Long-term trend evolution of the temperature of the groundwater upstream and downstream a stormwater infiltration basin

Tendance d'évolution sur le long terme de la température de nappe en amont et en aval d'un bassin d'infiltration d'eaux pluviales

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RÉSUMÉ

Les eaux souterraines constituent un maillon important du cycle urbain de l'eau. Tout changement en quantité ou qualité des eaux apportées peut impacter ses caractéristiques et en particulier sa température. Dans cet article, l'évolution à long terme de la température de nappe a été investiguée en amont et en aval d'un rejet d'un bassin d'infiltration d'eaux pluviales centralisé (BI) de manière à en évaluer son impact. Ainsi la température de nappe sur un bassin versant urbain a-t-elle été suivie sur 11 ans (2003-2013). La température d'air, la pluviométrie, la température en amont et aval et celle de l'eau issue du bassin versant alimentant le BI ont été analysées sur une base annuelle et mensuelle. La méthodologie développée pour tester une tendance d'évolution est basée sur le test de Mann-Kendall adapté pour prendre en compte l'autocorrélation et la saisonnalité des séries temporelles. Alors que la température de l'air, de l'eau issu du bassin versant et la pluviométrie ne montre pas de tendance d'évolution, la température de nappe en amont a subi une hausse de +0.2 to + 0.3°C sur la période ; hausse imputable à des facteurs anthropiques tels que l'utilisation de pompes à chaleur géothermiques. En aval, l'augmentation de température est encore plus marquée (de 1.5 à 2 fois plus). L'infiltration intentionnelle de BIs centralisés peut donc impacter sur le long terme la température de nappe. Cela plaide en la faveur de dispositifs de gestion des eaux pluviales à la source.

ABSTRACT

Groundwater is an important component in the water cycle. Changes in quantity and quality of water that feeds aquifers can impact groundwater characteristics in particular the temperature. In this article, the long-term evolution of the groundwater temperature is investigated upstream and downstream of an intentional centralized infiltration basin (IB) in order to evaluate its potential long-term thermal impact. Groundwater temperature in an urban catchment was then monitored over a 11 year period (2003-2013). Air temperature, rainfall, upstream - downstream water temperature and that at the outlet of the catchment feeding the IB were analyzed on annual and monthly basis.The methodology developed to test the trend is based on the Mann-Kendall test adapted to take into account auto-correlation and seasonality in the time series. Air temperature, rainfall and water temperature from the catchment did not show any evolution whereas an increasing trend in groundwater temperature upstream was found (+0.2 to + 0.3°C on the period) for which anthropic factors such as geothermal heating systems are suspected. Downstream the IB, warming is larger (from 1.5 times to twice higher). Intentional stormwater infiltration via a centralized basin could be responsible for a long-term effect on the groundwater temperature. However this effect could be attenuated by reducing the size of catchment areas drained by the infiltration systems or by promoting source control drainage systems.

KEYWORDS

Trend, long-term evolution, infiltration, temperature

1 INTRODUCTION

Groundwater is an important component in the local water cycle and an important resource for drinking water. Changes in quantity and quality of the water supplying aquifers (e.g. rain amount, anthropogenic factors) lead to shifts in characteristics of groundwater (e.g. solute contents, temperature) that can affect hydrological, chemical and biological equilibria.

If groundwater temperature below cities was found or estimated in the literature higher than in surrounding areas (e.g. about 0.02°C /year according to (Gunawardhana et al, 2011) or 3°C warmer than an undeveloped agricultural area at the same geographic location for (Craig and Heinz, 2009)), the effect of long-term infiltration as stormwater drainage option on groundwater warming is still seldom studied. Some studies addressed the question but on the base of some stormwater events (e.g. Foulquier et al, 2009).

Groundwater temperature in an urban catchment (the Chassieu catchment) has been monitored over the last decade in the context of long term survey developed by the OTHU (Field Observatory for Urban water Management- www.othu.org). In this article, the long-term behavior of the groundwater temperature is investigated upstream and downstream an intentional centralized infiltration basin.

2 METHODOLOGY AND EXPERIMENTAL SITE

2.1 Experimental site and series analyzed

The Chassieu catchment covers an industrial area of 185 ha. Its imperviousness coefficient is 0.70 and runoff coefficient around 0.35. The catchment is drained by a separate sewer system which also receives dry weather flows from cooling of industrial processes (that can be assumed to be clean). Stormwater is conducted to a retention basin followed by an infiltration one. Stormwater is then infiltrated into the groundwater with an unsaturated zone of 13 m. The volumes of the retention and infiltration basins are respectively 32 000 m^3 and 61 000 m^3. The ratio of infiltration area to effective surface of the catchment is 1.2%. At the outlet of the catchment and the retention basin, flow rate, pH, conductivity, temperature are continuously measured with a two minute time step. The rainfall intensity is also acquired at a one minute time step. Air temperature can be followed using the Meteo-France station data in the vicinity of the experimental site.

The infiltration basin is located over quaternary fluvial and glacial deposits mainly composed of coarse material (30 % of pebbles (diameter d > 20 mm), 45 % of gravels (2 mm < d < 20 mm), 20 % of coarse sand (0.2 mm < d < 2 mm) and, 5 % of fine sand (0.20 mm > d > 0.08 mm). The aquifer has an approximate local thickness of 30-35 m, a permeability of about $7\text{-}9{\cdot}10^{-3}$ m/s, a transmissivity of 0.0075-0.075 m²/s and a groundwater natural renewal of 110000 m^3d^{-1} on average (Burgéap,1995).

For this study two sets of piezometers were considered: one upstream and downstream (see Fig 1). Each set is composed of resp. 6 and 5 piezometers sunk at different depths in the saturated zone from 0 to -5 m below the water table. Water depth and physico-chemical parameters in particular the temperature are recorded in the piezometers with one hour time step.

Figure 1. Experimental site with the location of the set of upstream and downstream piezometers

2.2 Methodology of trend detection

Among many methods available for trend detection in climatic and hydrological studies, one of the most popular test is the Mann-Kendall method (M.K.). It is a rank-based nonparametric method to test for randomness against trend. The null hypothesis of this test (H_0) states that the data is a sample of n independent and identically distributed random variables. In this work H_0 is not rejected (a trend detected) if the *P-value* < 5%. Many authors have demonstrated that these two methods are no more effective for auto-correlated data series (e.g. Yue et al. 2002). In order to overcome this deficiency, an adapted Mann-Kendall method was developed. If one-lag autocorrelation is not significant (with the significance level of 5%), the original M.K. test is applied. If autocorrelation is found, the method performs the Adapted M.K. (test after removing the auto-correlated component in a data series estimated by the regression:

$$x(t) = at + rx(t-1) + b + \varepsilon_t$$

x: data series, t time step, a and b regression parameters, r the one-lag autocorrelation coefficient and ε_t the white-noise residuals.

It should be noted that the above analysis does not take into account seasonality, which can also affects trend detection results. The seasonality is characterized by mean values of each month in a monthly time series. If a seasonal effect is present, it is firstly removed before applying the above trend detection strategy. When a trend is detected, the slope of the trend is estimated by using a non-parametric index proposed by Sen (1968):

$$\beta = Median\left[(X_j - X_i)/(j-i)\right]_{i<j}$$

2.3 Series analyzed

In this study, the temperature considered for groundwater is that of the upper layer. The temperature of other layers (being correlated with the upper layer temperature) was only used to fill the gaps in the series of the upper layer both for upstream and downstream. Fig 2 shows the annual and monthly series of the upstream and downstream temperatures.

To analyse the potential evolution of the temperature in groundwater, climatic variables (i.e., air temperature and rainfall was also studied with series measured on the site. The period studied is 2003-2013 (11 years).

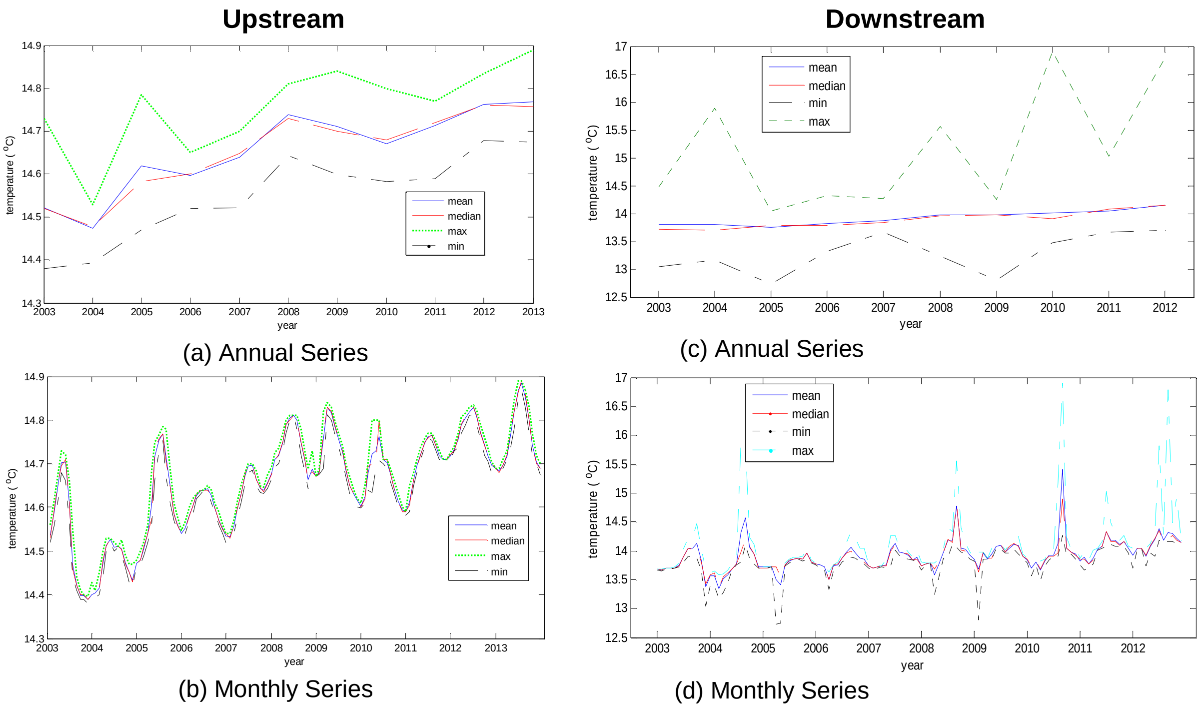

Figure 2. Annual and monthly groundwater temperature time series (a) and (b) upstream the infiltration basin, (c) and (d) downstream the infiltration basin

3 RESULTS AND DISCUSSION

The reader will find all the results in the report (Barraud et al, 2015).

On the period 2003-2013 (11 years) the climatic characteristics (mean, median, minimum and maximum air temperature and rainfall features (water depth, duration, median, mean intensity for different durations,…) tested on annual, monthly or event basis) and the water temperature from the catchment did not show any trend whereas an increasing trend in groundwater temperature both upstream and downstream was found.

The increase of groundwater temperature was confirmed by the method for all the variables studied on annual and monthly basis except for the maximum of temperature downstream and the temperature difference between the minimum and the maximum both upstream and downstream.

It is interesting to note that, if no effect was found on the differences of temperatures between the minimum and the maximum, these differences were much higher downstream (in average 0.2 °C upstream and 1.8°C downstream). This can be seen in Fig 2. It confirms results from Foulquier et al (2009). They showed an exacerbation of temperature all the more important that the ratio of infiltration area to effective runoff area of the catchment was low but this was demonstrated on event basis analysis and not on long periods.

Upstream (without influence of the infiltration system), an increase in temperature of +0.2 to + 0.3°C on the whole period depending on the variable was detected. If no rise in air temperature, stormwater regime or in incoming water temperature was found, the increase can be due to anthropic effects in particular the development of geothermal heat pumps in the region. The worming effect is in the same range as that of Gunawardhana et al. (2011) even if the results are of course site and climate dependent and related to the groundwater characteristics (depth, vadose zone, transmissivity …).

Downstream, the increase is also detected and is much larger (from 1.5 to twice higher in terms of Sen’s slope). The intentional stormwater infiltration via a centralized basin (here with a ratio of 1.2%) could be suspected to have a long-term effect on the temperature of the groundwater. However this effect could be attenuated by reducing the size of catchment areas drained by the infiltration systems and by promoting source control drainage systems.

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