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Investigation of riverbed filtration systems on the Parapeti river, Bolivia

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ABSTRACT

Riverbed filtration is a promising alternative method of drinking water production for developing countries which has been little investigated and is still poorly characterized. As it offers advantages on riverbank filtration in terms of production yield, riverbed filtration needs to be more deeply defined. Riverbed filtration systems set up in Camiri (southeastern Bolivia) were characterized by collecting field data about the systems production yields and the produced water quality. The first objective of this work is to propose a method for the prediction of the production yield of the riverbed filtration systems in Camiri. The second objective is to perform a general review of the water quality of the filtered water provided by these systems.

The water quality study results show that the Camiri's riverbed filtration systems act like filters, efficiently removing turbidity and microorganisms. Regarding the systems production yield, the field study results obtained are successfully compared to those predicted by the method developed in this work, based on the evaluation, in laboratory, of the characteristic permeabilities of the porous media of the studied systems. This comparison highlights the fact that a clogging of a part of the riverbed might be the reason of the observed drop over time of the production yield of Camiri's riverbed filtration systems.

1. Introduction

Most of developing countries, although they have a largely sufficient water supply, own neither techniques nor economic resources to allow their citizens to get a domestic and unlimited access to drinking water [27].

For these countries, there is an urging need to develop new alternatives to the classical techniques of drinking water production, adapted to their economic and social conditions.

One of these alternative techniques [6] is drinking water production by riverbed filtration (RBeF). The general principle of this technique is to rely on natural phenomena to produce supply water, needing a limited number of additional steps of sanitation [1,2]. This purification is obtained by the natural infiltration of water through the riverbed and the accompanying slow-sand filtration effect.

Studying this technique is a worthwhile research due to the involvement, in RBeF, of complex physical and chemical phenomena such as mass transport, granular filtration, and organic matter removal together with biological contamination abatement. Furthermore, a deep understanding of the physicochemical phenomena at stake in RBeF systems and a characterization of their key parameters are the first steps toward the development of standardized design rules of RBeF technology, allowing ultimately an optimized site-per-site implementation of the process. This objective is pursued as part of a Belgian WBI-funded project conducted in partnership with a water company in Bolivia.

1.1. Riverbed and riverbank filtration

RBeF is a method of drinking water production by natural infiltration of river water through riverbed. RBeF is similar to river bank filtration (RBF) [23] which is more widely used and documented.

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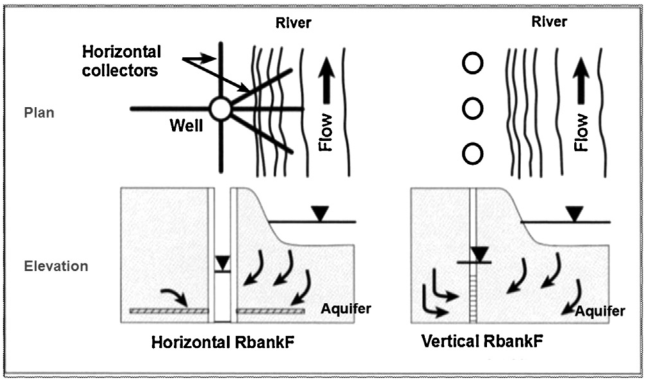

Fig. 1. Schematic representation of the two kinds of riverbank filtration systems: horizontal collectors connected to a single well (left) and vertical wells (right). Source: Figure adapted from Ray et al. [17].

RBF consists of the installation of wells collecting water within an aquifer that has a hydraulic connection with a river. Pumping water within the wells creates a continuous flow of surface water through the riverbank to the wells [26]. During its infiltration through the bank, the river water undergoes a combination of physical, chemical and biological processes: filtration, sorption, biodegradation, precipitation, redox reactions and dilution with groundwater. The filtration process retains the biggest particles present in the water, while the smaller ones are trapped on the riverbank particles surfaces by Van der Waals forces [15,22]. These processes highly increase the quality of the water, therefore decreasing the number of further treatment steps [11,21]. In the RBF systems studied by Singh et al. [21], only one additional step of disinfection is needed, most frequently ozonation or chlorination.

There are two kinds of RBF systems, schematically presented in Fig. 1. In the first kind, called "vertical" RBF, several wells are dug in the aquifer. In the second kind, called "horizontal" RBF, a single well is connected to multiple horizontal collectors in the aquifer [13].

RBeF is similar to horizontal RBF. A RBeF system is composed of a single well connected to one or several collectors dug in the riverbed and not in the aquifer (see Fig. 2). RBeF involves the same physical and chemical principles as RBF.

RBF and RBeF provide natural pre-treatment of river water, allowing the reduction of suspended matter, organic and microbial pollutions, along with many other pollutants. RBF has been extensively studied and characterized [4,9,11,14,16,19,21,25,28]. Thakur and Ojha [25] measured $N_{\log}$ of turbidity removal between 2 and 3 logs for a RBF system of the Ganga river. Singh et al. [21] report a reduction of more than 50% of the organic compounds concentration, the fecal coliforms concentration, and the color and UV absorbance, by the filtration of the Yamuna river water (India) by RBF. Dash et al. [4] report a removal of 99.9% of fecal coliforms by RBF systems at the Ganga river. All studies devoted to RBF show the excellent results obtained by these systems regarding turbidity, color and organic matter reduction.

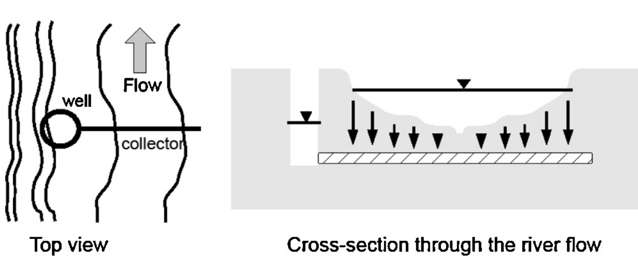

Fig. 2. Schematic representation of a riverbed filtration system.

A major drawback of RBF is the difficulty in predicting the system full-term production yield. In a not carefully designed system, the production yield usually decreases sharply during the first years of its operation until reaching a constant value. This loss of production yield comes mainly from one limiting factor: the decrease of the permeability of the riverbed due to its clogging. Clogging mainly comes from the capture of suspended particles, the development of biofilms and biological growth, and the geochemical reactions of dissolved constituents with aquiferous materials (the dissolved organic matter controlling the sorption processes) [18,30]. These mechanisms are difficult to model because of their dependency on various complex site conditions.

While RBF has been deeply studied since its appearance in 1870, RBeF has been far less investigated and is still poorly characterized. However, RBeF might offer an advantage on RBF in terms of production yield, as it exploits a larger area under the river (its whole width). Nevertheless, these characteristics might offer production yield advantages at the expense of the quality of the produced water. Therefore, it seems to be interesting to provide a general method for the characterization of a RBeF system production yield and to analyze the quality of its produced water.

1.2. Objective of this work

A RBeF installation set up in Camiri, a small rural town of southeastern Bolivia, has been characterized by obtaining qualitative and quantitative information about its operation. The first objective of this work is to propose a method for the prediction of the production yield of Camiri's RBeF systems. The second objective is to perform a general review of the water quality of the filtered water provided by these systems. Due to logistic reasons, no data could be obtained during the dry winter. This work therefore presents data obtained during the rainy summer, which is however, as presented below, the most favorable season for the operation of these systems.

2. Materials and methods

2.1. The RBeF systems of Camiri

2.1.1. General presentation

The town of Camiri is localized in a meander of the Parapeti river in the province of Santa Cruz, southeastern Bolivia. The 200-km-long Parapeti river originates in the Andes Cordillera and empties into the marshes of Izozog, in the Chaco plains. The mean annual flow of the Parapeti down the Cordillera is 79 m^3/s [10]. In Camiri, the supply of drinking water is carried out by the COOPAGAL Ltda company. The main origin of Camiri's drinking water is the Chorro stream originating in the mountain surrounding the town.

The Parapeti is highly concentrated in suspended matters coming from the mountains erosion. The climate in Camiri is subtropical with two very distinct seasons: a rainy season in summer and a dry season in winter. This results in large annual variations in the Parapeti's flow rate. The quality of the river water also varies strongly between these seasons. In Camiri, the Parapeti's water depth varies between 0.30 m and 4–5 m; its flow between 5 m^3/s and 1000 m^3/s; and its turbidity can vary between 8 and 4000 NTU [2]. The Chorro stream water can become very turbid during the rainy season, making the subsequent disinfection ineffective. As the Parapeti contains very low concentrations in anthropogenic pollutants but undergoes very high seasonal peaks in suspended matter, 7 RBeF systems were built in Camiri between