265

Egypt. J. Chem. **Vol. 65**, No. 4 pp. 617 - 631(2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Land Infiltration for Wastewater Treatment As Efficient, Simple, And Low-Cost Techniques: An Overview

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Abstract

Soil infiltration systems for wastewater treatment require very low energy and maintenance. They are very efficient, cost-effective, low energy consumption, as well as low construction techniques. They have been widely implemented all-over the world particularly for on-site, in remote areas, and in small communities. Currently, groundwater is in concern shortage worldwide due to the significant increasing and continuous withdrawn. It has been proved that soil wastewater infiltration system (SWWIS) is considering as an important on-site wastewater treatment, and as an alternative process for advanced wastewater treatment in terms of efficiency and operation and maintenance. In this systems, wastewater should be treated firstly by conventional physical/chemical or biological treatment followed by infiltration through aerated and unsaturated zone. In these infiltration systems the wastewaters are purified through several steps including physical adsorption, chemical reaction, and biodegradation. SWWIS's have exhibited an excellent and consistent capacity with respect to decomposing of organic contaminants, as indicated by chemical oxygen demands (COD) and biochemical oxygen demand (BOD5). Meanwhile, it is efficient in removing all the microbial contaminants as well. The challenge factors of the SWWIS are the clogging problem as well as the removal of phosphorous, and the nitrogen.

Keywords**:** infiltration for wastewater treatment; Wastewater infiltration, infiltration percolation; Factors affecting wastewater infiltration**;** groundwater Artificial Recharge**.**

1. Introduction

In few past decades, the decentralized treatment of domestic and municipal wastewaters in rural areas has been gained considerable importance all over the world [1, 2]. The direct and/or indirect discharge of wastewater to the environment cause severe pollution to the body of surface water that ultimately threatened man health and the aquatic lives [3, 4]. In the urban areas, the centralized wastewater treatment plants are easily implemented using the traditional systems of treatment such as sedimentation, activated sludge, and biofilm technologies [5, 6]. Other advanced treatment techniques are also employed for the municipal wastewater treatment, including; membranes, as well as sequencing batch reactors that are considered as a high energy consumers [7, 8]. Other low cost wastewater treatment techniques were also reported such as Up-flow Sludge Blanket (UASB), and Constructed Wetlands (CWL), in which the later requires available land area for construction [9]. For treatment of industrial wastewater, on the other hand, chemical and electro-coagulation are also employed for the elimination of toxic and/or hazardous chemicals and materials [10]. For rural areas and the scattered settlements; however; the conventional systems for the treatment of wastewater are not practically suitable due to the restricted economic condition, operation and maintenance cost, and piping construction [11, 12].

The increase in demand to additional resource of water has been increased the awareness toward the artificial recharge of wastewater as a groundwater supply all over the world [13]. Consequently, artificial recharge of treated sewage water into aquifer is an important technology as a tool for reuse of treated wastewater safely. Through such aquifer soil (as unsaturated zone) sewage is treated to certain stage to remove most of the

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Receive Date: 25 June 2021, Revise Date: 20 September 2021, Accept Date: 11 October 2021

DOI: 10.21608/EJCHEM.2021.82437.4062

biological load and partially reduce the level of certain chemical pollutants.

2. Wastewater Infiltration

The infiltration is the technique in which the wastewater and/or water on the land surface penetrates through the soil to reach the groundwater [14]. This technique is ultimately used for both soil sciences and hydrology. Such water infiltration maximum rate could be illustrated as infiltration capacity. This infiltration capacity is often calculated as meters per day. However, it is also could be illustrated by another unit as distance per time [15]. The water infiltration capacity decreases as well as the moisture content of the soil and/or surface layers of the soil increase. If the rate of precipitation of suspended solids, of wastewater, more than the rate of the infiltration, then the runoff on the surface of soil will occurs unless the presence of some physical barrier preventing such runoff.

Devices including permea-meters, infiltro-meters, and rainfall simulators could be used in order to measure the rates of infiltration. The infiltration of water is usually occurred by several ways such as; the effect of gravity, adsorption, capillary forces, as well as osmosis pressure. However, several characteristics of the soil could also play an important role in determine and control the water infiltration rate [16].

The water infiltration system could only continue processed, if there are some available rooms on the surface of the soil as additional water resource. The available volume, in the soil for additional water, depends essentially on the soil porosity as well as the rate of infiltration, at which the water previously infiltrated may goes directly from the soil surface to penetrate through the soil layers. The infiltration capacity is recognized as the maximum rate by which the water could be enter the soil under a given condition. This capacity of infiltration is usually analyzed by applying the hydrology transport models and/or mathematical models. By determine the infiltration, runoff, and channel flow, one can estimate the flow rates of the river and quality of stream water [17]. Figure (1) explains the water infiltration process as reproduced from United States geological survey [17].

It has been proved that soil wastewater infiltration system (SWWIS) is a good on-site treatment, and considered as an alternative method for advanced treatment of wastewater; in terms of the efficiency and cost of operation [18]. In this SWWIS, wastewater should be treated firstly via the conventional physical, chemical and/or biological system and then wastewater can be infiltrated through aerated/unsaturated zone.

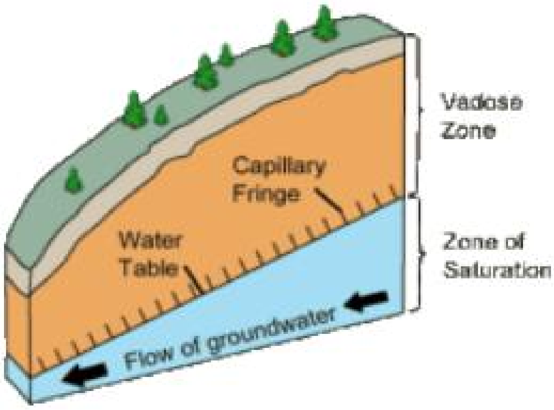

Fig. 1 Water infiltration process (reproduced from United States geological survey) [17].

The subjected wastewater can be then reclaimed through the following processes: chemical reaction, biodegradation, as well as adsorption. It has been approved that through SWWIS a consistent capacity to degrade several organic pollutant are measured by chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5). Almost recent studies about the SWWIS focus mainly on the design as well as the efficiency on pollutants removal [19], clogging [20], bio-clogging mechanism [21], as well as enhancement of nitrogen removal [18].

2.1. Infiltration-percolation

It must be taken in consideration that infiltration and percolation are classified as related processes, but they are different. Both of them are describing penetration of water through the soil. The infiltration process is known as downward-flow or penetration of water through surface of soil or rock [22]. On the contrary, the percolation is known as the flow of water into soil as well as fractured/porous rock. The infiltration rate known as the rate at which the soil, under specified conditions, absorbs falling rain, surface water, or melting snow. And it is illustrated as water depth per time [22].

On the other hands, percolation rate describes as the rate at which water goes down into the soil or permeable rock, although it is difficult to be measured directly. Usually, the rate of infiltration gives a fast reduces against the initial time from start of the infiltration. And then it outreaches a steady state due to eventual saturation of the soil.

At this stage, both infiltration rate and percolation rate are approximately equal, which is generally much lower than the initial rate of the surface infiltration. When the underlain soil layer is differ than the upper layer of the soil, such steady state of the infiltration rate will remarkably differ than the percolation rate. In the hydrologic modeling, the infiltration and percolation processes are usually modeled separately.

According to Bali et al. [23] infiltration percolation is considered as a rough as well as extended process of purification that is able to achieving a complete cleaning and oxidizing of the wastewater. The secondary treated effluent is utilized at irregular intervals through an infiltration basin of surface area of 100 m^2, to be allowed to percolate out of rough sand of not saturated soil in sequences. And every sequence is delivered a volume of 0.27 m^3 m^{-2} of the bottom of coarse sand. The analysis of different samples of the filtered water, sampled at 50, 100 and 150 cm of depths, indicated that the oxidation of these water samples was much relay on two main factors: a) the depth of bottom, as well as b) the temperature of water. The obtained results confirmed that the efficiency of oxidation was improved by high temperature of water. Moreover, in the hot summer season, above 90% of COD as well as above 94% of $N{-}NH_4$ were removed and oxidized, respectively. The study also demonstrated that the oxidation activities were mainly achieved in the upper layers of sand. However, the results of the total coliforms, faecal coliforms, and streptococci were disappointing, which were refer to high velocities of the poured water through the heterogeneity infiltration system, as well as high level of the water utilized pending every sequence of feeding. Furthermore, it was approved that the microorganism removal relay on the increases of the depth and the temperature of water.

On the other hand, infiltration-percolation process was adopted by Abali et al. [22] at the M'zar, the plant of wastewater treatment (WWTP). The study aimed to evaluate the purification as well as elimination of carbonaceous pollutants and nitrate compounds. The results of this study revealed that infiltration-percolation proved to be an advanced treatment technique for eliminating organic pollutants, including; biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), as well as total suspended solids (TSS). Meanwhile, this process increased the nitrate ions due to the oxidation of ammonium and nitrites to nitrates [24]. The presence of nitrates caused serious ecological problems, namely; the phenomenon of eutrophication. Therefore, it is necessary to eliminate the nitrate compounds before releasing the treated effluent into the environment. The obtained results were very encouraging that showed significant removal rate of nitrates ranged from 68 to 79%.

2.2. Types of Wastewater infiltration

The subsurface wastewater infiltration systems (SWWIS's), which considered as a typical sewage land-treatment technologies, have been greatly implemented and applied to various systems of wastewater treatment, including; livestock liquid wastes, domestic wastewater, and rural sewage during the past few decades because of their low costs of operation and management [25, 26].

The SWWIS's basically dependents on many processes for removal of pollutants, namely; filtration, biodegradation, chemical reaction, as well as adsorption which naturally occurring into the penetrated soil in order to purify and remove different contaminants from the given wastewater [18]. It was reported that SWWIS has superior efficiency of removal for both organic pollutants and phosphorous, which considered as a simple and effective decentralized technology for wastewater ecological treatment within the rural area [18]. However, the sustainable as well as effective removal of nitrogen by SWWISs remains the main defies facing the continuous increasing of environmental legislation for treatment of wastewater [27]. In addition, the removal of nitrogen may vary significantly if the SWWISs are faultily designed and/or managed. Generally, the vary biological nitrification and de-nitrification can be considered as the mechanism of nitrogen removal within an ecological treatment of wastewater for example SWWISs and constructed wetlands, where both of them needs environmental conditions such as anaerobic and aerobic, respectively [18, 28]. Nevertheless, in common and traditional SWWISs, it is difficult to be simultaneously implemented due to the arrangement limitation [29].

On the other hand, infiltration percolation is extensive and a very rustic purifying process that is capable of achieving a complete oxidized and de-contaminated wastewater. This technique is a very comprehensive process of treatment aiming at removing pathogens, oxidizing ammonia, as well as eliminating organic pollution. Furthermore, this infiltration percolation has been steadily more employed for treating of both primary and/or secondary effluents of wastewater due to low consumption of energy as well as low cost of maintenance. This system applying for the following: in the discontinuous treatment of wastewater; on permeable native soils, or buried sand filters. Additionally, the obtained infiltrated water percolates mainly into highly not saturated porous medium. And the final effluent of the treated water is to be collected by a system of drainage or percolates down into a designed underlying aquifer. In this system, the filter act like an aerobic fixed biomass reactor. When the final treated water is percolated within the filter, the water is treated by aerobic biological process where organic matters are mineralized and nitrogen compounds are oxidized. In most cases COD of the final filtered water is usually less than 50 mg L^{-1}. Meanwhile, the nitrogen compounds are oxidized into the upper layers of the filter. Therefore, the residual concentration of $N–NH_4$ becomes less than 1 mg L^{-1} [23].

3. Factors affecting the wastewater infiltration system

3.1 Infiltration and rainfall precipitation

Rainfall precipitation can influence the infiltration into several ways. Precipitation type, quantity, and period all of them have an important influence. This precipitation leads to faster rates of infiltration rather than any other types of precipitation events, for examples snow or sleet. With respect to precipitation quantity, the more rainfall occurs, the more water infiltration takes place till the land reaches the state of saturation, at which the capacity of infiltration is achieved. Meanwhile, the period of precipitation influence such capacity of infiltration likewise. When precipitation begins firstly, the infiltration of water is quickly happening as soil is still not saturated. The rate of water infiltration decelerates down as the rainfall continues by time, because of more and more saturation of the soil. Such link among the rainfall and the capacity of water infiltration determines the amount of water runoff that will happen. If the precipitation happens at a rate more rapid than the capacity of water infiltration, then the water runoff will happen [16].

3.2. Soil Porosity and Compaction

It is worth mentioning that the porosity of soils is one among the most critical factors in determining the capacity of infiltration. For example, soils such as clays have small sizes of pores, thus they have slower rates of infiltration and lower capacity of infiltration rather than other soils such as sands which have large sizes of pores. However, there is an exclusion of this basis that is when the clay soil is in a dried condition. Moreover, in such situation, clay soil can expand the great cracks that lead to high and fast capacity of infiltration. In addition, the compaction of soil is another factor that influences the capacity of infiltration. Such compaction of soils decreases the porosity through the soil and thus reduces the capacity of infiltration. Furthermore, the hydrophobic soil is often developed after the wildfires in the forests that can greatly reduce, decrease, or fully prohibit the infiltration of water through it [16].

A soil, which is formerly saturated with water, has no extra amplitude to accept and grasp extra water, as a result of that the capacity of infiltration has already reached to the point they not possible to receive any more water, and this also leads to surface runoff. If soil is partly saturated then infiltration of water can take place at a relatively moderate rate, while the completely not saturated soil could have the largest capacity of water infiltration [16]. On sandy loam soil, the rate of water infiltration below a litter cap can be greater by nine times or more than that on the bare surfaces.

3.3. Soil Porosity as affected Plants/Animals Residues

On the other hand, the presence of organic materials into the soil (such as plants and/or animals) increases the capacity of water infiltration. Vegetation of plants consists of roots at different directions that expanded through the soil. This creates fissures as well as cracks into the soil that increases the capacity of the soil and allows for rapid infiltration. The presence of vegetation in the soil could as well decrease the compaction of the surface that in terns lets for increasing the infiltration of water. On the contrary, when there is no vegetation of plant is exist in the soil; the rates of water infiltration could be relatively too low. This could lead to too much water runoff as well as raised the level of erosion. Similar to vegetation: the animals that digging the beneath of the soil can as well making cracks into the structure of such soil.

If the land of concern is wrapped by not enforceable surface, for example pavement, the infiltration cannot take place because of water couldn't be able to infiltrate within such surface. On the contrary, that would increase and enhance the water runoff. Often, such impermeable areas have drains of the storm to discharge straightway to water bodies (i.e. no infiltration occurs). If the land is covered by vegetation, this will also impacts the capacity of infiltration. Such vegetative covered land can lead to retaining the precipitation that could reduce the strength leading to more interception and minimal runoff. In addition, raised the plenty of vegetation drove to increase the level of evapo-transpiration that decreases the rate of infiltration. Debris and plants residues from vegetation such as stem and leaf covering the top of soil can increase the rate of water infiltration by safeguarding such soil from strong incidents of precipitation. Into the grasslands and semi-arid savannas, the rate of water infiltration through a given soil relies on the percentage of the land that covered by the basal, as well as the litter of the immortal bunches of grass. On the other hand, the few rates of water infiltration on the uncovered regions are mainly due to the existence of a seal of surface or crust of soil. The water infiltration within the tuft base is very fast where tufts directed water toward their own roots. However, if the land slope is high then the runoff will be occurred faster and more easily that leads to minimum rates of infiltration [30].

4. Wastewater treatment Technologies by Infiltration

4.1. Artificial Recharge

The artificial recharge is simply a process by which excess surface water is injected or directed in the underground to fill as aquifer using recharge wells by spreading on the surface in basins, or by altering natural conditions for the purpose to increase the infiltration. It is simply the technique of injecting or infiltrating wastewater in an aquifer through the surface systems like injection, basins, streambeds or canals. Figure (2) presents the movement of water from the earth surface to underground water-bearing strata through Man made systems where the stratum may store the infiltrated water for future reuse. Such Artificial recharge (i.e. planned recharge) is a simple way to store wastewater or water underground to be used as water resource whenever needed *[30]*.

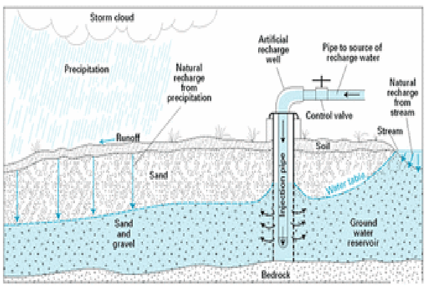

Fig. 2 *Artificial recharge of groundwater aquifers [30].*

The natural recharge of groundwater happens as precipitation falls on the surface of land, infiltrates in soils, as well as moves within the spaces of pore down to the table of water. In addition, the natural recharge could as well take place as a leak of surface-water from the source of water such as rivers, lakes, streams, and wetlands.

Artificial recharge can be occurred through injection of wastewater or water through the wells. This method is applied often to recharge deep water aquifers where application of water to the land surface is not effective at recharging these aquifers.

The objectives if the artificial recharge are one or more of the following:

- As water Storage, for the purpose of improving water management and to be available whenever needed,
- Preventing the salt water intrusion by forming up-coning along the coasts,
- Improvement the quality of the in filtered water due to the purification of wastewater for reuse purpose, and / or
- Restoring the level of present groundwater in the depleted aquifers.

4.2. Enhancing hydraulic loading rate (HLR)

Li et al. [25] mentioned that to improve hydraulic loading rate of water (HLR) for a given SWWIS the intermittent operation mode in treated domestic sewage should be utilized into the SWWIS. Their result indicated that the intermittent operation mode strongly participates in improving the HLR and the removal rate of pollutants. When the value of the ratio of wetting-drying (RWD) reached 1.0, the removal rate of pollutants increased by (20.7 ± 1.1)% for TN, (18.6 ± 0.4)% for TP, (13.6 ± 0.3)% for NH_3-N, (36.2 ± 1.2)% for TSS, (10.1 ± 0.3)% for COD, and (12.2 ± 0.5)% for BOD, compared with the rates of the contaminant removal under the continuous mode of operation. They reported that the rate of contaminant removal declines with increasing the HLR. The effluent of water quality met the Reuse of the "Urban Recycling Water" standard and the "Water Quality Standard for Scenic Environment Use" (GB/T 18921-2002) [25]. This is true even when the HLR value was as elevated as 10 cm d^{-1}. The values of hydraulic conductivity, the rate of contaminant removal of NH_3-N, the quantity of nitrifying bacteria, and oxidation reduction potential (ORP) all raised with reducing of the RWD. Furthermore, for the rates of the removal of TP, COD, as well as BOD under different RWDs, there were no significant differences ($p < 0.05$). And the suggested RWD in this respect was 1.0. Furthermore, Li et al. [25] examined the relative contribution of the pretreatment and the SWWIS in terms of removal of contaminant; they found that more than 80% of removal was achieved for NH_3-N, TN, TP, COD, as well as BOD by employing the SWWIS.

4.3. Rapid infiltration systems

A rapid infiltration systems (RIS) was constructed by Zhang et al. [31] as a cost effective option for treating wastewater due to low cost, their simplicity, as well as minimum consumption of energy. Layered double hydroxides (LDHs) as novel materials that are characterized by anion exchange capacity and high surface area encountered a problem of application into RIS because of its powdered form. In order to conquer this blemish, the Zn-LDHs compounds, including; AlZn-LDHs, CoZn-LDHs, as well as FeZn-LDHs, were synthesized by using the co-precipitation method and in-situ coated on the surface of natural bio-ceramic in order to synthesize composites of core-shell bio-ceramic Zn-LDHs. Furthermore, the characterization has been done by using X-ray Fluorescence Spectrometer (XRFS) and Scanning Electron Microscope (SEM), which proved that the Zn-LDHs compounds were successfully loaded on the surface of natural bio-ceramic. Experiments using the column tests showed that the bio-ceramic/Zn-LDHs effectively improved the removal achievement for phosphorus. In addition, the rates of removal of these bio-ceramic/FeZn-LDHs were 74.91% of total dissolved phosphorous (TDP), 82.31% of soluble reactive phosphorous (SRP), 71.58% of total phosphorous (TP), as well as 67.58% of particulate phosphorus (PP). In correlation with the natural bio-ceramic, the average rates of removal were improved by 41.33% for (TDP), 49.06% for (SRP), 32.20% for (TP), and 10.50% for (PP), consequently. In this respect, the given data of adsorption of phosphate were good described by using Freundlich equation model [31] of the bio-ceramic/Zn-LDHs as well as natural bio-ceramic; the only exception is for the bio-ceramic/CoZn-LDHs. On the other hand, the results indicated that the maximum capacity of adsorption of bio-ceramic/AlZn-LDHs (namely: 769.23 mg kg^{-1}) was about 1.77 times exceeds the natural bio-ceramic (as 434.78 mg/kg). Furthermore, the efficient phosphate desorption can be accomplished by utilizing of a mixture solution of 5 M NaCl and 0.1 M NaOH which was out-performed the natural bio-ceramic of 12.66% of AlZn-LDHs, 7.59% of CoZn-LDHs, as well as 18.95% of FeZn- LDHs.

On the other hand, the kinetic data of the bio-ceramic/Zn-LDHs were good described by using of the pseudo-second-order equation. By comparing the amount of phosphate removal by using of the natural bio-ceramic, little improvement was recorded in terms of the physical effects, but the chemical effects were improved of 122.67% for AlZn-LDHs, 111.89% for CoZn-LDHs, as well as 112.49% for FeZn-LDHs. Thus, the method of coating Zn-LDHs on the surface of bio-ceramic is effectively enhance the chemical efficiently into the removal of phosphate, supporting to that it can be used as probable substrates in the removal of phosphorus in the column RIS.

4.4. Infiltration and aeration technology

4.4.1. Wastewater infiltration and aeration

Wang and Zhang [1] reported that it is expensive and difficult to deal with wastewater contains high concentration of ammonium nitrogen (NH_4^+-N) in the rural area. In this study they employed the fine bubble aeration technology in a deep subsurface wastewater infiltration system (Figure 3) for the purpose of investigating the efficiency and the mechanism of nitrogen removal. The results indicated that the fine bubble aeration could enhance the effect of a deep subsurface wastewater infiltration system with respect to treatment of wastewater containing ammonia nitrogen. Such improvement can be attributed to the efficient degradation of nitrogen that could be achieved by such finite aeration. Furthermore, the characteristics of the treated effluent namely: Chemical Oxygen Demand (COD), total phosphorus (TP), and NH_4^+-N could be reached the first grade (A) standard requirements according to the “Discharge standard of pollutants for municipal wastewater treatment plants” (GB18918-2002). They concluded that the effect of the studied fine bubble aeration technology is useful for the treatment of wastewater contains high concentration of ammonium nitrogen.

4.4.2. Aeration and hydraulic loading rates (HLR’s)

The discontinuous aeration, as an operational and efficient promotion measures, that has been adopted to make proper conditions for nitrification and de-nitrification instantaneously in SWWISs [32, 27]. In addition, it has been confirmed that the absence of enough source of carbon would detain the de-nitrification process in the traditional SWWISs [26, 30].

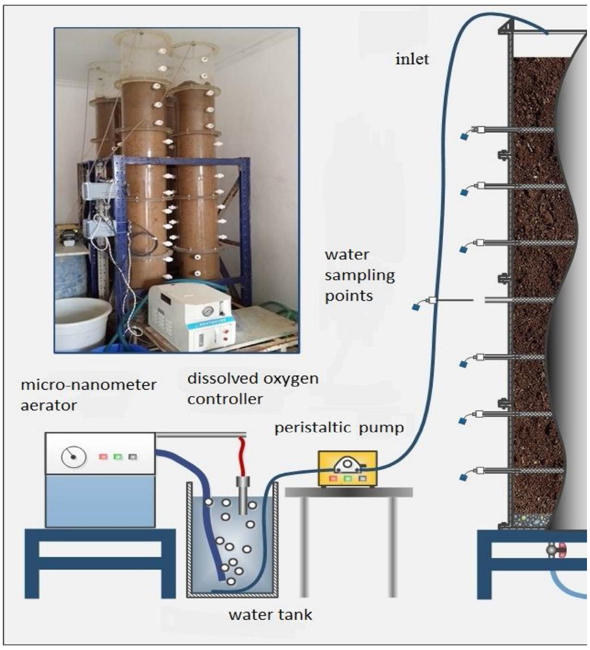

Fig. 3 Soil column setup supplied by fine bubbles aeration technology [1].

Nevertheless, low considerations have been given to the qualified valuation of discontinuous aeration as well as to the addition of the carbon source on improving of the elimination of nitrogen in SWWISs [18, 33].

The substrates, support matrix/material, are considered as one of the essential components in SWWISs. Besides, they as well have considerable physical, chemical, as well as biological rule for the removal of contaminants through SWWISs. Meanwhile, the substrates selection could take important improvements of treatment acts through SWWISs. Besides that, the former researches showed that different types of substrates for examples; sandy loam soil, brown soil, silt/clay loam, activated sludge, coal slag, and red clay have been already utilized in SWWISs for handling various wastewater [5]. Furthermore, HLR's are another important factor in SWISs with respect to the practical application for treatment of wastewaters that would influence the performance of treatment and as a potential clogging of SWWISs [19, 4]. It was indicated by Li et al. [19] and Yang et al. [4] that effectiveness's of the removal of most contaminants reduced as the HLR raised. Others proved that at low HLR between 0.01 and 0.10 $cm.d^{-1}$ it will be more appropriate for the removal of pollutants [19, 4, 34].

5. Treatment of wastewater via infiltration

5.1. Two stage Soil infiltration bioreactor

Kong et al. [35] designed an integrated two-stage soil infiltration bioreactor which was incorporated with pyrite-based (mixo-trophic) de-nitrification (SIBPD) for treatment of domestic wastewater. The benefit from intense ability of adsorption as well as good permeability of water were the infiltration through the soil could shorten time of operation, avoid clogging, as well as lower the cost of maintenance. Consequently, nitrification and respiration were both involved in aerobic stage (AES). In addition to that, nitrate was almost eliminated by pyrite-based mixo-trophic de-nitrification that was mostly happened in anaerobic stage (ANS). The system was fed by both synthetic as well as real wastewater for a period of 120 days at 1.5 h HRT, and SIBPD give high removal efficiency at 82.58% of TP, 92.84% of NH_4^+-N, as well as 14% of COD, along with 80.72% of nitrate that removed by using ANS. Efficiency of the removal of TN was 83.74% when applying a real wastewater. In comparison with the other process of sulfur-based, the pH of the SIBPD effluent was kept at the value between pH = 6.99 and 7.34, as well as the highest recorded SO_4^{-2} concentration was only at 64.63 mg L^{-1}. In addition, this investigation disclosed a feasible as well as promising application prospect of the on-site treatment of the domestic wastewater.

5.2. Infiltration combined with aeration

Furthermore, Karakurt-Fischer et al. [36] studied the concatenation of two steps of infiltration in a combination with an interpose aeration process, namely; sequential managed aquifer recharge technology (SMART). The results obtained proved to be a very promising process to refill the groundwater by using of impaired surface waters and/or treated wastewater effluents because of the effective deactivation of the microbial pathogens, in addition to that high enhanced the removal of lots of traces of organic materials. Furthermore, in order to reduce the physical footmark of these systems as well as conquer the drawbacks over the site-specific heterogeneity at such traditional managed aquifer recharge (MAR) areas, a new engineered process was designed for further advance of the SMART connotation. This present work studied the establishing of a subsurface bioreactor with a plug-flow pilot scale by providing greatly controlled hydraulic conditions. System as such pilot scale, with a considerably minimized physical footmark in correlation with traditional MAR systems, can be successfully implemented autonomous of the local hydrogeological conditions. In addition, the desirable condition of the redox treatment inside the studied bioreactor was accomplished by using of in-situ oxygen supply and delivery, in order to keep the conditions of the homogenous flow as well as eliminate the cost of the required energy. This study included the hydraulic conditions as well as the initial performance with respect to the removal of chemical components during initial operation of the SMART plus bioreactor. Furthermore, the obtained results suitable and simulated the penetration curves from the tracer test of the pulse injection that indicated positive establishing of the plug-flow conditions inside the bioreactor. Moreover, during the baseline operation, the obtained data assured similar trace of the organic chemical bio-transformation as formerly noticed in the laboratory as well as in the systems of the MAR field-scale throughout the times of transportation of >13 h [36].

5.3. Nitrification and denitrification

Kong et al. [37] studied the enhancement of de-nitrification performance of soil infiltration. A system of the soil infiltration, which integrated with the utilizing of sulfur autotrophic de-nitrification (SISSAD) for treating of the domestic wastewater, was improved (Figure 4). The achievement of SISSAD was assessed for treating of the artificial synthetic domestic wastewater. The results revealed that the nitrification due to aerobic respiration occurred mainly in the upper aerobic stage (AES) where the rate of the removal of COD, and NH_4^+-N was 88.44% and 89.99% respectively. On the other hand, the autotrophic de-nitrification took place into the bed where ANS, in which CO_2 was produced from AES as source of the inorganic carbon. Moreover, the obtained results showed that the SISSAD demonstrated a noticeable removal efficiency of COD, NO_3^--N, NH_4^+-N, and TP at 95.09%, 84.86% 95.25%, as well as 93.15%, respectively. In addition to that, this investigation showed that the improved system displays a promising application for the treatment of domestic wastewater within the near future.

In addition, Lei et al. [38] reported that the soil infiltration treatment (SIT) is a very inefficient system to remove ammonium from wastewaters at a concentration of TN > 100 mg L^{-1}. In that investigation a novel two steps SIT process was studied as an effective for the removal of both TN (at TN > 100 mg L^{-1}), as well as COD at the ratio of COD/TN equal to 3.2–8.6. Furthermore, in the first stage wastewater was first fed as inlet into a soil column, and the HLR was 0.06 m^3 m^{-2} d^{-1} for COD. The effluent from the first stage was directed into four soil columns as stage 2 at a HLR of 0.02 m^3 m^{-2} d^{-1} with various ratios of raw wastewater and an extra source of carbon. This study continued for total one year as field investigation. The balanced nitrification and de-nitrification study of the two stage SIT showed an outstanding removal of TN of > 90% from the examined wastewater.

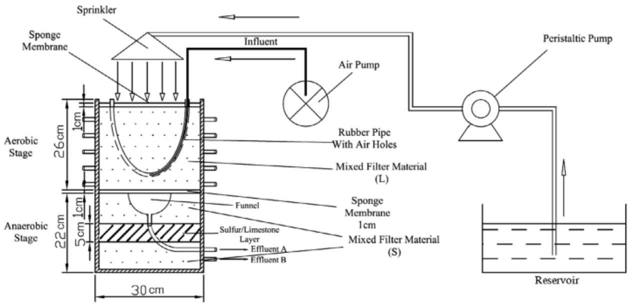

Fig. 4 A schematic diagram of the lab-scale SISSAD reactor [37].

5.4. Infiltration and Exfiltration (leaking-out)

Watanabe et al. [39] studied the impacts effect of infiltration (leaking-in) and exfiltration (leaking-out) on the quality and the flow of sewage in Hue, Vietnam. The investigators studied the quality and the flow of sewage by monitoring the sewer effluent of an area of residential drainage for a period of 68 and 82 days continuously throughout all dry and rainy seasons, respectively. The leaking-in was assessed depend on the minimum flow of the sewage before the morning. The tracer tests of lithium were carried out in order to assess the ratio of the leaking-out. Moreover, the obtained results revealed that the sewage of such targeted sewer was weakly in strength than the average sewage, even on days of no rain at dry season.

In addition, the electric conductivity (EC) observation demonstrated that the rainfall effectively reduced the concentration of the sewage EC for a maximum period of 228 h. Moreover, the predestined leaking-in calculated of about 62% and 11% of the total influx of the sewage to the sewer during the rainy as well as dry seasons, respectively. Furthermore, the test of tracer demonstrated that the ratios of the leaking-out during the rainy as well as dry seasons were 24.0% and 65.6%, respectively. The overall results of the balance of water showed that 23% of the supplied water for the region reached the effluent of the sewer within the dry season, but in the rainy season 123% drained to the sewer. These results demonstrate that in the dry season the leaking-out reduced the flux of the sewage, while within the rainy season the leaking-in remarkably raised the flux of the sewage as well as reduced the concentration of the sewage. This was a first investigation for studying of the impacts of leaking-in as well as leaking-out on the sewage in the area of Southeast Asia (Figure 5).

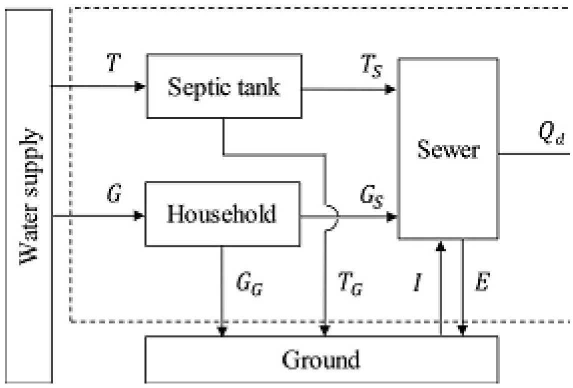

Fig. 5 System boundary and component reproduced from Watanabe et al. [39].

6. Wastewater infiltration for the removal of pollutants

6.1. Removal of phosphorous

The removal of phosphorus was studied in a column of modified constructed rapid infiltration system (CRIS) by Su et al. [40]. The mechanism of the phosphorus removal through such CRIS was investigated in the terms of the communities of microbes, enzymes, as well as their functions of metabolism. When the level of the COD of the inlet raised from 550 to 650 mg L^{-1} for almost 1,100 mg L^{-1}, the removal of the TP raised, with a concentration of the effluent for almost 0.16 mg L^{-1} TP in the CRIS. In addition to that, the matrix inside the column of the CRIS consisted of aluminum and iron, which interacted with phosphorus compounds of the wastewater, in order to obtain precipitates of phosphorus as indication of phosphorus removal. The results showed that the maximum produced phosphine in the CRIS were 1.73 and 0.24 mg m^{-3} in the column ventilator and matrix, respectively. Furthermore, the activity of the alkaline phosphatase, that has a strong positive effect on the removal of phosphorus, was concentrated into the upper part of the column. The results of the analysis of the high throughput sequencing revealed that the predominant phylum of bacteria inside the CRIS column was Proteobacteria (at the range from 49.33 to 51.8%). Moreover, the plenty of the Dechloromonas inside CRIS column through the lower and upper layers was 1.51 and 0.67%, respectively. The numbers of gene of the metabolism of phosphonate and phosphinate, the system of the phosphatidylinositol signaling, and the phosphotransferase system were 10,661, 24,468, and 20,909 inside the upper layer and 13,476, 27,408, and 31,192 respectively in the lower layer of the CRIS column.

6.2. Wastewater infiltration and nitrogen cycle

The SWIS was studied by Li et al. [41] using the method of the stable isotope tracer in order to detect the co-denitrification contribution for the purpose of releasing N_2O beside nitrification and denitrification (Figure 6). In addition, the effects of the nitrate addition modes were investigated. Furthermore, the obtained results demonstrated that the co-denitrification is greatly impacted by the pH, dissolved oxygen, as well as activity of the potential denitrification. However, they recommended that N_2O formation must be taken into consideration. When the addition of nitrate-nitrogen altered from once to intermittent, the contribution of the co-denitrification raised consequently from 1.87 ± 0.3% to 34.2 ± 3.8%. Moreover, as a result of such change, the emission of N_2O as well as rate of conversion raised from $5.17 \pm 1.4 \times 10^{-3}$ mg m^{-2} h to $6.77 \pm 1.7 \times 10^{-3}$ mg m^{-2} h and from 0.17 ± 0.02% to 0.232 ± 0.01%, respectively. In addition, they recommended that extra attentiveness should be given to the cycle of nitrogen inside the SWIS system. They added that in order to obtain an efficiently mitigation of the generation and conversion of N_2O, the careful measures should be taken in order to decrease the accumulation of the nitrate.

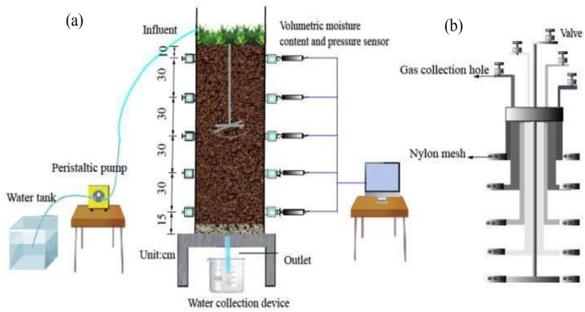

Fig. 6 Schematic diagram for a) the simulator of the SWIS, b) the sampler of the gas [41]

6.3. Wastewater infiltration and effects of temperature

The effects of temperature, namely; 7 ˚C, 13 ˚C, 18 ˚C, 25 ˚C, and 33 ˚C on the treatment of wastewater by using of a novel soil wastewater infiltration system (SWWIS), were studied by Yuan et al. [42]. Their results indicated that the low temperatures have negative effect on the removal of contaminants. They reported that the effectiveness's of the removal of contaminants raised with the raising of the temperature throughout the duration of experimental operation. In this respect, when the temperature was of 33 °C, the efficiencies of the removal of TN, NH_3-N, TP, and COD into the column of soil were 85.0%, 97.1%, 96.0%, and 98.3%, respectively. The overall period of this study, using tests of the lab-scale, was 50 weeks. It was concluded that the robustness of the SWWIS achieved treated water with a very high quality. And the best achievement was when the temperature of the operation was greater than 13 °C. Furthermore, the values of the oxidation reduction potential (ORP) reduced from the top to the bottom of the column of SWWIS soil in the period of the study process, meanwhile the values of pH raised. The results obtained can be a well guide to the application of SWWIS on a pilot-scale.

6.4. Wastewater treatment using garden land infiltration system (GLIS)

Land treatment system was studied by Duan et al. [43] as an appropriate for the treatment of sewage of the livestock because of the low cost of construction as well as high performance of the treatment. GLIS was employed for treating of wastewater of the dairy farm. The main objective was the removal of nutrient elements and the uptake of plant during the operation of the system. Moreover, the rates of the removal in the treated water with respect to COD, suspended solids (SS), total N (TN), total P (TP), NH_4^+-N, and total organic carbon (TOC) were 76.8%, 86.1%, 78.2%, 94.6%, 78.0%, and74.6%, respectively. About 9.1–13.1 kg $h^{-1}a$ of phosphorus and 79.4–81.6 kg ha^{-1} of nitrogen were removed from the system by harvesting of the ryegrass, which accounted of 17.0–24.6%, and 14.5–14.9% of the TP and TN into the treated effluent, respectively. Furthermore, these results indicated that the studied system has the advantage of high efficiency in the treatment of livestock sewage and the removal of nutrient by plant uptake. It was therefore, recommended to consider the GLIS as a viable alternative and efficient for treating of the wastewater of the dairy farm in the rural regions.

6.5. Phosphorus leaching from on-site wastewater treatment systems

It was reported by Eveborn et al. [44] that the leaching of phosphorus (P) from on-site systems for treating of wastewater contributes to the eutrophication phenomena. In the developed countries, septic systems with soil infiltration are the most common on-site treatment technique for the elimination of phosphorus (Figure 7). Nevertheless, the existing information of the long term removal of phosphorus into the systems of soil treatment is not, so far, well known. Meanwhile, the data utilized for estimating the removal of phosphorus from such systems are not reliable according to Eveborn et al., [44]. In the present study the filter beds for long term removal of P, for a period between 14 and 22 years, were studied. Samples were collected from four filter beds out of the community-scale soil treatment systems to investigate the long-term P removal as well as to determine the chemical mechanisms responsible for the observed removal. The Long-term removal of P was studied as well as calculated in one site by using of the approach of mass balance. In this study, the accumulated P was determined and was found that only 12% of the long-term load of P was removed by the materials of the bed. Moreover, that gives a very low overall capacity of the soil bed materials as a treatment system for phosphorus removal. In addition, the batch experiments as well as the chemical speciation modeling revealed that the precipitation of calcium phosphate wasn't an important indication of the long-term removal of P with the exclusion of only one site. It was concluded that the removal of P was induced by precipitating $AlPO_4$ and/or sorption into the poorly ordered compounds of aluminum, that proofed by the strong links between extractable oxalate of Al and P.

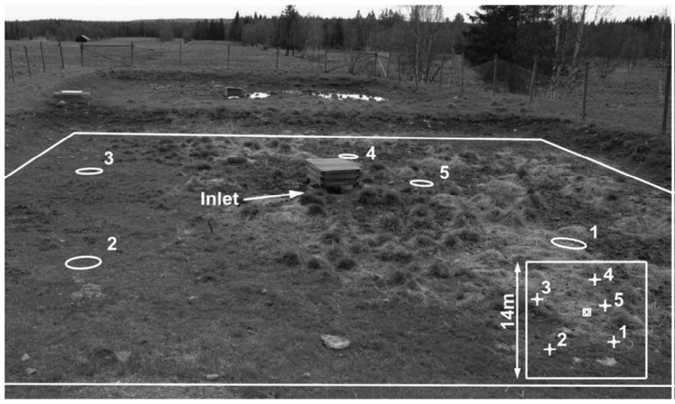

Fig. 7 Illustration of filter the bed and locations of sampling [44].

6.6. Wastewater infiltration in planted desert sand soil

A very interesting short-term column of the experimental study was conducted by Liu et al. [45] in order to simulate the process of wastewater infiltration within the desert sandy soil. They planted Alfalfa and irrigated them by fresh water as a control (CK), tertiary treated domestic wastewater (TTWW), secondary treated domestic wastewater (STWW), as well as untreated raw domestic wastewater (RWW). Furthermore, the impact of the application of different wastewater on the desert sandy soil, drainage water, as well as characteristics of the plant was investigated. Their experimental results showed that the desert sandy soil under investigation possess high infiltration rate, but hasn't soil structure, no organic matters, as well as no microbial communities. The use of different wastewater remarkably enhanced the growth of the alfalfa plant, and the biomass of TTWW, RWW, STWW were about 5.5, 4.3, and 2.9 times that of CK. In addition, the water rate of infiltration into the uncovered soil was high, high to low; TTWW, CK, RWW, STWW. The growth of plant significantly decreased the rate of infiltration, ca. 40% of TTWW as well as RWW. Furthermore, irrigation of wastewater as well as growth of plant reduced the zeta potential of soil, meanwhile raided the formation of aggregates as well as bacterial plenty as well as diversity inside the soil. In addition to that, on the top of the soil from 0 to 30 cm the E. coli, organic matters, nitrogen (N), and phosphorus (P) were accumulated. It was evidenced that all these pollutants could penetrate down into the deep of the soil as well as drainage water, as the wastewater irrigation proceed.

Therefore, it was demonstrated that the irrigation with domestic wastewater had a great potential on the recovering of desert soil vegetation as well as restoration of function. However, the E. coli, organic matters, N, and P in wastewater could give increase to contamination of both desert soil and groundwater.

6.7. Novel subsurface wastewater infiltration systems

The novel subsurface wastewater infiltration systems (SWWIS's) were reported by Yang et al. [12] for the purpose of developing the treatment of domestic wastewater. Moreover, the operating modes and the impacts of substrates on SWWISs removal performance were also investigated. And the obtained results revealed that optimal performance of the removal was attained by employing a system of sandy soil at an intermittent time of 6 hours as well as the ratio of wetting drying (RWD) of 1.0. Furthermore, the removal efficiencies of certain pollution parameters including COD, NH_4^+-N, as well as TP of best performing system of sandy soil reached to 94.81%, 75.02%, as well as 97.25%, respectively. And the average rate of removal of COD, NH_4^+-N, as well as TP of the system of sandy soil reached to 35.80, 2.79, as well as 0.74 gm d^{-1}, respectively. In addition to that, the treated outlet of this system of sandy soil indicated complete satisfaction of the limits of "The Reuse of Urban Recycling Water" (GB/T 18921- 2002) [12]. High-through put sequencing proved that the percentage of denitrifiers into the system of sandy soil, system brown soil, as well as system of Krasnozem reached to 25.31%, 64.79%, as well as 58.95%, respectively. Moreover, bacillus, pseudomonas, and uncultured anaerolineaceae were dominant functional genera within cycling of nitrogen and carbon of SWWISs. The overall conclusion is that the system of sandy soil infiltration is effective and achievable of only one household in reclaiming and treating of domestic wastewater.

7. Conclusions

1. Technology of the Sub-surface Wastewater Infiltration Systems (SWWISs) is widely used as onsite wastewater treatment systems (OWTSs), which hold much advantages including; less costs of construction, easy/low maintenance, and environmental friendly in rural areas.
2. High clogging risk and relative low total Nitrogen removal efficiency (at < 20%) are the disadvantages of SWWISs in rural areas.
3. Domestic wastewaters are generally characterized by large organic contaminants and high rate of loading mass that enhance and participate in the clogging of SWWISs.
4. The following factors are important to prevent the clogging of SWWISs: (a) the engineering design of the system of wastewater effluent distribution; (b) low hydraulic loading rate (HLR); (c) substrates; and (d) the relatively low frequency of the operation.
5. Rate of pollutant removal declines with increasing the hydraulic loading rate (HLR).
6. SWWISs filled with loess soil could be significantly removed the pollution parameters including BOD, COD, TP, and NH_4^+-N at a HLR of 2 cm d^{-1}.

7. The average rate of removal of BOD, COD, TP, and NH_4^+-N exceeded 85%, 90%, 98%, as well as 95% in all SWISs.
   Higher removal efficiencies of the total nitrogen compounds (TN) in non-aerated and intermittent aeration SWWISs with biochar addition ranged between 85% and 92%.
7. The disinfection performances of SWWISs were disappointed due to heterogeneous infiltration. Moreover, maintaining the surface of infiltration helps in giving uniform infiltration.
8. The poor disinfection of the total coliforms, faecal coliforms, as well as streptococci was attributed to high velocities of pouring water through the heterogeneity system of infiltration, as well as the high level of water applied in the period of each sequence of feeding. It was proved that the removal of microorganism rises with the depth and temperature of water.
9. The infiltration percolation permits oxidizing and disinfecting the secondary effluents of wastewater.
10. The SWWIS technique is utilized as a tertiary treating of wastewater to remove microorganisms of pathogen from the effluents of traditional plants of wastewater treatment.

Recommendations

1. Wastewater Infiltration Systems (SWWIS's) technique is a low technology method for the purpose of improving water quality for reuse in unrestricted irrigations. Moreover, this technique demonstrates a promising application of the treatment of domestic wastewater in a near future.
2. The fine technology of bubble aeration, in a deep system of the subsurface wastewater infiltration, could improve the removal of ammonia nitrogen which can be attributed to the effective degradation of nitrogen that attained by such limited aeration.
3. The objectives the artificial recharge are one or more of the following: (i) acts as water Storage, for the purpose of improving water management and to be available whenever needed, (ii) preventing the salt water intrusion by forming up-coning along the coasts, (iii) Improvement the quality of the in-filtered water due to the purification of wastewater for reuse purpose, and/or (iv) Restoring the level of present groundwater in the depleted aquifers.

Acknowledgment

The authors are in debt to the facilities provided by the following projects:

1. Titled "Towards Innovative and Green Water Reuse with Integrated Constructed Wetlands and Ferrate(VI) Treatment"- number (42688)- supported in whole or part by NAS and USAID, USA-Egypt Science Technology Joint Fund-(Cycle.19), and the (STDF-Egypt).
2. Titled "Development of the frame conditions for the establishment of an innovative water technology which couples anaerobic waste water treatment and biomass production in a bioreactor in the Mediterranean region"- number (31319)-FRAME, ERANETMED3-75, Fund (STDF-Egypt).

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الملخص العربى

تعد أنظمة الترشيح من خلال التربة والتي تحتاج إلى طاقة وصيانة منخفضة للغاية طريقة فعالة من حيث التكلفة لمعالجة مياه الصرف الصحي. تم تنفيذ هذه الأنظمة على نطاق واسع في جميع أنحاء العالم من أجل معالجة مياه الصرف الصحي في الموقع وفي المناطق النائية وفي المجتمعات الصغيرة. في الوقت الحالي هناك نقص في المياه الجوفية من نقص في جميع أنحاء العالم بسبب الزيادة الكبيرة في المياه المسحوبة. لقد ثبت أن نظام ترشيح مياه الصرف الصحي (SWWIS) يعتبر طريقة مهمة لمعالجة مياه الصرف الصحي في الموقع ، وطريقة بديلة متقدمه لمعالجة مياه الصرف الصحي امن حيث الكفاءة وتكلفة التشغيل. في SWWIS يتم معالجة مياه الصرف الصحي بالمعالجة الفيزيائية / الكيميائية أو البيولوجية التقليدية أولاً ، ثم يتبعها الترشيح من خلال المنطقة الهوائية وغير المشبعة. في نظام الترشيح هذا ، يتم تنقية مياه الصرف الصحى من خلال استخدام عدة خطوات بما في ذلك الامتزاز الفيزيائي والتفاعل الكيميائي والتحلل البيولوجي. أظهرت SWWIS قدرة ممتازة ومتسقة فيما يتعلق بتحلل المواد العضوية ، كما هو موضح من خلال قياس كل من متطلبات الأكسجين الكيميائي (COD) والطلب على الأكسجين الكيميائي الحيوي (BOD5).تتمثل عوامل التحدي في SWWIS في مشكلة الانسداد ، والفوسفور ، وإزالة النيتروجين ، فضلاً عن آليات الانسداد الحيوي.