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Soil aquifer treatment for wastewater treatment and reuse

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ABSTRACT

Soil aquifer treatment (SAT) is a managed aquifer recharge system in which the quality of the feed water (stormwater or wastewater treatment plant effluent) is further improved during soil passage. This paper provides an overview of SAT systems for wastewater treatment and reuse, and summarises design, removal efficiencies and pre-and post-treatment options as well as cost aspects of SAT using infiltration basins. SAT is an environment-friendly and robust multi-contaminant removal system which is effective in removing pathogens, nitrogen, bulk organic matter and the majority of organic micropollutants. The contaminant removal efficiency of SAT system, however, depends on several factors including source water quality, local hydrogeological conditions and process conditions applied. The performance of SAT system can be further improved by proper site selection and appropriate design of its components including pre- and post-treatment. SAT serves as an environmental and psychological barrier for water reuse applications. It is equally attractive for developed as well as developing countries and flexible enough to allow adaptation to local requirements by combining it with conventional (above the ground) natural or engineered water and wastewater treatment technologies.

1. Introduction

Development and application of innovative and environmentally sustainable technologies for water and wastewater treatment and reuse is getting increasing attention in order to address the global problems of water scarcity, escalating population growth and haphazard urbanization, pollution of water sources and high costs of water and wastewater treatment. A wide range of soil/aquifer-based and vegetation-based natural treatment systems (NTSs) have been applied for the treatment of drinking water, wastewater, and urban stormwater (Ray et al., 2002; Kadlec and Wallace, 2009; USEPA, 2012; NASEM, 2016). Such systems are low-cost, sustainable, robust, and multi-objective targeting simultaneous removal of different contaminants including suspended solids, pathogens, biodegradable organic matter, nutrients and organic micropollutants (OMPs) (Crites et al., 2006; Sharma and Amy, 2010; Sharma et al., 2012a).

In general, soil aquifer treatment (SAT) refers to artificial recharge or infiltration of wastewater effluent through the vadose (unsaturated) zone to recharge the underlying aquifers. It is an attractive managed aquifer recharge (MAR) and treatment technology for multiple contaminant removal which, in combination with other available water and wastewater treatment technologies, can produce effluent of acceptable quality for non-potable or indirect potable reuse (Idelovitch, 1978; Kanarek and Michail, 1996; Fox et al., 2001a, 2001b; USEPA, 2012; Angelakis, and Gikas, 2014). SAT technology can be applied to augment water supply in arid and semi-arid regions of the world where groundwater resources has been over exploited. It is equally attractive for developed as well as developing countries as it is robust, removes multiple contaminants, is environment-friendly, and minimizes the use of chemicals and energy (Wintgens et al., 2008; Muga and Mihelcic, 2008; Hochstrat et al., 2010). Implementation of SAT ensures sustainability of both surface water and groundwater sources within the context of integrated water resources management (NAP, 2008; Dillon et al., 2012). Furthermore, SAT provides innovative ways to promote safe wastewater reclamation/reuse including indirect potable reuse through use of appropriate environmental buffers and a psychological barrier (NAP, 2012; Gerrity et al., 2013).

1.1. SAT system components

Depending upon the local hydrogeological conditions and quality of the wastewater effluent available, SAT can be achieved

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using any of the three commonly employed recharge methods namely (i) infiltration basin (IB), (ii) vadose zone injection well (VZW) or (iii) direct injection well (DIW) (USEPA, 2006). The degree of pre-treatment required as well as hydraulic loading rate (HLR) applied will differ depending upon the recharge method employed. Typical components of a SAT system are presented in Fig. 1.

1.2. Advantages and limitations of SAT

The followings are the main advantages of the SAT system: (i) SAT improves the physical, chemical and microbial quality of source water during soil passage by removing particles, microorganisms, heavy metals, nitrogen, bulk organic matter and OMPs (in different SAT zones: interface, vadose zone and saturated zone). (ii) It provides seasonal and long-term storage without common problems in surface storage reservoirs like, evaporative losses and minimization of the external re-contamination of stored water and algal growth. (iii) It can serve as environmental and psychological barrier increasing public acceptability of reclaimed water thus promoting water recycling and reuse. (iv) It can also be utilized as a part of salt (sea) water intrusion barrier system in coastal aquifers. (v) It can be integrated with other conventional and advanced wastewater treatment systems to produce the water of desired quality for intended use. SAT can thus replace or support other treatment processes by providing a robust barrier and reduces the overall cost of wastewater treatment and water reuse.

Some of the limitations of SAT system are as follows: (i) The performance of SAT is site specific, and is feasible only when the local hydrogeological conditions, especially permeability, are favourable. It may not be applicable everywhere. (ii) There can be leaching of aquifer materials under reducing conditions, sometimes resulting in increased concentrations of iron, manganese, arsenic or fluoride in extracted water. (iii) Potential clogging of the infiltration basins, wells and aquifer due to accumulation of suspended matter or chemical precipitation is one of the main concerns, especially when the system is not properly designed, operated and maintained, and pre-treatment is inadequate. (iv) SAT may be only a limited barrier for certain contaminants such as persistent OMPs. There is potential of contamination of aquifers, in case of improper design and inadequate pre-treatment. (v) SAT has limited operational control and the performance is rather difficult to predict; it requires proper monitoring and regulations to avoid hazards. (vi) Excessive land area may be needed for spreading basins, which may not be available everywhere.

2. Contaminant removal mechanisms and efficiency

SAT has been practiced in different parts of the world using primary, secondary and tertiary effluents from wastewater treatment (Fox et al., 2001b; Nema et al., 2001). Different mechanisms, namely filtration, biodegradation, chemical precipitation, adsorption, ion exchange and dilution contribute to the attenuation of contaminant during soil passage in different zones of the SAT system (Fox et al., 2001b; Mansell et al., 2004; Abel, 2014). Among them, filtration, biodegradation and adsorption are dominant removal mechanisms. For the long-term sustainability of the SAT system, it should preferably be designed and employed targeting the removal of biodegradable contaminants.

The removal efficiencies of SAT systems are highly dependent on source water quality, the hydrogeological conditions on site, type of SAT system as well as process conditions applied (Kopchynski et al., 1996; Asano and Cotruvo, 2004; Cha et al., 2005; El-Hattab et al., 2007; Sharma et al., 2008a; Ak and Gunduz, 2013). The primary water quality improvement objective in SAT systems is to remove all suspended solids and micro-organisms. The reduction in dissolved organic carbon (DOC) concentration and removal of nitrogen species through biological processes are also key benefits. Both nitrification and denitrification can be achieved during SAT. However, nitrogen removal is a function of residence time, DOC to nitrogen ratio and redox conditions (Fox et al., 2001b; Sharma et al., 2012b; Abel et al., 2014). Phosphates and heavy metals can also be removed to some extent during SAT mainly by adsorption onto soil (Lee et al., 2004; Crites et al., 2006). Consequently, phosphate and heavy metal removal may not be suitable for long-term operation of SAT systems.

In an indirect potable reuse system, the residual humic substances present in effluent organic matter (EfOM) impart color and serve as a precursor to disinfection by-products (DBPs) while the nitrogen rich soluble microbial products (SMPs) present in EfOM represent a precursor to nitrogenous DBPs (N-DBPs) if extracted water is chlorinated upon recovery. In addition to concerns about bulk EfOM, there are various effluent-derived organic

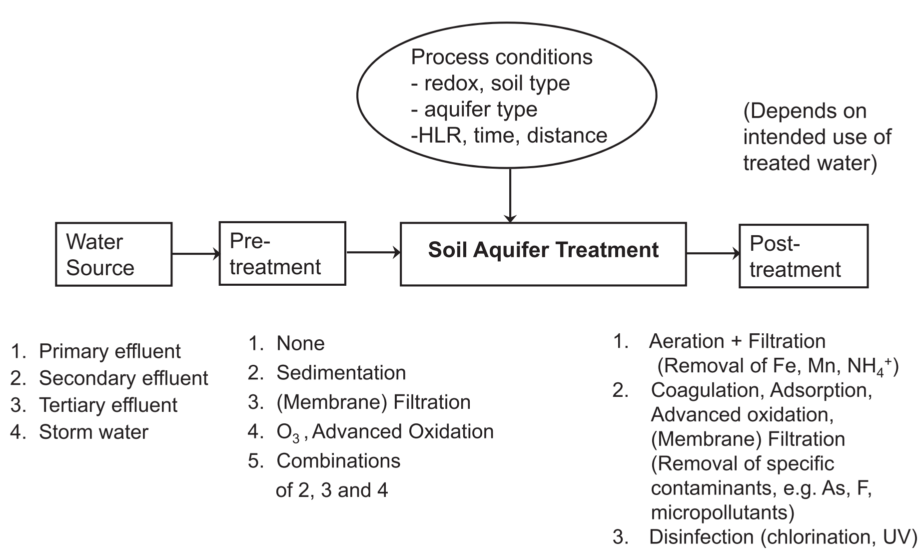

Fig. 1. SAT system components.