microorganisms do not receive enough energy from the organic compounds to help them grow. A prediction similar to the abovementioned results for the aerobic and anaerobic groundwater aquifers encounters nitrate deficiency. In addition, hard drug formulations were also observed in the products of a microbial reaction in the groundwater aquifer at very low concentrations.

II. MATERIALS AND METHODS

2.1. Methods for Underground Water Supply:

Table 1 compares the important engineering factors that are used in building an underground water supply system. (6) The injection wells adjacent to the modified water supplies can be used to reduce the transmission costs. While the flood spreading basins require the least degree of purification, the direct injection systems require the water quality equal to that of the drinking water. The ASR systems are employed with no use of membrane treatment when water is stored for irrigation purposes. Injection in unsaturated areas is a reliable new technology wherein disinfection and the removal of total suspended solids (TSS) are essential to help avoid clogging.

Table.1: Factors affecting the design of a water supply system

	Catchment basins	Unsaturated injection wells	Direct injection wells
Type of groundwater aquifer	unconstrained	unconstrained	constrained/unconstrained
Primary purification needs	low technology	decreasing TSS	high technology
Cost estimation (U.S. $)	distribution systemand land	25000-75000$ per well	500000-1500000$ per well
Capacity	100-200000 m^3/ha-d	1000-3000 m^3/d per well	2000-6000 m^3/d per well
Protective needs	drought and clogging	drought and disinfection	disinfection and return flow
Estimated efficiency	more than 100 years	5-20 years	25-50 years

Flood spreading is a direct feeding method whereby water moves from the surface of the earth to the underground aquifers through surface and deep penetration via the soil network. After feeding, water is transferred from the soil. The statuses of subsurface hydrology and geological stability decide the degree of surface penetration. The required capacity and the amount of water movement from the releasing area to the harvesting area are determined by some important features to be taken into account, particular among them being the physical and impermeable properties of subsurface deposits, the underground water depth, the specific yield, the thickness of the deposits, the hydraulic gradient and the pumping pattern. Most often, nitrogen is left out as part of the recovery system before flood spreading in order to eliminate the concern about the contamination of the groundwater nitrate and also simplify the processes required for obtaining the license for the storage systems. (6)

2.1.1. The Soil Aquifer Treatment (SAT) Systems:

The soil aquifer treatment (SAT) systems are usually designed and implemented in places where all the infiltrated water is retrieved to the surface through wells, drainage systems or soil settlement. The SAT systems with surface penetration basins require undetectable groundwater aquifers, unsaturatedzonesfree from barrier layers as well as soils with particles sufficiently big enough to increase the amount of superficial permeation. The sandy loam or loam is the best soil to be applied for designing the SAT systems. Recent studies on the performance of the SAT systems show positive results on the removal of dissolved organic carbon (DOC), rare organic matter and organic halides. Most of the rare organic matter compounds are eliminated to a great extent by degradation of organic matter, organic chlorine and organic bromine. The removal of the short-term DOCincreases if the aerosol status is maintained in the unsaturated region.

Table 2 illustrates the quality of the fluid outflow from a project conducted by Bouwer and Rice (1989) on the Salt River in West Phoenix, Arizona, signifying an example of the improvement of the secondary fluid quality in a

https://dx.doi.org/10.22161/ijreh.2.5.4 ISSN: 2456-8678

groundwater rechargeusing the by SAT system. This water quality improvement does not limit the SAT systems, and it is applicable in many underground water supply systems where aerobic or anaerobic conditions prevailand there is enough time for storage.In addition to their maintaining the optimum water transfer time in the underground aquifers, most SAT systems also improve water quality. (7)

The pre-treated fluid directly affects the concentration of degradable biomaterials that are usedin the deep penetration of the basins. Therefore, it is a parameter which can be controlled as part of a SAT system. Choosing the location,which has a direct impact on this system, is usually dependent on a number of applied factors, including deep penetration, the proximity of modified water installations or water conduits and the amount of land availability.

The operational state of the SAT systems with wet and dry cycles is the most common operational strategy. The main objective of the dry and wet cycle operations is to control the development of the clogging layers and to protect the high surface penetration. The operating conditions are also dependent on the environmental factors, including temperature, the precipitation rate and the amount solar radiation. Therefore, the operating conditions should be adjusted based on the characteristics of the location as well as the weather patterns. (8 & 9)

2.1.2.2. Design Needs:

At the City of Scottsdale Water Campus in Arizona, 27 wells were constructed to inject 40,000 m^3 per day of water into an unsaturated underground aquifer area after a reverse osmosis operation on the fluid. The groundwater depth in this area was estimated at about 150 meters. The wells employed in this method are principally dry wells. The dry wells are 10 to 50 meters high and 1 to 2 meters wide. As noted earlier, the clogging of these wells is inevitable, a problem which can be tackled using filters or filling the wellsup with gravel or any other material with high permeability, such as sand. Groundwater recharge should be performed in a way that the surface penetration coefficient is maintained. This is accomplished by filling the holes with water as well as making sure that thespeed of air transfer in the surrounding soils is not reduced.

Table.2: The water quality atthe SAT systems in Phoenix, Arizona

Parameter	Influent	Effluent
Total Solids Solved (TDS)	790	750
Total Suspended Solids (TSS)	11	1
Ammonium	16	0.1
Nitrate	0.5	5.3
Organic Nitrogen	1.5	0.1
Phosphate	5.5	0.4
Fluoride	1.2	0.7
Boron	0.6	0.6
Biochemical Oxygen Demand (BOD)	12	>1
Total Organic Carbon (TOC)	12	1.9
Zinc	0.19	0.03
Copper	0.12	0.016
Cadmium	0.008	0.007
Lead	0.082	0.066
Fecal Coliforms	3500	0.3
Total viruses	2118	1>

1) Chlorinated Fluids:

2) Fluids without Disinfection:

The hydraulic analyses required for designing such systems is the same as the equations for the unsaturated areas. Like the hydraulic equation of the soil conductivity coefficient of the unsaturated area, the recursive equation is used to estimate the recharge coefficient. The following equation was used to estimate the hydraulic conductivity of the soil:

(1)

$$k = \frac{Q}{2\pi Lw}\{\ln[\frac{Lw}{rw} + \sqrt{(\frac{Lw^2}{rw^2} - 1)}] - 1\}$$

K = the hydraulic conductivity (M/s); Q = the flow discharge (m^3/s); Lw = the depth of water in the distance between the lattice tubes located in the well (m); rw = the radius of the recharge well (m).

The saturated area that surrounds the unsaturated area of the injection wells is dependent on the depth of the impenetrable layer (Figure 3). When the height of the

https://dx.doi.org/10.22161/ijreh.2.5.4 ISSN: 2456-8678

bottom of the well to the impermeable layer is low, i.e. $S_i < 2L_w$, equation (1) is written as equation (2), which has more applications and is more economical. (10 & 12)

(2)

$$k = \frac{3Q\ln(\frac{Lw}{rw})}{\pi Lw(3Lw + 2Si)}$$

2.1.3.1. Direct Injection:

Direct injection is pumping the modified water directly into the groundwater area,which is usually conducted using wells. It is applied in a place where the groundwateris deep or in areas where the hydrological conditions are not suitable for flood spreading. Some of the cases where the direct injection method is used are the inappropriate conditions associated with low soil infiltration, undesirable topography for the establishment of basins, atendency for limited groundwater recharge as well asland shortage. The direct injection to a saline groundwater aquifer can result in a freshwater source whichcould beextractedor used in recycling, especially in the ASR system. (11)

The direct injection requireswater with higher quality than that in the flood spreading method, because there is no treatment in the unsaturated area or a shallow soil network treatment in this method.Moreover,there is also a need for protecting the hydraulic capacity of the injection wells, as these wells are exposed to physical, biological and chemical clogging. In many cases, the wells used for injecting and retrieval have been classified by EPA as class-V injection wells.

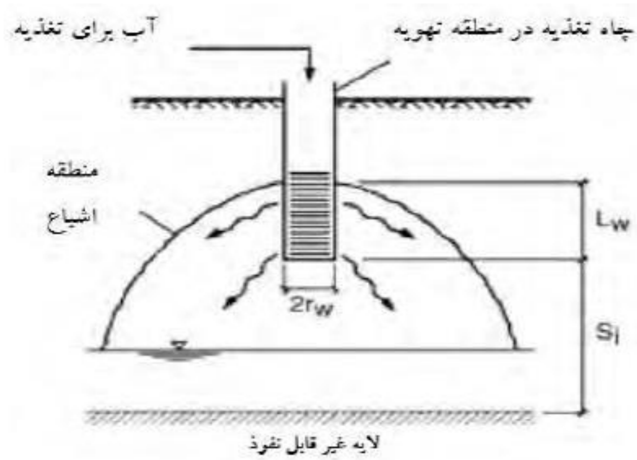

Fig.3: An injection well

The recharge well in the ventilation area
The water for recharge
The saturated area
The impermeable layer

To clean and maintain the inorganic compounds dissolved in the soil, certain chemical, physical, and microbiotic reactions are required so that thedissolved compounds would settleor keep stable. The chemical reactions that are important in the ability of a soil to dissolve inorganic compounds include ion exchange, sedimentation, absorption, chelating, complexing and weathering of the clay minerals. (12)

The dissolved organic compounds during recharge are exposed to biodegradation and absorption. The basic part of biodegradation occurs with the microorganisms adhered to the surface of the environment. The extent of biodegradation is strongly dependent on the nature of organic matter and the presence of electron receptors such as dissolved oxygen and nitrate. The biodegradable compounds in aerobic and anaerobic groundwater will not survive for a long time, and only the chemical compounds that have high solubility and high half-life, such as chlorine-soluble compounds, are worrying. Moreover, special groups of compounds require more time to settle due to the biological degradation reactions of their complexes. The final products of complete degradationunder anaerobic conditions include carbon dioxide, nitrogen, sulfite and methane and under anaerobic conditions include carbon dioxide, sulfate, nitrate, phosphate and water. Furthermore, the decomposition of the organic matter results in the residual of organic products that do not decompose considerably.

Residues on the protection of pathogenic microorganisms below the surface depend on several factors, including climate, soil composition, soil microflora counteraction, the flow rate and the type of microorganism. At temperatures below 4 °C, some microorganisms can survive for months and even years. The rate of gradual death almost doublesfor each 10 °C temperature increase at a temperature between 5 °C and 30 °C. Rain is an agent for the movement of bacteria and viruses that are filtered in the soil, hence increasing their transmission. (11)

In general, increasing the concentration of cations, dissolving organic matter, and also decreasing the pH, tend to favor the absorption of more viruses. Larger bacteria and sewage-related organisms are effectively cleaned from surface coverings after a superficial penetration within a short distance. Factors influencing the movement of viruses inthe groundwater are shown in Table 3. The improvement of purification (disinfection actions) can minimize and even completely clean the groundwater microorganisms, as compared to parameters such as recharge, the location selection and the management of a flood spreading system. If a microorganism increases in the groundwater system, creating a water-oxidation state can have a great effect on the amount of their being cleaned.

The constraints on the groundwater recharge consideringthe extraction of water for recovery should include health concerns, economic justifications, physical constraints, legal prohibitions, water quality constraints and the availability of the improved water. Among these constraints, the health concerns are the most important ones, which should be addressed throughout the whole recharge project. (11 & 12)

Table.3: Factors affecting the movement of viruses in underground water

Factor	Explanation
Soil type	The soils with fine and small texture are much better than the soils with light texture in keeping up the soil. Iron oxide increases the absorbance in soil. Muddy soils are usually very poorin absorption.
pH	Typically, absorption increases due to pH reduction, though the pattern is not definitive and depends on other factors.
Cations	Absorption is increased in the presence of cations. Cations help reduce the disposing agents of soil particles and viruses. Rain may separate the viruses from the soil, because their binding strength is weak.
Dissolved organic matter	They usually compete with viruses. No significant competition is observed in the usual concentrations in the sewage fluids. Humus and fulvic acids reduce the surface uptake of viruses in the soil.
Virus type	Virus absorption by soil varies between virus species and strains.
Flow rate	The higher the flow rate, the lower the surface absorption of the viruses.
Flow type	The movement of the viruses is less under the unsaturated flow condition.

2.3.1.2. Design Needs:

Like the injection well in the ventilation area, the most important problem in the direct injection wells is clogging by sedimentation. This blockage occurs at the edge of the tube wall holes, usually between the sand wall and the groundwater aquifer. Because the penetration coefficient in the groundwater aquifer is much higher than the penetration coefficient in the large basins, the injection wells are more sensitive to obstruction. The injection wells are continuously pumped to monitorthe flow of water and the clogging materials. The best way to prevent clogging in the injection wells is to treat the water before injection. (12)

III. CONCLUSION AND DISCUSSION

With the proximity of many communities to the limited availability of accessible water resources, water recycling and modification have become significant issues for maintaining and extending the available water resources. However, the use of this solution is associate with somedifficulties. (13) The problem with recharge is that the drinking groundwater aquifers are coterminous with and non-drinking groundwater aquifers. Some of the potential risks are associated withwith the contamination of the high-quality drinking groundwater resources by the low-quality water. Our shallow knowledge about the long-term effects of this pollution necessitates a conservative view about the implementation of policies concerning the groundwater recharge systems and increasing the quality standards of water.

The effortsmade by no engineerare based on the laxness of the possible risks, but with appropriate treatment and control processes, the quality objectives of water will be significant with an acceptable possible risk. However, it should be born in mind even with the advancement of scientific techniques, it cannot be strongly argued that the human and the environment health conditions will not be affected.

REFERENCES

[1] Kopchynski, T., Fox, P., Alsmadi, B. and M. Berner. 1996. "The Effects of Soil Type and Effluent Pre-Treat-ment on Soil Aquifer Treatment", Wat. Sci. Tech., 34:11, pp. 235-242.

[2] Piet, G.J. and B.C.J. Zoeteman. 1980. Organic Water Quality Changes During Sand Bank and Dune Filtration of Surface Waters in the Netherlands. Journal AWWA, 72(7) 400-414.

[3] American Water Works Association Research Foundation (AWWARF). 2001. "An Investigation of Soil Aquifer Treatment for Sustainable Water Reuse." Order Number 90855.

[4] Gordon, C., K. Wall, S. Toze, and G. O'Hara. 2002. "Influence of Conditions on the Survival of Enteric Viruses and Indicator Organisms in Groundwater" Management of Aquifer Recharge for Sustainability: A. A. Balkema Publishers. Lisse, p. 133-138.

[5] Stuyzand, P. J. 2002. "Quantifying the Hydrochemical Impact and Sustainability of Artificial Recharge Systems. Management of Aquifer Recharge for Sustainability: A. Balkema Publishers. Lisse, p. 77-82

[6] Fox, P. 1999. "Advantages of Aquifer Recharge for a Sustainable Water Supply" United Nations Environmental Programme/International Environmental Technology Centre International

Symposium on Efficient Water Use in Urban Areas, Kobe, Japan, June 8-10, pp. 163-172

[7] Bouwer, H., and R.C. Rice. 1989. "Effect of Water Depth in Groundwater Recharge Basins on Infiltration Rate." Journal of Irrigation and Drainage Engineering, 115:556-568

[8] Bouwer, H. 1988. "Systems for Artificial Recharge for Groundwater." Proceedings of the International Symposium. Annaheim, California. American Society of Civil Engineers.

[9] Bouwer, H. 1991. "Role of Groundwater Recharge in Treatment and Storage of Wastewater for Reuse." Water Science Technology, 24:295-302

[10] William, R.W., Margaret S.H., Carol J. H., (1989), Management of water resources for drought conditions, Institutional and management aspects, National Water Summary, Hydrologic Events and Floods and Droughts.

[11] Pyne, R.D.G. 2002. "Groundwater Recharge and Wells: A Guide to Aquifer Storage Recovery." Lewis Publishers, Boca Raton, Florida, p. 376

[12] Pyne, 1995. Groundwater Recharge and Wells: A Guide to Aquifer Storage and Recovery. CRC. Boca Raton.

[13] Eslamian, S. S. and S. T.Esfahani. The role of water reuse in sustainable agriculture and its necessity in the Zayandeh Rood Basin, The first conference on the comprehensive management of the Zayandeh Rood Basin, Isfahan, February, 2009.