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Elimination of turbidity and bacterial contamination in natural water sources (Ubangi river, Central Africa)

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Abstract. Having access to a natural source of water of sufficiently high quality for human consumption has become a strategic concern for the entire world. In fact, drinking water resources in developing countries are almost non-existent, as they are overused or polluted by intense human activity. Our study aims to develop a natural filter that reduces turbidity and eliminates human pathogens. The process developed should be inexpensive and minimize the use of chemical reagents, and should not be labor intensive. In this context, horizontal sand filtration that uses the natural process of water purification occurring in an aquifer can be regarded as the most suitable water treatment process for developing countries.

Keywords. Filtration, Pathogens, Turbidity, Chlorine demand

1. Introduction

Among the various treatments used to obtain drinking water from natural water sources, the standard methods make use of filtration with the addition of chemical reagents followed by sand or membrane filtration. Recent studies have demonstrated that slow filtration can reduce turbidity and a number of chemical and bacteriological contaminants. We propose to develop an inexpensive horizontal filtration pilot which, without adding reagents, can produce water of acceptable quality and can be used in tropical regions (1). The method developed presents—relative to other methods—the advantage of making better use of local skills, and of the materials available in developing countries. The pilot consists of a filter mass made up of sand of varying grades. This medium is held in place by a geomembrane covered with geotextile. The use of earth dykes and geosynthetic materials avoids the need for metallic or concrete tanks.

2. Materials and methods

2.1 Materials

2.1.1 The horizontal filtration pilot

The pilot is inspired by the installation built by Eaux de Paris at Villemer (Seine & Marne), but we are starting from river water, whereas the "Eaux de Paris" process is used for the treatment of spring water presenting high turbidity levels due to runoff during rainy periods. The pilot consists of a horizontal trench (with a very gentle gradient) 14 meters long and 1 meter deep, and is supplied with water, without the addition of coagulant, by a 1x1m^2 decanter located at the front end of the system. The trench is lined with geotextile and impermeable geomembrane, and filled with three successive vertical segments of sand of varying granulometry: 4-8mm over 3 meters, 0-4mm over 5 meters, and 2 meters of gravel (20-40mm). These different grades of sand, extracted from the Ubangi River, were obtained by sieving. The system is watertight and is exposed neither to light nor to ambient air (Figures 1a to 1c), unlike in Ghana (4). Four piezometers (P1, P2, P3 and P4) were placed in the various materials to enable monitoring of the characteristics of the water as it passes through the filter.

Figure 1a. The trench in which the pilot was built

Figure 1b. Installing the filtration materials: 4-8mm and 0-4mm sand separated from 20mm aggregate by geotextile

Figure 1c. View of the completed pilot (supply hatch, the 4 piezometers, and the receiver)

2.1.2 Analysis equipment

The following equipment was used for the physicochemical analyses: WTW Inolab pH-meter, WTW 330i/ST2100 (ISO) conductivity meter, Hach turbidimeter, incubator, Precisa XT 220A balance, WTW Oxi 330/SET oximeter, Uvikon 860 Kontran spectrophotometer, Varian Spectra AA 55 atomic absorption spectrometer.

The following equipment was used for the bacteriological analyses: incubators, Petri dishes, filtration manifold, sterile pipettes, filter membranes (0.45 μm), colony counters, clamps, water bath, and autoclave.

2.2 Methods

After connecting up the water supply, once the pilot had been built (November 26, 2009), the physical characteristics of the pilot (water flow rate and transit time) and the properties were studied. The flow rate is regulated by a float in the supply tank. The flow of water through the system was determined by reading the water meter on the input to the pilot. The transit time was analyzed by injecting a fluorescein tracer.

The analytical methods—based on the prevailing French AFNOR standards—made it possible to monitor, using the piezometers, the changes in the relevant physicochemical and bacteriological parameters of the water in the pilot. The results after the first year in operation are presented below.

3. RESULTS – DISCUSSION

3.1 Physical parameters of the pilot

3.1.1 Flow rate

The operation of the pilot was been monitored since the outset.

Figure 2 represents the flow of water through the pilot over 4 months. As the readings show, the rate is constant for the first 3 months, except in March (due to electricity outages). Overall, the average flow rate over the first 4 months is 8 m^3/day, or 330 L/h. The pump was replaced, due to an overvoltage problem, which accounts for the sudden increase in volume starting in April 2010.

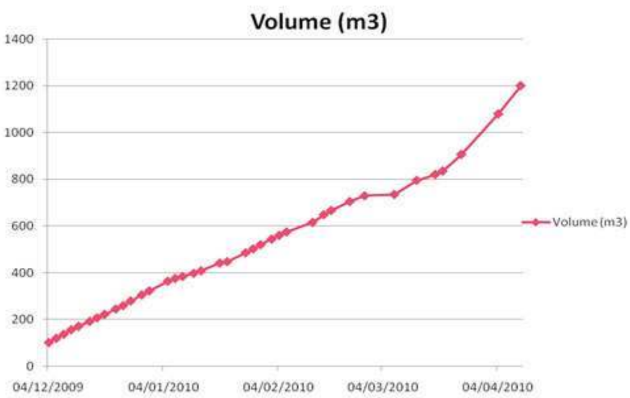

Figure 2. Volume of water measured at meter over 4 months' water connection

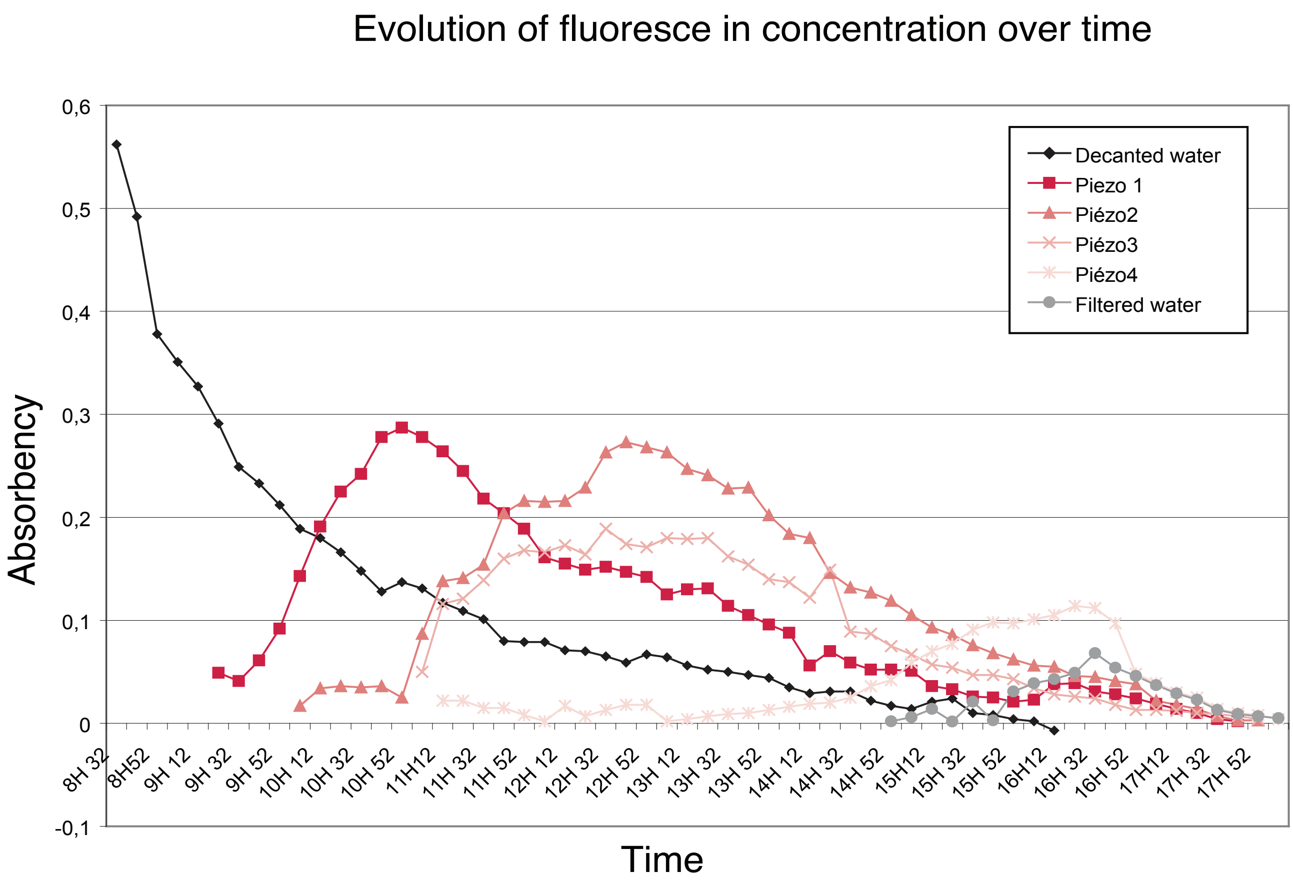

Figure 3. Monitoring of fluorescein content in pilot. *The X-axis represents the volume of water in m3 flowing through the pilot since June 26, 2009*

3.1.2 Pilot transit time

A fluorescein solution was added to the supply tank located after the decanter. The fluorescein content was monitored by absorption spectrometry at 496 nm, in the supply tank, at the piezometers, and in the receiver tank at different times (Figure 3), measuring the water volume.

Figure 3 represents the change in the fluorescein content over time in the various compartments (piezometers and receiver tank). From the addition of fluorescein in the supply tank to its appearance in the receiver tank took 7 hours 30 and required a volume of water close to 3000 liters. The average flow rate is therefore 400 L/h and the filtration rate is 0.4 m/h.

3.2 Physicochemical parameters of the water in the pilot

- The **turbidity** was monitored over a year, revealing—despite a few incidents (power cuts)—a regular decline in turbidity. In the first quantities drawn off (volume < 245.6 m^3), the turbidity corresponds to the washing of the sand in the system. The water produced thereafter meets the potability requirements in terms of turbidity (turbidity < 2NTU, Figure 4a). This quality is not influenced by the peaks in turbidity observed in the water flowing into the pilot, which are generally associated with bacterial contamination. In parallel to measuring turbidity, the total suspended solid (TSS) content was also measured.
- The turbidity and the **total suspended solid (TSS)** concentration are correlated. The generally accepted relationship is that for turbidity values below 20 NFU: TSS = 2 NFU. Considerable similarity is observed between variations in MES and turbidity. Despite the various incidents, the TSS count after one month's operation remains below 5 mg/L (Figures 5 and 6).

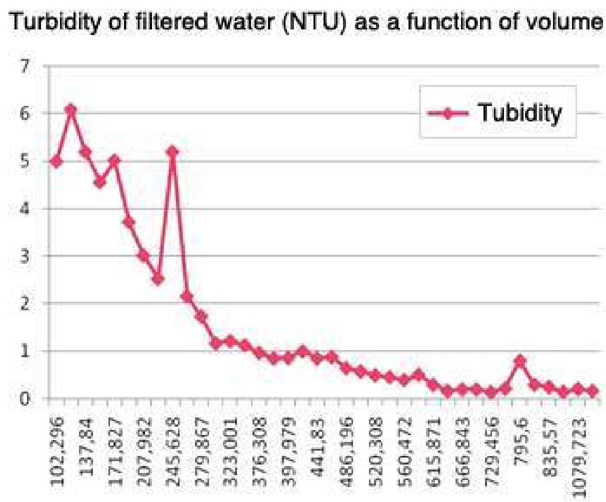

Figure 4a. Change in turbidity (in NTU) as a function of filtered water volume

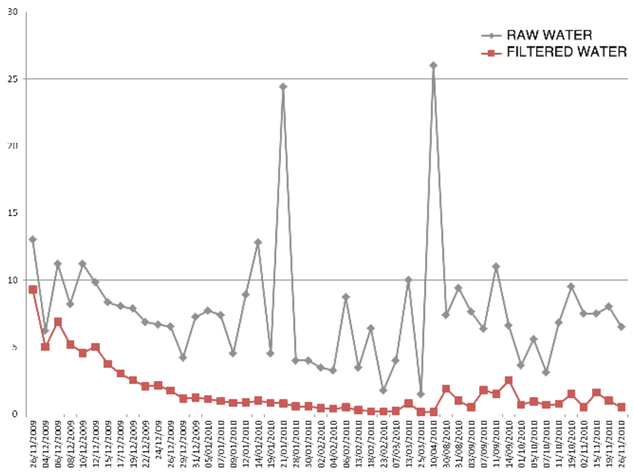

Figure 4b. Comparison of turbidity readings in the supply (RW) and receiver (FW) tanks

A significant decrease in turbidity is observed over time, with a very large abatement of turbidity as from the 2nd month of operation, relatively unaffected by variations in input water quality. Overall the turbidity is slightly below 1 NTU, allowing peaks in turbidity to be absorbed, and thus the associated contamination episodes to be diminished or even eliminated. The turbidity values obtained after filtration are acceptable under the prevailing standard (2 NTU).

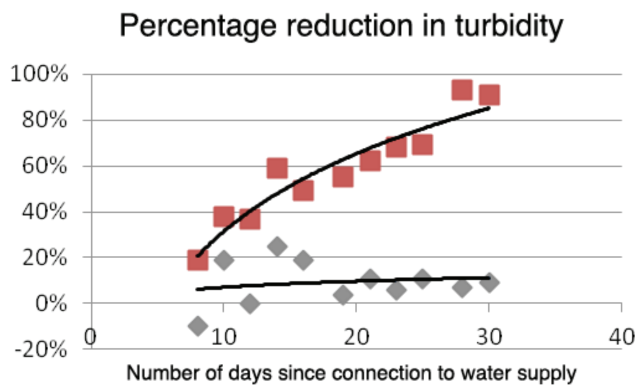

Figure 5. Reduction in turbidity at the decanter (blue) and outlet (red) over the first 30 days of use

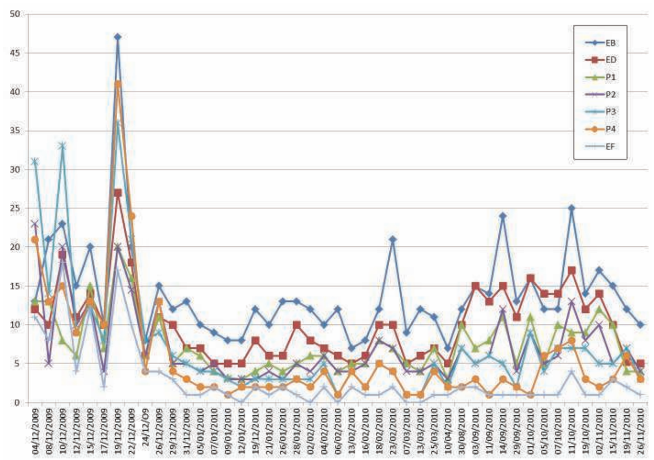

Figure 6. Change in TSS (mg/L) in each compartment

- Some water sources in the Central African Republic are contaminated with **iron**, an element that is not dangerous in low concentrations, but which can, after colloid precipitation, become a vector for bacteria and can give water an unpleasant taste.

Analysis of iron in the different compartments of the pilot shows a significant decrease between the river water, the decanted water, and the output water, due to oxidation of the ferrous ions. Finally, a sharp fall in the iron content is observed in the last compartment (Figure 7).

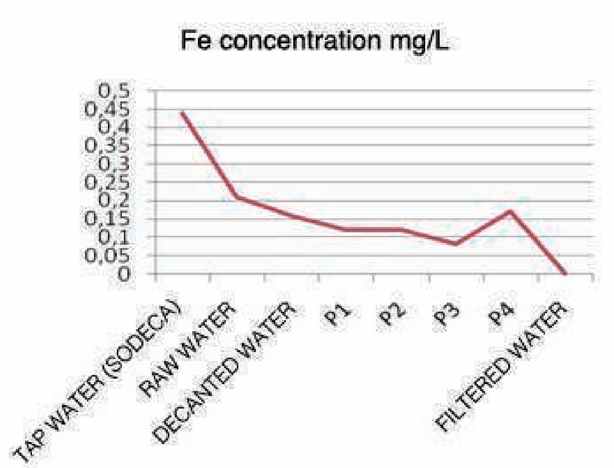

Figure 7. Change in dissolved iron content in the different compartments of the pilot (three months after startup)

- The oxygen and dissolved organic carbon (DOC) were measured in each compartment (Figure 8). The DOC and oxygen levels are inversely correlated. In the last 2 piezometers, as the iron and bacteria levels diminish, so does the consumption of oxygen. The level of dissolved organic carbon is still too high for drinking water (the requirement is DOC < 2 mg/L), but normal for water destined for the production of human drinking water after very limited disinfection with bleach.

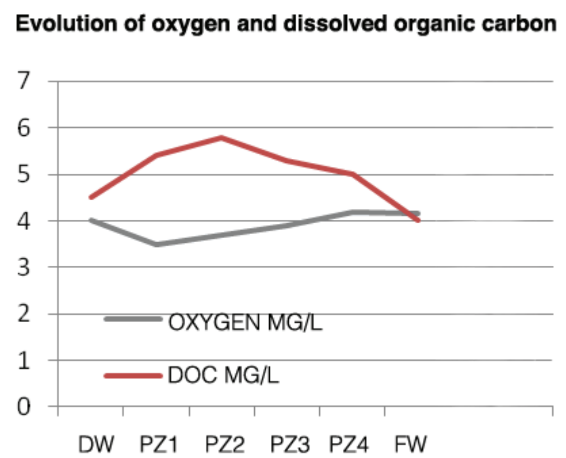

Figure 8. Change in oxygen and dissolved organic carbon in each compartment

3.3 Bacteriological parameters of the water in the pilot

Another objective in constructing this pilot was to eliminate a maximum of pathogenic microorganisms. The bacteriological analysis yields the following graphs (Figures 9 and 10):

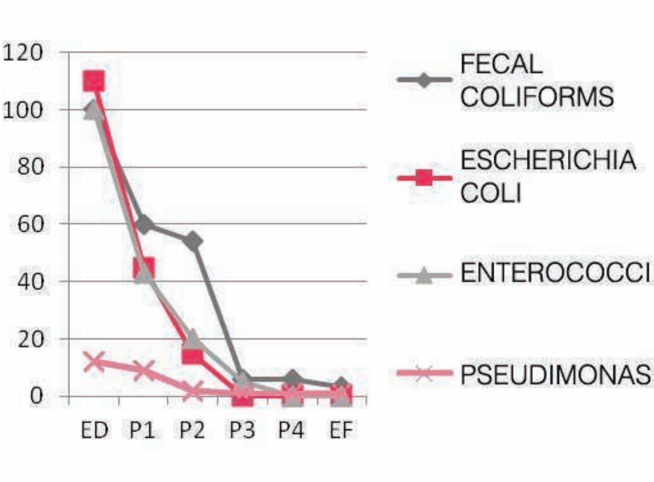

Figure 9. Change in bacterial contamination parameters in each compartment of the sand filter

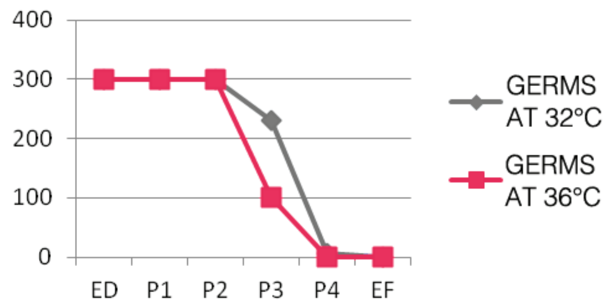

Figure 10. Change in viable germs in each compartment of the filter

These analyses show that abatement is consistent with the performance expected of this filter, which is in the order of 3 $\log_{10}$ for bacteria, but the concentration of bacteria in the input water was visibly insufficient to measure the abatement precisely. After filtering, the efficiency is at least 90% (Figure 9) for fecal coliforms and streptococci and 100% for microbial flora (Figure 10). Note that the raw water is clarified without adding any chemicals, and the chlorine demand is in the order of 3 mg/L of filtered water; for these reasons we believe that the objectives have been met.

4. Conclusion

With a water transit time of 7 hours 30 through the filter mass and an average flow rate of at least 400 L/h after the filter, the pilot eliminates micro-organisms and suspended particles to a large extent and renders most water suitable for a range of uses (domestic use, production of drinking water, and the needs of agriculture and industry). The set objectives were to significantly reduce the turbidity of the water so that it did not exceed 0.3 NTU, to eliminate nearly all pathogenic microorganisms and to reduce the organic matter to its non-biodegradable fraction by making maximum use of the filter mass. This technique should be of interest to small communities by virtue of its affordability as well as its ease of implementation, operation, sizing and maintenance.

5. Acknowledgements

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