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Effect of environmental and operating conditions on a full-scale trickling filter for well water treatment

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ABSTRACT

The effect of temperature, hydraulics and pollutant loading on a full-scale trickling filter performance for simultaneous ammonium, iron, and manganese removal was studied. Pollutant concentrations fluctuate sharply in raw well water, exceeding many times the maximum permitted limits. Measurements taken during the one-year continuous operation of the filter, as well as the 24 h experiments performed in various seasons, have shown a dependence of the pollutant removal efficiencies on temperature (8–28°C) and hydraulic loading (5–12 m^3/h) shocks. However, in all environmental and operating conditions, high removal efficiencies were achieved for ammonium, iron and manganese maintaining final concentrations at the filter outlet to below EC parametric values.

Keywords: Biological filter; Water treatment; Ammonium; Iron; Manganese; Hydrogen sulphide; Environmental and operating conditions

1. Introduction

Groundwater generally contains one or more contaminants such as hydrogen sulphide, ammonium, iron and manganese. For drinking water supply purposes, these contaminants need to be reduced to acceptable levels as they may cause health and aesthetical problems.

Hydrogen sulphide gas occurs naturally in some groundwaters. It is not a health risk at low concentrations but produces an offensive "rotten egg" or "sulphur water" odour and taste in the water [1,2].

Ammonia, in the form of ammonium, is commonly used in fertilizers and often exceeds the upper permitted limit of 0.5 mg NH_3–N/l [3]. Ammonia in drinking water is a potential cause of pipe corrosion and can complicate chlorination processes due to the creation of chloramines [4].

Removal of iron and manganese compounds is particularly important for septic reasons. They cause unpleasant taste of water and in aerobic conditions they form dark brown (manganese) or brown-red (iron) sediments [5]. In addition manganese has been found to affect the central nervous system [6]. The upper permitted limit (UPL) for iron and manganese in water is 0.2 and 0.05 mg/l respectively, according to the EC Directive [3].

The above pollutants may be removed chemically or biologically from a water supply. Physicochemical treatment methods include chemical oxidations, ion exchange, reverse osmosis or catalytic filtration. These methods are costly and in most cases satisfactory removal rates cannot be achieved [7].

Simultaneous biological removal of ammonium, iron and manganese is a difficult task since different redox potential conditions are necessary to activate biological oxidation of the three pollutants [8]. Various studies have

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focused on individual ammonium [9–12], iron [13–16] and manganese [17–20] oxidation, or combined iron and manganese biological removal [21–26] from polluted groundwater and surface water. However, only a few research groups have studied the simultaneous biological removal of ammonium, iron and manganese [27–32] using pressurized or series of filters.

Gouzinis et al. [5] and Tekerlekopoulou et al. [33,34], used pilot-scale trickling filters for the simultaneous removal of ammonium, iron and manganese. They concluded that simultaneous removal of the three pollutants in a single stage filter is feasible under low feed concentrations and filtration rates, while natural aeration provided the necessary oxygen concentration for bacterial growth and pollutant oxidation.

Various parameters such as temperature, hydraulic loading and size of the support media have been found to affect the process of biological removal in filters. Tang et al. referred that a high decrease in temperature can lead to the decrease of microbial enzyme activities [35]. Therefore oxidation and decomposition rates of the pollutants by microorganisms can be affected. Berbenni et al. concluded that manganese oxidation is inhibited at temperatures lower than 14°C and different options may be proposed for operations during colder seasons [36]. Tang et al. also reported that when the hydraulic loading increased, bioactivities are enhanced by the stronger washing of filter media [35]. However, with further increases of hydraulic loading, the volumetric loading of the reactor will be increased, and the hydraulic retention time will be reduced to a large extent thus affecting the biological treatment process. Different filtration rates were also used by Štembal et al. [31]. They proved experimentally that filtration rates as high as 22–24 m/h, may be efficiently applied for the removal of iron, manganese and ammonia in a single biofiltration step. Finally, a decrease of support media size improves the reactor's substrate removal efficiency but increases its backwashing requirements [33] and may affect aeration of the filter [37].

This paper is the continuation of a previous study [37] which presented the removal efficiency of ammonium, iron and manganese from well water using a full-scale trickling filter. The aim of this study was to examine the effect of temperature, hydraulics and pollutant loading on full-scale filter performance, using silicic gravel as support media. The application took place in the small village of New Vouprasio with about 200 inhabitants, in Western Greece.

2. Materials and methods

2.1. Groundwater wells and water characteristics

Two wells (A and B) were in operation providing maximum 20 m^3/h of water unsuitable for human consumption. Well A has increased concentrations of ammonium, well B increased concentrations of manganese, while both wells also have increased concentrations of iron and hydrogen sulphide. The characteristics of the raw well water, as well as the operation of the two wells were described in detail in a previous paper [37].

2.2. Full-scale trickling filter

The height of the filter is 3.5 m and only 1.5 m is filled with support media. Filter diameter is 2 m, thus resulting in a hydraulic surface loading of 191 m^3/m^2 d and a filtration rate of about 8 m/h. The support media is silicic gravel of mean diameter 5 mm and specific surface area of 11.74 cm^2/cm^3. The temperature difference between the incoming water (20–21°C) and the surrounding air was the driving force for air ventilation through the filter body. The dissolved oxygen concentration of the treated water was always above 7 mg/l at the bottom of the filter [37].

Initially, the raw water from the two wells was homogenized in a basin (homogenization tank). Water cascade into the homogenization basin increased dissolved oxygen concentration from about zero to about 5 mg/l. Hydrogen sulphide emissions were intense within the basin as the walls became light yellow due to elemental sulphur formation [38]. The water was then pumped to the top of the filter at a flow rate of 25 m^3/h and distributed through a stationary distributor. The redox potential varied from about 160 mV at the inlet of the filter to about 400 mV at the filter outlet, while pH ranged from 6.5 to 8.

The treated water then entered a chlorination basin where sodium hypochlorite was added. Filter backwash was necessary every two weeks during summer and every three weeks during winter according to the procedure described in Tekerlekopoulou et al. [37]. Inoculation procedure of the trickling was also described in detail in the same work.

2.3. Analytical methods

Hydrogen sulphide, ammonia, iron and manganese concentration measurements were taken according to the Standard Methods for the Examination of Water and Wastewater [39]. Hydrogen sulphide was determined by the iodometric method. Ammonia nitrogen concentration was determined by the phenate method. According to this method an intrinsic blue reagent indophenol is produced, which absorbs at 630 nm. Iron and manganese measurements were performed using an atomic absorption spectrophotometer (model GBC 932plus). pH and dissolved oxygen were measured using a Hanna HI9026 pH meter, and a Hanna HI9143 dissolved oxygen meter, respectively.

3. Results and discussion

Filter start-up took place in June 2008, and since July 2009 it has been under continuous operation. Sampling was performed once a week from the inlet and outlet, during the continuous operation of the filter.

Hydrogen sulphide concentrations of the raw water ranged from 1 to 1.3 mg/l. However, the water cascade in the homogenization tank and water aeration through the filter, led to complete hydrogen sulphide elimination at the filter outlet. Thus, hydrogen sulphide evolution will not be further discussed.

Fig. 1 presents the mean hourly volumetric flow rate as well as the mean temperature for the one year continuous operation of the filter. It is clear that water consumption substantially increased (twofold) during the warmer periods of the year, due to gardening and irrigation. All sudden decreases of water consumption observed were due to rainfall. Since the filter's capacity (feed pump) was 25 m^3/h, which was much higher than the actual water consumption, filter operation was intermittent. Thus, the filter was operated for time intervals of 5 min followed by a rest period of 7 min under normal operation, or longer during low consumption periods. Seasonal temperature variation was also observed during the one year operation of the filter (minimum temperature of 8°C in December 2008 and maximum temperature of 28°C in June 2009).

The one-year operation provided the opportunity to study the filter's response to pollutants and hydraulic loading shocks under real environmental conditions. The particular water quality of the two wells and their intermittent operation led to an intense dynamic environment for bacterial growth and pollutant oxidation.

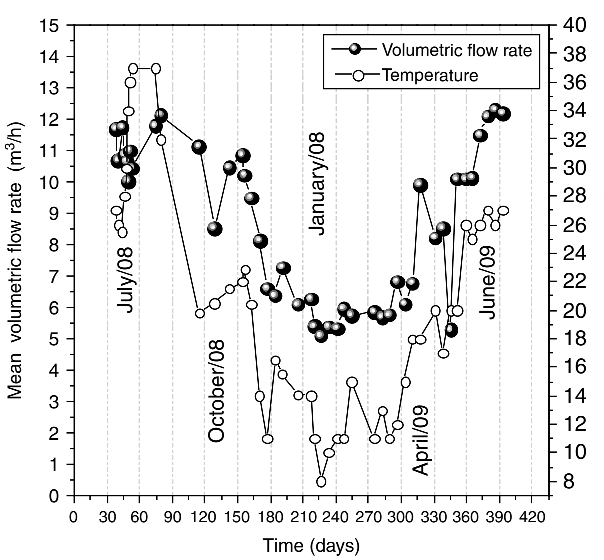

Fig. 1. Mean volumetric flow rate and temperature during one-year filter operation.

Fig. 2a–c presents the effect of temperature on filter removal efficiency for ammonium, iron and manganese, respectively. Ammonium removal seems to be slightly affected by temperature increase, while iron and manganese removal efficiencies showed a higher dependence on temperature changes. Being a biological filter, higher removal rates are attained during the warmer periods of the year. However, even during the winter months, all pollutant concentrations recorded at the filter outlet were well below the upper permitted limits. This was attributed to the high raw water temperature, which remained constant at 20°C throughout the year. The high thermal capacity of water was able to keep the filter and its biological community warm during winter.

Fig. 3a–c shows the effect of volumetric flow rate on filter removal efficiency of ammonium, iron and manganese, respectively. Fig. 3a and c demonstrate that ammonium and manganese are affected negatively by volumetric flow rate. The figures show that lower removal efficiencies are attained with high volumetric flow rates. Ammonium and manganese removal are net biological processes and an increase of the flow rate reduces the hydraulic retention time and thus reduces biological activity. On the contrary, iron removal efficiencies were affected positively by the volumetric flow rate increase. Iron removal is based both on physicochemical and biological oxidation. An increase of the flow rate increases oxygen transfer rate to the filter and consequently increases the physicochemical oxidation rate. It seems that this increase is higher than a possible decrease of biological oxidation rate and the final result is an increase of the total iron oxidation rate.

For all the pollutant concentrations and flow rates tested, the filter appeared to absorb hydraulic and pollutant loading fluctuations and always produced water of high quality. To further study the effect of temperature, hydraulics and pollutant loading on filter performance, 24 h measurements were performed during various seasons.

3.1. One day results

Three 24 h experiments were performed. The first was performed in November 2008, a period where high temperature differences were observed between day and night. Village water consumption was high since the rainfall period had not yet started and thus both wells were in intermittent operation, depending on water demand. The second experiment was performed in February 2009, when water consumption was minimal and low air temperatures prevailed, while the operation of the wells was controlled. The third experiment was performed in May 2009 in which temperatures and water consumption were high. Only well A was under continuous operation, thus the third experiment was characterized by very stable conditions.

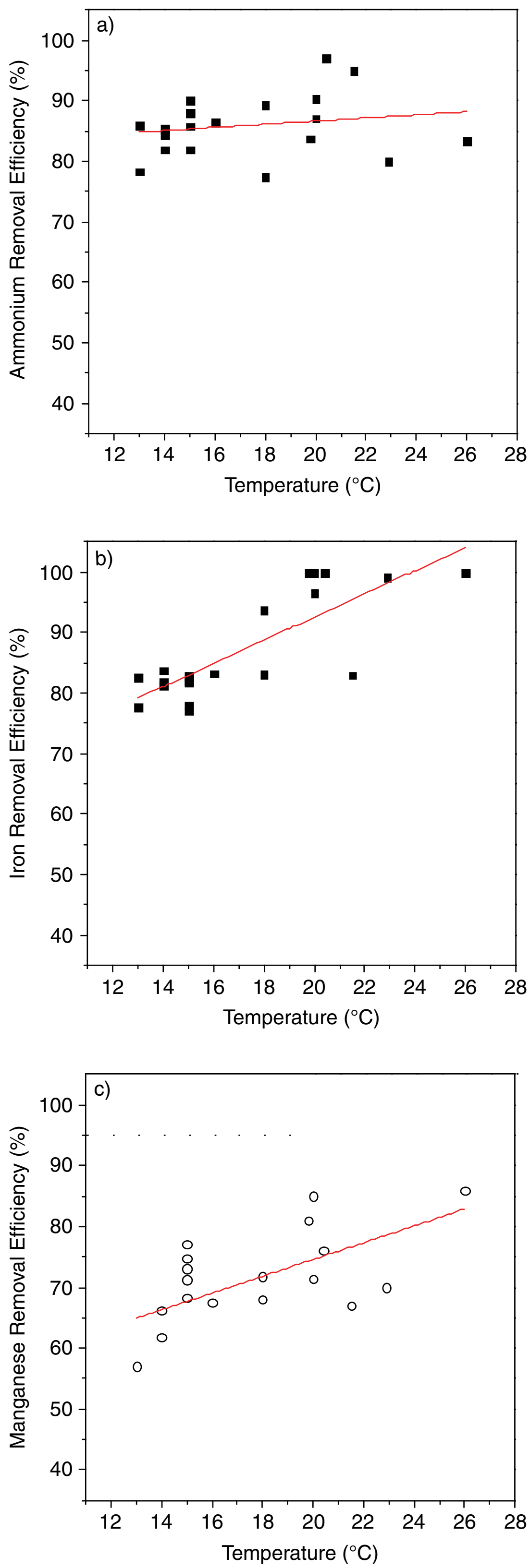

Fig. 2. Effect of temperature on filter efficiency for (a) ammonium (b) iron and (c) manganese removal during the one-year continuous operation of the filter.

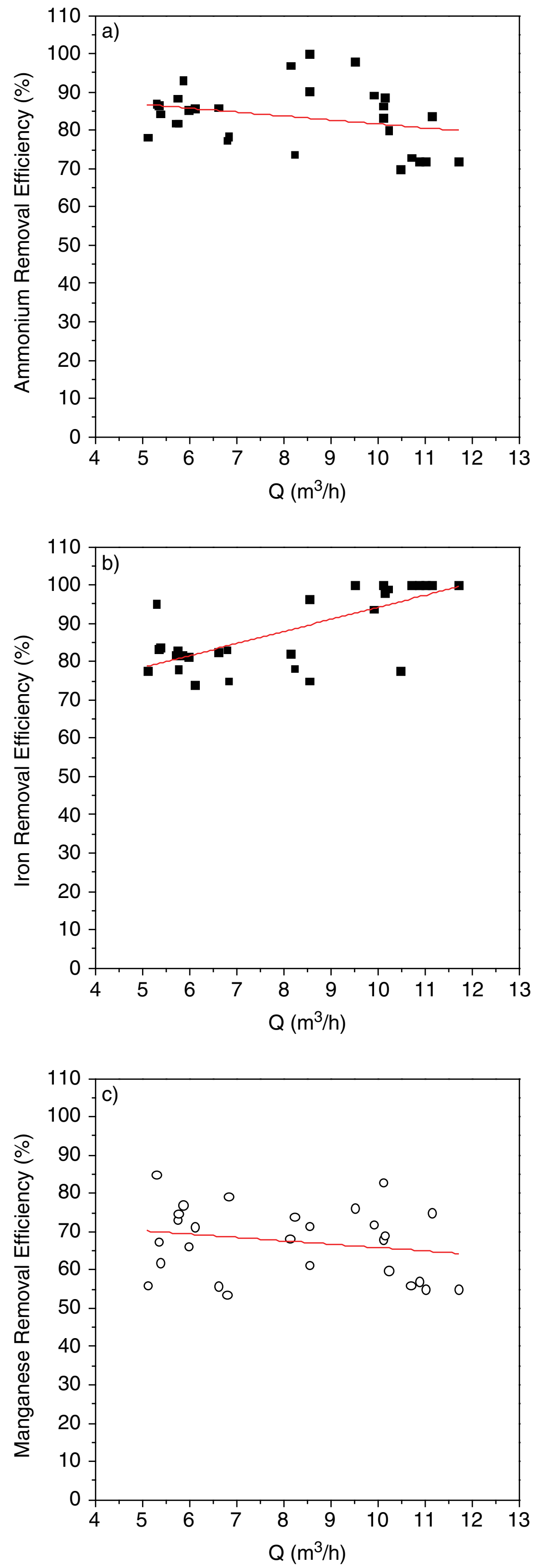

Fig. 3. Effect of volumetric flow rate on filter efficiency for (a) ammonium (b) iron and (c) manganese removal during the one-year continuous operation of the filter.

The first 24 h experiment took place 8–9 November 2008. The maximum temperature was 21°C (at midday), while the minimum temperature dropped to 8°C (at night). The mean hourly volumetric flow rate ranged between 5.5 and 12.5 m^3/h. Both wells A and B were under intermittent operation with inlet ammonium, iron and manganese concentrations ranging between 0.4–0.55 mg/l (Fig. 4a), 150–220 μg/l (Fig. 4b) and 45–55 μg/l (Fig. 4b), respectively. Figs. 3a and b show that pollutant concentrations at the filter outlet were well below the upper permitted limits, while mean removal rates were 96 ± 4.6%, 99.8 ± 0.4% and 69.5 ± 7.3%, for ammonium nitrogen, iron and manganese, respectively. It is again evident that manganese is the rate limiting pollutant. However, all pollutant concentrations recorded at the filter outlet were well below the upper permitted limits.

The second daily experiment took place from 21 to 22 February 2009. The maximum temperature reached 11°C, the minimum dropped to –0.5°C, while volumetric flow rate ranged between 0 and 13.3 m^3/h. Well A alone and wells A and B together were operated alternatively. Inlet ammonium, iron and manganese concentrations ranged between 0.18–0.8 mg/l (Fig. 5a), 160–390 μg/l (Fig. 5b) and 45–184 μg/l (Fig. 5b), respectively. Fig. 4a and b shows that even with inlet concentration fluctuations (due to well operation), the filter was capable of successfully removing all three pollutants while

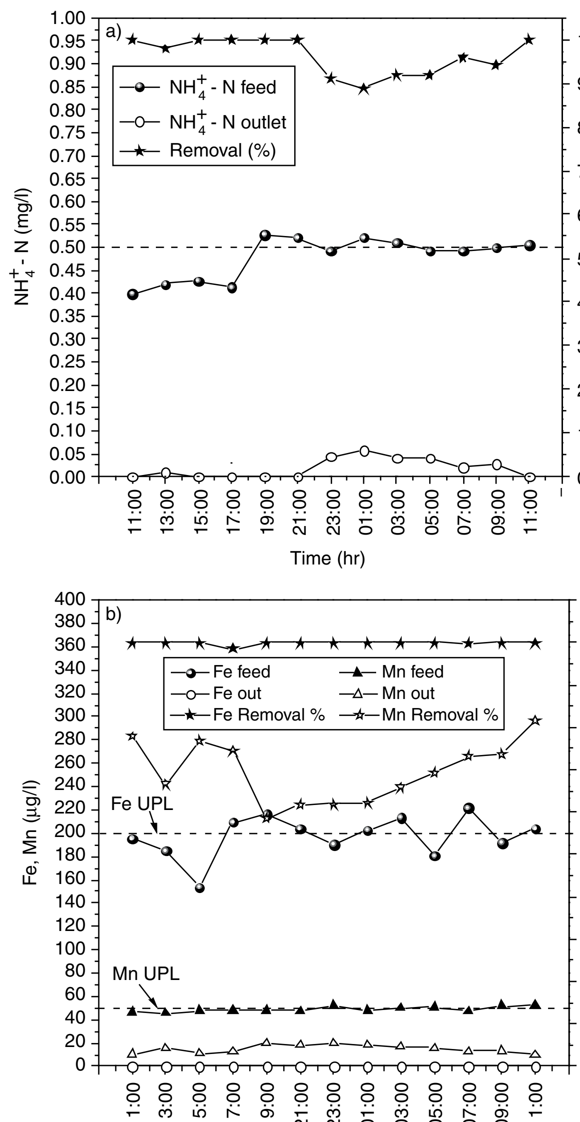

Fig. 4. Inlet and outlet concentrations of (a) ammonium, (b) iron and manganese during 24 h operation (8–9/11/2008).

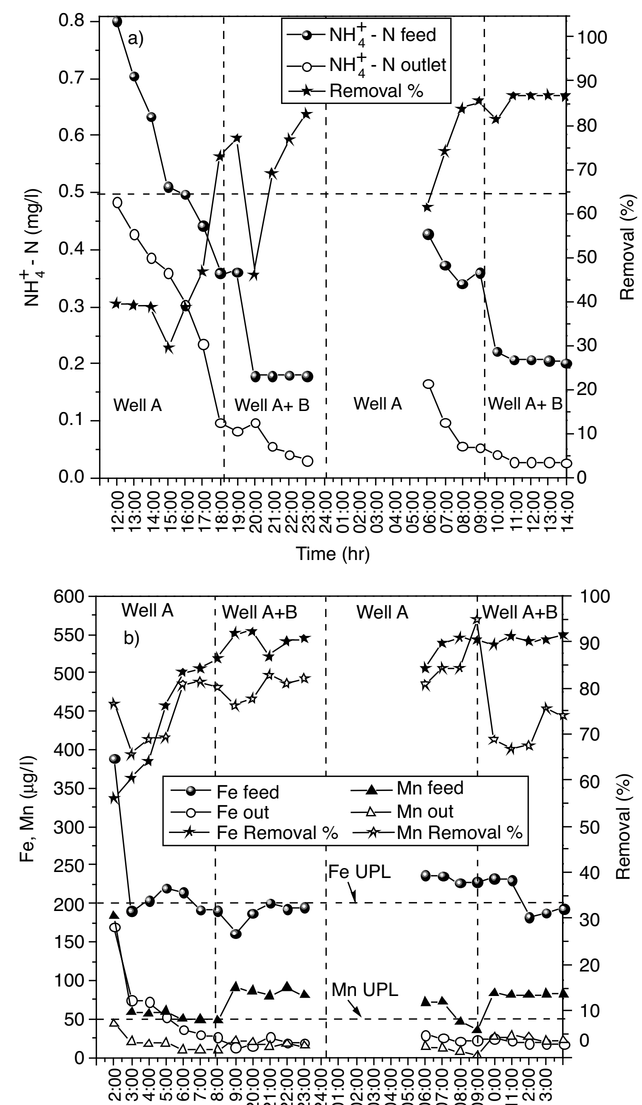

Fig. 5. Inlet and outlet concentrations of (a) ammonium, (b) iron and manganese during 24 h operation (21–22/2/2008).

maintaining their concentrations at its outlet under the maximum permitted limits.

The very low night temperatures seems to have slightly effect on the filter even when water flow had stopped for a few hours (from 23:00 to 05:00) and microorganisms were exposed to very cold conditions.

The third 24 h experiment took place from 16 to 17 May 2009. High air temperatures of between 18°C and 27°C were observed, while volumetric flow rate ranged between 6 and 12.1 m^3/h. Only well A was in operation with almost steady inlet ammonium, iron and manganese concentrations, between 0.42–0.54 mg/l (Fig. 6a), 179–191 µg/l (Fig. 6b) and 18–22 µg/l (Fig. 6b), respectively. Fig. 6a and b shows that ammonium nitrogen, iron and manganese concentrations at the outlet of the filter were almost completely eliminated and significant removal efficiencies were achieved, 98 ± 0.35, 100% and 100%, respectively.

From Fig. 6 it is evident that stable operating conditions result in very high filter efficiency. The absence of hydraulic loading and pollutant peaks provided a very stable environment for bacterial growth and pollutant oxidation was almost complete.

Temperature also seems to play a role on filter efficiency. The higher air temperatures observed during May probably led to the complete elimination of pollutants and improved removal efficiency. However, even during winter and at very low air temperatures the filter showed very good performance. As mentioned above this was attributed to the high water temperature, which remained constant at 20°C throughout the year.

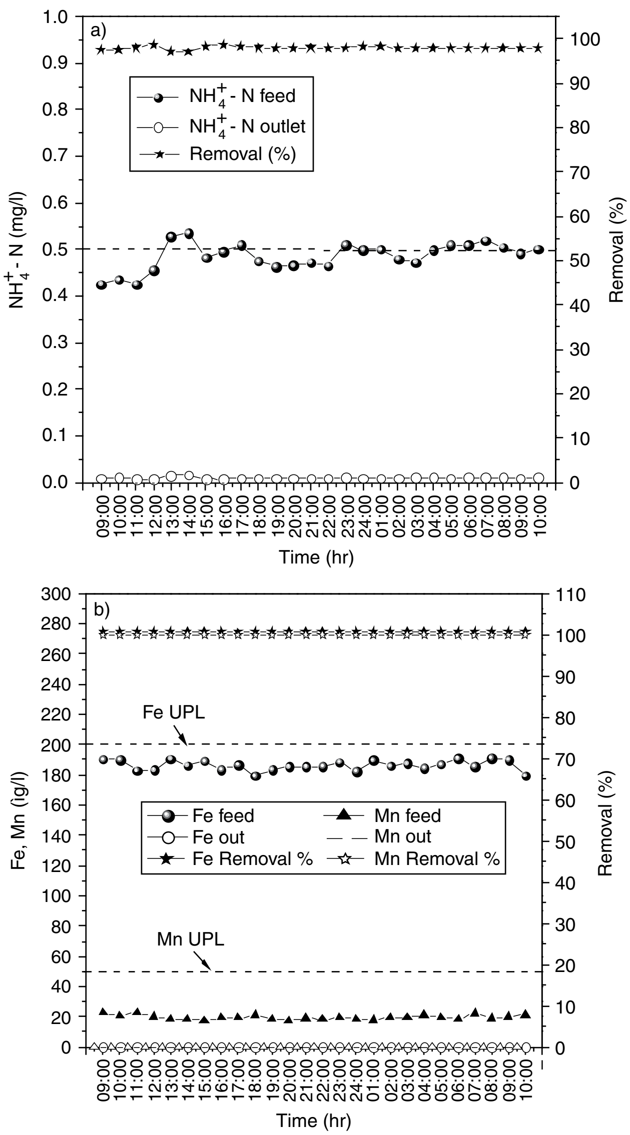

Fig. 6. Inlet and outlet concentrations of (a) ammonium, (b) iron and manganese during 24 h operation (16–17/5/2009).

4. Conclusions

The effect of environmental and operating conditions on a full-scale trickling filter for simultaneous ammonium, iron and manganese removal from well water was studied.

Measurements during the one-year operation of the filter showed that: (a) temperature increase positively affects iron and manganese removal rates, while ammonia seems to be rather unaffected, and (b) hydraulic load increase negatively affects ammonium and manganese removal while enhances iron oxidation.

The daily experiments revealed that pollutant concentration or hydraulic loading shocks result in a dynamic environment which negatively affects filter performance. However, in all operating conditions the filter was capable of successfully removing all three pollutants, maintaining their concentrations at its outlet below the maximum permitted limits.

For decades the inhabitants of New Vouprasio, could not use the polluted network water. The operation of the trickling filter drastically changed their lives. Today, they do not have to buy bottled water and more importantly they do not have to worry about their home potable water supply.

Acknowledgments

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