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Enhanced drinking water supply through harvested rainwater treatment

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SUMMARY

Decentralized drinking water systems represent an important element in the process of achieving the Millennium Development Goals, as centralized systems are often inefficient or nonexistent in developing countries. In those countries, most water quality related problems are due to hygiene factors and pathogens. A potential solution might include decentralized systems, which might rely on thermal and/or UV disinfection methods as well as physical and chemical treatments to provide drinking water from rainwater. For application in developing countries, decentralized systems major constraints include low cost, ease of use, environmental sustainability, reduced maintenance and independence from energy sources. This work focuses on an innovative decentralized system that can be used to collect and treat rainwater for potable use (drinking and cooking purposes) of a single household, or a small community. The experimented treatment system combines in one compact unit a Filtration process with an adsorption step on GAC and a UV disinfection phase in an innovative design (FAD – Filtration Adsorption Disinfection). All tests have been carried out using a full scale FAD treatment unit. The efficiency of FAD technology has been discussed in terms of pH, turbidity, COD, TOC, DOC, *Escherichia coli* and Total *coliforms*. FAD technology is attractive since it provides a total barrier for pathogens and organic contaminants, and reduces turbidity, thus increasing the overall quality of the water. The FAD unit costs are low, especially if compared to other water treatment technologies and could become a viable option for developing countries.

1. Introduction

Decentralized approaches to water supply issues have been already successfully applied in many parts of developing and transition countries. These decentralized solutions deal with both quality and availability problems and include the direct use of alternative water sources (groundwater, rivers or rainwater), household-based water treatment units, dual tap water systems and distribution and sale of ready-to-use treated water (Gadgil, 1998; Mintz et al., 2001; Belgiorno and Napoli, 2000).

As water shortages occur more often, the search for alternative water sources and ways to promote its rational use is relevant not only to water-stressed regions but also to secure a stable water supply that allows for rising water demand, rapid urbanization and climate change (Ghisi et al., 2006; Villareal and Dixon, 2005; Mun and Han, 2012; Belgiorno et al., 2013; Naddeo et al., 2013).

In some semi-arid areas of the world, rainwater harvesting has been promoted for a long time as a useful technology, able to provide local settlements with water. For example, in 50% of the Tanzania area, people completely rely on rainwater for their survival (Mbilinyi et al., 2005).

The efficiency and feasibility of rainwater-based supply systems have been studied by many authors (Eroksuz and Rahman, 2010; Ghisi et al., 2007; Ghisi and Ferreira, 2007; Jones and Hunt, 2010; Khastagir and Jayasuriya, 2010; Li et al., 2010; Rahman et al., 2012). Domènech and Saurí (2011) argue that for this kind of treatment units the economic feasibility can be determined through a detailed analysis of the end-user needs, usually restricted to a few options. In addition, in water stressed areas the economic feasibility threshold value tends to be lower.

Rainwater harvesting and treatment provides water directly to households allowing family members to have full control of their own water system, which greatly reduces centralized operation and maintenance costs. There are also examples of rainwater harvesting systems developed for entire settlements, in which water is withdrawn from roads or fields (Gould and Nissen-Petersen, 1999). The main disadvantages of rainwater harvesting are the dependence on rainfall seasonal variability, the uncertainty of precipitations and also the rainwater quality, which is characterized by a fluctuating behaviour; in addition, diseases may spread over a community since rainwater has to be stored, sometimes for a long period. Several techniques used to collect precipitation runoff over roads, fields or roofs after dry periods may provide final users with contaminated water supply due to deposited pollutants that are flushed away during precipitation (Zhu et al., 2004).

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Several technologies have already been explored or used, alone or in combination, as end-of-pipe systems to treat the fraction of rainwater that is to be used for drinking purposes (Sobsey, 2002). Some of these methods, such as boiling water, are traditionally and widely used, although they may not always be the optimal solution (Mintz et al., 2001) in terms of financial issues as well as final water quality.

Solar water disinfection (SODIS) is a basic technology used to improve the microbiological quality of drinking water by using solar radiation as to destroy pathogens (Mintz et al., 2001). A potential limitation of SODIS, besides its dependence on sunlight for disinfection, is that the treatment process is rather complex.

UV irradiation with lamps has raised renewed interest in recent years because of its well-documented ability to extensively (>99.9%) inactivate two waterborne, chlorine-resistant protozoans, *Cryptosporidium parvum* oocysts and *Giardia lamblia* cysts, at relatively low irradiation doses. However, UV lamp disinfection has some disadvantages when used as a drinking water disinfectant at household level. Organic matter, turbidity and certain dissolved contaminants can interfere with or reduce the efficiency of microbial inactivation. These lamps require periodic cleaning, especially if placed in a submerged configuration; moreover, they have a finite lifespan and must be periodically replaced (Gadgil, 1998).

Chemical treatment is widely used for disinfection purposes at full scale facilities. Of the drinking water disinfectants, free chlorine is the simplest, most widely used and the most affordable one. It is highly effective against nearly all water-borne pathogens, with the notable exception of *C. parvum* oocysts and the *Mycobacteria species* (Sobsey, 2002; Mintz et al., 2001). However, the socio-cultural acceptance of disinfection with chlorine-containing reagents is low in some cases, due to taste and odour impact problems (Murcott, 2005); in addition, chlorine gas storage poses significant health risks and is therefore used only at large water facilities

Slow sand filtration has been adapted for household use and is also known as Biosand filtration (BSF). Biosand filters are tanks filled with sand in which a bioactive layer is allowed to grow as a means of eliminating disease-causing microorganisms. Several studies show that BSF removes bacteria consistently, if not completely, on average in the range 81–100%, and protozoa by 99.98–100%. However, these filters have limited viruses removal efficiency (Lantagne et al., 2007; Naddeo and Belgiorno, 2007).

Furthermore, paper, fiber or fabric filters may be applied at household level. They can be effective in the removal of larger water-borne pathogens such as free-swimming larval forms (*cercariae*) of *schistosomes* and *Faciola species*, guinea worm larvae within their intermediate crustacean host (*Cyclops*), and bacterial pathogens associated with relatively large copepods and other zooplankton in water, such as the bacterium *Vibrio cholerae* (Sobsey, 2002). However, these filters are not recommended for the treatment of household water supply because their pores are too large to significantly retain viruses, bacteria and smaller protozoan parasites (Sobsey et al., 2008).

Activated carbon filters, often in the form of pressed blocks, followed by UV disinfection or pre-coated with silver (Ag), are used as table-top units for additional tap water treatment (Abbaszadegan et al., 1997). However, they have a only limited operating life (6–8 months) and relatively high costs.

This work focuses on an innovative decentralized system to collect and treat rainwater for potable use (drinking and cooking) of a single household or a small community. The tested unit is composed of a Filtration phase, followed by Adsorption on Granular Activated Carbon (GAC) and UV Disinfection, in an innovative design (FAD – Filtration Adsorption Disinfection).

2. Materials and methods

2.1. FAD treatment unit

The FAD system has been reported in Fig. 1. All tests have been carried out using a full scale FAD treatment unit at fixed flow rate (30 L/h) on harvested rainwater for a total treatment time of 25 h.

The unit is composed of two separate elements, and it can work both with and without pumping. The pre-filtration unit is provided with a membrane, characterized by a porosity of 75 μm. The FAD unit combines adsorption on GAC, microfiltration at 0.5 μm and UV disinfection. The microfiltration step is located immediately after GAC treatment and there the feed is exposed to UV light irradiation (Fig. 1), therefore this zone is hereafter referred as hybrid FAD zone. UV light is produced by a 15 W low pressure lamp made of hard quartz glass.

The rain has been harvested from the rooftop of a small building located in the experimental wastewater treatment station at the University of Salerno (Italy) in a conventional water tank of 2500 L, during the period ranging from December 2008 to May 2009. The water was then treated on site with the FAD unit. The collected rainwater was stored in the tank for no more than 19 consecutive days.

Tests have been carried out with and without UV light. In order to compare efficiencies, another set of experiments has been completed, using only the GAC adsorption step. The latter experimental setup has been characterized by identical operating conditions of the FAD unit in terms of GAC volume and available surface for adsorption; it has been housed into the twin reactor, in which both the membrane and the UV lamp were removed.

2.2. Analytical methods

Analytical measurements were made at the Environmental Engineering Laboratory of the University of Salerno, Fisciano (SA), Italy. The USEPA Standard Methods have been successfully used for microbiological analyses. Acetate cellulose filters (0.45 μm pore size, Millipore, USA) were employed for sample filtration while m-endo medium (Oxoid, Italy) and *Tryptone Bile X*-Glucuronide (TBX) medium (Oxoid, Italy) were used respectively for Total coliform and *Escherichia coli* retention.

The results were expressed in terms of Colony Forming Units per 100 mL (CFU/100 mL). Absorbance measurements were performed using a λ12 UV–Vis spectrophotometer (Perkin Elmer, USA). Turbidity was detected using a turbidimeter (Model 2100 N, Hach Lange AG, Germany). Total Organic Carbon (TOC) was determined using a Shimadzu TOC-5000A analyzer. Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) were measured following the AWWA–APHA–WEF Standard Methods (AWWA–APHA–WEF, 1998). The measurement of pH, conductivity and redox potential were carried out using a multiparametric probe (Hanna Instruments, USA).

3. Results and discussion

3.1. Rainwater characterization

During the harvesting period, rainwater quality has been constantly monitored, and results showed a fair stability in terms of chemical-physical parameters, as reported in Table 1 and accordingly plotted in Fig. 3. High turbidity and a consistent concentration of organic matter have been found; this is in accord with other previously published studies (Gould and Nissen-Petersen, 1999; Zhu et al., 2004). Finally, pH ranged from 5.5 to 7.1, with an average value of 6.3.