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An overview assessment of the effectiveness and global popularity of some methods used in measuring riverbank filtration

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ABSTRACT

This paper presents an overview assessment of the effectiveness and popularity of some methods adopted in measuring river bank filtration (RBF). The review is aim at understanding some of the appropriate methods used in measuring riverbank filtration, their frequencies of use, and their spatial applications worldwide. The most commonly used methods and techniques in riverbank filtration studies are: Geographical Information System (GIS) (*site suitability/surface characterization*), Geophysical, Pumping Test and borehole logging (*sub-surface*), Hydrochemical, Geochemical, and Statistical techniques (*hydrochemistry of water*), Numerical modelling, Tracer techniques and Stable Isotope Approaches (*degradation and contaminants attenuation processes*). From the summary in Table 1, hydrochemical, numerical modelling and pumping test are the frequently used and popular methods, while geophysical, GIS and statistical techniques are the less attractive. However, many researchers prefer integrated approach especially that riverbank filtration studies involve diverse and interrelated components. In term of spatial popularity and successful implementation of riverbank filtration, it is explicitly clear that the popularity and success of the technology is more pronounced in developed countries like U.S. and most European countries. However, it is gradually gaining ground in Asia and Africa, although it is not far from its infancy state in Africa, where the technology could be more important considering the economic status of the region and its peculiarity when it comes to water resources predicaments.

1. Introduction

Global industrial, economic and agricultural development and rapid human population growth are remarkably increasing the threat of surface water pollution, groundwater contamination and overexploitation. This has widened the gap and conflict between demand and supply of water for various uses, consequently accentuating additional challenges to water utilities worldwide (Ray, 2011). Population growth, surface water pollution and global climate change and variability are the frequently mentioned factors exacerbating the water resource scarcity and the cases of surface water pollution were particularly reported to have been increasing probably due to lack of environmental awareness or environmental apathy (Hoehn and Meylan, 2009; Abbas et al., 2004; Acharya, 2004). This further complicate access to fresh water to many communities despite the fact that the water is physically available (Banerjee et al., 2011; MacDonald et al., 2012). The situation is more challenging in arid and semi-arid areas of the tropical Africa (Halliru, 2012).

In response to this appealing situations, many water treatment technologies have been developed by water utilities such as; membrane filtration, soil aquifer treatment, and advanced oxidation (Maeng, 2010; Ray and Jain, 2011b). However, riverbank filtration though an old method has proved the best for its cost effectiveness and simple skill requirements (Stuyfzand and Juhàsz-Holterman, 2006). Historical evolution of riverbank filtration was first known with Glasgow Waterworks Company in the United Kingdom around 1810 (Ray et al., 2002a,b). However, the real popularization of the concept of riverbank filtration (RBF) starts in Germany around 1870 (Hiscock and Grischek, 2002), and gradually spread to other European countries for public and industrial water supply

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about 100 years ago (Hiscock and Grischek, 2002; Abdel-Lah, 2013). In many countries such as; Switzerland, France, Finland, Hungary, Germany, and the Netherlands, surface water has been treated to complement the existing water supply system through bank filtration (Tufenkji and Ryan, 2002; Ray et al., 2008; De Vet and Van Genuchten, 2009; De Vet et al., 2010; MacDonald et al., 2012). It has become an efficient and well accepted technique for the treatment of surface water in many of these European countries such as Switzerland where 80% of the drinking water comes from RBF wells, 50% in France, 48% in Finland, 40% in Hungary, 16% in Germany, and 7% in the Netherlands (Tufenkji and Ryan, 2002; Ray et al., 2008; De Vet and Van Genuchten, 2009; De Vet et al., 2010). Other countries like India (Ojha, 2011; Tyagi et al., 2013), China, and South Korea (Ray et al., 2008), Malaysia (Hamzah et al., 2006; Shamsuddin et al., 2014; Razak et al., 2015), Egypt and Jordan (Shamrukh and Abdel-Wahab, 2011a,b), have recently started implementing RBF for drinking water supply.

Riverbank filtration (RBF) is a technique in which the bed and bank of a river serve as treatment zones for the induced river water (Hunt et al., 2002; Ray et al., 2002a,b; Ray, 2011). This happens when wells are sufficiently placed adjacent to a river and pumped, the treatment zones remove most surface water pollutants (Grischek et al., 2002; Ray and Jain, 2011a). The riverbed serves as a natural filter to the induced water and removes the contaminants present in the surface water by overlapping physical, chemical, and biological processes (Singh et al., 2010; Abdel-Lah, 2013). Thus, as surface water infiltrates into the aquifer, and subsequently to the production wells, it undergoes riverbank filtration (RBF) thereby improving the quality of the river water (Levy and Agnieszka, 2013; Wojnar et al., 2013). The attenuation of the contaminants takes place mainly within the first 60 cm depth (depending on the aquifer thickness) of filtration at the surface of the riverbed via mechanical filtering, sorption and biological activity (Simpson and Meixner, 2012; Levy and Agnieszka, 2013; Wojnar et al., 2013). Suitable site for riverbank filtration are river sediments or alluvial aquifer, which mostly comprises layers of sand and gravel (Grischek et al., 2002; Hunt et al., 2002; Jaramillo, 2012), they can also be located in low permeable zones within the alluvial aquifer such as in silt and clay (Ray et al., 2008; Hubbs, 2006a). Recent study shows that riverbank filtration facilities can be applied along perennial and ephemeral rivers in desert countries (Ray, 2011), but special additional studies may be required to evaluate the connectivity of surface and ground water, dynamic variation of the redox zone(s), and the impacts of climate change before the actual application of this technology (RBF) in these arid countries (Ray, 2011; Hubbs, 2006b).

The current review is aimed at presenting an overview of the effectiveness and the global popularity of some methods used in measuring riverbank filtration technology. This will be helpful in facilitating the selection and quick understanding of searched papers on riverbank filtration studies.

In an attempt to achieve the stated objective, a number of studies and the techniques used in measuring river bank filtration were reviewed and reported these includes; Geophysical (Hamzah et al., 2006; Dor et al., 2011; Parsekian et al., 2014; Szalai et al., 2014), Hydrochemical (Akankpo and MU, 2011; Ibrahim et al., 2015; Othman et al., 2015), Geochemical (Samsudin et al., 2008; Thorp, 2013), Geographical Information Systems (GIS) (Razak et al., 2015), Tracer Techniques/Stable Isotope Approaches (Constantz, 2008; Dor et al., 2011; Harvey et al., 2011; Shamsuddin et al., 2014) Numerical Modelling (Schafer, 2006; Sandhu et al., 2011a; May and Mazlan, 2014; Shamsuddin et al., 2014), and Pumping Test (Caldwell, 2006; Schafer, 2006; Ibrahim et al., 2015). Summary of the categories and techniques employed in these studies, the sources and locations where the study was conducted were shown in Table 1.

1.1. Focus and categories perspectives of the review

Although a number of review papers on riverbank filtration studies have existed such as; (Hiscock and Grischek, 2002; Hubbs, 2006b; Sharma et al., 2009; Harvey et al., 2011; Jaramillo, 2012; Ray, 2011; Mustafa et al., 2014), the current review made additional effort for an in-depth survey of the global popularity of some of these methods used in measuring riverbank filtration efficiency.

The review was categorized into five major groupings: site suitability based, performance based, sustainability based, water quality based and temperature impacts based studies. Summaries of the classified categories, sources and locations, objective and the major findings were presented in Table 1. According to this classification, filtrate water quality associated studies attracts more attention, probably because, it is less challenging to undertake compared to other categories. Secondly, the performance based category was given precedence because of the need to assess the performance of the facility without much delay. Sustainability based studies was the third category, because after performance the next thing will be the question of sustainability (e.g. yield), will the current yield be sustainable? The impacts of temperature on riverbank filtration process though crucial, but it has not been given much attention, possibly due to numerous and complex assessments involve, like the effects of temperature on redox reaction and viscosity among others. Ironically, site suitability based category (that should have been studied at first) was the least prioritized, probably because of the complexities involves in determining the suitable site for riverbank filtration, because it is site specific and may require the integration of many methods such as geophysical and GIS techniques (Razak et al., 2015; Ghazali et al., 2015).

It is explicitly clear that the popularity and successful implementation of riverbank filtration technology is more concerted in the developed countries such as U.S. and most European countries (Ray, 2008), and then in Asian countries such as Indian (Ojha, 2011; Tyagi et al., 2013), China, South Korea (Ray et al., 2008), Malaysia (Hamzah et al., 2006; Shamsuddin et al., 2014; Razak et al., 2015), and was least in African countries where the technology is still at its infancy stage. At present only Egypt and Jordan were reported to have started applying this technology in the African continent (Shamrukh and Abdel-Wahab, 2011a,b), probably because of low level of economic base and lack of awareness of the technology itself.

1.2. Efficiency of riverbank filtration

It is difficult to make generalization as to the procedures for identifying the factors affecting the efficiency of riverbank filtration, the fact that these factors are sites specific. Therefore the efficiency of RBF largely depends on local conditions including the hydrology and hydrogeology of the site, the geochemistry of water (from both, the river and the aquifer), the geochemistry of microbial populations, and associated metabolic activity (Hiscock and Grischek, 2002; Lee and Lee, 2010). Other factors are soil texture and quality (Ray, 2011; Mustafa et al., 2014). The soil texture should exhibit filtering properties. Thus, limestone and dolomite bedrocks, rich in fissures allowing rapid water passage are not favourable for attenuation of contaminants.

The overall design of RBF systems requires detailed hydrogeological site investigation, knowledge about the hydrological characteristics of the catchment as well as defining the catchment area (Grischek et al., 2002; Stuyfzand and Juhàsz-Holterman, 2006). Suitable sites for RBF are sand and gravel aquifers with hydraulic conductivities $kf > 10^{-4}$ m/s, a minimal thickness of 5 m and a good hydraulic connection to the adjacent surface water