New Approach to Understand the Removal Efficiency of Some Anions in Well Water by Slow Sand Filtration

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Authors’ contributions

This work was carried out in collaboration between all authors. Authors BY and ZC designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors AMA, BY and EKME managed the analyses of the study. Author PA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARRB/2018/38905

Received 20th November 2017
Accepted 23rd January 2018
Published 30th January 2018

ABSTRACT

Aims: Slow sand filtration (SSF) is a simple technique widely used for the treatment of drinking water. However, little attention has been accorded to the improvement of the understanding of this process model. The main objective of this work is to develop a numerical tool allowing the prediction...
Materials and Methods: This evaluation was done by comparing data from contaminated well water filtered through the laboratory columns with the same diameter (5 cm) but filled with sand to various heights (5 cm, 10 cm and 15 cm).

Results: Decontamination efficiency of slow sand filtration was determined in terms of selected physicochemical parameters such as sulphates, chlorides and total hardness. Results indicated significant difference in levels of sulphates and chlorides in filtered water through the three sand bed heights whereby decontamination efficiency of these parameters was found to be better at the highest sand bed (15 cm).

Keywords: Slow sand filtration; well water; decontamination; sand bed depth pollutants; modeling.

1. INTRODUCTION

Water has always been inseparable from human activity and it plays a decisive role in the lives of humans, animals and plants, it is unarguably the most essential and precious natural resource for life on earth. It is a universal solvent and as a solvent it provides the ionic balance and nutrients, which support all forms of life [1,2].

Water is generally obtained from two principal natural sources; surface water such as fresh water lakes, rivers, streams, and groundwater such as borehole water and well water [3].

Unfortunately, industrialization and human activities have partially or totally turned our environment into dumping sites for waste materials [4]. As a result, many water resources have been rendered polluted and hazardous to human and other living systems [5].

Water is typically qualified as polluted when it is impaired by anthropogenic contaminants and it does not either support a human utilisation and/or undergoes a marked shift in its ability to support its constituent biotic communities [6]. Deposition of anthropogenic contaminants in groundwater from many human activities has been implicated for an increase in those contaminants concentration above recommended levels [7,8].

In many parts around the world, the major source of water used to meet the domestic, agricultural and industrial needs is the groundwater. The groundwater is defined as water that is found underground in cracks and spaces in soil, sand and rocks [2] and various physicochemical parameters have a significant role in determining the potability of this water [9].

In Morocco, groundwater is a main source of water supply in most rural communities. It has good microbiological and biological properties in general and requires a specific treatment to improve its chemical quality.

Such treatment can be provided by slow sand filtration. This process has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens, organics and reducing turbidity [10].

Slow sand filters can be constructed from local materials, mainly from properly graded sand/gravel and standard piping and can operate without the use of specialized equipment. Also, slow sand filters operate under gravity flow conditions and energy and its on-going energy demand is minimal [10].

This study was carried out to evaluate the efficiency of slow sand filtration in removing the charge of anthropogenic chemical contaminants from well water in the Marrakech region in Morocco and try to facilitate the understanding of the mechanism of this filtration process.

2. MATERIALS AND METHODS

The Draa Lasfar region is located in northwest of the Mrabtine zone at approximately 10 Km in the west of Marrakech city (Fig. 1). It is located a few hundred meters from the Tensift River, close to a rural community of about 5790 ha, which 65% are occupied by farmland.
Well water samples were collected once a month for three months between March and May 2017.

Well water samples were taken directly from wells in sterile glass bottles of 250 milliliters capacity [10,11,12], after rinsing the bottles three times with sample water. In order to collect the samples directly from well, a bottle with a string attached to neck was used. Another long clean string was tied to the end of sterile string and the bottle was lowered into the water allowed to be filled up. Then the bottle was raised and stopped. The collected samples were transported to the laboratory in ice within an insulated container and analyzed within 24 hours of collection. Temperature and pH of each sample was measured using mercury filled glass thermometer and digital pH meter respectively. Total hardness of the samples was estimated using Total hardness test kit.

Concentration of sulfates and chlorides in water samples was measured and expressed in mg/l.

In this study, sand is conceptualized as a porous medium which is considered as a continuous environment, cohesive or not, presenting internally a volume fraction accessible to a fluid. This "vacuum" volume fraction, composed specially of pores constitutes the porosity of the filtration bed. It is through these vacuums that the water flow processes take place in sand bed filtration [13].

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**Fig. 1. Drâa Lasfar mine geographic situation in Marrakech region**

**Fig. 2. Migration of contaminants through the sand bed filtration**
The sand used was collected from Tensift river bed. The sand is first washed three times with demineralised water and oven dried at 105°C before use.

Sieve analysis of the sand is done using a series of sieves of size 300 μm, 150 μm, 90 μm, and 75 μm. D10 (effective size) and D60 sizes were 0.136 and 0.252 respectively giving uniformity coefficient as 1.9173. The Table 1 shows sieve analysis of the sand (2 kg).

The decontamination efficiency of slow sand filtration process was determined by percolation of contaminated well water through laboratory columns with the same diameter filled to various heights with sand.

To understand the effect of sand bed depth on dynamics of water pollutants (in this study, sulfates and chlorides, calcium and magnesium), this study was carried out on 3 columns of the same diameter (D = 5 cm) [14] filled to different heights with sand; 5 cm, 10 cm [14] and 15 cm [14,15].

All columns were closed at both ends with perforated caps. The upper cap hole was large enough to receive a tube from a peristaltic pump and allow air circulation. A test tube was connected to the hole in the lower cap to collect filtrated water. The collected filtered water samples were stored in ice in an isolated container and analyzed within 24 hours of collection.

Statistical analyses were performed using Statistical Package for Social Sciences. Removal efficiencies of sand filters for the studied pollutant were assessed by ANOVA. This treatment was done to determine if there were significant differences between pollutant concentrations in influent and effluent.

All statistical analyses were done at 95% level of confidence (p =.05).

3. RESULTS AND DISCUSSION

Total hardness, sulphates and chlorides concentrations in recovered solutions (effluent) are shown in Table 2 and Figs. 3, 4 and 5, respectively.

These results show that anions changed continuously in effluents according the filtration process time, whereas total hardness seems to be unchangeable in both water before (influent) and after filtration (effluent).

These results show also that the removal efficiency of filtration (to decontaminate) water depends greatly on the sand bed depth. Thus, the long filter eliminates more anions than the smaller ones.

The speed of this removal efficiency of filtration becomes increasingly weak and tends to stabilize and reach a maximum equilibrium value (MEV). This value remains almost equal to the initial water concentration (influent). This finding can be justified by saturation of fixation sites of pollutants anions on the sand bed filter, which is translated at the end of filtration process (100 min) by recovering a water solution which is roughly similar to the initial water solution (influent).

### Table 1. Sieve analysis of the sand

<table>
<thead>
<tr>
<th>Sieve size(mm)</th>
<th>Retained weight (g)</th>
<th>% of retained weight</th>
<th>% of cumulative weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>342</td>
<td>17.1</td>
<td>17.1</td>
</tr>
<tr>
<td>0.15</td>
<td>1366.11</td>
<td>68.3</td>
<td>85.4</td>
</tr>
<tr>
<td>0.09</td>
<td>224.72</td>
<td>11.2</td>
<td>96.6</td>
</tr>
<tr>
<td>0.075</td>
<td>29.05</td>
<td>1.5</td>
<td>98.1</td>
</tr>
<tr>
<td>0.001</td>
<td>38.1</td>
<td>1.9</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 2. Results of physicochemical analyses of wells water before filtration

<table>
<thead>
<tr>
<th>Wells water</th>
<th>Sulphates</th>
<th>Chlorides</th>
<th>Oxidisability</th>
<th>Total hardness</th>
<th>Nitrites</th>
<th>Nitrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells water</td>
<td>84,98</td>
<td>1349</td>
<td>3,2</td>
<td>112</td>
<td>0,019</td>
<td>57,82</td>
</tr>
<tr>
<td>Moroccan standard</td>
<td>400</td>
<td>750</td>
<td>5</td>
<td>30</td>
<td>0,5</td>
<td>50</td>
</tr>
</tbody>
</table>
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Fig. 3. Evolution of total hardness of filtrate water (effluent)

Fig. 4. Evolution of chlorides concentration in filtrate water (effluent) according to the time of filtration

Fig. 5. Evolution of sulphates concentration in filtrate water (effluent) according to the time of filtration
Table 3. Evolution of Cl\textsuperscript{-}, SO\textsubscript{4}\textsuperscript{2-} and total hardness according to the time of filtration

<table>
<thead>
<tr>
<th>Sand bed depth</th>
<th>Filtration time (min)</th>
<th>Cl\textsuperscript{-}</th>
<th>SO\textsubscript{4}\textsuperscript{2-}</th>
<th>TH</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 cm</td>
<td></td>
<td>1349</td>
<td>85.02</td>
<td>112</td>
</tr>
<tr>
<td>10 cm</td>
<td></td>
<td>1349</td>
<td>85.02</td>
<td>112</td>
</tr>
<tr>
<td>15 cm</td>
<td></td>
<td>1349</td>
<td>85.02</td>
<td>112</td>
</tr>
<tr>
<td>20 min</td>
<td>1207</td>
<td>76.00</td>
<td>88</td>
<td>88</td>
</tr>
<tr>
<td>40 min</td>
<td>826.12</td>
<td>71.66</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>60 min</td>
<td>1295</td>
<td>74.02</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>80 min</td>
<td>1315</td>
<td>78.80</td>
<td>102</td>
<td>102</td>
</tr>
<tr>
<td>100 min</td>
<td>1334</td>
<td>80.92</td>
<td>94</td>
<td>94</td>
</tr>
</tbody>
</table>

Statistical analyses of this results show that sand bed depth had no significant effect on removal efficiency of Ca and Mg. Although total hardness of the effluents was almost unchanged with increasing sand bed depth; there was no significant difference in effluent total hardness at depths 5 cm, 10 cm and 15 cm and influent before filtration.

Chlorides in effluents decreased significantly \( (p = .05) \) in filtered effluents as compared with the unfiltered effluents although there were significant differences in chlorides increment at the three levels of depth (5, 10 and 15 cm). Decrease in chlorides was found to be at its highest level \( (1164 \text{ mg/l}) \) at 5 cm depth \( (t=20 \text{ min}) \) and at its lowest level \( (1207 \text{ mg/l}) \) at 5 cm depth \( (t=20 \text{ min}) \) (Fig. 4).

Sulphates decreased significantly \( (p = .05) \) with an increase in sand bed depth. Sulphates were found to be high in unfiltered effluents, but lower at all the three levels of experimental depths. Significant differences in sulphates were also observed among the three experimental depths (5 cm, 10 cm and 15 cm) with the highest reduction being observed at 15 cm depth and the lowest reduction at 5 cm depth (Fig. 5).

In this study, the removal rates of anion pollutants are similar to those mentioned in other studies using sand filters for the treatment of wastewater [16]. These studies mentioned also that longer depths of sand filters can be applied effectively as tertiary treatment for secondary effluents to decontaminate wastewater [17].

3.1 Modelling

Classical filtration theory, elaborated by Iwasaki [18] takes into account a solute transport and mass balance equations [19,20,21,22], is the most commonly used approach for evaluating migration, retention (sink term for solids deposition) and detachment (source term for solids deposition) [23].

The removal efficiency of anions by sand filtration is directly related to sand bed depth and residence time of anions in sand bed. This process can be described as time-dependent [24,25]. This finding is justified by the effect of time on the reactions between anions and their fixation sites on sand filter; these reactions include mainly complexation, adsorption and precipitation of anions on the sand surface, and their diffusion in the pores of sand [24].

Under these conditions, the Ci-Cf/Ci \( (Ci = \text{initial concentration}, \text{cf} = \text{final concentration}) \) ratio known as the extraction-ratio or elimination-ratio measures in general the rate of extraction \( (Ke) \) of a pollutant. The process of elimination of pollutants by sand filtration is exponential [13].

We consider Ct = Ci-Cf the concentration of pollutant fixed by the sand filter or the resident concentration of pollutant in the sand filter:

\[
\frac{dCt}{dt} = -KL \cdot Ct
\]

with K is filtration coefficient
\[
\frac{dCt}{Ci} = -KL \cdot dt
\]
\[
\frac{dCt}{Ci} = -K \cdot L \cdot t
\]
\[
\text{Ct/Ci} = \exp (-KL \cdot t)
\]
\[
\text{Ct} = Ci \cdot \exp (-KL \cdot t)
\]

(1)
In addition, expression of pollutant concentration at the exit of the column is:

\[ Cf = Ci - Ct \]

becomes: \[ Cf = Ci (1 - \exp (-K L t)) \].

The coefficient \( K \) is an expression which accounts for all different parameters which intervene in the transfer of pollutant from contaminated water into sand filter.

4. CONCLUSION

This study demonstrated that decontamination of well water using river sand as a medium in slow sand filter is feasible. The efficiency of this filtration to remove anion pollutants was generally higher at higher filter depths. This can be attributed to the exposition of new fixation sites of anion pollutants on the sand surface that facilitates the adsorption process. Nevertheless, efficiency of slow sand filter to reduce total hardness at different filter depths is not significant.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES