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Drinking water from surface and ground water: production costs and influence of the climate change

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Abstract Drinking water production may be affected by climate changes (i.e. intense rainfall events and high temperature periods) which impact on the availability and quality of the water source, above all surface water bodies. Efforts are being made to adopt the best strategies in the drinking water treatment plant (DWTP) management under these adverse conditions, with the aims to guarantee potable water and optimizing water production costs.

This study refers to the large DWTP of Ferrara, Italy (2.5 10^7 m^3/year of water distributed in 2021) which treats surface water (Po River) for around 70 % and alluvial well water for the remaining 30 %.

It presents the results of an analysis of the annual drinking water production costs and the related items before and during COVID-19 pandemic. A focus is then done on the effects the climate change may cause on the water quality at the source, the resulting management needs, and the final production costs. It emerges that production costs are increased during the years due to the increased costs of energy, chemicals and activated carbon. Water withdrawal is the issue which most affects the final production costs due to the high energy consumption.

Keywords: climate change, drinking water treatment plant, groundwater, production costs, surface water

1. Introduction

A drinking water treatment plant (DWTP) must guarantee the production of a water flow able to satisfy the demand of the served users and the respect of the national quality standards for the drinking use. DWTPs may sometimes treat both surface and groundwater and the contributions of the different sources may change depending on their quality and availability. In the case of withdrawal of surface water, DWTPs must face problems related to unavoidable variations of chemical and physical characteristics of the surface water due to variable hydroclimatic conditions in the area. The main factors responsible of these changes are temperature and rain. An increment in temperature favors the evaporation, may reduce flow rate, enhance biodegradation of the organic matter, and promote algae growth. Intense rain events result in land runoff and consequent transport of particles into the surface water and resuspension of settled particles causing an increment of the turbidity and of the concentration of (micro)pollutants dissolved or attached to the conveyed or resuspended particles (Delpla et al., 2009; Li et al., 2014).

The Mediterranean basin, located in the subtropical region, is identified as a potential climate change "hot spot" as it shows the strongest response to global-scale warming (Diffenbaugh & Giorgi, 2012). In the 20th century, there was a relevant increment in temperature and a decrement in precipitation in the basin, causing an intensification of drought events (Baronetti et al., 2020). These climate conditions influence the hydrological behavior of the Po River (Marchina et al., 2017) which is the feeding of the DWTP in Ferrara, directly (70 %) and by alluvial wells (30 %).

The current study focuses on the costs of the annual production of drinking water at Ferrara DWTP in the three-year term (2019, 2020, and 2021), before and during the COVID-19 pandemic. The impact of climate changes on Po River quality and the resulting effects on drinking water production costs is also evaluated with reference to rain and temperature variations.

2. Materials and methods

2.1. Study area

Po River is located in the northern part of Italy and with a length of 652 km, is the longest Italian river. Its drainage basin extends over an area of around 71,000 km^2 mainly in the plane, see Figure 1A.

The DWTP of Ferrara, managed by Hera SPA, is located in Pontelagoscuro, 50 km far from the river estuary (Figure 1A). With an average flow rate of 1000 L/s (maximum 1400 L/s) it provides water to 10 municipalities (around 240.000 inhabitants) and industrial activities with a distribution network of around 2000 km. The water supply consists of withdrawal from Po River as well alluvial wells directly fed by Po River. On a yearly basis, the water fed to the plant is from surface water for around 70% and from wells for the remaining 30%.

The DWTP is equipped with specific treatments according to the two different sources. The treatment train is reported in Figure 1B where it is clearly shown the separate as well as the common steps to which the two types of water are subjected to.

2.2 *Selection of reference period*

The analysis of the production costs at the DWTP of Ferrara refers to three years (2019, 2020 and 2021) covering an interval before and during COVID-19 pandemic in order to compare the effects of different consumption patterns characterizing that period.

2.3 *Data processing*

The annual costs of drinking water production are estimated taking into account the energy consumption of the specific steps and the additional costs due to their demands (see Table 1).

Table 1. Description of the additional cost for each step at the DWTP of Ferrara.

Step	Additional costs
Sedimentation	consumption of aluminium polychloride (PAC-HB), if Po River turbidity > 60 NTU
Clariflocculation	consumption of aluminium polychloride (PAC-HB)
Pre-oxidation	consumption of potassium permanganate (before clariflocculation that is coagulation/flocculation/precipitation)
Alluvial wells water withdrawal	regeneration/replacement of alluvial wells
Biological activated carbon (BAC) filtration	periodical replacement of the granular medium (every 3 years)
Chlorination	production of chlorine dioxide by hydrochloric acid and sodium chlorite
Sludge	consumption of polyamine and polyelectrolyte; sludge disposal

Oxidation and sedimentation for alluvial well water treatment do not consume energy so they do not involve drinking water production costs.

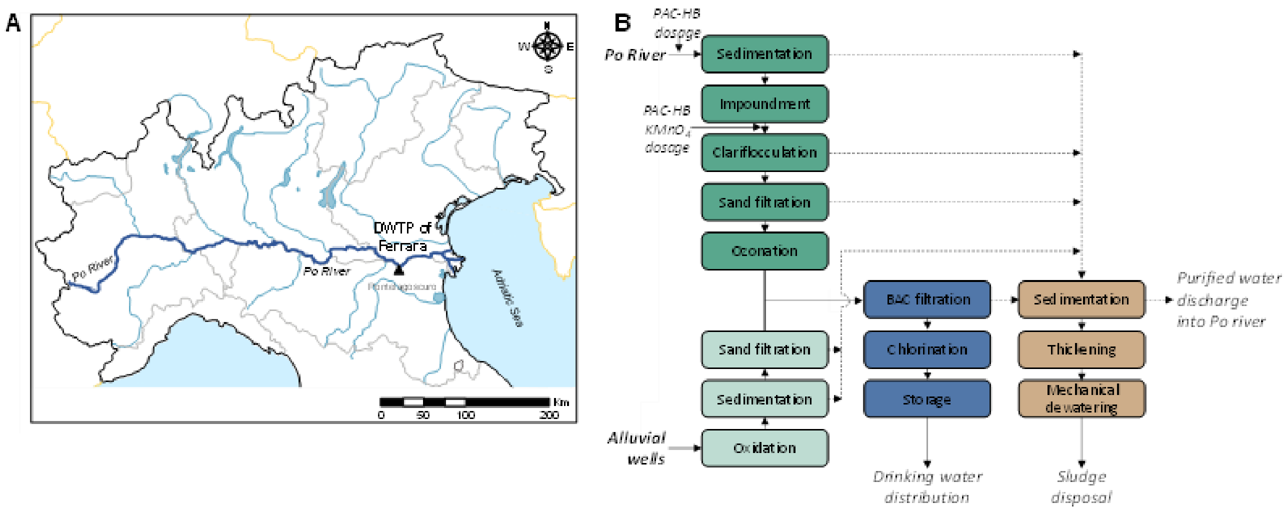

Figure 1. A) Location of the DWTP of Ferrara (black triangle). The blue line represents the Po River, the light blue lines are the main rivers and lakes in the map, the gray lines correspond to the borders of the Italian Regions and the black line is the Italian boundary. B) The treatment trains at the DWTP of Ferrara for the two water sources (PAC-HB: aluminium polychloride, BAC: biological activated carbon).

3. Results and discussion

The amounts of water withdrawn from the Po River and the alluvial wells are key elements for the estimation of the annual costs for drinking water production. During the three years under study, the total amount decreased, from 2.75 x 10^7 m^3 in 2019 to 2.52 x 10^7 m^3 in 2021. This was from surface water for 68-69% and from alluvial wells for 31-32%. The costs to produce drinking water at the plant of Ferrara referring to 2019, 2020, and 2021 are shown in Figure 2A for surface water and Figure 2B for alluvial wells water. It emerges that the increment over the period is mainly due to the rising of the energy cost, from 0.145 €/kWh in 2019 to 0.182 €/kWh in 2021. In addition, there was also an increment in the cost of some chemicals added to the water during the different treatments (e.g., sodium chlorite increased from 0.535 €/kg in 2019 to 0.680 €/kg in 2021). Looking at the overall production costs from surface water and alluvial well water, the most influencing issue is water withdrawal because of (*i*) the high energy consumption (in 2021 the costs due to energy needs were 1.60 cent €/m^3 for surface water and 3.46 cent

€/m^3 for alluvial well water) and (*ii*) the regeneration/replacement of alluvial wells (in 2021 it amounted to 0.55 cent €/m^3). Only in 2019 it was necessary to replace the exhausted granular activated carbon (GAC), resulting in an increment of the costs for the BAC filtration of surface water (2.28 cent €/m^3) and alluvial well water (1.06 cent €/m^3), as compared to those related to 2020 (0.50 cent €/m^3 for surface water and 0.237 cent €/m^3 for alluvial wells water) and to 2021 (0.59 cent €/m^3 for surface water and 0.27 cent €/m^3 for alluvial wells water) in which BAC filtration costs took into account only the energy consumption. To sum up, the annual costs for drinking water production are due for 55-60% to surface water treatments and for 40-45% to alluvial well water ones.

The variability of Po River water quality during climate changes impacts the efficacy of some treatments present in the DWTP of Ferrara. To mitigate them, adjustment of operations of the different processes are required resulting in a variation of the costs of drinking water production.

Rainfall events increase the dissolved organic matter (DOM) and in particular turbidity in the Po River (Marchina et al., 2017). Consequently, the production costs of drinking water in the DWTP of Ferrara may increase due to higher coagulant dosages, chemical addition to control pH, decrement in the filter run time, more frequent GAC replacement, higher disinfectant demand and higher sludge production. In pre-oxidation, the reaction of potassium permanganate with organic material is still non completely understood and thus the dose of the chemicals may need to be optimized to satisfy DOM demand, as remarked in Anderson et al. (2023). If not effectively removed through coagulation, high DOM may accelerate the saturation of GAC filters as organic material occupies binding sites in the activated carbon pores, as remarked by Anderson et al. (2023) and Li et al. (2014). In the chlorination step, DOM not retained in previous treatment steps may react with the disinfectant, leading to disinfection byproducts. At the same time, a higher dosage is necessary to cope with the DOM demand and the need for adequate free chlorine residual levels in the distributed water, according to the legal standards (Anderson et al., 2023; Ritson et al., 2014).

Long periods without rainfall lead to drought conditions causing a reduction of Po River water supply. Patterns in precipitation may also affect DOM characteristics It was found that more hydrophilic DOM may be present during drought events, which are less removed by coagulation (Anderson et al., 2023; Ritson et al., 2014).

Temperature rising tends to enhance coagulation, flocculation, and sedimentation because it (*i*) promotes hydrolysis of coagulants, (*ii*) produces flocs which are bigger, less strong and less prone to re-form and (*iii*) decreases water viscosity (Fitzpatrick et al., 2004; Ritson et al., 2014). At the same time however, it promotes biodegradation of the organic matter and may cause an increment in the DOM content in the surface water (Po River) which deteriorates the quality of water source (Ritson et al., 2014).

An increment of the ambient temperature influences the gas partitioning, resulting in a lower dissolved oxygen concentration which may create conditions more prone to algal blooms. In addition, DOM from algal sources contains more nitrogen compounds and this may be related to negative impacts. In fact, it is more difficult to be removed and thus its presence may favor eutrophication of water bodies, causing a long-term risk. DOM is also linked to the formation of undesired disinfectant by-products (Ritson et al., 2014).

In the DWTP of Ferrara, the mix of two different water sources (surface and alluvial well water) is a way to mitigate the adverse effects of the climate change. Groundwater is more stable in terms of water quality than surface water (Novakova & Rucka, 2019) and thus in the case of really high turbidity of Po River water, the withdrawal from alluvial wells increases. Moreover, at the DWTP the addition of aluminium polychloride in the sedimentation step on the basis of the influent turbidity (Table 1) improves DOM removal and reduces the residual organic load to the following treatments. The presence of the impoundment (Figure 1B) of a large capacity (around 250 000 m^3) allows (*i*) to have a water reservoir for at least 3 days, to cope with emergency situations; (*ii*) to equalize water physical-chemical properties; (*iii*) to reduce turbidity; and (*iv*) to promote photo- and bio-degradation of organic compounds. The combination of pre-ozonation and BAC filtration improves the removal of the most recalcitrant compounds (among them pesticides) due to the action of ozone able to transform persistent compounds into smaller oxidized products more prone to be retained and degraded in the GAC filter, thus acting as a biological activated carbon.

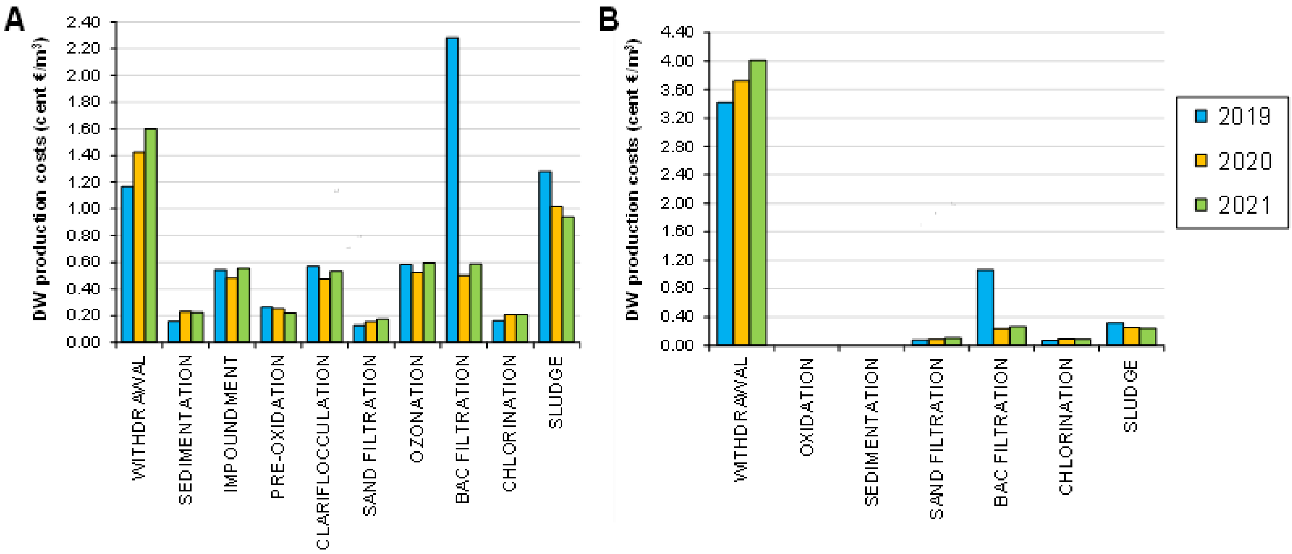

Figure 2. Drinking water (DW) production costs from surface water (A) and alluvial well water (B) in 2019, 2020, 2021.

4. Conclusion

This study analyses the annual costs for drinking water production at the DWTP of Ferrara before and during COVID-19 pandemic. Even if the total water withdrawn amount decreased from 2019 and 2021, the annual production costs increased, from 9.58 cent €/m^3 in 2019 (without including GAC replacement) to 10.35 €/m^3 in 2021, as a result of the considerable increment of energy and some chemical cost.

Climate change is expected to cause quality and quantity variations in the Po River which may have an impact on some of the treatments at the DWTP of Ferrara and in the resulting annual costs of drinking water production. In order to mitigate the adverse effects of the main climate changes, an accurate management of the plants become necessary. The DWTP of Ferrara has already adopted good strategies: among them a major withdrawal from alluvial wells when the surface water turbidity is really high and the addition of aluminium polychloride in the sedimentation step to favor DOM removal. In addition, impoundment step and the combination of pre-ozonation and BAC filtration represent reliable treatments able to favor and complete the different removal mechanisms which characterize the different (micro)pollutants expected mainly in surface water.

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