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PAPER

Exploring the impacts of tourism and weather on water consumption at different spatiotemporal scales: evidence from a coastal area on the Adriatic Sea (northern Italy)

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Abstract

The growth of tourism in the last decades has left behind a significant footprint on water resources, which is particularly evident in the regions affected by water scarcity or consistent seasonal population fluctuations. However, only limited efforts were spent in evaluating the effects of tourism on water consumption with regard to specific non-residential users such as bathing facilities. The current work aimed at providing an insight into the effects of seaside tourism on water consumption in a case study coastal area in northern Italy that is typically subjected to high tourist fluctuations throughout the year. Analyses were carried out at multiple spatiotemporal scales—from urban to user level, and from yearly to daily scale—by exploiting hourly flow data collected at the inflow points of the area and at some touristic users (i.e. nine bathing facilities and a holiday home). In addition, the impact of weather—temperature and rainfall—on water use was explored. The study revealed consistent inflow fluctuations in the area concerned based on tourism (with a ratio between the maximum and minimum monthly average inflow of about 15.7) and demonstrated that the touristic component of water inflow was considerably higher than the residential component at the height of tourist season (i.e., 176 L/s against 42 L/s). Moreover, significant variations in the water inflow due to tourism and weather were also observed on a daily scale, along with considerable water consumption fluctuations in bathing facilities.

1. Introduction

Climate change, growing population, and urbanization are nowadays increasing water demands in several areas and being of raising concerns on water resource availability (Suero *et al* 2012, Nguyen *et al* 2015). In this era of rapid changes and relevant environmental issues, an adequate planning and management of water systems is of great importance to evaluate whether water resources can meet future demand scenarios (Avni *et al* 2015). In this regard, accurate demand estimation is a crucial requirement to implement strategies addressed at developing efficient systems (Aksela and Aksela 2011) which can face the challenges of climate variability and increasing population (Agudelo-Vera *et al* 2013, Bolorinos *et al* 2020). Indeed, an effective water planning and management cannot prescind from the knowledge of how water resources are used across space and time (Sanchez *et al* 2018) and their footprint on the energy sector (Chini and Stillwell 2019).

That is why, in the last decades, several studies were developed to explore the drivers, the characteristics, and the patterns of water consumption (Cominola *et al* 2019). Concerning water consumption drivers, it was demonstrated that water use is typically dependent on a variety of factors, spacing from sociodemographic (March and Saurì 2010, Grafton *et al* 2011) to geographic (Salvaggio *et al* 2014) and climatic (Chang *et al* 2014, Xenochristou *et al* 2020). In greater detail, it was observed that changes in people's habits typically reflect in changes in water consumption (Kalbusch *et al* 2020, Alvisi *et al* 2021). Concerning water consumption characteristics and patterns, analyses have been mainly carried out with regard to the residential sector. Within this context, several studies were conducted to evaluate and predict the pattern of residential water use at multiple levels of spatial aggregation, ranging from the urban scale (e.g. Billings and Day 1989, Gato-Trinidad and Gan 2011) up to the household (e.g. Cole and Stewart 2013, Cardell-Oliver 2013) or end-use level (e.g. DeOreo *et al* 1996, Beal *et al* 2011). Moreover, advances in technology and the advent of smart metres enabled the collection of water consumption data at very high temporal resolution, i.e. from sub-daily up to few seconds (Cominola *et al* 2015). This also allowed the development of techniques for water end-use disaggregation (e.g. Mayer *et al* 1999, Kowalski and Marshallsay 2003, Nguyen *et al* 2013, Mazzoni *et al* 2021a, Bethke *et al* 2021), water conservation (Cominola *et al* 2021), and household leakage detection (e.g. Luciani *et al* 2019) along with the development, calibration and validation of residential water demand models (e.g. Blokker *et al* 2010, Rathnayaka *et al* 2017a, 2017b).

However, it is worth noting that the aforementioned studies about water consumption were conducted specifically as regards the residential sector. This was mainly due to the fact that residential users typically account for the largest portion of water consumption users. However, residential users may consume a much smaller portion of the overall volume of water provided by water utilities as a consequence of industries and other services in the area (Aksela and Aksela 2011). In the light of the above, analysis of water consumption at the non-residential level recently gained more attention (e.g. Morales and Heaney 2014, Attallah *et al* 2021). Research in the non-residential field was mostly carried out in the case of schools or campuses (e.g. Bonnet *et al* 2002, Farina *et al* 2013, Horsburgh *et al* 2017, Clifford *et al* 2018), office buildings (e.g. Wu *et al* 2017), and sport facilities (e.g. Lewis *et al* 2015, Maglionico and Stojkov 2015). In addition, given the relevance that water consumption may have in the commercial, industrial, and tertiary sector, some descriptive and predictive models of non-residential water consumption were also developed (e.g. Blokker *et al* 2011, Pieterse-Quirijns *et al* 2013, Barua *et al* 2013).

Within this framework, an important role is nowadays being played by tourism. Tourists, who typically use water for several purposes and activities, have generally a direct and an indirect impact on water consumption (Gössling *et al* 2012, Hadjikakou *et al* 2013, Garcia *et al* 2020). On the one hand, direct water consumption spaces from personal hygiene and laundry to recreational activities, such as the use of spas, saunas, and pools (Gössling and Peeters 2014, Morote *et al* 2016a, Hof *et al* 2018). On the other hand, an additional, indirect water consumption in tourist sector can be related to activities such as food production, accommodation facility cleaning, garden irrigation, catering or shopping services, snowmaking, and sport course maintenance (Gopalakrishnan and Cox 2003, Rixen *et al* 2011, Gössling and Peeters 2014). Clearly, direct and indirect tourist water consumption—which is expected to grow by up to 90% by year 2050 (Gössling and Peeters 2014)—leaves behind a significant footprint on water resource (Fernandes *et al* 2020). In this context, some studies (e.g. Yang *et al* 2011) demonstrated that tourists can consume even more water than residents on a per capita basis, whereas some others (e.g. Lamei *et al* 2009) reported that serious environmental problems may be caused in tourist areas when freshwater is produced, due to high energy consumption and uncontrolled disposal of materials in the environment. These issues are particularly evident in the case of scarcely resilient water systems, such as intermittent networks (Reyes *et al* 2017).

In literature, the effects of tourism on water consumption were mostly analysed specifically with regard to locations typically subjected to water scarcity issues and where tourism can mostly affect water resource availability, such as Mediterranean (e.g. Hof and Schmitt 2011, Rico *et al* 2019) Atlantic (e.g. Ruiz-Rosa *et al* 2017), or African coasts (e.g. Gössling 2002, Lamei *et al* 2009). On the one hand, as regards the spatial level of detail, almost all the studies were conducted either at the urban scale (e.g. Toth *et al* 2018) or by investigating a specific user type, mainly hotels (e.g. Bohdanowicsz and Martinac 2007, Deyà-Tortella and Tirado 2011, Rico *et al*, 2019, Deyà-Tortella *et al* 2019, Tirado *et al* 2019). On the other hand, as regards the temporal level of detail, it is worth noting that most of the studies conducted analysed the effects of tourism on water consumption at the annual (e.g. Morote *et al* 2018, Rico *et al* 2019, Ramazanova *et al* 2021), seasonal (e.g. Hof *et al* 2018, Garcia *et al* 2020), or monthly scale (e.g. Hof and Schmitt 2011), without going deeper at a weekly, daily, or sub-daily level. The only exception, as far as the authors are aware, is represented by research conducted by Kara *et al* (2016), which included the 5 min resolution monitoring of water consumption at 13 users of interest for tourism (e.g. a restaurant, a café, two hostels, a museum, a public toilet, etc) in the city of Antalya, Turkey. In any case, these facilities were monitored for a limited period (i.e. five days), whereas water consumption patterns were used for modelling purposes without exploring the impact of tourism on those.

In the European Mediterranean regions, a wide spread of tourism—in particular, seaside tourism—was experienced since the 1960s (Morote *et al* 2016b). Clearly, this had considerable effects on economy, land use, urbanisation, and infrastructures in most countries of the Mediterranean area. Today's seaside tourists generally spend their days of vacation in accommodation facilities (e.g. hotels, guesthouses, resorts, holiday homes, campsites, etc) that are often located in proximity to beach resorts. In particular, during the day, tourists typically spend their time at the beach and several of them settle into the many bathing facilities available along the coast.

Figure 1. Overview of the northern Italy region (panel (a)) featuring the case study DMA on the Adriatic coastline, i.e. touristic DMA (panel (b)) and an additional, inland DMA, i.e. residential DMA (panel (c)) considered as a baseline.

Bathing facilities are multifunctional establishments consisting of a leisure area on the beach with Sun loungers and parasols, a restaurant and/or a café, and sanitary services with toilets, and cold and hot showers. In addition, some facilities also include sport courts and a pool. Moreover, although most of the bathing facilities are typically open only in summer (when seaside tourism is high), it is worth noting that, in some cases, the facility restaurant remains open also during the winter period (when it is mainly attended by residents and locals).

Bathing facilities are widespread in European Mediterranean coastal areas, specifically with regard to Greece, Spain, and Italy. In Italy, recent analyses revealed the presence of a total of 11 000 bathing facilities over about 3300 km of beach (Legambiente 2019), indicating, on average, about 3.3 bathing facilities per km of beach. However, to date no studies have focussed on water consumption in bathing facilities, despite their considerable diffusion.

Based on the above considerations, the aim of the current work is to provide an insight into the effects of seaside tourism on water consumption, with regard to a coastal area in northern Italy typically subjected to high tourist fluctuations throughout the year. In greater detail, the area concerned features a high number of bathing facilities, whose characteristics of water consumption were investigated trying to fill the gap of unavailability of studies exploring these non-residential users. Moreover, the work aims to explore the impacts of climatic variables, such as temperatures and rainfalls, on the water consumption in the area over the tourist season.

Unlike other studies, the analyses were carried out at different levels of spatial and temporal detail (i.e. from urban to user scale, and from yearly to daily scale, respectively). In particular, analyses at the user scale were conducted with regard to a group of nine bathing facilities—for which hourly-resolution water consumption data were available over a period of three months during tourist season—in order to explore the characteristics of water consumption of this type of user. Additionally, the results obtained were compared against the ones of a nearby area not significantly affected by tourist flows and where water consumption is mainly tied to residential users.

The study is structured as follows: section 2 (*case study*) provides an overview of the case study area concerned and its characteristics, along with the data made available by water utilities; section 3 (*methodology*) describes the main characteristics of the analysis conducted; section 4 (*results and discussion*) illustrates the most relevant results achieved at multiple spatiotemporal scales; lastly, in section 5 (*conclusions*), some final observations about the study and its implications are provided.

2. Case study

The study focussed on the analysis of water use in a northern Italy region, close to the Adriatic Sea (figure 1(a)), featuring a District Metered Area (DMA) on the Adriatic coast (figure 1(b)) and an additional, inland DMA (figure 1(c)), considered here as a baseline.

The first DMA (hereinafter denoted as *touristic DMA*) supplies five seaside resorts in the municipality of Comacchio (Province of Ferrara), with a resident population of around 8000 inhabitants. The area is of interest for seaside tourism, which is the major economic source during summer period. As in most seaside resorts, the area is characterised by strong population fluctuations and, consequently, a considerable variability in the number of users over the year. Specifically, the total resident population of the municipality of Comacchio (where the touristic DMA is located) is of about 23 000 inhabitants, whereas, at the height of the tourist season, the ratio between floating and resident population is typically of about 3.5, as shown in figure 2(a).

The touristic nature of the area was detailed in table 1, which shows the tourist accommodation capacity with respect to different facility types. In particular, it is worth noting that: (i) the municipality of Comacchio could potentially host a number of tourists which is about six times the number of residents; and (ii) the vast

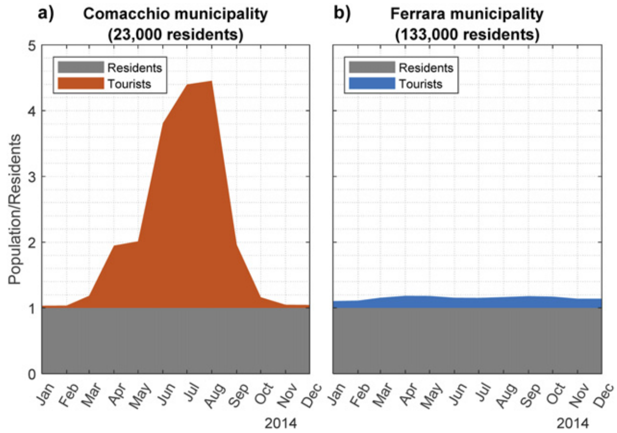

Figure 2. Monthly profiles of resident and floating population in the Comacchio and Ferrara municipalities where the two DMAs considered in the case study are located.

Table 1. Touristic DMA capacity with respect to different accommodation facilities.

Accommodation facility	Capacity (tourists)	Capacity (%)
Hotels	3441	2.5%
Camping sites	20 372	15.0%
Holiday homes/rentals	111 737	82.5%
Total	135 550	100%

majority of facilities is represented by accommodations in holiday homes/rentals (i.e. 82.5%), whereas the capacity of hotels and camping sites is much more limited. Therefore, the tourism of the area could be defined as 'residential tourism'. In greater detail, the residential tourism of the area includes both local people residing in accommodation facilities or reaching their second homes only at the weekend (i.e. short-term tourists) and weekly or longer-period visitors (i.e. long-term tourists).

A second DMA (hereinafter denoted as *residential DMA* given its mainly residential nature) was considered only as a baseline to compare the results of the analysis of the impacts of tourism on water consumption achieved in the case of the touristic DMA. The residential DMA is about 55 km west from the area on the Adriatic coast where the touristic DMA is located and covers part of the suburb of the city of Ferrara and its Province, with a resident population of about 20 000 inhabitants. It is worth noting that the total floating population (i.e. tourists) of the municipality of Ferrara is generally constant throughout the year and represents only a small fraction of the resident population, as shown in figure 2(b).

Specifically, data about resident and floating population shown in figure 2 refer to the municipalities of Comacchio and Ferrara since they are the results of a demographic analysis conducted at the municipality level. However, as regards the impacts of tourism in the DMAs concerned (which are only a part of the municipalities), it should be considered that: (i) the tourist component of the touristic DMA is expected to be even higher than the one reported in the case of the Comacchio municipality, since this municipality is of interest especially for seaside tourism, thus tourists typically stay in the proximity of beach resorts (which coincide with the touristic DMA); and (ii) the tourist component in the residential DMA is expected to be even lower than the one reported in the case of the Ferrara municipality, since the city is of interest especially for cultural tourism and thus tourists typically stay in the proximity of city centre (which is not included in the residential DMA).

From an operational standpoint, the water utilities managing the water distribution networks of the two DMAs made available:

- Hourly-resolution flow data collected at each inlet and outlet point of both the DMAs throughout the year 2014;
- Hourly-resolution water consumption data collected at 9 bathing facilities located in the touristic DMA from June 19, 2014, to September 15, 2014 (i.e. over a period which nearly coincides with the tourist season in the DMA). Specifically, the bathing facilities subjected to monitoring represent about 8.7% of the total number of 103 facilities located in the touristic DMA.

In addition, given the prevalent number of holiday home accommodations in the touristic DMA, the high-resolution water consumption monitoring for a period of almost 3 weeks was conducted in the case of a holiday home occupied by a family of tourists. It is worth highlighting that, although such data refer to an individual household, monitoring was performed with the aim of qualitatively exploring the patterns of water consumption with regard to one sample of the most widespread type of tourist accommodation facilities in the DMA.

3. Methods

The water discharge inflow in the two DMAs considered in the case study and the water consumption observed at the monitored users of the touristic DMA (i.e. bathing facilities and the holiday home) were analysed at different levels of spatiotemporal detail. Moreover, qualitative and quantitative analyses were conducted to evaluate the impacts of climatic variables on water use, such as daily cumulative rainfall depth and daily average temperature. Please note that all variables appearing in the *methods* section were listed and detailed in table S1 (supplementary material (https://stacks.iop.org/ERIS/2/025005/mmedia)).

3.1. DMA level

At the DMA level, the time series of the net discharge inflow at the hourly temporal resolution was obtained through water balance, as shown in equation (1):

$$Q_i^j = \sum_{n=1}^{N_i} Qin_{i,n}^j - \sum_{o=1}^{O_i} Qout_{i,o}^j \tag{1}$$

where Q_i^j is the hourly average net discharge inflow of the DMA i at time j (i.e. at the jth hour of the period between January 1 and December 31, 2014, $j = 1, \ldots, 8760$), $Qin_{i,n}^j$ is the hourly average discharge inflow through the nth inflow point of DMA i ($n = 1, \ldots, N_i$ given the number N_i of inflow points in DMA i) and $Qout_{i,o}^j$ is the hourly average discharge outflow through the oth outflow point ($o = 1, \ldots, O_i$ given the number O_i of outflow points in DMA i).

Analyses were then carried out considering three different levels of temporal detail:

- On the yearly scale, the average monthly net discharge inflow Qm_i^{Jm} over the Jmth month of the year 2014 was calculated in the case of each DMA i by considering the hourly average net discharge inflow time series (i.e. Q_i^j, with j ranging from the first to the last hour of the Jmth month of 2014).
- On the seasonal scale, the average daily net discharge inflow Qd_i^{Jd} over the Jdth day of the period between June 19 and September 15, 2014 (for which water consumption data at the monitored bathing facilities were also available) was calculated in the case of each DMA i by considering the hourly average net discharge inflow time series (i.e. Q_i^j, with j ranging from the first to the last hour of the Jdth day of the period).
- On the daily scale, two analyses were carried out. First, the daily profile of the net discharge inflow of each DMA [i.e. a set of hourly inflow coefficients C_H^t ($t = 1, \ldots, 24$)] was calculated with regard to weekdays and weekend days/holidays of the period between June 19 and September 15, 2014, as shown in equation (2):

$$C_H^t = \frac{\frac{1}{D}\sum_{d=1}^{D} Q_i^{t,d}}{\frac{1}{T}\frac{1}{D}\sum_{t=1}^{T}\sum_{d=1}^{D} Q_i^{t,d}}. \tag{2}$$

  Where $Q_i^{t,d}$ is the hourly net discharge inflow at hour t ($t = 1, \ldots, T$ with $T = 24$) of weekday or weekend day d ($d = 1, .., D$) and D is the number of weekdays or weekends/holidays occurring in the period. Therefore, the numerator indicates the average net discharge inflow of DMA i at hour t on weekdays or weekend days/holidays, whereas the denominator represents the average hourly net discharge inflow on weekdays or weekend days/holidays.

In addition, cluster analysis was conducted with the aim of exploring the relationship between the daily profiles of the net discharge inflow and day types (i.e. weekdays and weekend days/holidays). Specifically, clustering was conducted by applying the K-means algorithm (Lloyd 1982). From an operational standpoint, daily profiles were partitioned into a number K of classes based on the K-value leading to the highest average value of the silhouette parameter (Rousseeuw 1987) and correlation was assessed by cross-checking the cluster associated with each daily profiles and its corresponding day type.

3.2. User level (bathing facilities, holiday home)

In the case of the $N_{BF} = 9$ monitored bathing facilities of the touristic DMA, analyses of the water consumption recorded over the period between June 19 and September 15, 2014, were conducted at two different temporal scales:

- On the seasonal scale, the hourly water consumption of all the N_{BF} bathing facilities was aggregated at the daily temporal resolution as shown in equation (3):

$$qd^{Jd} = \frac{1}{T}\sum_{t_{Jd}=1}^{T}\sum_{b=1}^{N_{BF}} q_b^{t_{Jd}} \tag{3}$$

where qd^{Jd} is the daily average consumption (discharge) of all the N_{BF} bathing facilities included in the touristic DMA over the Jdth day of the period considered, and $q_b^{t_{Jd}}$ is the hourly water consumption observed in the bth bathing facility ($b = 1, \ldots, N_{BF}$) at time t of the Jdth day (i.e. at the tth hour of the Jdth day of the period considered).

In addition, the correlation between the daily water consumption of all the bathing facilities monitored and the daily net discharge inflow in the touristic DMA was studied for the period concerned.

- On the daily scale, the daily profile of the water consumption of all the N_{BF} bathing facilities [i.e. a set of hourly consumption coefficients c_H^t ($t = 1, \ldots, 24$)] was calculated with regard to weekdays and weekend days/holidays, as shown in equation (4):

$$c_H^t = \frac{\frac{1}{D}\sum_{d=1}^{D}\sum_{b=1}^{N_{BF}} q_b^{t,d}}{\frac{1}{T}\frac{1}{D}\sum_{t=1}^{T}\sum_{d=1}^{D}\sum_{b=1}^{N_{BF}} q_b^{t,d}} \tag{4}$$

where $q_b^{t,d}$ is the hourly water consumption (discharge) in the bth bathing facility at hour t of weekday or weekend day d, and D is the number of weekdays or weekends/holidays occurring in the period.

Furthermore, in the case of the holiday home for which water consumption monitoring was conducted at 1 s resolution over a period of 18 days at the height of the tourist season (i.e. between late July and late August), data were aggregated and averaged at the hourly temporal resolution as shown in equation (5):

$$\widehat{qh}^{Jh} = \frac{1}{S}\sum_{s_{Jh}=1}^{S} \hat{q}^{s_{Jh}} \tag{5}$$

where $\widehat{qh}^{Jh}$ is the hourly average water consumption (discharge) over the Jhth hour of the 18 day monitoring period considered ($Jh = 1, \ldots, 432$) and $\hat{q}^{s_{Jh}}$ is the water consumption (discharge) recorded at sth second of the Jhth hour of the monitoring period considered ($s_{Jh} = 1, \ldots, S$ with $S = 3600$). In addition, the daily profile of water consumption was calculated as shown in equation (4).

3.3. Impact of climatic variables on water use

Given the heterogeneous characteristics of seaside tourism in the area (i.e. presence of short- and long-term tourists) the impacts of climatic variables on water use were also evaluated. This was due to the fact that different types of seaside tourists were expected to react differently to bad weather conditions.

Specifically, two additional analyses were conducted with respect to the two DMAs and the set of all the N_{BF} bathing facilities monitored, exploiting two kinds of climatic data, that is daily cumulative rainfall depth and daily average temperature observed at two meteorological stations located in the residential and touristic DMA.

- A qualitative analysis was performed by comparing the trend of the daily net discharge inflow in the two DMAs and daily bathing facilities water consumption against the ones of daily rainfall depth and average temperature, with the scope of exploring the impacts of rainfall and temperature variations on water use.
- A quantitative analysis was conducted by evaluating the weekly distribution of the daily average net discharge inflow in the two DMAs and the daily water consumption (discharge) of the bathing facilities for: (i) rainy days only; (ii) rainless days only; and (iii) all the days of the period between June 19 and September 15, 2014. The weekly distributions were calculated as shown in equations (6)–(8):

$$Qw_{rain} = \frac{1}{Dw_{rain}}\sum_{dw=1}^{Dw_{rain}} Q_{rain}^{dw} \tag{6}$$

$$Qw_{rainless} = \frac{1}{Dw_{rainless}}\sum_{dw=1}^{Dw_{rainless}} Q_{rainless}^{dw} \tag{7}$$

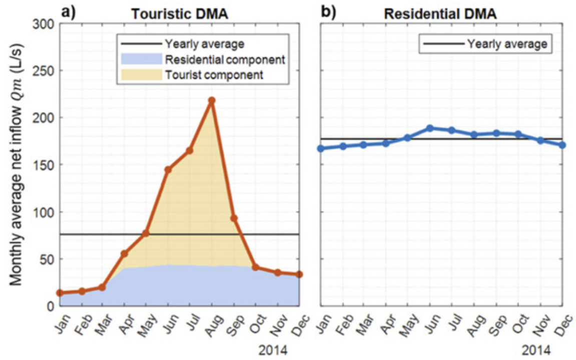

Figure 3. Monthly average net discharge inflow in the (a) touristic and (b) residential DMA. The estimate of the net discharge inflow components of the touristic DMA is shown in panel (a).

$$Qw = \frac{1}{Dw}\sum_{dw=1}^{Dw} Q^{dw}. \quad (8)$$

In the preceding equations, Qw_{rain} is the daily average DMA net discharge inflow (resp. bathing facilities water consumption) with regard to the all the Dw_{rain} rainy days of type w (i.e. Mondays, Tuesdays, etc) of the period; Q^{dw}_{rain} is the daily average DMA net discharge inflow (resp. bathing facilities water consumption) with regard to the dwth rainy day of type w of the period ($dw = 1, \ldots, Dw_{\text{rain}}$); Qw_{rainless} is the daily average DMA net discharge inflow (resp. bathing facilities water consumption) with regard to the all the Dw_{rainless} rainless days of type w of the period; Q^{dw}_{rainless} is the daily average DMA net discharge inflow with regard to the dwth rainless day of type w of the period ($dw = 1, \ldots, Dw_{\text{rainless}}$); Qw is the daily average DMA net discharge inflow (resp. bathing facilities water consumption) with regard to the all the days of type w of the period; Q^{dw} is the daily average DMA net discharge inflow (resp. bathing facilities water consumption) with regard to the dwth day of type w of the period ($dw = 1, \ldots, Dw$).

4. Results and discussion

4.1. DMA level

The trend of the monthly average net discharge inflow Qm of the touristic DMA over the year 2014 was shown in figure 3(a), where it was also compared against the one of the residential DMA (figure 3(b)).

Specifically, considerable variations in the monthly net discharge inflow were observed in the touristic DMA (where the ratio between the maximum and minimum monthly average inflow was of about 15.7, being the extreme monthly average inflow values of about 14 and 218 L/s) whereas less significant variations emerged in the case of the residential DMA (where the ratio was of about 1.1).

Firstly, it is worth noting that the trend of monthly discharge inflow in the touristic DMA (shown in figure 3(a)) almost reflected the one of the ratio between tourists and residents shown in figure 2: in fact, both the highest net inflow and the highest tourist flow were observed between June and August 2014. To further explore the impact of tourism in the touristic DMA, the tourist and residential contribution of water inflow were individually evaluated under the hypotheses that: (i) the seasonal behaviour of resident population is comparable to the one of the residential DMA; (ii) water inflow in the touristic DMA can be entirely related to resident population when the number of tourists is negligible, i.e. from October to March (as shown in figure 2). The analysis revealed that the highest ratio between the tourist and the residential component of water inflow in the touristic DMA (shown in figure 3(a)) was of about 4.2: in fact, at the height of the tourist season (i.e., August 2014, when also tourist flows were the highest), the residential component of water inflow in the DMA was of about 42 L/s, whereas the tourist component was of 176 L/s. This result was comparable with the findings achieved when the highest ratio between tourists and residents in the touristic DMA was investigated (figure 2(a)), being, in that case, equal to about 3.5. In greater detail, it emerged that the increase in water inflow due to tourism is more than proportional to the increase in the total population, in agreement with the observations made by Toth *et al* (2018).

As far as the residential DMA is concerned, the highest net discharge inflow over year 2014 was observed in the month of June, although the highest number of tourists was observed in mid seasons. This is mainly related to the limited contribution of tourism in the residential DMA, being the maximum ratio between tourists and residents of only 0.2 (against the value of about 3.5 observable in the touristic DMA) and being the impact of

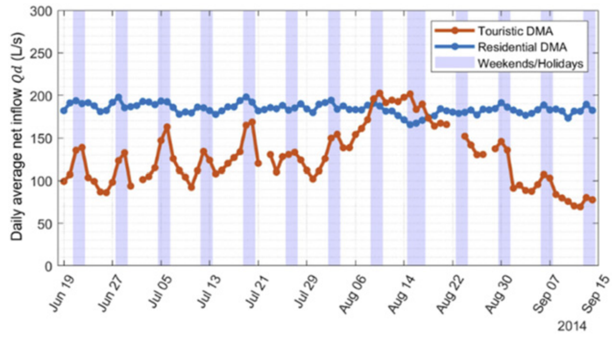

Figure 4. Daily average net discharge inflow over summer period in the two DMAs considered in the case study.

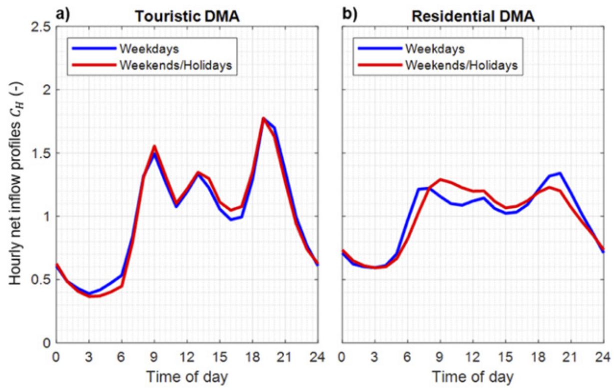

Figure 5. Hourly inflow profiles of the two DMAs concerned on summer weekdays and weekend day/holidays.

tourism negligible compared to seasonal factors. Hence, the above considerations confirm that the effects of tourism flows on water use are evident especially in the cases where the number of tourists is not negligible compared to the number of residents.

The trend of the daily average net discharge inflow *Qd* of the touristic DMA over the period between June 19 and September 15, 2014 was shown in figure 4, where it was also compared against the one of the residential DMA over the same period.

Specifically, considerable variations in the net discharge inflow occurred in the touristic DMA from weekdays to weekends/holidays (and vice versa), being the daily net discharge inflow typically higher in the case of weekends/holidays. In fact, the daily average net discharge inflow over the selected period was of about 120.88 L/s in the case of weekdays and 145.09 L/s in the case of weekend days and holidays, because of local people residing in accommodation facilities or reaching their second homes only at the weekend (i.e. short-term tourists). In addition, at a larger scale, a significant increase in the average net discharge inflow due to long-term tourism was observed in mid-August and especially around August 15, which is National Holiday and typically coincides with the height of the summer season in Italy. On the contrary, no significant variations in the daily average net discharge inflow were observed in the case of the residential DMA, being the weekend average net discharge inflow (i.e. 185.80 L/s) in line with the one observed on weekdays (i.e. 183.48 L/s). Moreover, as opposed to the touristic DMA, a slight decrease was observed around August 15. This was most likely due to the high number of residents leaving their homes for summer holidays.

On a daily scale, the inflow profiles obtained in the case of the touristic DMA (i.e. coefficients C_H shown in figure 5(a)) did not show any substantial difference between weekdays and weekend days/holidays, confirming that, despite the increase in the water use at the weekend due to local tourism, people tend to consume water in the same manner during the day, independently of day type. However, despite the small fluctuations of the daily inflow between weekdays and weekends/holidays, considerable differences in the daily profiles were observed for the residential DMA (figure 5(b)) where, for instance, the inflow was typically more distributed throughout the morning at the weekend, whereas the evening peak was typically the highest on weekdays. This confirmed the changes in most of the residents' habits at the weekend, since they typically stop working on Saturday and Sunday.

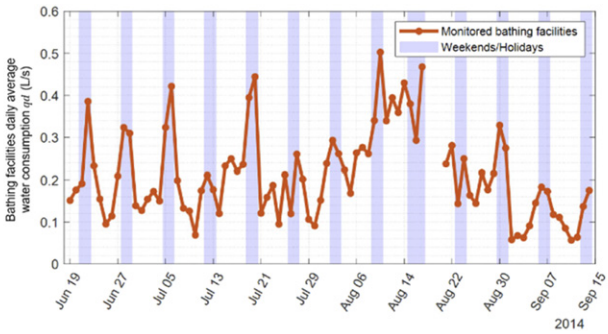

Figure 6. Daily average water consumption (discharge) over summer period in the monitored bathing facilities.

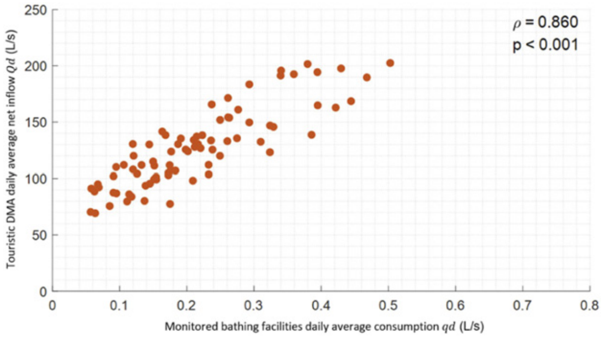

Figure 7. Results of the correlation analysis between the daily net discharge inflow in the touristic DMA and the daily water consumption (discharge) in the monitored bathing facilities.

The above considerations were further supported by the results of cluster analysis aimed at investigating the relationship between daily water use profiles and day types. The preliminary silhouette curve analysis carried out showed that, in the case of both the touristic and the residential DMA, the average silhouette was the highest for $K = 2$. The K-means algorithm was subsequently applied to cluster the daily inflow profiles into $K = 2$ partition classes and the clustered profiles were compared against their respective day type (i.e. weekdays, weekend days/holidays). The analysis revealed that, as regards the residential DMA, 100.0% of the profiles associated with the first (resp. second) cluster were related to weekdays (resp. weekend days/holidays), whereas, in the case of the touristic DMA, the degree of correlation between clustered profiles and day types was of 52.6% only. These results confirmed that, during the tourist season, no substantial differences in the daily profiles of the net inflow occurred between weekdays and weekends in the touristic DMA, differently from the residential DMA, where people tend to change substantially their water use habits at the weekend.

4.2. User level (bathing facilities, holiday home)

As regards the $N_{\mathrm{BF}} = 9$ bathing facilities monitored in the touristic DMA over the period between June 19 and September 15, 2014, the trend of the daily water consumption of all the establishments was shown in figure 6.

Consistent daily fluctuations were observed on the trend shown in figure 6, with the water consumption of the monitored bathing facilities being typically higher on weekend days or holidays because of short-term tourism. Specifically, the average water consumption (discharge) observed on weekdays in all the $N_{\mathrm{BF}} = 9$ monitored bathing facilities was of about 0.18 L/s, whereas it increased to 0.29 L/s on weekend days and holidays. The above results were projected by considering the total number of 103 bathing facilities in the touristic DMA and led to an expected total water consumption of about 2.02 L/s in the case of weekdays and 3.29 L/s in the case of weekends and holidays, i.e. the 1.67% and the 2.27% of the total net discharge inflow of the touristic DMA. Therefore, it emerged that the water use in bathing facilities affects the water balance of the touristic DMA only on a limited basis.

The results of the correlation analysis between the daily net discharge inflow in the touristic DMA and the daily water consumption (discharge) in all the monitored bathing facilities over the selected period were shown figure 7, where each dot was related to a day of the period.

Specifically, a high correlation (i.e. $\rho = 0.860$) emerged from the analysis, meaning that, on average, water consumption in bathing facilities was the highest on days when the net inflow in the touristic DMA was the

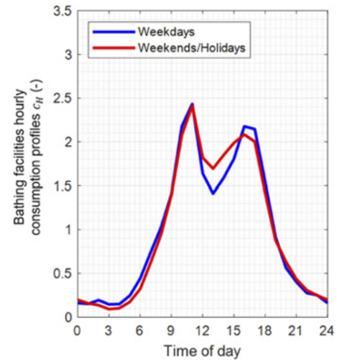

Figure 8. Hourly water consumption profiles in bathing facilities on summer weekdays and weekend days/holidays.

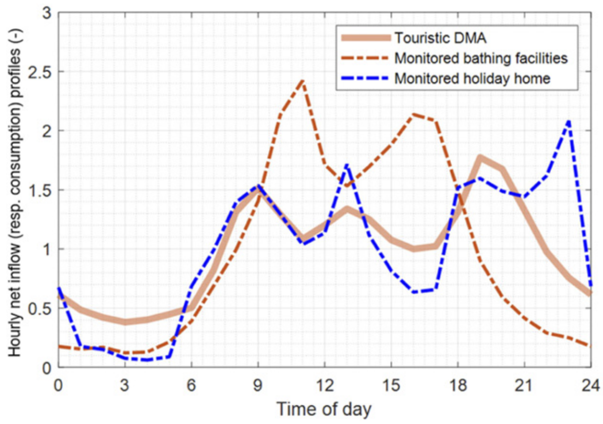

Figure 9. Comparison between hourly average normalized net discharge inflow profile of the touristic DMA (orange continuous line) and the hourly average normalized water consumption (discharge) profiles in the monitored bathing facilities (orange broken line) and holiday home (blue broken line).

highest too, despite the little contribution of bathing facilities on the water balance of the DMA. This is believed to be related to the fact that short- and long-term tourists consume water not only when they are at the beach (i.e. in the bathing facilities), but also when they return to their accommodation facilities or second houses to have a shower, use the toilet, prepare meals, etc.

On a daily scale, the hourly profiles of water consumption of all the monitored bathing facilities (i.e., coefficients c_H) on weekdays and weekend days/holidays were calculated using equation (4) and were shown in figure 8. Specifically, despite the considerable variations in the water consumption of bathing facilities between weekdays and weekend days (see figure 6), no substantial differences emerged in the two average profiles, with the only exception of midday and the early afternoon.

Both the profiles shown in figure 8 revealed a first peak in late morning (between 10 and 11 a.m.) and a second peak in the afternoon (between 3 and 4 p.m.). In particular, the former peak was reasonably assumed to be due to the arrival of people to the bathing facility and the simultaneous start of cooking activities within the bathing facility restaurant (if present), whereas the second peak was likely to be related to the more frequent use of water for showering during the hottest hours of the day, along with the use of water to cool down the sandy substrate of volley, tennis, and soccer courts. However, the weekend profile kept slightly higher in the central hours of the day. This was most likely to be due to the fact that, on Saturday and Sunday, more people (and, in particular, short-term tourists) have lunch at the bathing facility restaurants and stay at the beach all day long, whereas, on weekdays, long-term tourists often return at their accommodation facilities for lunch.

The hourly profile of water consumption related to the holiday home subjected to high-resolution monitoring was shown in figure 9 (blue dashed line), where it was also compared against the water consumption profile related to bathing facilities (orange dashed line) and the net inflow profile observed in the touristic DMA (orange continuous line), with no distinction between weekdays and weekends/holidays.

On the one hand, it is worth noting that the hourly water consumption profile of the holiday home was different from the ones typically reported in other studies exploring the water consumption pattern of households (e.g. Mayer *et al* 1999, DeOreo *et al* 2011, Beal and Stewart 2011) which were generally characterized

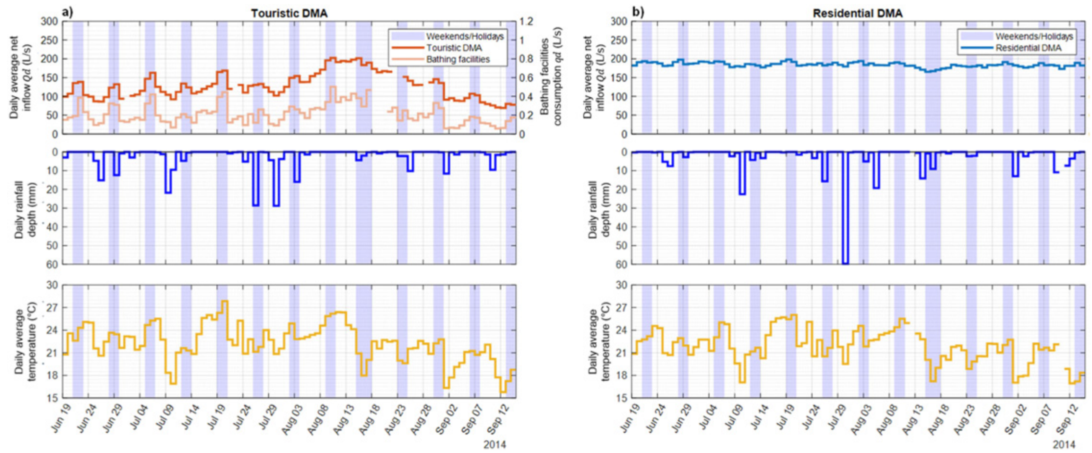

Figure 10. Comparison between the daily net discharge inflow observed in the two case study DMAs (resp. the daily water consumption in the monitored bathing facilities) and climatic variables (i.e., daily temperature, daily cumulative rainfall depth) over summer period.

by two peaks in the morning and at dinner time respectively. This was reasonably assumed to be related to different people's habits and behaviours during vacation periods, when they can wake up later, stay at home for lunch, and go to bed later.

On the other hand, peak consumption times of the bathing facilities differed from the ones of the touristic DMA net inflow (further confirming that, on average, the water consumption activity at the bathing facilities did not significantly affect the water balance of the DMA). Specifically, peak times at the bathing facilities were observed when the DMA net inflow was relatively low, and vice versa. The complementarity between these two profiles suggested that the peaks observed in the hourly profile of the DMA net inflow were mainly due to the activity of short- and long-term tourists at their accommodation facilities rather than water use in the bathing facilities.

The above considerations were also confirmed by the trend of the hourly water consumption profile observed at the monitored holiday home, which kept substantially in line with the one of the DMA net inflow and further suggests the greater impact of water use in the accommodation facilities on the water balance of the touristic DMA.

4.3. Impact of climatic variables on water use

The impact of climatic variables on water use (i.e. water inflow at the DMA level or water consumption at the level of bathing facilities) was first explored qualitatively by comparing the trend of the daily water discharge inflow observed in the touristic and the residential DMAs over the tourist season against: (i) the trend of the daily cumulative rainfall depth (mm/day); and (ii) the trend of the daily average temperature (°C). The results of the comparison were shown in figure 10, where the trend of the daily water consumption in the monitored bathing facilities was also included.

In general, a considerable sensitivity of water inflow to both rainfall and temperature emerged in the case of the touristic DMA, where drops in the water use were observed in the case of rain or temperature decrease. By way of example, with regard to the sixth weekend of the period considered (i.e. 26–27 July 2014), a daily cumulative rainfall depth of about 30 mm was observed and the DMA daily average net inflow resulted smaller (of around 50–60 L/s) than the one observed at the previous weekend, when no rainfall was registered. Specifically, this was related to a reduction in the daily average net inflow of about 30%. Accordingly, a reduction of about 0.2 L/s (i.e. 50%) was observed in the case of the bathing facilities daily average water consumption. Similar observations can also be made in the case of other rainy weekends (i.e. 28–29 June, 12–13 July, and 2–3 August 2014).

Such drops in water use were particularly evident in the case of bathing facilities and were most likely due to the fact that people typically do not stay at the beach when the weather is bad, thus only small volumes of water are generally consumed in the bathing facilities in those days. Moreover, since short-term tourists usually move to the coast only in case of good weather and long-term tourist tend to do alternative activities when the weather does not allow them to stay at the beach (e.g. sightseeing in nearby cities), the impact of rainfalls or drops in the average temperature reflected also on the water inflow of the DMA, as observable in figure 10. It is also worth noting that, in the light of the aforementioned behaviours of tourists in case of bad weather—and

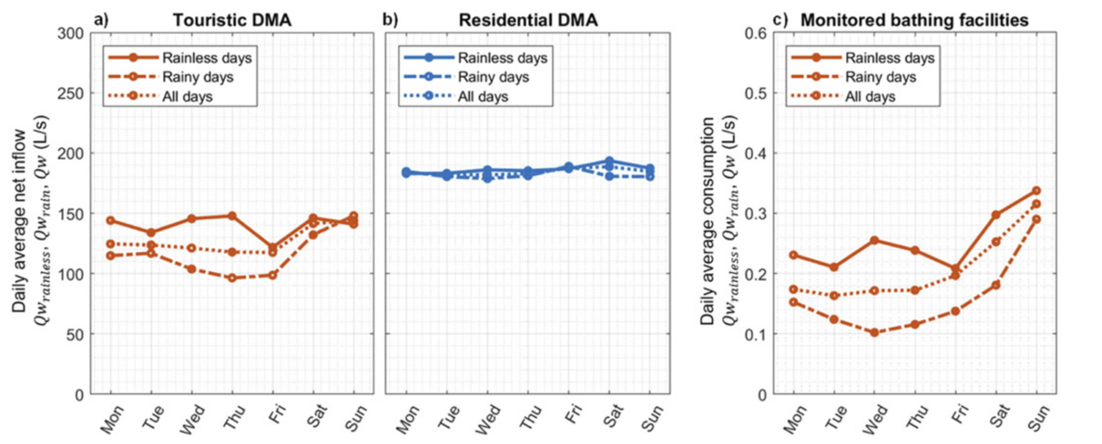

Figure 11. Weekly distribution of the daily average water inflow in the two DMAs concerned (resp. water consumption in the monitored bathing facilities) for rainy days, rainless days and all the days of summer period.

given also the rapid reaction of short-term tourists with respect to adverse weather conditions—no lagged effects between rainfall and changes in the water use were observed.

Instead, no substantial variations in the water inflow of the residential DMA were observed in the case of bad weather during the period considered. This was reasonably assumed to be related to the very nature of the DMA, where the daily indoor water consumption in household is not generally affected by rainfalls or anomalous temperature values, and where the outdoor water consumption (e.g. garden irrigation) is believed to impact on the water balance of the DMA only modestly.

The above considerations were further supported by the results of the quantitative analysis conducted to evaluate the weekly distribution of the average daily water inflow in the two DMAs concerned (resp. the average daily water consumption in the monitored bathing facilities) with regard to: (i) rainy days; (ii) rainless days; and (iii) all the days of the tourist season. From an operational standpoint, the daily average water discharge inflow (resp. consumption) over the different days of the week was calculated as indicated in equations (6)–(8) and was shown in figure 11.

In particular, the touristic DMA showed considerable variations in the net discharge inflow based on rainfall (figure 11(a)), being the daily average net discharge inflow over the overall tourist season of 140.0 L/s in the case of rainless days and 115.8 L/s (i.e. 17.3% decrease) in the case of rainy days. On the other hand, the daily average net inflow of the residential DMA (figure 11(b)) was almost unaffected by rainfall, ranging from 186.4 L/s in the case of rainless days to 182.1 L/s in the case of rainy days (i.e. 2.3% decrease).

The higher sensitivity of the touristic DMA to rainfall was also confirmed by the analysis of the daily average water consumption observed in the bathing facilities (figure 11(c)), which ranged between 0.254 L/s (rainless days) and 0.158 L/s (rainy days), thus revealing a decrease of about 37.9% in the case of rain.

5. Conclusions

The study conducted explored the characteristics of water use in a coastal area on the Adriatic Sea (northern Italy) where tourism has a considerable impact during summer period. From an operational standpoint, water use was analysed at different levels of spatiotemporal detail and compared against the one of a nearby residential area not significantly affected by tourism.

The following outcomes emerged:

- Variations in the number of monthly tourists can be related to variations in the monthly water inflow. In the case of the touristic DMA concerned, the average monthly water inflow ranged between 14 L/s 218 L/s based on tourist flows. Specifically, at the height of tourist season, the tourist component of water inflow in the area concerned was considerably higher than the residential component (i.e., 176 L/s against 42 L/s).
- In the tourist season, large weekly fluctuations in the daily water inflow (with a significant increase on weekend days and holidays) were observed in the touristic DMA, as an effect of the number of short-term tourists reaching beach resorts only at the weekend. Weekly fluctuations were not observed in the case of the residential DMA.
- No differences between weekday and weekend hourly profiles of net discharge inflow were observed in the touristic DMA, meaning that tourists typically consume water in the same manner on weekdays and

at the weekend. In contrast, significant variations in the hourly profiles were observed in the case of the residential DMA.

- Water consumption in bathing facilities did not represent a significant component of the total water consumption in the touristic DMA, being less than 3% of the daily net discharge inflow of the DMA. However, significant variations in the daily water consumption were observed in bathing facilities between weekdays and weekend days, because of the increase in tourist flows at the weekend.
- The hourly profiles of water consumption in bathing facilities differed from the ones of the water inflow in the touristic DMA. Specifically, peak consumption times in the bathing facilities occurred when the DMA inflow was low, and vice versa.
- Similarities between the hourly profile of the touristic DMA and the one of water consumption in the monitored holiday home were observed, revealing that tourists are most likely to consume water within their accommodation facilities.
- Climatic variables significantly impact on water consumption in the case of the touristic DMA, due to the fact that tourists typically reach beach resorts only in case of good weather. Specifically, in the tourist season, a 17% decrease in the touristic DMA water discharge inflow was observed during rainy days, along with a drop of about 38% in the water consumption of bathing facilities. In contrast, the residential DMA did not show high sensibility to climatic variables, being the average decrease in the case of rain of about 2% only.

Beyond the findings achieved, it is worth making the following observations.

First, the current unavailability of more recent water data did not allow the analyses to be extended to periods after the year 2014 and, in particular, to the period when COVID-19 restrictions were implemented. However, no considerable differences in the results are likely to be observed when more recent data are considered given the low variability in tourist flows in the touristic DMA from year to year, at least with regard to the last decade (Regione Emilia Romagna 2021). Moreover, tourist flows in the touristic DMA were not strongly affected by COVID-19 restrictions. In fact, although some studies revealed considerable drops in the water consumption related to the stop of city and thermal tourism due to the restrictions imposed in the first months of the year 2020 (Bich-Ngoc and Teller 2020, Mazzoni *et al* 2021b), it is worth noting that these measurements were gradually lifted in early summer in most of the European countries. Therefore, the impacts of COVID-19 lockdowns on seaside tourism were rather limited.

Second, due to the nature of the case study, the results obtained may be applied to other contexts of seaside areas where short-term tourism is present, whereas they may not apply to the case of sites only—or mostly—characterized by long-term tourism. In greater detail, due to the fact that long-term tourists typically stay for the overall holiday period despite the weather, a lower sensitivity of water consumption to climatic variables would be expected in those areas, at least at the DMA level. However, changes in the water consumption of some individual users—not only bathing facilities, but also pools, golf courts, wellness areas, etc—could be observed because of the alternative activities tourists generally do in case of bad weather.

In conclusion, the study demonstrated that seasonal tourism and climatic variables largely influence water consumption in the coastal area concerned.

The results of the analyses—describing the behaviour of the DMA considered in face of changes in tourist or climatic conditions—can aid the water utility responsible for water distribution in this coastal area in better understanding the characteristics of water consumption and its main components, thus moving towards a more efficient management of the water system. In fact, especially with regard to tourist areas in coastal regions with limited availability of drinking water, a careful management of water systems is even more required to satisfy users' needs without depleting excessive amounts of water or energy. This typically includes the adoption of strategies aimed at an optimal management of the network (e.g. by controlling tank filling, pump scheduling, or valve activation/closure), whose efficiency can be evaluated also based on the findings of this study.

Furthermore, since the analyses of water consumption up to the level of single user allowed to understand which types of users are mostly impacting on water balance—and revealed that most of the water used in the touristic DMA was tied to accommodation facilities—the outcomes presented may also support the water utility in preventing the waste of water at those users. This could be achieved, for example, by incentivizing the installation of low-flow devices, providing feedback to customers, or developing awareness-rising campaigns. Lastly, the water utility could apply the outcomes of the study to carry out future research aimed at evaluating whether systematic changes in the water tariff could lead to benefits in terms of water conservation.

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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