Monitoring of changes in illicit drugs, alcohol, and nicotine consumption during Ramadan via wastewater analysis

Evsen Yavuz Guzel

Received: 5 January 2022 / Accepted: 11 July 2022 / Published online: 18 July 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
Illicit drug use is a global problem imposing social, economic, and health burdens on society. Wastewater-based epidemiology is an approach based on calculating the consumption of substances in the target population by analyzing the concentrations of human metabolic excretion products of licit and illicit substances in wastewater. This study estimated the changes in illicit drugs (cocaine, amphetamine, methamphetamine, ecstasy (3,4-Methylenedioxymethamphetamine), heroin, and marijuana (THC)), alcohol, and nicotine consumption in Adana Province during Ramadan compared to normal periods using wastewater-based epidemiology. An overall decrease was observed during the Ramadan Period, most strongly for ecstasy (29%) followed by heroin (19%). For cocaine, the variation was the slightest (8.6%). The differences were statistically significant for ecstasy, heroin, nicotine, and alcohol but not for cocaine, amphetamine, methamphetamine, and marijuana. This study is the first to show changes in the use of illicit drugs, alcohol, and nicotine under the influence of religious beliefs. In addition, there is limited data about illicit drugs, alcohol and nicotine abusers/users in Ramadan. This study provides information on the literature on this subject.

Keywords Wastewater-based epidemiology · Ramadan · Illicit drugs · Nicotine · Alcohol · Adana Province

Introduction
Illicit drug use is a global problem and a social, economic, and health burden on society (Castiglioni et al. 2006). Consumption of illicit drugs, alcohol, and nicotine in cities or regions is often monitored through questionnaires, patient medical records, and police reports (Mackuľak et al. 2019). Wastewater-based epidemiology (WBE) is an increasingly popular approach to providing information on drug use and abuse due to its objectivity, cost-effectiveness, potential to increase data accuracy, and ability to reveal near real-time data (Thomas et al. 2012; Ort et al. 2014; van Wel et al. 2016a, b; Lorenzo and Picó 2019; Verovšek et al. 2020). WBE is based on identifying human metabolic excretion products (biomarkers) of licit and illicit drugs in wastewater (Zuccato et al. 2005; Zarei et al. 2020). It also allows tracking of temporal variations in drug consumption to identify trends and compare drug use across cities, regions, and countries (Daglioglu et al. 2019; Verovšek et al. 2020). However, data obtained by these methods may be affected by subjective factors (sampling, chemical analysis, stability of biomarkers in wastewater, limitations in back-calculation (e.g., calculating population size)).

Since its first implementation by Zuccato e al. (2005), WBE has been continuously developed and improved (Castiglioni et al. 2013). For instance, in 2012, a group of scientists supported by the European Monitoring Center for Drugs and Drug Addiction (EMCDDA) and the European Cooperation in Science Technology (COST) program founded the Sewage analysis CORe group (SCORE) to bring experts together to discuss, develop and standardize the WBE approach (EMCDDA 2016). In 2020, studies covering 82 cities and 18 countries in the European Union including Adana in Turkey were carried out (EMCDDA 2021).

There are various studies on the assessment of illicit drugs, alcohol, and nicotine consumption in countries such as China (Gao et al. 2017), Canada (Metcalfe et al. 2010), Greece (Gatidou et al. 2016), and Finland (Kankaanpää et al. 2016) via WBE. In Turkey, such studies have gained
momentum in the last 5 years (Daglioglu et al. 2019, 2021; Mercan et al. 2019; Guzel et al. 2020; Asicioglu et al. 2021; Kuloglu et al. 2021). Likewise, WBE has been used to investigate changes in using illicit drugs, alcohol, and nicotine on various occasions (festivals, special events, COVID-19 pandemic period, etc.) (Mackul’ak et al. 2015; van Wel et al. 2016a; Mackuľak et al. 2019; Benaglia et al. 2020; Bijlsma et al. 2020). Benaglia et al. (2020), in their study comparing the Australian festival with the Swiss Festival, reported that the number of illicit drugs observed by wastewater analysis was consistent with the drug seizure statistics (Benaglia et al. 2020). Meanwhile, another study conducted on wastewater collected in 6 festivals in Europe reported that the most frequently detected drugs were cocaine, ecstasy, cannabis, and ketamine (Bijlsma et al. 2020). During the COVID-19 pandemic, a study conducted in the Austrian state of Tyrol stated that the consumption of recreational drugs (COC and MDMA) decreased during the quarantine process (Reinstadler et al. 2021). Finally, another study conducted during the period of lockdown in the COVID-19 pandemic in European cities reported that ecstasy levels decreased by 50% compared to previous years (Been et al. 2021). Likewise, Ramadan was selected in the current study as the sampling period since it covers a one-month-long period, which is important for Muslims in terms of religion. During Ramadan, the ninth month of each year on the Islamic calendar, adult Muslims must refrain from consuming any food, drinks, or oral medication from sunrise to sunset (Aveyard et al. 2011; Hershkop and Bisharat 2020) and fast for 1 month as a part of their beliefs. Moreover, the month of Ramadan is a period during which Muslims are expected to manifest that they have control over their physical desires (Çelen 2014). Since Ramadan can occur in any of the four seasons, the fasting time varies between 11 and 18 h per day, depending on sunrise and sunset (Aslam and Assad 1986). Despite the common practice of fasting, Ramadan-specific customs, lifestyles, and social habits may vary among Islamic countries (Aadil et al. 2004). Turkey is also among those countries with Islamic culture since most of the population is Muslim, as referred to in the European Commission report (European Commission (EC) 2019).

The drugs included in the study were cocaine (COC), amphetamine (AMPH), methamphetamine (METH), ecstasy (3,4-methylenedioxymethamphetamine (MDMA)), heroin (HER), marijuana (THC), alcohol (ethanol), and nicotine. However, some of these were investigated through their metabolites, for instance; benzoylecgonine (BE) for COC, morphine (MOR) for HER, 11-nor-9-carboxy-Δ9-tetrahydrocannabinol (THC-COOH) for THC, ethyl sulfate (EtS) for alcohol, and cotinine for nicotine. To the best of our knowledge, the present study aiming at estimating the consumption of these 6 illicit drugs, alcohol, and nicotine is the first to show changes in their consumption during Ramadan by WBE.

Materials and methods

Standards and materials

BE, AMPH, METH, MDMA, MOR, THC-COOH, and their deuterated analogues used as internal standards (BE-d3, MOR-d3, THC-COOH-d3, MDMA-d5) were purchased from Lipomed (Arlesheim, Switzerland). EtS and EtS-d5 were obtained from Restek (Bellefonte, PA, USA). Cotinine and cotinine-d3 were purchased from Toronto Research Chemicals (TRC) (Ontario, Canada). Oasis HLB cartridges (6 mL/500 mg) were obtained from Waters Corporation (Milford, MA, USA). Glass-fiber filters (Whatman® glass microfiber filters, Grade GF/F, 0.7 μm) were purchased from Merck, (Darmstadt, Germany) as well as ammonium acetate, liquid chromatography grade methanol, ultrapure water, acetonitrile, and acetic acid (98 % purity).

Sampling period and location

Adana Province is the sixth-largest province of Turkey with a population of 2.2 million. In 2019, when this study was conducted, Ramadan lasted from Monday, May 6, to Monday, June 3. Samples were collected from Seyhan wastewater treatment plant (WWTP), the biggest in Adana serving approximately 1,151,000 people, for 1 week during Ramadan (21–27 May 2019) and 1 week after Ramadan as a normal week (11–17 June 2019). The average WWTP influent flow rate was 164,600 m3/day during the sampling period. The real daily flow rates were used for back-calculation. The flow rates were 151347.7 ± 23780.2 m3/day for Ramadan week, and 177798.7 ± 6886.3 m3/day for normal week.

Wastewater sampling

Composite 24-h influent samples were collected for 7 days starting on Tuesday of each week at 09.00 h and transferred to the laboratory in an icebox (< 4 °C). Wastewater samples of 100 mL were taken every half hour using an automatic sampler (ASP-Station 2000, vacuum system RPS20 Endress+Hauser, Reinach, Switzerland) into 250 mL polyethylene terephthalate (PET) bottles. The samples were stored in a freezer at – 20 °C, and analysis was completed within 48 h.
Analytical procedure and data treatment

Sample preparation and extraction

The samples were filtered with 0.7 μm glass-fiber filters and an internal standard mix containing cotinine-d₃ (2 ng/L), and individual deuterated internal standards (20 ng/L) of each drug were added to water samples that were passed through Oasis HLB cartridges. The extraction methods for the illicit drug analysis, and alcohol (EtS) and nicotine (cotinine) analysis were used according to Daglioglu et al. (2019), Daglioglu et al. (2020), and Guzel et al. (2020). The accuracy and reliability of the sample preparation and liquid chromatography-mass spectrometry (LC-MS/MS) method used in this study have been confirmed by interlaboratory studies of the SCORE group for quality control.

Instrumental analysis

Chromatographic analyses were carried out by LC-MS/MS (CBM-20A LC equipped with SIL-20A/HT automatic sampler and 8030 mass spectrometer, Shimadzu, Kyoto, Japan). The same method was used for the analysis of illicit drugs and cotinine. Aliquots of 10 μL were injected and separated by gradient chromatography at a flow rate of 0.4 mL/min at 40 °C using a pentfluorophenylpropyl (PFPP) column (50 mm × 2.1 mm, 5 μm) (Restek Allure®, Bellefonte, PA, USA). The gradient program was component A (10 mmol/L ammonium formate in ultrapure water) plus 5% B (methanol) maintained for 0.1 min, linearly increased to 95% B in 10 min, isocratic for 5.0 min, then returned to the initial conditions in 0.05 min, and equilibration for 4.95 min; total run time was 20 min. Oven, desolvation line, and heat block temperatures were, respectively, 40 °C, 250 °C, and 400 °C. Detector and interface voltages are 1.88 and 4.5 kV. Electrospray ionization in the positive polarity (ESI+) and multiple reaction monitoring were used for quantitative mass spectrometric analysis.

EtS was separated chromatographically using a biphenyl column (100 mm × 2.1 mm, 2.7 μm) (Restek Raptor®, Bellefonte, PA, USA). Injection volume was 10 μL, column temperature 30 °C, and flow rate of 0.4 mL/min at a gradient program of A (ultrapure water with 0.1% acetic acid) and 5% B (acetonitrile) for 1 min, 35% B for 2.5 min, returning to 5% B at 2.5 min, and 5.5 min for equilibration; total run time was 5.5 min. EtS was analyzed in the negative ionization mode (ESI−).

Specific MS parameters such as fragmentor voltage and collision energies (CE) were optimized. The selected fragment ions and CE used for the instrumental analysis are shown in Table 1 including retention times, calibration ranges, and limits of quantitations (LOQs) for all target analytes. Limits of detections (LODs) and LOQs of target substances have been determined using US Environmental Protection Agency (USEPA 2016). MeOH was injected before each sequence. In addition, after every 20 samples, internal quality control samples were analyzed. This procedure was applied to analyze illicit drugs, nicotine, and alcohol biomarkers.

Extraction efficiency, accuracy, precision, and matrix effect studies were conducted with water at different concentration levels for each analyte by spiking illicit drugs at

| Drug abbreviation | Ret. time (min) | Calibration range (ng/L) | LOQ (ng/L) | Precursor (m/z) | Product-1 (m/z) | CE-1 (V) | Product-2 (m/z) | CE-2 (V) |
|-------------------|-----------------|--------------------------|------------|-----------------|----------------|---------|----------------|---------|
| EtS               | 3.5             | 100–100000               | 100        | 125.1           | 97.0           | 17      | 79.9           | 30      |
| COT               | 4.3             | 500–20000                | 500        | 177.0           | 53.0           | −47     | 80.0           | −25     |
| AMPH              | 8.7             | 5–200                    | 5.2        | 136.1           | 91.1           | −20     | 119.1          | −15     |
| METH              | 9.5             | 1–200                    | 1.4        | 150.1           | 91.1           | −20     | 119.1          | −15     |
| MDMA              | 9.7             | 2–200                    | 2.9        | 194.1           | 105.1          | −23     | 135.1          | −21     |
| MOR               | 4.9             | 1–200                    | 1.6        | 286.1           | 165.1          | −42     | 153.2          | −45     |
| THC-COOH          | 9.0             | 5–200                    | 5.2        | 345.3           | 299.2          | −20     | 193.1          | −27     |
| BE                | 5.1             | 2–200                    | 2.5        | 290.1           | 168.1          | −19     | 105.1          | −30     |
| EtS-d₅            | 3.5             | 130.0                    | 98.0       | 19              | 80.0           | 19      | 80.0           | 28      |
| COT-d₃            | 4.2             | 180.0                    | 80.0       | −26             | 101.0          | −26     | 101.0          | −25     |
| BE-d₃             | 5.0             | 292.6                    | 171.1      | −21             | 108.1          | −21     | 108.1          | −48     |
| MOR-d₃            | 4.6             | 289.2                    | 165.0      | −43             | 201.1          | −43     | 201.1          | −28     |
| MDMA-d₅           | 8.9             | 199.1                    | 165.1      | −13             | 135.1          | −13     | 135.1          | −23     |
| THC-COOH-d₃       | 9.2             | 348.1                    | 330.2      | −16             | 302.2          | −16     | 302.2          | −22     |

min minute, V voltage, EtS ethyl sulfate, COT cotinine, AMPH amphetamine, METH methamphetamine, MDMA 3,4-methylenedioxymethamphetamine, MOR morphine, THC-COOH 11-nor-Δ9-THC carboxylic acid, BE benzoylecgonine
50, 150, and 250 ng/L; COT at 1000, 3000, and 5000 ng/L; and EtS at 1000, 5000, and 25,000 ng/L into tap water and wastewater samples. Analyses at each concentration level were repeated six times. Obtained results of non-spiked water samples were subtracted before recovery calculations. The standard deviation (SD), relative standard deviation, and recovery values of the above-mentioned repeatability studies were calculated. Method recoveries were in the range of 85–114% for illicit, nicotine, and EtS. The accuracy was 91.5–121% and the precision was not greater than 22.1% for intraday and interday measurements. The matrix effects of illicit drugs at 50, 150, and 250 ng/L; COT at 1000, 3000, and 5000 ng/L; and EtS at 1000, 5000, and 25,000 ng/L in tap water were in the range of 86–108% for all analytes. No marked carry-over was observed for all of the analytes. LODs for illicit drugs were estimated between 0.5 and 2.5 ng/L; for EtS 30 ng/L and cotinine 10 ng/L. The method’s correlation coefficients were higher than 0.99. Three levels of quality control (QC) samples (50, 150, and 250 ng/L for illicit drugs; 1000, 3000, 5000 ng/L for cotinine; 1000, 5000, and 25,000 ng/L for EtS) were prepared which were spiked with deuterated internal standards. Method validation parameters were given for all spiking levels in Table S1.

**Data analysis and back-calculations**

The consumption of target substances was back-calculated considering concentrations of biomarkers, wastewater flow, the size of the population served by the WWTP, and applying a correction factor regarding human metabolism. Illicit drugs, nicotine, and alcohol consumption were back-calculated using the concentrations (Table S2) of the parent drug (AMPH, METH, and MDMA) or metabolite (BE for COC, MOR for heroin, THC-COOH for THC, COT for nicotine, and EtS for ethanol) in wastewater, the daily average flow rate of WWTPs (L/day) (Table S3), and correction factors (COC: 3.59, AMPH: 3.3, METH: 2.3, MDMA: 1.5, HER: 3.04, THC-COOH: 152, nicotine: 3.3, and alcohol: 3320) (van Nuijs et al. 2011; Castiglioni et al. 2015; van Wel et al. 2016a; Mastroianni et al. 2017). The amount of therapeutic morphine was obtained and subtracted for heroin back-calculations (van Nuijs et al. 2011). Since morphine amount metabolized from codeine was about 10% of codeine dose (Bowery 2007), it was overlooked in this study. The amount of therapeutic morphine used in Adana Province during the sampling period, obtained from the Provincial Health Directorate, was 0.004 g/day. The back-calculation equations of Daglioglu et al. (2021) were used for illicit drugs, and Guzel et al. (2020) for nicotine and alcohol. With the data obtained from the Turkish Statistical Institute (TUIK), the estimated consumption per capita has been adjusted for the age range of 15–64. The average number of cigarettes smoked by 1000 people per day was calculated using the average amount of nicotine absorbed by the body during smoking (1 mg (Hukkanen et al. 2005; Koob and Le Moal 2006)). Following, back calculation results for nicotine were stated as mg/day/1000 inhabitants (or piece of cigarette/day/1000 inhabitants); for COC, AMPH, METH, HER, MDMA, THC-COOH were stated as mg/day/1000 inhabitants. Finally, alcohol was expressed as mL/day/1000 inhabitants.

**Statistical methods**

Statistical analysis was performed using IBM SPSS Statistics Version v25.0 (Armonk, NY: IBM Corp.). One-Sample Kolmogorov-Smirnov test was used to determine the normality of the data. Wilcoxon signed-rank test or T test were applied depending on the normal distribution to investigate the changes between normal and Ramadan periods. One-way ANOVA or Kruskal-Wallis test were used to compare the means of more than two groups, and two-way ANOVA was used to compare the means of multiple group variables when applicable (p < 0.05).

**Results and discussion**

**Illicit drugs use during normal week and Ramadan**

Figure 1 shows the per capita illicit drug consumption during the normal week and Ramadan. All illicit drugs were detected in all samples. Table 2 shows the mean, standard deviation, and minimum and maximum values of illicit drugs consumption measured during the normal week and Ramadan. Average estimated consumption during the normal week and during Ramadan were respectively calculated as 21 mg/day/1000 inhabitants and 19 mg/day/1000 inhabitants for COC; 8.9 mg/day/1000 inhabitants and 8.2 mg/day/1000 inhabitants for AMPH; 8.5 mg/day/1000 inhabitants and 7.6 mg/day/1000 inhabitants for METH; 46 mg/day/1000 inhabitants and 37 mg/day/1000 inhabitants for AMPH; 46 mg/day/1000 inhabitants and 37 mg/day/1000 inhabitants for MDMA; and 7187 mg/day/1000 inhabitants and 5271 mg/day/1000 inhabitants for THC. The trend is similar to all illicit drugs, with a decrease in consumption observed during Ramadan.

In the present study, the highest decrease during the Ramadan was for MDMA with 29%. The consumption of MDMA was between 67 and 109 mg/day/1000 inhabitants in the normal week and between 39 and 76 mg/day/1000 inhabitants during Ramadan. A significant change was noted for MDMA during the Ramadan (p value: 0.009). When the daily MDMA consumption estimate in this study was examined, it was determined that the usage on Friday was lower than on the other days in both sampling periods (normal week and Ramadan). Referred to as the party drug, MDMA
is used in higher amounts on weekends (Vuori et al. 2014). Estimated consumption of MDMA was reported as 130 mg/day/1000 inhabitants in Adana province in 2016–2017 (Daglioglu et al. 2019). MDMA values determined in both sampling periods in Adana Province are less than the estimated consumption determined in Greece (530 mg/day/1000 inhabitant) (Gatidou et al. 2016) and higher than the study conducted in China (1.5 mg/day/1000 inhabitant) (Khan et al. 2014).

COC, the third least consumed substance in Adana, was observed to range between 14 and 25 mg/day/1000 inhabitants in the normal week and between 15 and 23 mg/day/1000 inhabitants during Ramadan. The least change in Ramadan was detected for COC (8.6% reduction), which is not statistically significant (p value: 0.383). In a study conducted in 11 provinces in Turkey in 2020, the mean estimated COC consumption was reported as 14.07 mg/day/1000 inhabitants (Daglioglu et al. 2021). Although

![Fig 1](image-url) The weekly pattern of consumption estimates for illicit drugs during Ramadan and a normal week (note that the y-axis is different for each compound)

| Illicit Drug | Sampling period | Per capita consumption estimates (mg/day/1000 inhabitant) | Mean ± SD | Min–Max |
|--------------|-----------------|----------------------------------------------------------|-----------|---------|
| COC          | Normal week     | 21 ± 3.9                                                 | 14–25     |
|              | Ramadan         | 19 ± 2.7                                                 | 15–23     |
| AMPH         | Normal week     | 8.9 ± 1.3                                                | 6.8–11    |
|              | Ramadan         | 8.1 ± 0.9                                                | 6.6–9.2   |
| METH         | Normal week     | 8.5 ± 1.8                                                | 5.9–11    |
|              | Ramadan         | 7.5 ± 1.1                                                | 6.2–9.3   |
| HER          | Normal week     | 46 ± 6.6                                                 | 37–58     |
|              | Ramadan         | 37 ± 6.3                                                 | 27–45     |
| MDMA         | Normal week     | 84 ± 15                                                  | 67–109    |
|              | Ramadan         | 60 ± 12                                                  | 39–76     |
| THC          | Normal week     | 7187 ± 1973                                              | 4321–9579 |
|              | Ramadan         | 5271 ± 1203                                              | 3457–7156 |
estimated COC consumption was higher than observed in China (2.8 mg/day/1000 inhabitant) (Khan et al. 2014) and Finland (3.5 mg/day/1000 inhabitant) (Kankaanpää et al. 2016), it was lower than in many other cities (Gatidou et al. 2016; Mastroianni et al. 2017; Foppe et al. 2018; Mercan et al. 2019; Asicioglu et al. 2021).

In this study, METH was the least consumed illicit drug (METH mean value = 8.1 mg/day/1000 inhabitant) followed by AMPH. It was determined that the estimated consumption of AMPH and METH decreased quantitatively during Ramadan. Nevertheless, this decrease was determined to be statistically not significant (AMPH (p value: 0.165), METH (p value: 0.338)). In the study by Daglioglu et al. (2020) in Turkey, the mean METH was 34.5 mg/day/1000 inhabitants. When the relevant studies in the literature were investigated, the highest AMPH consumption was measured as 1537 mg/day/1000 inhabitants in a study conducted in 19 cities in Europe (Thomas et al. 2012). The AMPH values obtained in the present study, which were 8.9 mg/day/1000 inhabitants in the normal week and 8.2 mg/day/1000 inhabitants in Ramadan, were well below the estimated consumption observed in many other studies (41.8 mg/day/1000 inhabitant (Asicioglu et al. 2021), 61.4 mg/day/1000 inhabitant (Mercan et al. 2019), 722.5 mg/day/1000 inhabitant (Foppe et al. 2018), 90 mg/day/1000 inhabitant (Mastroianni et al. 2017)).

It was observed that estimated HER consumption decreased statistically significantly during Ramadan compared to the average of a normal week (37 mg/day/1000 inhabitant; 46 mg/day/1000 inhabitant respectively) (p value: 0.025). Daglioglu et al. 2021 previously estimated HER consumption as 42 mg/day/1000 inhabitants. Likewise, Daglioglu et al. 2019 estimated HER consumption of 31 mg/day/1000 inhabitants in Adana. When mean values of these studies for Adana were compared to values observed in the current one, there was an increasing trend in HER use. In the current study, the average amount of HER use is well below the reported values for the USA (2495 mg/day/1000 inhabitant) (Foppe et al. 2018), yet above the value obtained in Costa Rica (14 mg/day/1000 inhabitant) (Causanilles et al. 2017).

THC was the most frequently used illicit drug, with an average of 7187 ± 1973 mg/day/1000 inhabitants in the normal week and 5271 ± 1203 mg/day/1000 inhabitants during Ramadan. There was no statistically significant difference in the consumption of marijuana (p value: 0.085) during Ramadan. Marijuana, originating primarily from western Balkans or Morocco, is Turkey’s most frequently seized drug (EMCDDA 2019). Regarding another study in Turkey considering THC consumption, the highest figures were observed predominantly in summer in Gaziantep (another city near Adana). At the same time, it was the fall in Adana during which marijuana consumption was relatively high (Daglioglu et al. 2021).

### Nicotine and alcohol use during normal week and Ramadan

The nicotine metabolite cotinine and the alcohol metabolite EtS were measured in all samples. The average estimated nicotine consumption in a normal week was 2811 mg/day/1000 inhabitants and during Ramadan it was 2119 mg/day/1000 inhabitants. Regarding alcohol, the consumption in a normal week was 4727 mL/day/1000 inhabitants and 3502 mL/day/1000 inhabitants during Ramadan. Table 3 shows the mean, standard deviation, minimum and maximum alcohol (ALC) and nicotine (NIC) consumption values during the normal week and Ramadan.

Assuming that a single cigarette contains 1 mg of nicotine, it was found that 2.8 cigarettes/person/day were smoked in a normal week, decreased to 2.1 cigarettes/person/day in Ramadan. Turkey Tobacco and Alcohol Market Regulatory Authority (TAPDK) 2019 sales data indicate daily cigarette consumption per person of 2.1 cigarettes. While the average of tobacco use obtained in this study was similar to TAPDK data, it was lower than the value of 4.7 cigarettes reported by the Global Adult Tobacco Survey in 2015 (Asma et al. 2015).

In 2015, the per capita annual alcohol consumption in Turkey was 1.4 L of pure alcohol, and according to 2010 World Health Organization (WHO) data, alcoholic beverage consumption in Turkey was reported to account for approximately one-third of the world average (Buzrul 2016). In this study, the estimated annual alcohol consumptions per person (+ 15 age) were 1.3 L for Ramadan and 1.7 L for normal week. In a study conducted between 2016 and 2017 using WBE in Adana, the annual estimated alcohol consumption per person (+ 15 age) was 1.5 L (Daglioglu et al. 2020), while in 2019, it was 1.8 L (Guzel et al. 2020).

In Fig. 2, there was a 26% reduction in alcohol consumption and 25% in nicotine consumption per person during Ramadan compared to the regular week. While there was no significant change for illicit drug use on Friday.

| Table 3 | Per capita consumption estimates of nicotine and alcohol |
|---------|--------------------------------------------------------|
| **Sampling period** | **Per capita consumption estimates** | **Mean ± SD** | **Min-Max** |
| **NIC (mg/day/1000 inhabitant)** | Normal week | 2811 ± 257 | 2449–3164 |
| | Ramadan | 2119 ± 310 | 1435–2372 |
| **ALC (mL/day/1000 inhabitant)** | Normal week | 4727 ± 633 | 4267–6100 |
| | Ramadan | 3502 ± 772 | 2113–4522 |
during Ramadan, a significant change was observed in alcohol and nicotine use (Fig. 2). Similarly, in the study of Çelen (2014), it was found that the month of Ramadan was associated with lower alcohol use. Similarly, when the literature was reviewed, it was found that there was an inverse relationship between church attendance and excessive drinking behavior (Michalak et al. 2007). Friday is considered a holy day for Muslims, and praying as a community is particularly common. During Ramadan, a time when Muslims give extra importance to worship, nicotine and alcohol use decreases even more on Fridays.

In the current study, the average estimated consumption of nicotine (2811 mg/day/1000 inhabitants) and alcohol (4727 mL/day/1000 inhabitants) detected during a normal week was found to be lower than the amounts observed in previous studies conducted in Adana (Daglıoğlu et al. 2020). In a study on alcohol consumption conducted in Turkey, the average estimated consumption varied from 1687.8 to 5657.8 mL/day/1000 inhabitants (Guzel et al. 2020) with an average of 4865.8 mL/day/1000 inhabitants. In the same study, nicotine consumption in Turkey varied from 987 to 4281 mg/day/1000 inhabitants, and the average was 2911.5 mg/day/1000 inhabitants.

In the study of Ghouri et al. (2006), it was reported that smoking would probably decrease during Ramadan, as smokers would not be able to smoke during the fasting period, that is, during the daylight. Studies reported that the onset of Ramadan was used as an incentive to encourage stopping smoking since obligatory non-smoking during Ramadan could cause many regular smokers to quit (Ghouri et al. 2006; Aveyard et al. 2011; Hershkop and Bisharat 2020). This study determined that nicotine use decreased in Ramadan, which confirms the results of the previous studies. There is no study reporting the number of fasting people in Adana province. Studies show that, during Ramadan, Muslim patients arbitrarily change their prescription drug regimen without any medical consultation (Aslam and Assad 1986; Aadil et al. 2004). This study, which compared the use of illicit drugs, alcohol, and nicotine, showed that the use of all these substances decreased during Ramadan.

Uncertainties and limitations of the study

Studies using the WBE approach have some uncertainties and limitations, such as sampling, chemical analysis, stability of biomarkers in wastewater, and limitations in
back-calculation (e.g., calculating population size) (Mastroianni et al. 2017). The standard uncertainties and limitations for biomarkers were instrumental measurement (i.e., errors in flowmeter measurement, calibration errors), real-time population estimation, the significant variance of nicotine among each cigarette (0.4–1.2 mg) in different brands, and differences in the excretion factor due to influences of gender, diet, enzymes, age, and drug usage. Therefore, it should not be overlooked that the population of Adana does not consist of only Muslims. The aim of this study, the variations in Ramadan was based on the fact that Turkey is among the countries with a predominantly Muslim population. Each of these limits is likely to affect per capita substance consumption calculations. Nonetheless, WBE is of paramount importance in profiling drug consumption in real-time and monitoring changing trends, where other methods are unavailable.

Conclusions

To sum up, we observed a significant decrease in MDMA, HER, nicotine, and alcohol consumption during Ramadan compared to normal week. However, there was no difference in COC, AMPH, METH, and THC-COOH consumption. Also, the study showed the effectiveness of wastewater epidemiology as a method for evaluating the consumption of illicit drugs, alcohol, and nicotine, particularly its usefulness in monitoring swiftly changing trends during periods such as Ramadan or different interests. Finally, this study is the first to show changes in the use of illicit drugs, alcohol, and nicotine under the influence of religious beliefs. In addition, there is limited data about illicit drugs, alcohol and nicotine abusers/users in Ramadan. Finally, this study provides information on the literature on this subject.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-022-22016-w.

Acknowledgements The author would like to thank Asli Atasoy and Ismail Ethem Goren for their valuable technical support in field and laboratory studies. This study was presented as “Best poster” at the conference “Testing Waters 5” (Brisbane, 28 September - 1 October 2021).

Author contribution All of the research, methodology, validation, data curation, original drafting, writing, visualization, and editing were done by the author Eysen Yavuz Guzel.

Funding The author did not receive support from any organization for the submitted work.

Data availability All data generated in this study is found in this manuscript.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The author declares no conflict of interest.

References

Aadil N, Houti IE, Moussamih S (2004) Drug intake during Ramadan. Br Med J 329:778–782. https://doi.org/10.1136/bmj.329.7469.778
Asicioglu F, Kaloglu Genc M, Tekin Bulbul T et al (2021) Investigation of temporal illicit drugs, alcohol and tobacco trends in Istanbul city: Wastewater analysis of 14 treatment plants. Water Res 190:116729. https://doi.org/10.1016/j.watres.2020.116729
Aslam M, Assad A (1986) Drug regimens and fasting during Ramadan: a survey in Kuwait. Public Health 100:49–53. https://doi.org/10.1016/S0033-3506(86)80086-5
Asma S, Mackay J, Song SY, et al (2015) Global adult tobacco survey. http://gatsatlas.org/pdf/mobile/index.html#p=90. Accessed 5 Apr 2021
Aveyard P, Begh R, Sheikh A, Amos A (2011) Promoting smoking cessation through smoking reduction during Ramadan. Addiction 106:1379–1380
Been F, Emke E, Matias J et al (2021) Changes in drug use in European cities during early COVID-19 lockdowns - A snapshot from wastewater analysis. Environ Int 153:106540. https://doi.org/10.1016/j.envint.2021.106540
Benaglia L, Udrisard R, Bannwarth A et al (2020) Testing wastewater from a music festival in Switzerland to assess illicit drug use. Forensic Sci Int 309:1–8. https://doi.org/10.1016/j.forsciint.2020.110148
Bijlsma L, Celma A, Castiglioni S et al (2020) Monitoring psychoactive substance use at six European festivals through wastewater and pooled urine analysis. Sci Total Environ 725. https://doi.org/10.1016/j.scitotenv.2020.138376
Bowery NG (2007) Codeine. xPharm Compr Pharmacol Ref 1–4. https://doi.org/10.1007/B978-0-08055232-3.61504-1
Buzurul S (2016) Alcohol Consumption in Turkey. J Food Heal Sci 2:112–122. https://doi.org/10.3153/jfhs16012
Castiglioni S, Zuccato E, Crisci E et al (2006) Identification and measurement of illicit drugs and their metabolites in urban wastewater by liquid chromatography–tandem mass spectrometry. Anal Chem 78:8421–8429. https://doi.org/10.1021/ac061095b
Castiglioni S, Bijlsma L, Covaci A et al (2013) Evaluation of uncertainties associated with the determination of community drug use through the measurement of sewage drug biomarkers. Environ Sci Technol 47:1452–1460. https://doi.org/10.1021/es302722f
Castiglioni S, Senta I, Borsotti A et al (2015) A novel approach for monitoring tobacco use in local communities by wastewater analysis. Tob Control 24:38–42. https://doi.org/10.1136/tobaccocontrol-2014-051553
Causanilles A, Kinyua J, Ruttkies C et al (2017) Qualitative screening for new psychoactive substances in wastewater collected during
a city festival using liquid chromatography coupled to high-resolution mass spectrometry. Chemosphere 184:1186–1193. https://doi.org/10.1016/j.chemosphere.2017.06.101

Çelen A (2014) Influence of holy month Ramadan on alcohol consumption in Turkey. J Relig Health 54:2122–2133. https://doi.org/10.1007/s10943-014-9875-6

Daglioglu N, Guzel EY, Kilercioglu S (2019) Assessment of illicit drugs in wastewater and estimation of drugs of abuse in Adana Province, Turkey. Forensic Sci Int 294:132–139. https://doi.org/10.1016/j.forscintr.2018.11.012

Daglioglu N, Atasoy A, Asadi A et al (2020) Estimation of alcohol consumption by using wastewater-based epidemiology in Adana Province, Turkey. Environ Sci Pollut Res 27:31884–31891. https://doi.org/10.1007/s11356-020-09056-w

Daglioglu N, Guzel EY, Atasoy A, Gören İE, Daglioglu N (2020) Comparison of community illicit drug use in 11 cities of Turkey through wastewater-based epidemiology. Environ Sci Pollut Res 28:15076–15089. https://doi.org/10.1007/s11356-020-11404-9

EMCDDA (2016) Wastewater analysis and drugs: a European multi-city study. 1–5. https://doi.org/https://www.emcdda.europa.eu/topics/pods/waste-water-analysis

EMCDDA (2019) Turkey country drug report 2019. https://www.emcdda.europa.eu/publications/country-drug-reports/2019/turkey’en

EMCDDA (2021) Perspectives on drugs-wastewater analysis and drugs: a European multi-city study. https://www.emcdda.europa.eu/publications/html/pods/waste-water-analysis_en

European Commission (EC) (2019) Demographic situation: Turkey. https://eacea.ec.europa.eu/national-policies/eurydice/content/population-demographic-situation-languages-and-religions-103_en

Foppe KS, Hammond-Weinberger DR, Subedi B (2018) Estimation of the consumption of illicit drugs during special events in two communities in Western Kentucky, USA using sewage epidemiology. Sci Total Environ 633:249–256. https://doi.org/10.1016/j.scitotenv.2018.03.175

Gao T, Du P, Xu Z, Li X (2017) Occurrence of new psychoactive substances in wastewater of major Chinese cities. Sci Total Environ 575:963–969. https://doi.org/10.1016/j.scitotenv.2016.09.152

Gatidou G, Kinyua J, van Nuijs ALN et al (2016) Drugs of abuse and alcohol consumption among different groups of population on the Greek Island of Lesvos through sewage-based epidemiology. Sci Total Environ 563–564:633–640. https://doi.org/10.1016/j.scitotenv.2016.04.130

Ghouri N, Atcha M, Sheikh A (2006) Public health influence of Islam on smoking among Muslims. BMJ 332. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1360407/pdf/bmj3320029.pdf

Guzel EY, Atasoy A, Gören İE, Daglioglu N (2020) Estimation of alcohol and nicotine consumption in 11 cities of Turkey using wastewater-based epidemiology. Drug Test Anal. https://doi.org/10.1002/dta.2979

Hershkop E, Bisharat B (2020) Ramadan and smoking cessation. Isr Med Assoc J 22:264. https://www.imaj.org.il/Files.UploadPublic/IMAJ0/423/211603.pdf

Hukkainen J, Jacob P, Benowitz NL (2005) Metabolism and disposition kinetics of nicotine. Pharmacol Rev 57:79–115. https://doi.org/10.1124/pr.57.1.3

Kankaanpää A, Ariniemi K, Heinonen M et al (2016) Current trends in Finnish drug abuse: wastewater based epidemiology combined with other national indicators. Sci Total Environ 568:864–874. https://doi.org/10.1016/j.scitotenv.2016.06.060

Khan U, van Nuijs ALN, Li J et al (2014) Application of a sewage-based approach to assess the use of ten illicit drugs in four Chinese megacities. Sci Total Environ 487:710–721. https://doi.org/10.1016/j.scitotenv.2014.01.043

Koob GF, Le Moal M (2006) Nicotine. In: Neurobiology of Addiction. Elsevier, pp 243–287

Kuloglu M, Mercan S, Yayla M et al (2021) Monitoring geographical differences in illicit drugs, alcohol, and tobacco consumption via wastewater-based epidemiology: six major cities in Turkey. Sci Total Environ 797:149156. https://doi.org/10.1016/j.scitotenv.2021.149156

Lorenzo M, Picó Y (2019) Wastewater-based epidemiology: current status and future prospects. Curr Opin Environ Sci Heal 9:77–84. https://doi.org/10.1016/j.coesh.2019.05.007

Macelik T, Grubic R, Gál M et al (2015) Evaluation of different smoking habits during music festivals through wastewater analysis. Environ Toxicol Pharmacol 40:1015–1020. https://doi.org/10.1016/j.etap.2015.10.007

Macelik T, Brandebruvá R, Grenčíková A et al (2019) Music festivals and drugs: wastewater analysis. Sci Total Environ 659:326–334. https://doi.org/10.1016/j.scitotenv.2018.12.275

Mastroianni N, López-García E, Postigo C et al (2017) Five-year monitoring of 19 illicit and legal substances of abuse at the inlet of a wastewater treatment plant in Barcelona (NE Spain) and estimation of drug consumption patterns and trends. Sci Total Environ 609:916–926. https://doi.org/10.1016/j.scitotenv.2017.07.126

Mercan S, Kuloglu M, Tekin T et al (2019) Wastewater-based monitoring of illicit drug consumption in Istanbul: preliminary results from two districts. Sci Total Environ 650:231–238. https://doi.org/10.1016/j.scitotenv.2018.11.345

Metcalfe C, Tindale K, Li H et al (2010) Illicit drugs in Canadian municipal wastewater and estimates of community drug use. Environ Pollut 158:3179–3185. https://doi.org/10.1016/j.envpol.2010.07.002

Michalak L, Trocki K, Bond J (2007) Religion and alcohol in the U.S. National Alcohol Survey: how important is religion for abstention and drinking? Drug Alcohol Depend 87:268–280. https://doi.org/10.1016/j.drugalcdep.2006.07.013

Ort C, van Nuijs ALN, Berset J-D et al (2014) Spatial differences and temporal changes in illicit drug use in Europe quantified by wastewater analysis. Addiction 109:1338–1352. https://doi.org/10.1111/add.12570

Reinstdalger V, Ausweger V, Grabher AL et al (2021) Monitoring drug consumption in Innsbruck during coronavirus disease 2019 (COVID-19) lockdown by wastewater analysis. Sci Total Environ 757:144006. https://doi.org/10.1016/j.scitotenv.2020.144006

Thomas KV, Bijlsma L, Castiglioni S et al (2012) Comparing illicit drug use in 19 European cities through sewage analysis. Sci Total Environ 432:432–439. https://doi.org/10.1016/j.scitotenv.2012.06.069

USEPA (2016) Definition and Procedure for the Determination of the method detection limit, revision 2

van Nuijs ALN, Castiglioni S, Tarcommuic I et al (2011) Illicit drug consumption estimations derived from wastewater analysis: a critical review. Sci Total Environ 409:3564–3577. https://doi.org/10.1016/j.scitotenv.2010.05.030

van Wel JHP, Gracia-Lor E, van Nuijs ALN et al (2016a) Investigation of agreement between wastewater-based epidemiology and survey data on alcohol and nicotine use in a community. Drug Alcohol Depend 162:170–175. https://doi.org/10.1016/j.drugalcdep.2016.03.002

van Wel JHP, Kinyua J, van Nuijs ALN et al (2016b) A comparison between wastewater-based drug data and an illicit drug use survey in a selected community. Int J Drug Policy 34:20–26. https://doi.org/10.1016/j.drugpo.2016.04.003

Verovšek T, Krizman-Matasic I, Heath D, Heath E (2020) Site- and event-specific wastewater-based epidemiology: current status and
future perspectives. Trends Environ Anal Chem 28. https://doi.org/10.1016/j.teac.2020.e00105

Vuori E, Happonen M, Gergov M et al (2014) Wastewater analysis reveals regional variability in exposure to abused drugs and opioids in Finland. Sci Total Environ 487(1):688–695. https://doi.org/10.1016/j.scitotenv.2013.11.010

Zarei S, Salimi Y, Repo E et al (2020) A global systematic review and meta-analysis on illicit drug consumption rate through wastewater-based epidemiology. Environ Sci Pollut Res 27:36037–36051. https://doi.org/10.1007/s11356-020-09818-6

Zuccato E, Castiglioni S, Fanelli R (2005) Identification of the pharmaceuticals for human use contaminating the Italian aquatic environment. J Hazard Mater 122:205–209. https://doi.org/10.1016/j.jhazmat.2005.03.001

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.