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Impact of COVID19 restrictions on organic micropollutants in wastewater treatment plants and human consumption rates

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HIGHLIGHTS
• Two full-scale WWTPs monitored for 2-years at the turn of COVID19 pandemic.
• General increase during the COVID19 restrictions period in OMPs consumption rate.
• WWTPs performances not negatively affected by the higher influent OMPs concentration.
• Quality of the treated effluents comparable before and during the pandemic period.

ABSTRACT
COVID19 pandemic and the consequent restrictions to constrain SARS-CoV-2 spreading produced several impacts on the worldwide population. The present study focused on 10 Organic Micropolllutants (illicit drugs, pharmaceuticals including some antibiotics and caffeine) and aimed to assess: (1) if COVID19 pandemic restrictions affected the load of those contaminants released into the sewage network and consequently the removal achieved by the Wastewater Treatment Plants; (2) if pursuant to the COVID19 pandemic, there was a change in population consumption rates of the same compounds through the wastewater-based epidemiology (WBE) approach. Two full-scale wastewater treatment plants (WWTPs) located in Central Italy were chosen as case studies, which are distinguished by different characteristics of the catchment area and water treatment layouts. The study was based on a 2-years monitoring activity of the concentration of the above organic micropolllutants, traditional water quality parameters (COD, TSS, nitrogen compounds, total phosphorous) and flow rate in the influent and effluent. The statistical analysis of the monitoring data showed an increase of the influent load of most of the organic micropolllutants. A decrease from 22% to 18% of the median removal efficiency was observed for carbamazepine in the WWTP with the lower treatment capacity only. The other compounds were removed roughly at the same rate. The application of the WBE approach demonstrated an increase in the consumption rate of cocaine, trimethoprim, sulfamethoxazole, sulfadiazine, carbamazepine and above all caffeine during the COVID19 restrictions period. These results highlight that COVID19 pandemic affected people's lifestyle and habits also as far as drugs consumption is concerned, which in turn might have an impact on the treatment efficacy of plants and finally on the receiving water body quality. Therefore, it is mandatory to keep monitoring to improve knowledge and eventually to implement the required measures to address this new problem.

Keywords: Antibiotics, Caffeine, Contaminants of emerging concern, Illicit drugs, Pharmaceuticals, Wastewater-based epidemiology.

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1. Introduction

The worldwide spread of the virus SARS-Cov2, since February 2020, produced several impacts on the population, additionally to those on health that caused only in Italy 128,110 deaths (World Health Organization, 2021). Most countries imposed various measures to constrain SARS-CoV-2 spreading, such as shutting down schools, industries, businesses, travels suspension and international and state boundaries closure. These restrictions have strongly affected people’s lifestyle and habits, with consequences in various fields. Concerning the environment, these effects were studied by many authors as concerns different points of view. Among the others, Chen et al. (2021) analysed the impact on air quality due to the reduction of transportation traffic during COVID19 outbreak; Rodgers et al. (2021) examined changes in food waste production since the start of the COVID19 pandemic in the U.S. and Italy; Yunus et al. (2020) quantitatively demonstrated the improvement in surface water quality during the COVID19 lockdown period. An overview of the effects of COVID19 on the environment was provided by Elsai et al. (2021), which highlighted a deterioration of wastewater quality mainly due to the presence of SARS-CoV-2 RNA. Moreover, the authors suggest that wastewater is expected to be loaded with antibiotics and similar medications due to the increased use of their prescriptions during the COVID19 pandemic.

Taking into account the aforementioned studies and that the pandemic is still under evolution, it is compulsory to keep monitoring and to improve the knowledge about the impacts of the applied restrictions on both social life and the environment (Bontempi, 2021). Among the different strategies to achieve this double purpose, the continuous survey on sewage characteristics, in the influent and effluent of the wastewater treatment plants (WWTPs), can represent a valid and easy to implement tool. More specifically, monitoring the influent quality allows assessing the load of pollutants released into the sewage network by the served population, which in turn provides indirect information about the habits, lifestyle and state of health of people. Similarly, the removal efficiency of the WWTPs and thus the effluent quality depends on the influent load, besides the operational parameters of the plants. Therefore, it can be also evaluated the impacts of the changes in the habits and lifestyle of people on the residual concentrations of specific contaminants present in the final effluent, which can be spilled into the environment or reused for several applications (Di Marcantonio et al., 2021). A wide variety of contaminants is gaining increasing attention from the public, legislators and scientists; the so called Organic Micropollutants (OMPs), which includes licit and illicit drugs, pharmaceuticals, personal care products and many others (European Commission, 2019; The European Parliament and the Council of the European Union, 2020).

Concentrations of OMPs measured in the influent to WWTPs can be used to apply the wastewater-based epidemiology (WBE), which is a well-known technique that provides information about population lifestyle, behaviour and health; as consequence, it can be used as a descriptor for social, demographic and economic changes (Lorenzo and Picó, 2019). WBE is mostly applied to monitor the consumption of illicit drugs, alcoholics and tobacco (Castigliaioni et al., 2014; Thomas et al., 2012). Nevertheless, recent studies explored the possibility to track other substances such as pharmaceuticals and pesticides, with different aims. For example, the adherence of a population to some drug therapies and the human exposure to pesticides were assessed through WBE (Riva et al., 2020; Rousis et al., 2021).

The present study aims to investigate the impact of the COVID19 pandemic on the presence of licit and illicit drugs in wastewaters and therefore on the removal efficiency of WWTPs. Particularly, the main purposes of the study are: (1) to assess if the restrictions imposed to contain the COVID19 pandemic affected the load of OMPs released into the sewage network and consequently the performance of Wastewater Treatment Plants; (2) to assess through WBE approach if pursuant to the COVID19 pandemic, there was a change in population consumption rates of the same OMPs. The study focused on OMPs belonging to the classes of illicit drugs, pharmaceuticals and caffeine. These compounds were selected since they are the most abundant in the influent to the plants, based on previous investigations by the same research group (Di Marcantonio et al., 2021, 2020). Additionally, for the group of pharmaceuticals the selection was made on compounds not specifically used to treat COVID19, to verify a change in the habits of the population related to the socioeconomic restriction and not to the disease itself. Two full-scale WWTPs located in Central Italy were chosen as case studies, which are distinguished by different characteristics of the catchment area and water treatment layouts. The assessments were based on the data collected through a 2-years monitoring activity of the influent and effluent characteristics of the selected plants (from January 2019 to December 2020). Along with OMPs, traditional water quality parameters were also monitored in the same samples (i.e. total suspended solids, chemical oxygen demand, ammonia, nitrite and nitrate nitrogen and total phosphorous).

To the best of the authors’ knowledge, very scarce is the available literature on the effects of the COVID19 pandemic restrictions on the consumption rates of OMPs; besides, the few papers considered only a limited number of contaminants. For instance, Been et al. (2021) focused on illicit drugs, whereas Reinstadler et al. (2021) also added some selected pharmaceuticals and caffeine. Both studies used the same investigation approach as the present work, i.e. the WBE. Particularly, the snapshot study carried out in different European cities by Been et al. (2021) proved that the impact of the COVID19 pandemic caused heterogeneous effects on the use of illicit drugs. Reinstadler et al. (2021) detected a change in the consumption patterns of recreational drugs, alcohol and pharmaceuticals for short-term applications in Innsbruck, Austria. Finally, Kuroda et al. (2021) provided a model-based evaluation on the occurrence, removal in WWTPs and ecotoxicological effects of therapeutic agents associated with COVID19 treatment during pandemic events. They suggested that traditional WWTPs are not capable of efficient elimination of the selected pharmaceuticals. However, no real-scale studies investigated if the restrictions adopted to limit SARS-CoV-2 transmission affected the removal rate of OMPs achieved in urban WWTPs and as consequence the quality of the final effluents to the plants, which is one of the issues though considered by the present paper. Finally, Italy, having been one of the hardest hit countries in the world during the first wave of COVID19 pandemic, represents a case study of particular interest with regards to the impact of COVID19 on the population.

2. Materials and methods

2.1. Sample collection at the WWTPs

The monitoring campaign included two different periods: (1) Reference period (from 2019/01/01 to 2020/03/08, for 19 samples in total) before the beginning of the COVID19 pandemic; (2) COVID19 Restrictions period (from 2020/03/09 to 2020/12/31, 23 samples in total) after the beginning of the pandemic spread in Italy. Particularly, during the latter period, the Italian Government imposed extraordinary social distancing measures to limit viral transmission, which highly impacted the habits of the population. A level of the restrictions imposed by the Government is provided by the Oxford COVID19 Government Response Tracker. The Stringency Index is calculated based on the data from 4 policy indicators, reporting a number between 1 and 100 to reflect the level of government actions. Particularly, the Italian Stringency Index during the COVID19 Restrictions period ranged from 51 to 93 (Hale et al., 2021).

Two different WWTPs, both located in Central Italy, were chosen to perform the monitoring campaign. The first one, WWTP A, provides services for a densely urbanized region. Its authorized treatment capacity (referred to as Authorized PE) amounts to 780000 population equivalent (PE). The pre-treatment segment of the treatment line consists of bar screening and degreasing-degritting tanks. Primary treatment segment follows, with settlement tanks. Then secondary treatment is constituted by aerobic activated sludge reactors followed by secondary settlement tanks. Final disinfection is achieved by sodium hypochlorite addition (according to local legislation, final disinfection is operated only during the seaside season, i.e. from May to September). WWTP B is located in a countryside area and has an Authorized PE of 90000 PE. The water treatment line consists of the main
following stages: fine screens and degritting-degreasing tanks as pre-
treatments; primary settlement tanks; secondary treatment made up by
the activated sludge process including pre-denitrification followed by the
organic carbon oxidation-nitrification, and then secondary settlement
tanks; chlorination (in operation only during the bathing season from
April to September); tertiary treatment stage made up by sand filtration
and UV disinfection.

The authors recognize that there might have been used more represen-
tative ways to collect samples, as widely reported in the scientific literature
(Castiglioni et al., 2014; Ort et al., 2010). However, since the hydraulic re-
tention times (HRTs) of both investigated WWTPs are quite long (average
HRT of 11 h and 16 h for WWTP_A and WWTP_B, respectively), it was pre-
ferrred to apply a collecting procedure based on grab samples of the influ-
ent and effluent of the plants drawn at specific time intervals. To produce reli-
able data, some rules were applied based on the results of previous investi-
gations carried out by the same research group (Di Marcantonio et al.,
2021). Indeed, it was seen that the highest concentrations of the target
OMPs occurred around the middle of the week and at 11 a.m. Therefore,
in the present study all the samples were collected at these times. Further-
more, the monitoring activity was spread along a wide time interval,
i.e., about 2 years, thus allowing to catch different patterns due to weather
changes, habits modifications, etc. Finally, the results were statistically
analysed.

A summary of the sampling campaign and plants characteristics is re-
ported in Table 1. The determination of the following ten micropollutants
along with six water quality parameters was carried out in the collected
samples: cocaine (COC), methamphetamine (MET), benzoylcegonine
(BEG), lincomycin (LCN), trimethoprim (TMT), sulfamethoxazole (SMX),
sulfadiazine (SDZ), carbamazepine (CBZ), ketoprofen (KTP), caffeine
(CAF), total suspended solids (TSS), chemical oxygen demand (COD),
ammonia, nitrite and nitrate nitrogen (NH4-N, NO2-N and NO3-N, respec-
tively) and total phosphorous (Ptot). Additionally, the average daily
loads of COD and CODt were calculated as described in Di Marcantonio
et al. (2020). All the boxplot graphs presented in this study, which display
different statistical elements, were built using the R software (R Core
Team, 2019). Specifically, the boxplot graphs show the interquartile range,
which represents the difference between the upper and lower quartiles (i.e. the 75th and the 25th percentiles, respec-
tively). The bar inside the box indicates the median value (the 50th per-
centile). The dots represent the outliers.

Contaminant loads and population consumption rates were determined
as stated by Reinstadler et al. (2021) and summarized below. Particularly,
the population actually served by the plants during the experimental
study (Experimental PE, as reported in Fig. 3) was calculated based on
the COD concentrations measured in the influent. Whereas the value of
110 g/d/person of COD was assumed as per capita equivalent of COD re-
leased daily by each person to the sewage (Metcalf and Eddy, 2015). There-
fore, the Experimental PE was calculated as follows:

\[
\text{Experimental PE [n · inhabitants]} = \frac{\text{COD}_{\text{load}}}{110} 
\]

where COD_{load} [g/d] is the COD load in the influent to the plants (i.e. the
measured concentration of COD [g/l] multiplied by the average daily
influential volumetric flow rate [L/d]). The value of the treatment capacity
of the plants set by the local Authorities was used as a reference (Authorized
PE).

The population normalized mass load (PNL) was obtained according to the
following formula (Eq. (2)):

\[
\text{PNL [mg/d/1000 inhabitants]} = \frac{C_{\text{infl}} \cdot F}{\text{Experimental PE} \cdot 1000} 
\]

where C_{infl} represents the influent concentration of each contaminant
[mg/L], F is the average influent volumetric flow rate [L/d].

The per capita intake (I) was calculated based on Eq. (3):

\[
I [mg/d/inhabitant] = \frac{C_{\text{infl}} \cdot F \cdot \text{CF}}{\text{Experimental PE}} 
\]

where CF [adim] is the specific correction factor used to back-estimate the
population consumption of each compound, according to the principles of
wastewater-based epidemiology (Thai et al., 2019). The coefficient takes
into due consideration the human body excretion ratio of the target com-
pound and its stability during the movement in the sewers. The CF values
were set to: 3.59, 7.3, 13, 2.6, for BEG, CBZ, COC and MET, respectively
(Reinstadler et al., 2021), and to 1.25, 5.3 and 1.8 for KTP, SMX and
TMT, respectively (Thiebault et al., 2017). When the CF was not available
in the scientific literature, it was assumed equal to 1.

Unpaired t-test and Wilcoxon test were alternatively applied (depend-
ing on the characteristics of each series of data). Specifically, for each pa-
rameter and contaminant, the Shapiro-Wilk test and F-test were firstly
applied in order to verify which between t-test and Wilcoxon test was suitable
to assess the statistical difference between the data obtained in the two dif-
ferent monitoring periods (i.e. Reference period and COVID19 restriction
period). The unpaired t-test is a parametric test that proves the signifi-
cance of the difference among two independent and unpaired groups, based
on the comparison of their means. The test is reliable only if the data are nor-
normally distributed (checked through Shapiro-Wilk normality test); besides,
two formulations are available depending on the homoscedasticity of the
groups (verified with the F-test) (Conover, 1999). Wilcoxon test, a non-
parametric test, was applied when the assumption about the normality of
the compared groups of data was not verified. The aim of the test is
the same of the t-test, but based on the comparison of the medians. When the
test resulted to be unsuitable, the Wilcoxon test was applied.

Particularly, the test used in each case was reported in Table S.M. 5. The
R package "stats" was used to perform the aforementioned statistical tests

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### Table 1

| WWTPs characteristics and number of samples collected during the monitoring campaign. |
|----------------------------------|------------------|----------------|------------------|
| Name of the monitored WWTPs | Authorized PE | Av. Sewage catchment area | Reference period | COVID19 restrictions period |
| WWTP_A | 780'000 | 2.96 | 100 | 10+ |
| WWTP_B | 90'000 | 0.22 | 22 | 9+ |

* Sampling dates: WWTP A 2019/02/13, 2019/03/04, 2019/03/27, 2019/04/09, 2019/04/17, 2019/05/17, 2019/08/29, 2019/11/12, 2020/03/08; WWTP B 2019/02/10, 2019/05/14, 2019/07/29, 2019/09/17, 2019/10/16, 2019/11/14, 2019/12/03, 2019/12/04, 2020/01/12, 2020/03/08.

** Sampling dates: WWTP A 2020/03/12, 2020/04/09, 2020/06/18, 2020/06/24, 2020/07/27, 2020/08/07, 2020/09/23, 2020/10/13, 2020/10/29, 2020/11/12, 2020/12/05, 2020/12/11, 2020/12/16; WWTP B 2020/04/11, 2020/06/30, 2020/07/09, 2020/07/15, 2020/07/30, 2020/08/10, 2020/09/09, 2020/10/21, 2020/11/17, 2020/12/16.

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These tests were applied to all the variables and parameters analysed: OMPs concentrations, water quality parameters concentrations, OMPs removal efficiencies, Experimental PE, PNL, human intakes and influent volumetric flow rate. The p-values assessed with the appropriate test are indicated in figures and tables by the following significance symbols: * for <0.05, ** for <0.01, *** <0.001 and – for no significant difference.

3. Results

3.1. OMPs occurrence in wastewater during reference period and COVID19 restrictions period

OMPs influent concentrations in the two WWTPs during restrictions and reference periods are shown in Fig. 1. Corresponding minimum, maximum and median values can be found in Table S.M. 3. Looking at Fig. 1, it seems that the median values (represented by the black vertical lines inside the box) were higher during the COVID19 Restriction period for most of the compounds in both WWTPs.

The only exceptions were represented by MET and LCN in WWT_B, which did not show any variation, and by KTP in WWTP_A whose influent concentration decreased during the same period. CAF was the compound that showed the most relevant increase of the median in influent concentration in both plants (i.e. from 9 μg/L to 36 μg/L and from 12 μg/L to 38 μg/L for WWTP_A and WWTP_B, respectively), followed by BEG (i.e. from 1 μg/L to 2 μg/L for WWTP_A and WWTP_B respectively) and KTP but only in WWTP_B (i.e. 1.29 μg/L). These trends were confirmed by the statistical analysis for MET, COC, BEG, TMT, CBZ and CAF in the influent of WWTP_A, and for BEG, SDZ, TMT, SMX, KTP and CAF in the influent of WWTP_B. Particularly, BEG, TMT and CAF were present at higher concentrations in the influent of both plants during the COVID19 Restrictions compared to the values measured in the Reference period.

To obtain a better qualitative description of the presence of OMPs in wastewater, the value of the frequency of detection, FD, was also calculated (following Eq. (1)). The results, reported in Table 2, show higher FD (of at least 5%) in the influent during the COVID19 Restrictions period for most of the OMPs (i.e. COC, MET, SMX, TMT, LCN, SDZ) in both WWTPs. This indicates that a wider range of OMPs was released in the wastewater during the COVID19 Restrictions period.

The statistical analysis of the differences between the effluent concentrations measured in the two periods highlighted a significant difference for CAF, SMX and CBZ in WWTP_B (as reported in Table S.M. 4). Specifically, CAF was detected at a lower median concentration in the effluent during the pandemic, whereas SMX and CBZ were at a higher concentration (as reported in Table S.M. 3). In WWTP_A only CBZ showed a statistically relevant increase of the effluent concentration. For some OMPs (i.e. BEG, SMX, TMT), also the FD was higher in the effluent.

Concentrations of the main water quality parameters, such as COD, NH₃, TSS, did not change significantly during the two periods of observation (data reported in Fig. S.M.1).

3.2. WWTPs treatment efficiency

The OMPs removal efficiency of the plants is shown in Fig. 2. For WWTP_A, the values measured in the two periods of monitoring remained
almost the same, as also confirmed by the statistical analysis (the symbols reported on the left side of Fig. 2 indicate p-values always above 0.05). This finding, along with the higher influent concentration observed, explains the slightly increased value of the effluent median concentrations (results reported in Table S.M. 3), even if it was statistically verified only for CBZ (to 0.125 μg/L from 0.185 μg/L as measured in the Reference period, see Table S.M. 4).

In WWTP_B, the impact of the pandemic in terms of plant performance was more relevant for some OMPs. An improvement was observed in the case of CAF and KTP, whereas a decrease was measured for CBZ (i.e. the median value decreased from 22% to −18%). The removal efficiency also changed for BEG in the two periods, with a slight improvement of the median value.

Fig. 2. Removal efficiency of OMPs in WWTP_A and WWTP_B. Symbols on the left-end side of the plots indicate the statistical significance of the differences between the two time periods.

Fig. 3. Trend of the Experimental PE as compared to the Authorized PE.
3.3. Change of consumption rates

The population equivalent (PE) is considered a sensitive parameter for the estimation of consumption rates using the WBE approach. PE represents the population of the catchment area served by the WWTP. In the present study, a comparison between the Authorized PE and the Experimental PE was carried out for the Reference and COVID19 Restrictions periods, as shown in Fig. 3. Looking at Fig. 3, it can be noted that for WWTP_A, the Experimental PE values are equally distributed around the authorized value during both periods of monitoring; therefore, it can be inferred that the influent load to the plant fitted the design value and also did not change due to COVID19 restrictions which obliged most of the people to do smart working at home. The large treatment capacity likely determined an equalization effect on the influent variations of the monitored compounds. Differently, in the WWTP_B the Experimental PE remained almost below the Authorized PE value during both periods of interest. However, by performing the statistical analysis, it was proven that these changes in the PE could not be considered significant in both plants, since the p-value was always far above 0.05. The same conclusion was found out for the average daily flow rate (Fig. S.M.2), thus further confirming that the number of people served by the two plants remained pretty the same before and after the beginning of the COVID19 pandemic.

Fig. 4 shows the Population normalized load (PNL) in WWTP_A and WWTP_B for the Reference and COVID19 Restrictions periods. Looking at the PNL of OMPs released from the catchment area of WWTP_A, a significant increase can be pinpointed for MET, BEG, TMT, SMX, CBZ and CAF. Whereas in WWTP_B only the PNL of BEG, TMT, SDZ and CAF showed to be significantly affected by the pandemic restrictions. The statistical analysis of the water quality parameters and related PNL (reported in Fig. S.M.3) proved the absence of any significant difference in the two periods of time. This proves that the change in the population habits only affected the OMPs influent load released to the sewage and therefore entering the plants. The PNL was then used to calculate the per capita intake (I) to finally estimate the actual consumption trend of the population during the two periods of interest (summarized in Table 3). The median I value resulted to be higher during the COVID19 Restrictions period for all the compounds monitored in the influent to WWTP_A. However, the statistical analysis of these data demonstrated that a significant increase occurred only for some OMPs. Particularly, among the illicit drugs BEG and MET intake increased by 1.16 mg/day/inhabitants and 0.030 mg/day/inhabitants, respectively. Among pharmaceuticals, TMT intake increased during the COVID19 Restrictions period by 0.053 mg/day/inhabitants. The rise of CAF intake was the most relevant; equal to 7.678 mg/day/inhabitants as a median.

The intakes changed more consistently for the population served by WWTP_B. Particularly, a significant increase was depicted for BEG (2.837 mg/day/inhabitants), the antibiotics SMX, TMT and SDZ (0.832, 0.073 and 0.008 mg/day/inhabitants, respectively), the anti-inflammatory KTP (0.248 mg/day/inhabitants) and CAF at the highest extend (14.040 mg/day/inhabitants).

4. Discussions

Based on the analysis of the data above carried out, it can be assessed that during the pandemic period WWTP_A maintained average removal efficiencies comparable to that measured before, despite the increases observed in the influent concentrations for some contaminants. WWTP_A serves a large sewage catchment area (100 km² densely populated) and it can be considered as a big plant being the Authorized PE equal to 780′000 PE, corresponding to an average flow rate of 2.9 m³/s. These characteristics were likely responsible for the equalization effect on the higher OMPs concentration entering the plant; as a consequence, the removal capability was not affected and the effluent concentrations did not show any significant change during the COVID19 Restrictions period. The only exception
is represented by CBZ. This assumption was finally confirmed in terms of OMPs effluent load (data reported in Fig. S.M. 4).

Differently, the WWTP B serves a smaller area and has a much lower treatment capacity (i.e. average flow rate 0.2 m$^3$/s); these characteristics can explain the wider differences observed in the removal efficiencies and consequently on the effluent quality during the two periods of monitoring. Therefore, a plant with a lower treatment capacity is less resilient to a change in the influent characteristics.

A comparison of the results from the statistical analysis performed on all the considered parameters (i.e. daily flow rate, PE, water quality parameters and OMPs) proved that the observed differences between the two monitored periods are significant only for the OMPs concentrations. Furthermore, it showed that in the two urban areas served by the plants, the number of burdening people did not change significantly, although the activation of smart working and the limitations posed on several activities (e.g. commercial, recreational). The only relevant effect must be thus related to a change in the consumption rate of specific substances.

Looking at the different classes of OMPs monitored in the study (classified as illicit drugs, antibiotics, other pharmaceuticals which include caffeine), some considerations can be formulated to explain the consumptions trends highlighted above. They can be considered only speculative due to the multiplicity and complexity of the factors involved and the limited availability of data.

4.1. Illicit drugs

In both plants a significant increase in cocaine consumption was observed in terms of BEG PNL. Interestingly, Been et al. (2021), which monitored the COVID19 pandemic impact on the use of illicit drugs in 7 cities (4 different European countries), showed that only in Italy, and particularly in Milan, there was an increase in cocaine consumption. Accordingly to the main trend detected by Been et al. (2021), Reinstadler et al. (2021) measured a slight decrease of BEG loads during the first months of lockdown in Innsbruck.

In the present study, a statistical increase of MET PNL was detected only in WWTP_A. Interestingly, Reinstadler et al. (2021) measured a slight decrease of BEG loads during the first months of lockdown in Innsbruck.

In the presence of the population to the medicine use.

4.2. Antibiotics

During the pandemic period, the PNL of TMT and SMX significantly increased in the influent of WWTP_A, as well as TMT and SDZ in WWTP_B. The three antibiotics are listed in the Report on medicines use during COVID19 epidemic of the Italian Medicines Agency, AIFA (The Medicines Utilisation Monitoring Centre, 2020); however, they are not specifically associated with the treatment of COVID19. An opposite trend was depicted by Reinstadler et al. (2021) who observed a decline of the TMT PNL and others pharmaceuticals for short-term application during the lockdown in Innsbruck. The differences observed among countries can be strongly related to the traditional aptitude of the population to the medicine use.

4.3. Other pharmaceuticals and caffeine

The two other pharmaceuticals monitored were KTP, an anti-inflammatory drug, and CBZ, an anticonvulsant agent. Only the PNL of CBZ showed a statistical increase among the two monitoring periods exclusively in WWTP_A. CBZ is primarily used in the treatment of epilepsy and neuropathic pain; however, it can be applied also in the case of schizophrenia or bipolar disorders being a mood stabilizer (Anmella et al., 2020). The increasing PNL of CBZ can be related to the reported impact on the mental health of the population that lockdown and quarantine had in big cities, such as the case of WWTP_A (Spano et al., 2021). Reinstadler et al. (2021) did not measure the same rise in CBZ consumption, probably because they monitored only the early weeks of lockdown.

A relevant increase of CAF PNL was observed in both plants during the COVID19 Restriction period. The CAF consumption also seemed to rise in Innsbruck during the lockdown, but it was not statistically proven. In Italy, CAF consumption is not related only to social interaction, as indeed reported by Reinstadler et al. (2021) in Austria, but it comes also from several products which were proved to be consumed to a higher extent at home during the lockdown, such as coffee, tea, soft drinks, chocolate, etc. (Scacchi et al., 2021).

5. Conclusions

The present study aimed at investigating if the COVID19 restrictions caused a change in the OMPs consumption rate by using the WBE methodology. According to this, the aim was achieved by monitoring the influent concentrations of 10 target OMPs in the inlet of 2 full-scale WWTPs chosen as representative of different sizes and characteristics. These concentrations were then compared with those measured before the start of the pandemic.

The statistical analysis of the collected data showed that there was a general increase during the COVID19 Restrictions period in the consumption rate (expressed as Population Normalized Load, PNL) of OMPs: particularly of the illicit drug BEG, the antibiotics TMT, SMX and SDZ, the anticonvulsant agent CBZ and above all of CAF. These increases can be related to the changes in the habits and health/mental state of the population due to the pandemic, as very well represented by the statistical significant changes in the PNL of MET.

The impact of the pandemic in terms of WWTP performance was more relevant for some OMPs (e.g. CBZ) and only in the WWTP with the lower treatment capacity; nonetheless, the quality of the treated effluent changed only slightly. Therefore, the bigger the size of the plant, the higher the resilience capacity versus changes in the pollutant released load.

About the application of the WBE approach, despite the limited data due to the relatively short monitoring period, it was confirmed to be a
valid and easy tool to monitor the impact of COVID-19 restrictions on the habits of the population. Since the pandemic, unfortunately, still seems to be far to be concluded, the WBE analysis should be included as a regular monitoring activity.

CRediT authorship contribution statement

Di Marcantonio: Conceptualization, Methodology, Formal analysis, Visualization, Writing - Original Draft. Chiavola: Conceptualization, Validation, Writing - Review & Editing. Cecchini: Project administration. Ceci: Resources. Spizzirri: Project administration. Boni: Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sciotenv.2021.152327.

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