



## Prioritization of organic contaminants in a reclaimed water irrigation system using wide-scope LC-HRMS screening

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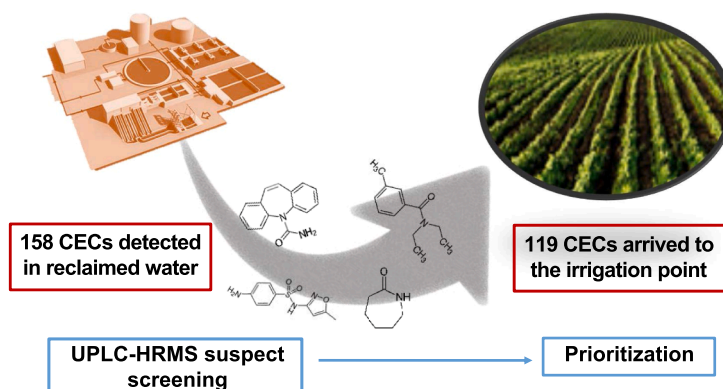
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### HIGHLIGHTS

- A simple and low-cost approach was used for wide-scope analysis of CECs in water.
- CEC footprint was characterized with an LC-HRMS suspect screening method.
- 158 CECs were tentatively identified in water used for crop irrigation.
- Site-specific CECs were prioritized based on their occurrence and ecotoxicity.

### GRAPHICAL ABSTRACT



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### ABSTRACT

A prioritization procedure was developed and implemented at the local level to identify the most relevant organic contaminants of emerging concern (CECs) in an agricultural area irrigated with reclaimed water. A wide-scope screening methodology based on UPLC-HRMS analysis was applied to holistically characterize the CEC

**Abbreviations:** ACN, Acetonitrile; AU, Arbitrary Units; CEC, Contaminants of Emerging Concern; DEET, N, N-Diethyl-meta-toluamide; DSFP, Digital Sample Freezing Platform; EQS, Environmental Quality Standards; ERA, Ecotoxicological Risk Assessment; EtAc, Ethyl Acetate; FWHM, Full Width at Half Maximum; logIE, Ionization Efficiency; MBR, Membrane BioReactor; MEC, Measured Environmental Concentration; MeOH, Methanol; NOEC, No Observed Effect Concentration; NTS, Non-Target Screening; PFAS, PerFluoroAlkyl Substances; PNEC, Predicted No Effect Concentration; RC, Regenerated Cellulose; RTI, Retention Time Index; RQ, Risk Quotient; UPLC-HRMS, Ultra Performance-Liquid Chromatography coupled to High-Resolution Mass Spectrometry; WFD, Water Framework Directive; WRP, Water Reclamation Plant.

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Non-target screening  
Water reuse  
Circular economy  
Micropollutant  
Water analysis  
Agriculture  
Ecotoxicological risk assessment

footprint in water and its spatial and temporal variations. One hundred and fifty-eight CECs, including pharmaceuticals, industrial chemicals, and pesticides, among others, were identified with a confidence level of 2 in the water samples investigated. After water treatment in the reclamation plant and transport within the irrigation channel network, more than a hundred compounds were still detected at the location where water is abstracted for crop irrigation. Compound ecotoxicity and occurrence (semi-quantified concentrations or peak intensity) were the parameters used to prioritize CECs in the water used for irrigation. Results pointed at venlafaxine, O-desmethyl-venlafaxine, galaxolidone, theophylline/paraxanthine, oxybenzone, and N-phenyl-1-naphthylamine, among others, as CECs of concern in the investigated area. This study provides a simple and cost-effective approach to detecting site-specific priority pollutants that could otherwise be overlooked by national or European regulations. The prioritization tool provided contributes to rationally designing monitoring and attenuation programs and efficiently managing water resources, by ensuring the safety of reclaimed water applications.

## 1. Introduction

Climate change-derived effects on water resources and the current unsustainable agricultural system force to irrigate crops or refill aquifers with reclaimed water to fulfill water demand in arid and semi-arid regions worldwide [1]. One of the risks associated with water reuse is related to its content of organic contaminants of emerging concern (CECs), e.g., pharmaceuticals, industrial chemicals, pesticides, etc. The removal of CECs from water is one of the greatest challenges for current wastewater treatment technologies [2]. Water reclamation usually involves an advanced tertiary treatment to improve the removal of nutrients, pathogens, or suspended solids and thereby, reach the minimum quality requirements set in Europe to ensure the safety of water reuse in agricultural irrigation [2,3]. However, these water treatments, which include advanced oxidation processes and/or advanced membrane-based technologies, are also not capable of depleting CEC concentrations in water and provide removal efficiencies specific to each CEC and treatment. Thus water reuse applications are a source of CECs in the environment.

The transfer and accumulation of CECs into soils and crops irrigated with reclaimed water have been demonstrated in both lab-controlled and field studies over the past few years [4–8]. Irrigation with reclaimed water has also been identified as a relevant source of organic CECs in aquifers underneath agricultural fields [9,10]. Despite such evidence, current water reuse legislation in Europe (Regulation 2020/741) [3] has not set parametric values for CECs, and protection against this type of contamination relies on water managers that must elaborate a water reuse risk management plan. This plan aims at preventing potential risks on humans and ecosystems health, by ensuring that this practice will not affect the fulfillment of current European water policy, for instance, regarding the environmental quality standards set for priority substances included in the Directive 2013/39/EU [11] and the consideration of river basin-specific pollutants [12].

The treatment technologies used for water reclamation, as well as the anthropogenic activities that generate the wastewater, which varies in time and space, condition the CECs eventually present in reclaimed water. For instance, as regards the CEC time trends in wastewater, the occurrence of antibiotics or antidepressants may increase during fall and winter [13,14], while that of the insect repellent N, N-Diethyl-meta-toluamide (DEET) may rise during summer [15], in both cases due to increased use of these substances during the corresponding seasons. As for the spatial distribution of CECs, the different usage of DEET among regions is also reflected in its wastewater concentrations [15].

The huge diversity of CECs present in water matrices, which include anthropogenic pollutants and their transformation products, makes the routine monitoring of all of them unfeasible. This calls for the development of prioritization schemes that allow the identification of the most relevant site-specific pollutants so that effective monitoring programs can be conducted. This also supports water managers in their task of protecting human and ecosystem health from CEC pollution. Intensive monitoring and effect-based analysis can be used for CEC prioritization [16]. However, this approach requires a huge collaborative effort to generate sufficient background knowledge in terms of CEC occurrence

and associated environmental risk and usually implies long and extensive monitoring programs, which are costly in terms of human and material resources. Therefore, such a prioritization procedure is not affordable to identify relevant site-specific pollutants at the local scale. On the contrary, its feasibility to define nationwide priority substances was demonstrated in the Slovak Republic, where CEC monitoring and associated risk assessment were conducted in more than 400 sites for 10 years [17].

Prioritization approaches need to be supported by wide-scope screening monitoring methods that allow the characterization of the CEC footprint in the water. Although not a single analytical technology allows the monitoring of the whole spectrum of organic CECs present in water, liquid chromatography coupled with high-resolution mass spectrometry (LC-HRMS) enables the analysis of CECs over a wide range of polarities. Its combination with compound databases and mass spectral libraries allows the implementation of suspect screening workflows, that reveal the most relevant features in a sample and provide information to elucidate their identity. Experimental evidence used for structure elucidation includes accurate mass data of parent and fragment ions, isotopic pattern, and fragmentation pattern. Moreover, the use of retention time prediction models contributes to reducing the number of false positives [35].

In this context, the objectives of this study were i) to develop a simple and low-cost prioritization approach based on LC-HRMS wide-scope screening and CEC toxicity to comprehensively select the most relevant site-specific pollutants, and ii) to apply this approach in a reclaimed water-based irrigation system to identify the most relevant CECs being released with water reuse. Overall, the work performed also aimed at increasing the current knowledge on CEC occurrence in reclaimed water scenarios and supporting decision-making in this field.

## 2. Materials and methods

### 2.1. Reagents and chemicals

All the solvents used were ultra-performance liquid chromatography-mass spectrometry (UPLC-MS) grade. Acetonitrile (ACN) and water for UPLC-HRMS analysis were purchased from Thermo Fisher Scientific Inc. (Waltham, MA, USA). Methanol (MeOH), ethyl acetate (EtAc), and water for sample preparation, formic acid (purity, >98%), and ammonium acetate were obtained from Merck (Darmstadt, Germany). The isotopically labeled standards diflufenican-*d*<sub>3</sub>, bentazone-*d*<sub>7</sub>, linuron-*d*<sub>6</sub>, MCPA-*d*<sub>3</sub>, benzophenone-*d*<sub>10</sub>, imidacloprid-*d*<sub>4</sub>, and terbuthylazine-*d*<sub>5</sub> were purchased from either Merck (Darmstadt, Germany) or Toronto Research Chemicals (Toronto, ON, Canada). Regenerated cellulose (RC) membrane syringe filters (0.2 μm pore size) were supplied by Sartorius Stedim Lab (Stonehouse, UK).

### 2.2. Case study area and sample collection

The study area was located in the Baix Llobregat Agrarian Park (Catalonia), an agricultural area that covers more than 3400 ha and produces over 35,000 tonnes/year of food, mainly horticulture [18].

This area is partially irrigated with reclaimed water from the nearby water regeneration plant (WRP) of Gavà-Viladecans, distributed through a network of irrigation channels (see map in Fig. 1). The treatment capacity of this WRP is 64,000 m<sup>3</sup>/day of wastewater of urban and industrial origin (and a population equivalent of 300,000). In this plant, approximately half of the wastewater undergoes conventional activated sludge (CAS) treatment and the other half is derived to a separate treatment line comprising sand filtration, primary decantation, treatment in two biological reactors with nitrogen and phosphorus removal, six membrane bioreactor (MBR) filtration trains, and final chlorine disinfection for its reclamation. All the water discharged into the irrigation channels is MBR-treated. A scheme of the WRP is provided in Fig. S1 as supporting information [19].

Four locations were sampled in summer 2021 (28<sup>th</sup> July) and winter 2022 (12<sup>th</sup> January) (location details provided in Fig. 1 and Table S1 as supporting information). WRP influent (A) and effluent (B) were collected as 24-h composite samples. Reclaimed water discharged into the channels (C) and water abstracted for irrigation downstream (mix of reclaimed and surface water) (D) were collected as grab water samples (Fig. 1). The flow of reclaimed water discharged at the time of sampling was 22,714 m<sup>3</sup>/day in summer and 13,637 m<sup>3</sup>/day in winter.

### 2.3. Sample pre-treatment

For wide-scope screening of CECs in the water samples, the water was lyophilized and the residue obtained was re-dissolved in a series of solvents. This simple and low-cost sample treatment method allows sample pre-concentration and reduces the loss of compounds that may eventually occur with various extraction approaches [20,21]. Briefly, 500 mL of water was fortified with 125 ng of the isotopically labeled standard compounds (final extract concentration of 50 ng/mL) and frozen for its lyophilization. After freeze-drying, the water sample was sequentially reconstituted in 15 mL of MeOH and 15 mL of EtAc. Then, the organic extract obtained was centrifuged at 4000 rpm for 5 min. The supernatant was evaporated under a soft stream of nitrogen to an approximate volume of 1 mL and reconstituted with MeOH to a final volume of 5 mL. Immediately before UPLC-HRMS analysis, an aliquot of 2 mL of this extract was evaporated to 500  $\mu$ L, diluted with 500  $\mu$ L of UPLC-grade water, and filtrated with an RC syringe filter (0.2  $\mu$ m) (x200-fold concentrated sample) for UPLC-HRMS analysis.

The standard solutions containing the calibrants of the retention time index (RTI) model were prepared by diluting a methanolic concentrated

mixture (1  $\mu$ g/mL) (Tables S2 and S3) with UPLC-grade water in a proportion 1:1 (v/v). A matrix-matched calibration curve to be used for compound semi-quantification was constructed by dissolving appropriate amounts of a methanolic concentrated mixture containing the calibrants for the ionization efficiency model (Table S4) in a pool of all sample extracts. Blank samples were prepared by treating and processing UPLC-grade water aliquots like field samples.

### 2.4. UPLC-HRMS analysis

An Acquity UPLC system from Waters (Milford, MA, USA) coupled to a hybrid quadrupole-orbitrap Q-Exactive mass spectrometer (Thermo Fisher Scientific, San Jose, CA, USA) was used for UPLC-HRMS analysis. For the chromatographic separation, a reversed-phase column Purosphere® STAR RP-18 end-capped Hibar® 150  $\times$  2.1 mm, 2  $\mu$ m (Merck, Darmstadt, Germany) was employed. The injection volume was set to 10  $\mu$ L and the flow rate to 0.3 mL/min. A generic chromatographic gradient was used to achieve an optimal distribution of the wide polarity range of the CECs potentially present in the investigated samples and, hence, high-quality spectral information. This gradient started with 95% of the aqueous mobile phase. After 1 min, a linear organic gradient was initiated and kept for 17 min until reaching 97% of the organic mobile phase. This organic proportion was maintained for 2.5 min and, then, initial conditions were restored in 1 min. Finally, re-equilibration of the chromatographic column was done by maintaining the initial conditions for 3.5 min. In total, the duration of the analytical run was 25 min. HRMS analysis was performed both in positive and negative ionization modes and, depending on this condition, the composition of the mobile phase used for the chromatographic separation was selected. For positive ionization, water and ACN, both with 0.1% formic acid, were used. For negative ionization, water and ACN, both with 5 mM ammonium acetate were used.

The HRMS analysis was performed using a heated electrospray ionization (HESI) source operated in either the negative or positive mode. Ion source conditions were: spray voltage, + 3000 V in positive mode, - 2500 V in negative mode; capillary temperature, 350  $^{\circ}$ C; sheath gas, 40 arbitrary units (AU); auxiliary gas, 10 AU; spare gas, 2 AU; probe heater temperature, 300  $^{\circ}$ C. Nitrogen gas (>99.98%) was used as the sheath, auxiliary and spare gases. HRMS data were acquired in both data-dependent (DDA) and data-independent acquisition (DIA) modes, so that MS<sup>2</sup> data were available for those ions overlooked in the DDA mode. DDA recorded the full scan data over the  $m/z$  range 66.7 –



Fig. 1. Study area next to the Llobregat River delta in Barcelona, Spain, and sampling locations. A) WRP influent, B) WRP effluent, C) discharge of the WRP effluent (reclaimed water) into the irrigation channel network, D) location at the irrigation channel network where water is abstracted for crop irrigation (mixture of reclaimed water and surface water).



1000, which covers the great majority of CECs (full width at half maximum (FWHM) resolution of 70,000 at 200  $m/z$ ) and  $MS^2$  data (FWHM resolution of 17,500 at 200  $m/z$ ) for the five most intense ions with intensity above  $10^5$  counts. A normalized collision-induced dissociation energy (NCE) of 35 was set for the acquisition of  $MS^2$  data, with 0.1 s of ion accumulation. In DIA, MS data were acquired using the *all-ion fragmentation* mode with two NCE: 0 (full scan, FWHM resolution of 70,000 at 200  $m/z$ ) and 35 ( $MS^2$  data, FWHM resolution of 35,000 at 200  $m/z$ ).

For the first campaign, triplicates were analyzed for each sampling point, in positive and negative modes. After their analysis, no appreciable differences in the detected compounds (false positives or negatives) were observed and, thus, replicates were avoided in the following campaign to reduce the time-consuming efforts derived from sample processing.

The solutions containing the RTI model calibrants were also analyzed with the chromatographic settings used in this work in each ionization mode to derive the corresponding calibration curves based on Quantitative Structure-Retention Relationship (QSRR) (Figs. S2 and S3 in supporting information) as described in Alizadeh et al., 2021 [22] and available at <http://rti.chem.uoa.gr/>.

## 2.5. UPLC-HRMS data processing

Both DDA and DIA data were processed using the *Digital Sample Freezing Platform* (DSFP, <https://dsfp.norman-data.eu/>), a software developed within the NORMAN network to archive LC-HRMS data for retrospective evaluation of polar and semi-polar CECs in different environmental matrices [23]. The DSFP performs peak picking (mass error < 5 ppm), componentization of the adducts, isotopes, and in-source fragment peaks for each feature, normalizes the peak retention time, and extracts the corresponding  $MS^2$  data. Peak annotation was based on the *mzCloud* suspect list (S19) [24] available at the Suspect List Exchange database of the NORMAN Network (<https://www.norman-network.com/nds/SLE/>). The *mzCloud* database includes a highly curated spectral library for thousands of CECs, acquired with HRMS-orbitrap analyzers, in most cases, over a wide range of collision energies), which ensures spectral reproducibility for comparison purposes with the experimental data obtained at the various collision energies applied (uploaded into the DSFP separately).

After data processing, the DSFP returned a list of candidates, for which it included the chemical name, structural data, absolute maximum intensity of the observed signals, mass error, predicted retention time, and RTI plausibility (based on the retention time of the standard calibration mixture), and the number of coincident fragments. Then, a manual evaluation of the results was performed to remove false positives, and include additional evidence for compound identification when missing (e.g., isotopic fit, adducts, RTI, spectral fragmentation pattern, etc.). For this purpose, experimental chromatographic and spectral information was revised via *Xcalibur v. 4.1* software (Thermo Fisher Scientific, San Jose, CA, USA). Normalized areas were calculated by dividing the absolute chromatographic peak area of each analyte by the chromatographic peak area of the isotopically-labeled standard (imidacloprid- $d_4$ ).

## 2.6. Semi-quantification of CEC concentrations

Following the methodology recently developed by Alizadeh et al. [25], the concentrations of the CECs detected in the water used for irrigation (D) were semi-quantified for CEC prioritization. The semi-quantification method used is based on the ionization efficiency (logIE) of the CECs during the analysis. For this, matrix-matched calibration curves were constructed within the range of 30–1000  $\mu\text{g/L}$  for various standard calibrants (Table S4) and the reference compound (dichlorvos), using imidacloprid- $d_4$  as the internal standard at a final concentration of 100  $\mu\text{g/L}$ . Then a quantitative structure-activity

relationship (QSAR) model was constructed using the slope ratio between each calibrant and dichlorvos to predict the logIE of a given compound in the sample (Fig. S4). The predicted logIE allows obtaining a calibration curve slope for each compound of interest to estimate its concentration. The calculations were done using an open-access online tool available at <http://trams.chem.uoa.gr/semi-quantification/>.

## 2.7. CEC prioritization

The environmental risk of each tentatively identified compound was assessed by calculating its risk quotient (RQ). For this, the highest concentration semi-quantified for a given compound in the water used for irrigation was compared with its predicted no-effect concentration (PNEC), thereby assessing the worst-case scenario. PNEC values corresponded to the lowest Environmental Quality Standard (EQS) in surface waters in the case of regulated compounds, while toxicity data (experimentally obtained or alternatively, QSAR-predicted) were used for non-regulated CECs. PNEC values were extracted from the NORMAN ecotoxicity (<https://www.norman-network.com/nds/ecotox/lowestPneCSIindex.php>) and INERIS (<https://substances.ineris.fr/fr/>) databases.

The RQ value was used to categorize the risk (Table S5) and prioritize thereby the most environmentally relevant CECs. According to the risk categories established, no risk for aquatic organisms could be expected for RQ values below 0.1, while RQ values between 0.1 and 1, between 1 and 10, and above 10 suggest low, moderate, and high risk, respectively, for exposed organisms [26]. Moreover, considering the large number of CECs present in the water samples, an evaluation of the ecotoxicological risk of the CEC mixture present in the water used for irrigation was also performed, following the concentration addition model described by Backhaus and Faust [27].

## 3. Results and discussion

### 3.1. Characterization of the CEC footprint in the water

After LC-HRMS data processing, a total of 2773 and 2257 candidates were obtained in the summer and winter samples, respectively. Data filtration to remove “naturally occurring” compounds (i.e., chemicals whose origin is natural and, thus, not anthropogenic) and features with less than three fragments matching the spectral database reduced the list of candidates to 723 and 580 for summer and winter, respectively. After the manual evaluation of these candidates, and the rational search of CECs typically found in these water matrices, as reported in the literature, a total of 158 CECs (129 compounds in the four water samples collected in summer and 145 in the four water samples collected in winter) were tentatively identified with a confidence level of 2, following Schymanski's scale [28] (Table 1). This means that the exact mass, the isotopic fit, and the fragmentation pattern matched with those in the spectral libraries used (*mzCloud*, Massbank), and a plausible retention time was also obtained. Tentative identification of most of the features of interest was based on  $MS^2$  spectra done with the evaluation of DDA data. The chromatographic areas obtained for each compound in each sample and sampling campaign are provided as supporting information in Tables S6 (winter) and S7 (summer).  $MS^2$  fragments matching with database information for each compound are also provided as supporting information in Tables S8 (winter) and S9 (summer).

Pharmaceuticals, pesticides, and industrial chemicals were the CEC classes most frequently detected in the investigated waters. More than 50% of the CECs tentatively identified were pharmaceuticals, which is in agreement with the domestic origin of the wastewater. Although antidepressants, anxiolytics, antibiotics, and non-steroidal anti-inflammatories (NSAIDs) were among the most common pharmaceuticals tentatively detected, antihypertensive and antihistaminic drugs, or medicines prescribed for diabetes or epilepsy were also identified. For instance, carbamazepine, one of the most recalcitrant CECs in the environment, was tentatively detected in all the water samples along

Table 1

List of compounds identified with the suspect screening approach, including their exact mass,  $m/z$ , formula, ionization mode, retention time, chemical category, and presence in each sampling campaign.

N°	Compound	Exact mass	$m/z$	Formula	Ion. mode	RT	Category	Campaign
1	1,2-Benzisothiazol-3(2 H)-one	151.0092	152.0170	C <sub>7</sub> H <sub>5</sub> NOS	+	6.56	Industrial chemical	S
2	1,5-Naphthalenediamine	158.0844	159.0922	C <sub>10</sub> H <sub>10</sub> N <sub>2</sub>	+	4.7	Other	S
3	10,11-Dihydro-10,11-dihydroxycarbamazepine	270.1004	271.1077	C <sub>15</sub> H <sub>14</sub> N <sub>2</sub> O <sub>3</sub>	+	6.77	Pharmaceutical	S/W
4	10,11-Dihydro-10-Hydroxycarbamazepine	254.1055	255.1128	C <sub>15</sub> H <sub>14</sub> N <sub>2</sub> O <sub>2</sub>	+	7.38	Pharmaceutical	S/W
5	2-(3,4-Dimethoxyphenyl)– 5-methylamino-2-isopropylvaleronitrile	290.1994	291.2072	C <sub>17</sub> H <sub>26</sub> N <sub>2</sub> O <sub>2</sub>	+	8.04	Pharmaceutical	S/W
6	2(3 H)-Benzothiazolone	151.0092	152.0170	C <sub>7</sub> H <sub>5</sub> NOS	+	8.56	Other	S
7	2-(Methylthio)benzothiazole	181.0020	182.0098	C <sub>8</sub> H <sub>7</sub> NS <sub>2</sub>	+	13.45	Pesticide	S
8	2-Ethyl-1,5-dimethyl-3,3-diphenylpyrrolinium (EDDP)	277.1830	278.1908	C <sub>20</sub> H <sub>23</sub> N	+	9.7	Pharmaceutical	W
9	2-Ethylhexyl diphenyl phosphate	362.1647	363.1725	C <sub>20</sub> H <sub>27</sub> O <sub>4</sub> P	+	17.99	Industrial chemical	S
10	2-Mercaptobenzothiazole	166.9863	167.9941	C <sub>7</sub> H <sub>5</sub> NS <sub>2</sub>	+	10.03	Industrial chemical/ Pesticide	S/W
11	3,3,5,5-Tetramethyl-1-pyrroline N-oxide	141.1154	142.1231	C <sub>8</sub> H <sub>15</sub> NO	+	7.82	Other	W
12	3-Hydroxycotinine	192.0898	193.0977	C <sub>10</sub> H <sub>12</sub> N <sub>2</sub> O <sub>2</sub>	+	1.85	Drug of abuse	S/W
13	4-Androstene-3,17-dione	286.1932	287.2011	C <sub>19</sub> H <sub>26</sub> O <sub>2</sub>	+	12.44	Other	S/W
14	4-Formylaminoantipyrine	231.1007	232.1086	C <sub>12</sub> H <sub>13</sub> N <sub>3</sub> O <sub>2</sub>	+	5.18	Pharmaceutical	S/W
15	4'-Hydroxy-diclofenac/5-Hydroxy-diclofenac	311.0115	312.0193	C <sub>14</sub> H <sub>11</sub> Cl <sub>2</sub> NO <sub>3</sub>	+	11.25	Pharmaceutical	S/W
16	4-Indolecarbaldehyde	145.0527	146.0605	C <sub>9</sub> H <sub>7</sub> NO	+	7.97	Other	W
17	4-Phenylbutyric acid	164.0837	165.0915	C <sub>10</sub> H <sub>12</sub> O <sub>2</sub>	+	10.72	Pharmaceutical	S/W
18	5-Hydroxymeprazole	361.1096	362.1174	C <sub>17</sub> H <sub>19</sub> N <sub>3</sub> O <sub>4</sub> S	+	6.62	Pharmaceutical	W
19	6-Methylthioguanine	181.0422	182.0500	C <sub>6</sub> H <sub>7</sub> N <sub>5</sub> S	+	4.21	Other	S
20	8-Hydroxy-mirtazapine	281.1528	282.1606	C <sub>17</sub> H <sub>19</sub> N <sub>3</sub> O	+	5.83	Pharmaceutical	S
21	8-Hydroxyquinoline	145.0527	146.0605	C <sub>9</sub> H <sub>7</sub> NO	+	6.79	Industrial chemical	S/W
22	Acephylline	238.0702	237.0629	C <sub>9</sub> H <sub>10</sub> N <sub>4</sub> O <sub>4</sub>	-	3.27	Other	W
23	Acetaminophen	151.0633	152.0711	C <sub>8</sub> H <sub>9</sub> NO <sub>2</sub>	+	4.36	Pharmaceutical	S/W
24	Acetaminophen sulfate	231.0201	232.0279	C <sub>8</sub> H <sub>9</sub> NO <sub>5</sub> S	+	3.69	Pharmaceutical	S/W
25	Acetyl sulfamethoxazole	295.0626	296.0704	C <sub>12</sub> H <sub>13</sub> N <sub>3</sub> O <sub>4</sub> S	+	8.11	Antibiotic	S/W
26	Amisulpride	369.1722	370.1800	C <sub>17</sub> H <sub>27</sub> N <sub>3</sub> O <sub>4</sub> S	+	5.95	Pharmaceutical	S/W
27	Amitriptyline	277.1831	278.1909	C <sub>20</sub> H <sub>23</sub> N	+	10.16	Pharmaceutical	S/W
28	Ampyrone/ 4-aminoantipyrine	203.1058	204.1136	C <sub>11</sub> H <sub>13</sub> N <sub>3</sub> O	+	4.26	Pharmaceutical	S/W
29	Atenolol	266.1630	267.1708	C <sub>14</sub> H <sub>22</sub> N <sub>2</sub> O <sub>3</sub>	+	4.01	Pharmaceutical	S/W
30	Azithromycin	748.5085	749.5163	C <sub>38</sub> H <sub>72</sub> N <sub>2</sub> O <sub>12</sub>	+	6.88	Antibiotic	S/W
31	Azoxystrobin	403.1168	404.1246	C <sub>22</sub> H <sub>27</sub> N <sub>3</sub> O <sub>5</sub>	+	13.01	Pesticide	S/W
32	Azoxystrobin acid	389.1011	390.1090	C <sub>21</sub> H <sub>25</sub> N <sub>3</sub> O <sub>5</sub>	+	11.19	Pesticide	W
33	Benzothiazole	135.0142	136.0208	C <sub>7</sub> H <sub>5</sub> NS	+	9.79	Industrial chemical	S
34	Benzoylcegonine	289.1314	290.1392	C <sub>16</sub> H <sub>19</sub> NO <sub>4</sub>	+	6.05	Drug of abuse	S/W
35	Bezafibrate	361.1080	362.1159	C <sub>19</sub> H <sub>20</sub> ClNO <sub>4</sub>	+	11.55	Pharmaceutical	S/W
36	Bisoprolol	325.2253	326.2331	C <sub>18</sub> H <sub>31</sub> NO <sub>4</sub>	+	7.61	Pharmaceutical	S/W
37	Boldenone	286.1932	287.2011	C <sub>19</sub> H <sub>26</sub> O <sub>2</sub>	+	10.75	Other	S/W
38	Boscalid	342.0326	343.0404	C <sub>18</sub> H <sub>12</sub> Cl <sub>2</sub> N <sub>2</sub> O	+	13.24	Pesticide	W
39	Bupropion	239.1076	240.1155	C <sub>13</sub> H <sub>18</sub> ClNO	+	7.71	Pharmaceutical	W
40	Butyropheneone	148.0888	149.0966	C <sub>10</sub> H <sub>12</sub> O	+	13.61	Pharmaceutical	W
41	Caffeine	194.0803	195.0882	C <sub>8</sub> H <sub>10</sub> N <sub>4</sub> O <sub>2</sub>	+	5.18	Other	S/W
42	Caprolactam	113.0840	114.0910	C <sub>6</sub> H <sub>11</sub> NO	+	4.79	Industrial chemical	S/W
43	Carbamazepine	236.0949	237.1027	C <sub>15</sub> H <sub>12</sub> N <sub>2</sub> O	+	9.56	Pharmaceutical	S/W
44	Carbamazepine-10,11-epoxide	252.0899	253.0977	C <sub>15</sub> H <sub>12</sub> N <sub>2</sub> O <sub>2</sub>	+	8.53	Pharmaceutical	S/W
45	Carbendazim	191.0694	192.0773	C <sub>9</sub> H <sub>9</sub> N <sub>3</sub> O <sub>2</sub>	+	4.95	Pesticide	W
46	Carboxy-ibuprofen	236.1048	235.0974	C <sub>13</sub> H <sub>16</sub> O <sub>4</sub>	-	2.8	Pharmaceutical	W
47	Cetirizine	388.1553	389.1632	C <sub>21</sub> H <sub>25</sub> ClN <sub>2</sub> O <sub>3</sub>	+	10.04	Pharmaceutical	S/W
48	Chlorpheniramine	274.1236	275.1315	C <sub>16</sub> H <sub>19</sub> ClN <sub>2</sub>	+	7.18	Pharmaceutical	W
49	Ciprofloxacin	331.1332	332.1410	C <sub>17</sub> H <sub>18</sub> FN <sub>3</sub> O <sub>3</sub>	+	5.91	Antibiotic	S/W
50	Citalopram	324.1637	325.1716	C <sub>20</sub> H <sub>21</sub> FN <sub>2</sub> O	+	9.03	Pharmaceutical	S/W
51	Clopidogrel	321.0590	322.0668	C <sub>16</sub> H <sub>16</sub> ClNO <sub>2</sub> S	+	13.02	Pharmaceutical	W
52	Clopidogrel carboxylic acid	307.0433	308.0512	C <sub>15</sub> H <sub>14</sub> ClNO <sub>2</sub> S	+	6.88	Pharmaceutical	S/W
53	Cocaine	303.1470	304.1548	C <sub>17</sub> H <sub>21</sub> NO <sub>4</sub>	+	7.37	Drug of abuse	S/W
54	Cotinine	176.0949	177.1022	C <sub>10</sub> H <sub>12</sub> N <sub>2</sub> O	+	1.86	Drug of abuse	S/W
55	Coumarin	146.0367	147.0446	C <sub>9</sub> H <sub>6</sub> O <sub>2</sub>	+	9.03	Pharmaceutical	W
56	Cyprodinil	225.1266	226.1344	C <sub>14</sub> H <sub>15</sub> N <sub>3</sub>	+	12.15	Pesticide	W
57	DEET (N, N-Diethyl-meta-toluamide)	191.1310	192.1388	C <sub>12</sub> H <sub>17</sub> NO	+	10.91	Pesticide	S/W
58	Desacetyl-diltiazem	372.1507	373.1585	C <sub>20</sub> H <sub>24</sub> N <sub>2</sub> O <sub>3</sub> S	+	8.1	Pharmaceutical	S/W
59	Desmethyl-citalopram	310.1481	311.1559	C <sub>19</sub> H <sub>19</sub> FN <sub>2</sub> O	+	8.9	Pharmaceutical	S/W
60	Desmethyl-diazepam	270.0559	271.0638	C <sub>15</sub> H <sub>11</sub> ClN <sub>2</sub> O	+	10.4	Pharmaceutical	S/W
61	Dextromethorphan	271.1936	272.2014	C <sub>18</sub> H <sub>25</sub> NO	+	8.55	Pharmaceutical	S/W
62	Dextrorphan/Levorphanol	257.1780	258.1858	C <sub>17</sub> H <sub>23</sub> NO	+	6.57	Drug of abuse	S/W
63	Diazepam	284.0716	285.0794	C <sub>16</sub> H <sub>13</sub> ClN <sub>2</sub> O	+	11.86	Pharmaceutical	S/W
64	Diazinon	304.1010	305.1088	C <sub>12</sub> H <sub>21</sub> N <sub>2</sub> O <sub>3</sub> PS	+	15.35	Pesticide	S/W
65	Dibutyl phthalate	278.1518	279.1596	C <sub>16</sub> H <sub>22</sub> O <sub>4</sub>	+	16.39	Industrial chemical	W
66	Diclofenac	295.0167	296.0245	C <sub>14</sub> H <sub>11</sub> Cl <sub>2</sub> NO <sub>2</sub>	+	13.35	Pharmaceutical	S/W
67	Dicyclohexylamine	181.1830	182.1910	C <sub>12</sub> H <sub>23</sub> N	+	6.97	Industrial chemical	S
68	Dicyclohexylurea	224.1889	225.1967	C <sub>13</sub> H <sub>24</sub> N <sub>2</sub> O	+	11.54	Industrial chemical	S
69	Diethyl phthalate	222.0892	223.0970	C <sub>12</sub> H <sub>14</sub> O <sub>4</sub>	+	12.36	Industrial chemical	W
70	Diltiazem	414.1613	415.1691	C <sub>22</sub> H <sub>26</sub> N <sub>2</sub> O <sub>4</sub> S	+	9.09	Pharmaceutical	S/W

(continued on next page)

Table 1 (continued)

N°	Compound	Exact mass	m/z	Formula	Ion. mode	RT	Category	Campaign
71	Diphenhydramine	255.1623	256.1701	C <sub>17</sub> H <sub>21</sub> NO	+	8.93	Pharmaceutical	S/W
72	Diphenylamine	169.0892	170.0970	C <sub>12</sub> H <sub>11</sub> N	+	14.07	Pesticide	S
73	Diuron	232.0170	233.0248	C <sub>9</sub> H <sub>10</sub> Cl <sub>2</sub> N <sub>2</sub> O	+	11.19	Pesticide	S/W
74	Ecgonine methyl ester	199.1208	200.1281	C <sub>10</sub> H <sub>17</sub> NO <sub>3</sub>	+	1.81	Drug of abuse	S/W
75	Emtricitabine	247.0426	248.0505	C <sub>8</sub> H <sub>10</sub> FN <sub>3</sub> O <sub>3</sub> S	+	3.85	Pharmaceutical	S/W
76	Ephedrine	165.1153	166.1232	C <sub>10</sub> H <sub>15</sub> NO	+	4.65	Drug of abuse	W
77	Epoxiconazole	329.0731	330.0809	C <sub>17</sub> H <sub>13</sub> ClFN <sub>3</sub> O	+	13.11	Pesticide	W
78	Fenofibric acid	318.0658	319.0737	C <sub>17</sub> H <sub>15</sub> ClO <sub>4</sub>	+	13.31	Pharmaceutical	S/W
79	Flecainide	414.1378	415.1456	C <sub>17</sub> H <sub>20</sub> F <sub>6</sub> N <sub>2</sub> O <sub>3</sub>	+	9.17	Pharmaceutical	S/W
80	Fluconazole	306.1040	307.1118	C <sub>13</sub> H <sub>12</sub> F <sub>2</sub> N <sub>6</sub> O	+	6.63	Pharmaceutical/ Pesticide	S/W
81	Flufenamic acid	281.0663	282.0741	C <sub>14</sub> H <sub>10</sub> F <sub>3</sub> NO <sub>2</sub>	+	14.39	Pharmaceutical	S/W
82	Gabapentin	171.1259	172.1337	C <sub>9</sub> H <sub>17</sub> NO <sub>2</sub>	+	4.77	Pharmaceutical	S/W
83	Galaxolidone	272.1776	273.1854	C <sub>18</sub> H <sub>24</sub> O <sub>2</sub>	+	16.48	Other	S/W
84	Hydroxy-bupropion	255.1026	256.1104	C <sub>13</sub> H <sub>18</sub> ClNO <sub>2</sub>	+	6.76	Pharmaceutical	S/W
85	Ibuprofen	206.1306	207.1385	C <sub>13</sub> H <sub>18</sub> O <sub>2</sub>	+	13.63	Pharmaceutical	W
86	Imidacloprid	255.0523	256.0601	C <sub>9</sub> H <sub>10</sub> ClN <sub>5</sub> O <sub>2</sub>	+	7.39	Pesticide	W
87	Isoproturon	206.1419	207.1497	C <sub>12</sub> H <sub>18</sub> N <sub>2</sub> O	+	10.95	Pesticide	S/W
88	Ketamine	237.0920	238.0998	C <sub>13</sub> H <sub>16</sub> ClNO	+	6.1	Drug of abuse	S/W
89	Ketoprofen	254.0942	255.1021	C <sub>16</sub> H <sub>14</sub> O <sub>3</sub>	+	11.42	Pharmaceutical	S/W
90	Lamotrigine	255.0078	256.0156	C <sub>9</sub> H <sub>7</sub> Cl <sub>2</sub> N <sub>5</sub>	+	6.73	Pharmaceutical	S/W
91	Lamotrigine 2-N-glucuronide	432.0477	432.0477	C <sub>15</sub> H <sub>16</sub> Cl <sub>2</sub> N <sub>5</sub> O <sub>6</sub> <sup>+</sup>	+	5.04	Pharmaceutical	S/W
92	Lauryl diethanolamide	287.2460	288.2539	C <sub>16</sub> H <sub>33</sub> NO <sub>3</sub>	+	13.1	Industrial chemical	S/W
93	Levamisole	204.0721	205.0799	C <sub>11</sub> H <sub>12</sub> N <sub>2</sub> S	+	5.23	Pharmaceutical	S/W
94	Levofloxacin/ofloxacin	361.1437	362.1516	C <sub>18</sub> H <sub>20</sub> FN <sub>3</sub> O <sub>4</sub>	+	5.83	Antibiotic	S/W
95	Lidocaine	234.1732	235.1810	C <sub>14</sub> H <sub>22</sub> N <sub>2</sub> O	+	6.09	Pharmaceutical	S/W
96	MDMA	193.1102	194.1181	C <sub>11</sub> H <sub>15</sub> NO <sub>2</sub>	+	5.77	Drug of abuse	S/W
97	Mebendazole	295.0956	296.1035	C <sub>16</sub> H <sub>13</sub> N <sub>3</sub> O <sub>3</sub>	+	9.13	Pharmaceutical	S/W
98	Memantine	179.1674	180.1752	C <sub>12</sub> H <sub>21</sub> N	+	7.68	Pharmaceutical	S/W
99	Metformin	129.1014	130.1092	C <sub>4</sub> H <sub>11</sub> N <sub>5</sub>	+	1.22	Pharmaceutical	S/W
100	Methadone	309.2092	310.2170	C <sub>21</sub> H <sub>27</sub> NO	+	10.48	Pharmaceutical	S/W
101	Metoclopramide	299.1400	300.1478	C <sub>14</sub> H <sub>22</sub> ClN <sub>3</sub> O <sub>2</sub>	+	6.34	Pharmaceutical	S/W
102	Metoprolol	267.1834	268.1912	C <sub>15</sub> H <sub>25</sub> NO <sub>3</sub>	+	6.64	Pharmaceutical	S/W
103	Metoprolol acid	267.1470	268.1548	C <sub>14</sub> H <sub>21</sub> NO <sub>4</sub>	+	5.1	Pharmaceutical	S/W
104	Metribuzin-desamino	199.0779	200.0858	C <sub>8</sub> H <sub>13</sub> N <sub>3</sub> OS	+	8.53	Pesticide	S
105	Mirtazapine	265.1579	266.1657	C <sub>17</sub> H <sub>19</sub> N <sub>3</sub>	+	6.29	Pharmaceutical	W
106	Mycophenolic acid	320.1259	321.1338	C <sub>17</sub> H <sub>20</sub> O <sub>6</sub>	+	11.01	Antibiotic	S/W
107	N,N'-diphenylguanidine	211.1110	212.1188	C <sub>13</sub> H <sub>13</sub> N <sub>3</sub>	+	6.48	Industrial chemical	S/W
108	N-Acetyl-5-aminosalicylic acid	195.0531	196.0609	C <sub>9</sub> H <sub>9</sub> NO <sub>4</sub>	+	5.36	Pharmaceutical	S/W
109	N-Acetylaminopyridine	245.1164	246.1242	C <sub>13</sub> H <sub>15</sub> N <sub>3</sub> O <sub>2</sub>	+	5.15	Pharmaceutical	S/W
110	Naproxen	230.0942	229.0864	C <sub>14</sub> H <sub>14</sub> O <sub>3</sub>	-	7.12	Pharmaceutical	S/W
111	Nicotine	162.1157	163.1235	C <sub>10</sub> H <sub>14</sub> N <sub>2</sub>	+	1.84	Drug of abuse	S/W
112	N-Phenyl-1-naphthylamine	219.1048	220.1126	C <sub>16</sub> H <sub>13</sub> N	+	15.81	Industrial chemical	S/W
113	O-desmethyl-tramadol	249.1728	250.1807	C <sub>15</sub> H <sub>23</sub> NO <sub>2</sub>	+	5.33	Pharmaceutical	S/W
114	O-Desmethyl-venlafaxine	263.1885	264.1963	C <sub>16</sub> H <sub>25</sub> NO <sub>2</sub>	+	6.11	Pharmaceutical	S/W
115	Omeprazole sulfone	361.1096	362.1174	C <sub>17</sub> H <sub>19</sub> N <sub>3</sub> O <sub>4</sub> S	+	7.45	Pharmaceutical	W
116	Oxazepam	286.0509	287.0587	C <sub>15</sub> H <sub>11</sub> ClN <sub>2</sub> O <sub>2</sub>	+	9.89	Pharmaceutical	S/W
117	Oxybenzone	228.0786	229.0864	C <sub>14</sub> H <sub>12</sub> O <sub>3</sub>	+	14.44	Other	S/W
118	Pentaethylene glycol (PEG)	238.1416	239.1494	C <sub>10</sub> H <sub>22</sub> O <sub>6</sub>	+	4.11	Industrial chemical	S/W
119	Perfluorobutanesulfonic acid (PFBS)	299.9502	298.9429	C <sub>4</sub> HF <sub>9</sub> O <sub>3</sub> S	-	9.01	Industrial chemical	S/W
120	Perfluorobutanoic acid (PFBA)	213.9864	212.9792	C <sub>4</sub> HF <sub>7</sub> O <sub>2</sub>	-	5.81	Industrial chemical	S/W
121	Perfluoroheptanoic acid (PFHpA)	363.9768	362.9696	C <sub>7</sub> HF <sub>13</sub> O <sub>2</sub>	-	9.4	Industrial chemical	W
122	Perfluorohexanoic acid (PFHxA)	313.9800	312.9728	C <sub>6</sub> HF <sub>11</sub> O <sub>2</sub>	-	8.5	Industrial chemical	S/W
123	Perfluorooctanoic acid (PFOA)	413.9737	412.9664	C <sub>8</sub> HF <sub>15</sub> O <sub>2</sub>	-	10.25	Industrial chemical	S/W
124	Perfluoropentanoic acid (PFPeA)	263.9833	262.9760	C <sub>5</sub> HF <sub>9</sub> O <sub>2</sub>	-	7.4	Industrial chemical	S/W
125	Pregabalin	159.1259	160.1337	C <sub>8</sub> H <sub>17</sub> NO <sub>2</sub>	+	4.76	Pharmaceutical	S/W
126	Propranolol	259.1572	260.1650	C <sub>16</sub> H <sub>21</sub> NO <sub>2</sub>	+	8.34	Pharmaceutical	S/W
127	Quetiapine	383.1667	384.1745	C <sub>21</sub> H <sub>25</sub> N <sub>3</sub> O <sub>2</sub> S	+	8.11	Pharmaceutical	W
128	Ritalinic acid	219.1259	220.1337	C <sub>13</sub> H <sub>17</sub> NO <sub>2</sub>	+	5.89	Drug of abuse	S/W
129	R-Methyl-benzotriazole (R=1, 4, 5)	133.0640	134.0718	C <sub>7</sub> H <sub>7</sub> N <sub>3</sub>	+	7.37	Industrial chemical	S/W
130	R-Methyl-benzotriazole (R=1, 4, 5)	133.0640	134.0718	C <sub>7</sub> H <sub>7</sub> N <sub>3</sub>	+	7.46	Industrial chemical	W
131	Rosuvastatin	481.1683	482.1761	C <sub>22</sub> H <sub>28</sub> FN <sub>3</sub> O <sub>6</sub> S	+	10.75	Pharmaceutical	S
132	Secbumeton	225.1589	226.1667	C <sub>10</sub> H <sub>19</sub> N <sub>5</sub> O	+	8.27	Pesticide	S/W
133	Sertraline	305.0738	306.0816	C <sub>17</sub> H <sub>17</sub> Cl <sub>2</sub> N	+	10.52	Pharmaceutical	S/W
134	Sitagliptin	407.1180	408.1259	C <sub>16</sub> H <sub>15</sub> F <sub>6</sub> N <sub>5</sub> O	+	7.24	Pharmaceutical	S/W
135	Sotalol	272.1194	273.1272	C <sub>12</sub> H <sub>20</sub> N <sub>2</sub> O <sub>3</sub> S	+	4.16	Pharmaceutical	S/W
136	Sulfamethoxazole	253.0521	254.0599	C <sub>10</sub> H <sub>11</sub> N <sub>3</sub> O <sub>3</sub> S	+	7.87	Antibiotic	S/W
137	Sulpiride	341.1409	342.1487	C <sub>15</sub> H <sub>23</sub> N <sub>3</sub> O <sub>4</sub> S	+	4.55	Pharmaceutical	S/W
138	Tapentadol	221.1779	222.1857	C <sub>14</sub> H <sub>23</sub> NO	+	6.88	Pharmaceutical	S/W
139	Tebuconazole	307.1451	308.1529	C <sub>16</sub> H <sub>22</sub> ClN <sub>3</sub> O	+	13.33	Pesticide	W
140	Temazepam	300.0665	301.0743	C <sub>16</sub> H <sub>13</sub> ClN <sub>2</sub> O <sub>2</sub>	+	10.97	Pharmaceutical	S/W
141	Terbutryn	241.1361	242.1439	C <sub>10</sub> H <sub>19</sub> N <sub>5</sub> S	+	10.46	Pesticide	S/W
142	Testosterone propionate	344.2351	345.2429	C <sub>22</sub> H <sub>32</sub> O <sub>3</sub>	+	13.82	Drug of abuse	S/W
143	Tetradecylamine	213.2456	214.2534	C <sub>14</sub> H <sub>31</sub> N	+	13.32	Industrial chemical	S/W
144	Tetrakis(2-hydroxypropyl)ethylenediamine	292.2362	293.2440	C <sub>14</sub> H <sub>32</sub> N <sub>2</sub> O <sub>4</sub>	+	1.85	Industrial chemical	S/W
145	Theobromine	180.0647	181.0725	C <sub>7</sub> H <sub>8</sub> N <sub>4</sub> O <sub>2</sub>	+	3.92	Other	S/W

(continued on next page)

Table 1 (continued)

N°	Compound	Exact mass	m/z	Formula	Ion. mode	RT	Category	Campaign
146	Theophylline	180.0647	181.0725	C <sub>7</sub> H <sub>8</sub> N <sub>4</sub> O <sub>2</sub>	+	4.38	Other	S/W
147	Tramadol	263.1885	264.1963	C <sub>16</sub> H <sub>25</sub> NO <sub>2</sub>	+	6.71	Pharmaceutical	S/W
148	Tri(chloropropyl) phosphate	326.0008	327.0086	C <sub>9</sub> H <sub>18</sub> Cl <sub>3</sub> O <sub>4</sub> P	+	12.5	Industrial chemical	S/W
149	Tributyl citrate	360.2148	361.2226	C <sub>18</sub> H <sub>32</sub> O <sub>7</sub>	+	16.14	Industrial chemical	S
150	Tributyl phosphate	266.1647	267.1725	C <sub>12</sub> H <sub>27</sub> O <sub>4</sub> P	+	14.93	Industrial chemical	S/W
151	Triethanolamine	149.1052	150.1130	C <sub>6</sub> H <sub>15</sub> NO <sub>3</sub>	+	1.24	Industrial chemical	S/W
152	Triethylene glycol monobutyl ether	206.1518	207.1596	C <sub>10</sub> H <sub>22</sub> O <sub>4</sub>	+	7.54	Industrial chemical	S/W
153	Triisobutyl phosphate	266.1647	267.1725	C <sub>12</sub> H <sub>27</sub> O <sub>4</sub> P	+	14.97	Industrial chemical	W
154	Trimethoprim	290.1378	291.1457	C <sub>14</sub> H <sub>18</sub> N <sub>4</sub> O <sub>3</sub>	+	5.64	Antibiotic	S/W
155	Triphenyl phosphate	326.0708	327.0786	C <sub>18</sub> H <sub>15</sub> O <sub>4</sub> P	+	15.06	Industrial chemical	W
156	Tris(2-butoxyethyl) phosphate	398.2433	399.2511	C <sub>18</sub> H <sub>39</sub> O <sub>7</sub> P	+	15.6	Industrial chemical	S/W
157	Venlafaxine	277.2042	278.2120	C <sub>17</sub> H <sub>27</sub> NO <sub>2</sub>	+	7.66	Pharmaceutical	S/W
158	Vildagliptin	303.1946	304.2025	C <sub>17</sub> H <sub>25</sub> N <sub>3</sub> O <sub>2</sub>	+	4.47	Pharmaceutical	S/W

DEET: Diethyltoluamide; MDMA: 3,4-Methylenedioxymethamphetamine; S: summer; W: winter

with its three main metabolites (10,11-dihydro-10,11-dihydroxycarbamazepine, 10,11-dihydro-10-hydroxycarbamazepine, and carbamazepine-10,11-epoxide), showing negligible degradation in the WRP or the irrigation channel network, in line with previous studies that showed poor performance of MBR systems in the elimination of this drug [29]. As regards antibiotics, four out of the six compounds tentatively identified in the WRP influent, viz., ciprofloxacin, ofloxacin/levofloxacin, sulfamethoxazole, and trimethoprim, were recalcitrant to water reclamation and potential degradation processes during water circulation in the irrigation channel network, and hence, present in the water used for irrigation (D) (Tables S6 and S7). The presence of antibiotics is an environmental concern, as it may contribute to generating antimicrobial resistance of the environmental microbiota and their subsequent associated problems [13].

As for pesticides, 16 compounds, including two metabolites, were tentatively identified in the investigated samples. Features identified as azoxystrobin, its metabolite azoxystrobin acid, boscalid, carbendazim, and metribuzin-desamino presented their highest area in the water used for irrigation, suggesting that, probably, the source of these contaminants is not the WRP but pesticide application in the surroundings. Some of the pesticide-associated features were only observed in one campaign or presented remarkable differences between campaigns, probably reflecting the pesticide pattern of use. For instance, DEET, diuron, and the metabolite metribuzin-desamino were tentatively identified mainly in the samples collected in summer, while boscalid, carbendazim, cyprodinil, epoxiconazole, and tebuconazole were present mainly in the water collected in winter. The agrochemicals tentatively identified are predominantly used as fungicides, herbicides, and, to a lesser extent, insecticides.

The WRP also treats pre-processed wastewater from diverse industrial activities located in the area and, hence, another main chemical group found in the water samples was industrial chemicals. Most industrial CECs have multiple sources and, thus, it is difficult to identify their origin. The tentatively detected compounds included perfluoroalkyl substances (PFAS), organophosphates, phthalates, and benzotriazole and benzothiazole derivatives, among others. These contaminants are mainly used as plasticizers, flame retardants, surfactants, coating and packaging, food additives, and adhesives, or related to tire wear and road runoff. PFAS were widespread in the samples and persistently present in both sampling campaigns. These compounds are widely used in many manufacturing processes and are commonly reported in the aquatic environment, mostly coming from the discharge from wastewater treatment plants [30,31].

The urban origin of the wastewater also resulted in the tentative identification of legal and illicit drugs of abuse in the reclaimed water irrigation system. Eleven different compounds were identified within this category, including five metabolites. Nicotine and its two major metabolites (cotinine and 3-hydroxy cotinine) were detected in both campaigns, although only cotinine persisted after water reclamation.

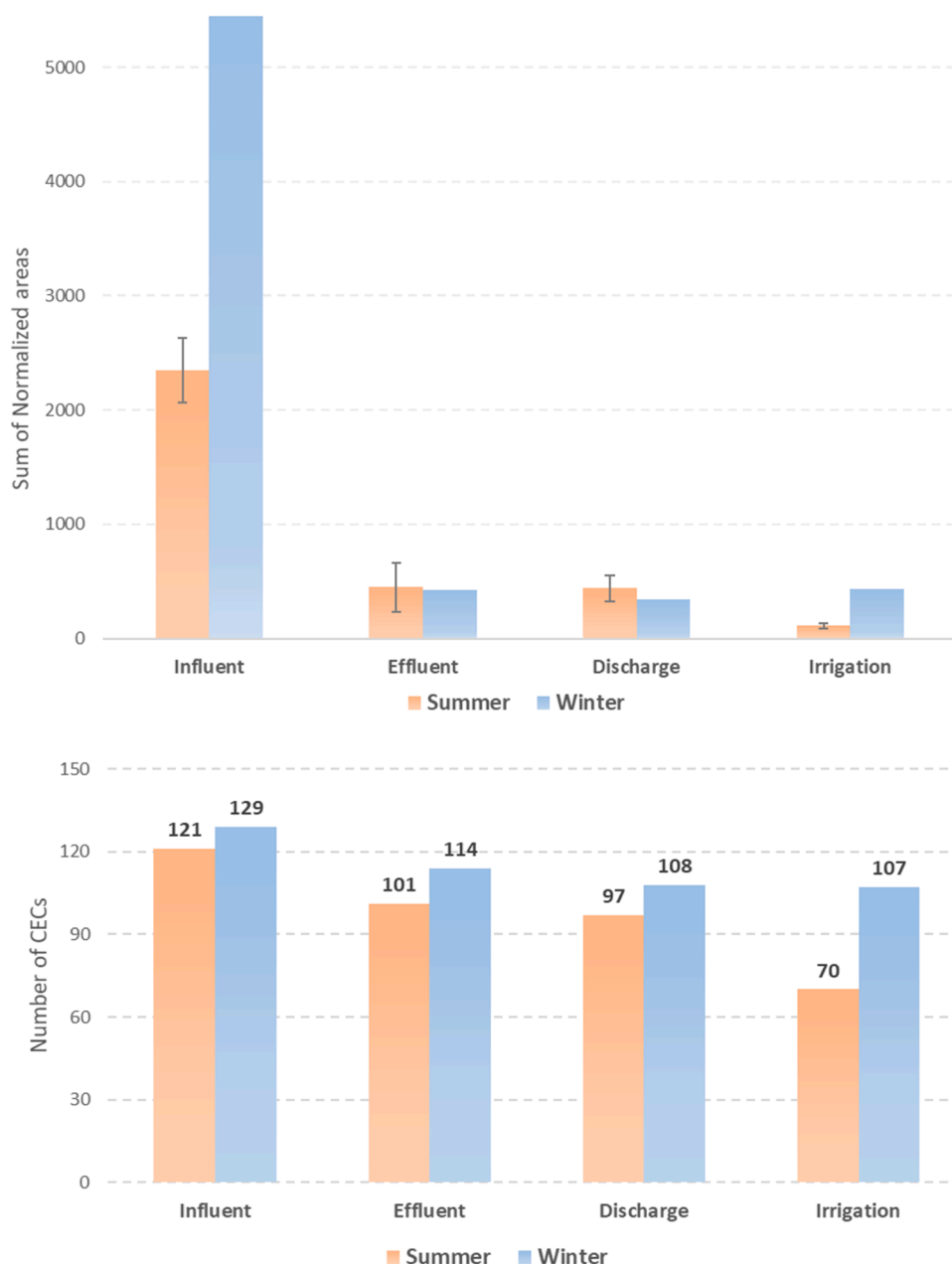
Similarly, cocaine and its metabolites benzoylecgonine and ecgonine methyl ester were also present in the investigated waters, but ecgonine methyl ester was the only one surviving the regeneration treatment. MDMA, ketamine, and ephedrine were also found in either one or both campaigns.

Finally, tens of CECs without a grouping category were also tentatively detected, including compounds such as caffeine, theophylline, and theobromine, coming from the coffee, tea, and cacao metabolism, respectively, the UV filter oxybenzone (included in the third watch list from the European Commission [32]), or galaxolidone, a metabolite of the personal care product galaxolide, among others.

### 3.2. CECs dynamics

MBRs combine biological treatments and membrane-based separation techniques. In terms of CEC removal, their efficiency is highly variable, providing removals from 0% to 93.5% for the same compound, depending on the case study [33]. This efficiency depends on many factors, including the compound physical-chemical properties, biological conditions, specific microbial communities, MBR configuration, etc. The main removal processes that CECs experience in MBR systems are biodegradation, adsorption, and filtration but, when removal is not complete, CECs reach the MBR effluents [34,35]. Fig. 2 summarizes the dynamics of the CECs tentatively detected in each sample and campaign (based on the data from Tables S6-S7) in terms of the number of CECs detected and the total area. As can be seen in Fig. 2A, considering the sum of the normalized areas of each analyte, the CEC load was partially removed during water reclamation (81% and 92% of removal in summer and winter, respectively). There was also a clear decrease in the CEC load in summer during the water residence time in the irrigation channels (75%), from the reclaimed water discharge point to the abstraction point for irrigation. The irrigation system under study consists of several surface channels where CECs can still be bio- and/or photo-degraded, or even the transformation products can be transformed back into their parent compounds. Both degradation processes may be enhanced during summer compared to winter because the water temperature in the irrigation channels is higher (30 °C approximately) and daylight is longer. The use of this parameter (sum of normalized areas) to evaluate CEC dynamics is useful but has to be read with caution since the analytical technique used (UPLC-ESI-HRMS) is subject to matrix effects that may vary among the investigated samples, and hence, affect the observed area of each feature in each matrix.

Although based on the observed chromatographic peak areas, considerable mitigation of CEC load in the reclaimed water irrigation system under study could be inferred, the total number of CECs present in the water used for irrigation was remarkably high. Out of the 121 and 129 compounds tentatively detected in the WRP influent sample in summer and winter, respectively, 70 (summer) and 107 (winter) were still present in the water used for irrigation (Fig. 2B). Fig. 3 shows the



**Fig. 2.** CEC dynamics in the study area, including removal efficiency in the WRP and irrigation channels. A) Sum of the normalized areas of the CECs tentatively identified in each sample and sampling campaign, and B) number of CECs tentatively identified in each sample and sampling campaign.

distribution of contaminants in the four sampling points in each campaign, highlighting the number of compounds that were common in two or more samples, or were only detected in one sample. As can be seen, 26 (summer) and 24 (winter) compounds were completely degraded during the WRP treatment, including CECs such as nicotine or acetaminophen (specific compounds are shown in [Tables S6 and S7](#)). Most of these compounds showed different behaviors between campaigns, demonstrating that many factors may affect the WRP removal efficiency. Nevertheless, the incoming concentration level of the contaminants may also be decisive in the elimination rates. Water composition in terms of CECs from the WRP effluent to the discharge point into the channels was very similar. This could be expected as the water is pumped through an underground tubing and it is not subjected to external agents. Up to 61 compounds in summer and 92 compounds in winter were found in all samples, revealing the recalcitrance of most of the CECs tentatively identified. Moreover, this is in line with the fact that

warmer conditions may enhance the bio- and photodegradation processes along the surface irrigation channels. As shown in [Fig. 3](#), 98% of the CECs tentatively detected came directly from the WRP, becoming the main source of contamination in the water used for irrigation.

### 3.3. CEC prioritization

Prioritization of the CECs tentatively identified in the water used for irrigation was done based on their highest semi-quantified concentration in these samples and their lowest PNEC value in freshwater (see [Section 2.6](#)) [25]. [Table 2](#) summarizes semi-quantified concentrations of the CECs found in the water used for irrigation in winter and summer, their respective PNEC, and calculated RQ values, as well as the associated risk.

CEC concentrations ranged from 0.3 ng/L for 2-(3,4-dimethoxyphenyl)-5-methylamino-2-isopropylvaleronitrile in summer



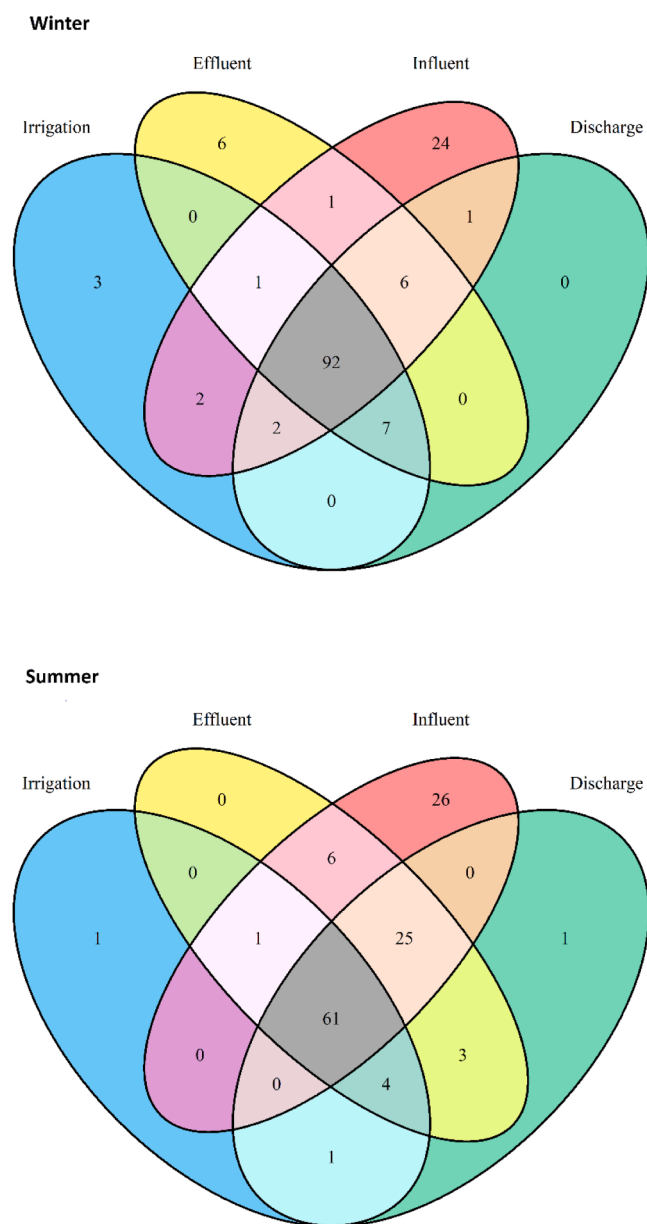


Fig. 3. Van Venn diagrams showing the diversity of the tentatively identified CECs in the investigated samples in summer and winter.

to 97  $\mu\text{g/L}$  for caprolactam in winter. Most of the compounds presented concentrations below 1  $\mu\text{g/L}$ . Although higher concentrations were obtained, in general, in winter compared to summer, the semi-quantified concentrations were in agreement with the typical concentrations observed for these CECs in wastewater treatment plant effluent or surface water (ranging in the  $\text{ng/L}$  level). For example, higher concentrations of antidepressants and antibiotics (e.g., venlafaxine, O-desmethylvenlafaxine, amitriptyline, or sulfamethoxazole) were detected in the winter water samples than in the summer ones, in line with their prescription rates, also higher in winter than in summer [14]. Some of the highest concentrations found in the samples corresponded with compounds included in any of the four watch lists established in the field of water policy under Directives 2008/105/EC and 2013/39/EU from the European Commission [11,32,36–38], pointing to their environmental relevance. These were the antidepressant venlafaxine and its metabolite O-desmethyl-venlafaxine (423 and 1070  $\text{ng/L}$ , respectively), the sunscreen agent oxybenzone (4180  $\text{ng/L}$ ), metformin (5230  $\text{ng/L}$

and, in a lesser extent, sulfamethoxazole (133  $\text{ng/L}$ ), ofloxacin/levofloxacin (8.4  $\text{ng/L}$ ), diclofenac (12  $\text{ng/L}$ ), azoxystrobin and its metabolite azoxystrobin acid (41 and 35  $\text{ng/L}$ , respectively), fluconazole (21  $\text{ng/L}$ ), ciprofloxacin (3.6  $\text{ng/L}$ ), trimethoprim (6.4  $\text{ng/L}$ ) or tebuconazole (1.9  $\text{ng/L}$ ). Moreover, the pesticides diuron and isoproturon, two priority substances established in the European Commission WFD [12], were detected at maximum concentrations of 27 and 28  $\text{ng/L}$ , respectively.

Regarding their ecotoxicological risk, 14 out of 119 tentatively identified CECs showed an individual RQ over 1 and, therefore, presented a concentration potentially toxic for the aquatic environment. From these, O-desmethyl-venlafaxine would pose the highest risk with an RQ value of 175; then, venlafaxine and galaxolidone (a metabolite of the personal care product galaxolide) would present high risk ( $\text{RQ} > 10$ ) and the rest of compounds moderate risk ( $1 < \text{RQ} < 10$ ). This last category included industrial chemicals (2-ethylhexyl diphenyl phosphate, N-phenyl-1-naphthylamine, and caprolactam), pharmaceuticals (carbamazepine, sulfamethoxazole, and temazepam), tire wear compounds (N,N'-diphenylguanidine), and caffeine and its metabolite theophylline. The remaining CECs detected in water used for irrigation did not pose a risk per se to exposed organisms. Previous studies have reported toxic effects on aquatic organisms after exposure to a mixture of contaminants at concentrations below the No Observed Effect Concentration (NOEC) [39], which points out potential additive effects of the CEC mixtures. Following a concentration addition model [27], in which all CECs are supposed to have a similar mode of action on aquatic organisms, an approximation to the worst-case scenario for the CEC mixture toxicity is given and it should only be understood as that. The  $\text{RQ}_{\text{mix}}$  was 298 and 20 for the winter and summer campaigns, respectively, representing an environmental risk in both cases, being 10 times higher in winter than in summer.

As an alternative to the semi-quantification of CEC levels to assess their occurrence, we also developed a simpler prioritization procedure based on a scoring system that uses the CEC chromatographic peak area and frequency of detection instead. For this, scoring values were assigned to each CEC comparing its position with the percentiles 20, 40, 60, 80, and 100 of the maximum absolute chromatographic peak area (maximum four points) and PNEC (maximum 5 points). Moreover, a maximum of one additional point could be assigned depending on the CEC frequency of detection (one or both campaigns). The proposed scoring system is summarized in Table S10. Table S11 shows the score of each compound broken down among the three evaluated parameters and the total score. Then, the priority lists obtained with both methods were compared. There was a 76% and 80% of similarity between the lists when comparing either the 25 compounds or the 50 compounds at the top of both lists, respectively (Table S12). Thus, this simpler approach, despite presenting stronger deficiencies in terms of accuracy and precision compared to the semi-quantification-based prioritization, could also be used as an approximation for the prioritization of CECs at the local level.

The prioritization approaches here presented do not consider synergistic or antagonistic toxic effects that may occur due to the co-occurrence of various CECs in the water, as they are based on the individual toxicity of the compounds. Moreover, the integration of additional aspects like CEC persistence and bioaccumulation potential in the prioritization approach could enlarge the list of site-specific priority substances. Nevertheless, with their limitations, the prioritization procedures here presented allow the cost-effective selection of the most relevant compounds in terms of aquatic toxicity at the local level, considering also the potential spatial and temporal variabilities of the CEC mixture. The implementation of prioritization approaches to identify contaminants of special concern can be used by decision-makers and water authorities to adopt control and attenuation measures to avoid or at least, minimize the risk of CEC pollution.

Table 2

Compounds detected at the water used for irrigation in summer and winter, semi-quantified levels, and potential toxicological risk (expressed as risk quotient, RQ).

Rank	Compound	Concentration (ng/L)		Risk Quotient (RQ)			
		Winter	Summer	Max Conc.	PNEC (ng/L)	RQ	Risk category
1	O-Desmethyl Venlafaxine	1070	44.0	1070	6.1	175	HR
2	Venlafaxine	423	14.0	423	6.1	69.3	HR
3	Galaxolidone	1730	72.0	1730	100	17.3	HR
4	Theophylline/ Paraxanthine	672	n.d.	672	100	6.72	MR
5	Oxybenzone	4180	155	4180	670	6.24	MR
6	N-Phenyl-1-naphthylamine	242	106	242	60	4.03	MR
7	2-Ethylhexyl diphenyl phosphate	n.d.	60.0	60.0	18	3.31	MR
8	Terbutryn	176	91.0	176	65	2.70	MR
9	Carbamazepine	82.0	37.0	82.0	50	1.63	MR
10	N,N'-diphenylguanidine	1280	1.80	1280	860	1.49	MR
11	Caprolactam	97,400	43.0	97,400	67,400	1.45	MR
12	Caffeine	1690	n.d.	1690	1200	1.41	MR
13	Sulfamethoxazole	133	17.0	133	100	1.33	MR
14	Temazepam	85.0	31.0	85.0	71	1.20	MR
15	Tris(2-butoxyethyl) phosphate	102	37.0	102	140	0.728	LR
16	3,4-Methylenedioxyamphetamine (MDMA)	118	n.d.	118	216	0.546	LR
17	Secbumeton	26.0	2.90	26.0	48	0.545	LR
18	Flecainide	260	56.0	260	640	0.407	LR
19	Ofloxacin/levofloxacin	8.40	2.10	8.40	21	0.401	LR
20	Sitagliptin	363	20.0	363	920	0.394	LR
21	Butyrophenone	683	n.d.	683	1750	0.390	LR
22	Diuron	n.d.	27.0	27.0	70	0.383	LR
23	Carbendazim	156	n.d.	156	150	0.356	LR
24	2-ethyl-1,5-dimethyl-3,3-diphenylpyrrolinium (EDDP)	23.0	n.d.	23.0	85	0.276	LR
25	Sulpiride	1120	65.0	1120	4090	0.274	LR
26	10,11-Dihydro-10,11-dihydroxycarbamazepine	511	203	511	1910	0.268	LR
27	Clopidogrel carboxylic acid	154	17.0	154	650	0.238	LR
28	Diclofenac	12.0	n.d.	12.0	50	0.230	LR
29	Lidocaine	1070	120	1070	4670	0.229	LR
30	Oxazepam	82.0	14.0	82.0	370	0.221	LR
31	Amisulpride	312	n.d.	312	1430	0.218	LR
32	Azoxystrobin	41.0	6.70	41.0	200	0.205	LR
33	Perfluorooctanoic acid	21.0	34.0	34.0	180	0.190	LR
34	Azoxystrobin acid	35.0	n.d.	35.0	210	0.166	LR
35	Diazinon	1.60	0.60	1.60	10	0.163	LR
36	Propranolol	52.0	n.d.	52.0	410	0.128	LR
37	Tapentadol	313	14.0	313	2470	0.127	LR
38	Tramadol	967	36.0	967	8650	0.112	LR
39	Diltiazem	25.0	n.d.	25.0	230	0.108	LR
40	Amitriptyline	14.0	n.d.	14.0	140	0.098	NR
41	Diphenylamine	n.d.	116	116	1200	0.097	NR
42	Isoproturon	28.0	7.00	28.0	320	0.088	NR
43	Fluconazole	21.0	15.0	21.0	250	0.083	NR
44	Cetirizine	32.0	7.20	32.0	410	0.077	NR
45	Desacetyl diltiazem	27.0	n.d.	27.0	360	0.076	NR
46	O-desmethyiltramadol	640	37.0	640	9120	0.070	NR
47	dextrophan/levorphanol	76.0	2.00	76.0	1360	0.056	NR
48	Gabapentin	564	94.0	564	10,000	0.056	NR
49	desmethylcitalopram	26.0	n.d.	26.0	500	0.053	NR
50	Perfluorobutanesulfonic acid	102	215	215	4080	0.053	NR
51	Desmethyldiazepam	22.0	9.00	22.0	430	0.051	NR
52	10,11-Dihydro-10-Hydroxycarbazepine	199	54.0	199	4030	0.050	NR
53	2-(Methylthio)benzothiazole	n.d.	53.0	53.0	1140	0.046	NR
54	Ciprofloxacin	n.d.	3.60	3.60	89	0.041	NR
55	Methadone	33.0	0.59	33.0	840	0.039	NR
56	Bisoprolol	113	n.d.	113	3180	0.036	NR
57	Metformin	5230	66.0	5230	156,000	0.034	NR
58	2-Mercaptobenzothiazole	24.0	n.d.	24.0	760	0.032	NR
59	8-Hydroxyquinoline	16.0	64.0	64.0	1990	0.032	NR
60	Levamisole	55.0	2.40	55.0	1810	0.031	NR
61	Flufenamic acid	11.0	0.40	11.0	400	0.028	NR
62	Memantine	52.0	9.40	52.0	1840	0.028	NR
63	Perfluoroheptanoic acid	13.0	n.d.	13.0	500	0.026	NR
64	3,3,5,5-Tetramethyl-1-pyrroline N-oxide	342	n.d.	342	13,800	0.025	NR
65	Lamotrigine	248	107	248	10,000	0.025	NR
66	Tri(chloropropyl) phosphate	n.d.	171	171	7390	0.023	NR
67	Dicyclohexylamine	n.d.	74.0	74.0	1600	0.022	NR
68	Diazepam	6.0	3.50	6.00	290	0.021	NR
69	Diethyl phthalate	319	n.d.	319	16,000	0.02	NR
70	N-Acetylaminoantipyrine	1810	525	1810	100,000	0.018	NR
71	Cocaine	39.0	n.d.	39.0	2280	0.017	NR
72	Sotalol	100	n.d.	100	6520	0.015	NR
73	Ketamine	77.0	12.0	77.0	5710	0.014	NR

(continued on next page)

Table 2 (continued)

Rank	Compound	Concentration (ng/L)		Risk Quotient (RQ)			
		Winter	Summer	Max Conc.	PNEC (ng/L)	RQ	Risk category
74	Triethanolamine	155	n.d.	155	11,000	0.014	NR
75	Trimethoprim	6.40	n.d.	6.40	500	0.013	NR
76	Ephedrine	42.0	n.d.	42.0	3620	0.012	NR
77	Mebendazole	2.00	n.d.	2.00	160	0.012	NR
78	Metoprolol acid	622	127	622	49,900	0.012	NR
79	Perfluoropentanoic acid	23.0	47.0	47.0	3910	0.012	NR
80	Tributyl phosphate	769	182	769	66,000	0.012	NR
81	2-(3,4-dimethoxyphenyl)-5-methylamino-2-isopropylvaleronitrile	14.0	0.30	14.0	1570	0.009	NR
82	Acephylline	106	n.d.	106	13,200	0.008	NR
83	Diphenhydramine	8.10	n.d.	8.10	990	0.008	NR
84	Sertraline	0.70	n.d.	0.70	91	0.008	NR
85	Tebuconazole	1.90	n.d.	1.90	240	0.008	NR
86	Dicyclohexylurea	n.d.	42.0	42.0	5910	0.007	NR
87	Vildagliptin	73.0	13.0	73.0	9750	0.007	NR
88	Ketoprofen	12.0	n.d.	12.0	2100	0.006	NR
89	Theobromine	636	n.d.	636	100,000	0.006	NR
90	Bupropion	22.0	n.d.	22.0	4400	0.005	NR
91	Cotinine	46.0	n.d.	46.0	10,000	0.005	NR
92	Pentaethylene glycol	1000	n.d.	1000	202,000	0.005	NR
93	Ritalinic acid	72.0	n.d.	72.0	14,200	0.005	NR
94	2(3 H)-Benzothiazolone	n.d.	54.0	54.0	14,000	0.004	NR
95	Boscalid	43.0	n.d.	43.0	11,600	0.004	NR
96	Clopidogrel	12.0	n.d.	12.0	3210	0.004	NR
97	4-Formylaminoantipyrene	2870	1600	2870	1000,000	0.003	NR
98	4-indolecarbaldehyde	20.0	n.d.	20.0	6080	0.003	NR
99	N, N-Diethyl-meta-toluamide (DEET)	n.d.	277	277	88,000	0.003	NR
100	Dextromethorphan	9.10	n.d.	9.10	3320	0.003	NR
101	Metoprolol	25.0	n.d.	25.0	8600	0.003	NR
102	3-Hydroxycotinine	36.0	n.d.	36.0	20,600	0.002	NR
103	Carbamazepine-10,11-epoxide	4.80	n.d.	4.80	2570	0.002	NR
104	Citalopram	36.0	0.60	36.0	16,000	0.002	NR
105	Emtricitabine	46.0	15.0	46.0	23,800	0.002	NR
106	Ampyrone/ 4-aminoantipyrene	24.0	n.d.	24.0	32,500	0.001	NR
107	Atenolol	98.0	n.d.	98.0	150,000	0.001	NR
108	Bezafibrate	2.00	n.d.	2.00	2300	0.001	NR
109	Chlorpheniramine	1.60	n.d.	1.60	1560	0.001	NR
110	Ecgonine methyl ester	46.0	n.d.	46.0	88,800	0.001	NR
111	Fenofibric acid	2.00	n.d.	2.00	2350	0.001	NR
112	Metribuzin-desamino	n.d.	28.0	28.0	46,800	0.001	NR
113	Mirtazapine	1.40	n.d.	1.40	1000	0.001	NR
114	Pregabalin	43.0	21.0	43.0	66,100	0.001	NR
115	Perfluorobutanoic acid	9.50	10	10.0	27,800	0.0004	NR
116	Hydroxy-bupropion	n.d.	1.90	1.90	11,800	0.0002	NR
117	Perfluorohexanoic acid	n.d.	30.0	30.0	140,000	0.0002	NR
118	Benzoyllecgonine	269	n.d.	269	6840,000	0.00004	NR
119	1,2-benzisothiazol-3(2 H)-one	n.d.	1.10	1.10	379,000	0.000003	NR

n.d.: not detected; HR: high risk; MR: moderate risk; LR: Low risk; NR: no risk.

#### 4. Conclusion

A cost-effective wide-scope screening method was applied to holistically characterize the CEC footprint in the water of a reclaimed water-based irrigation system, and its seasonal and spatial variations. Site-specific priority CECs were selected based on their abundance and potential toxicity risk. Although this approach presents some analytical limitations, e.g., highly polar and apolar compounds may not be covered, and missing compounds in the suspect lists used (e.g. transformation products), it expands with no doubt the chemical space covered by target methods. This work revealed the presence of more than one hundred CECs in the water used for crop irrigation during winter (79 CECs in summer). Considering the worst-case scenario, these CEC mixtures may pose a high toxicity risk to freshwater organisms, and these CECs may eventually be transferred into crops. However, further research is needed to confirm their fate.

Finally, it may be worth emphasizing that the methodology developed can be widely implemented in any other location, opening the door to detecting local contaminants that could be missed with the national or European regulations, rationally designing monitoring and attenuation programs, and supporting legislators in their way to manage the water

contamination issue and ensure the safety of water reuse applications.

#### Environmental implication

Contaminants of emerging concern (CECs) are well-known “hazardous materials” with an extended ubiquity in the environment. They are poorly removed during wastewater treatments and thus, the use of reclaimed water for irrigation may be a source of CECs in the environment. The work described in this research paper contributes to a better knowledge of the fate of these organic pollutants in a specific agricultural area irrigated with reclaimed water and proposes a cost-effective methodology to identify the most relevant site-specific contaminants in terms of occurrence and toxicity. The method proposed can be implemented in any other location to increase the knowledge of CEC distribution in the environment and associated environmental risks.

#### CRedit authorship contribution statement

**Manuel García-Vara:** Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Dana Orlando-Véliz:** Methodology,

Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Rocío Bonansea**: Methodology, Writing – review & editing, Visualization. **Cristina Postigo**: Methodology, Validation, Writing – review & editing. **Miren López de Alda**: Conceptualization, Methodology, Validation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

### 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.

### Data availability

Data will be made available on request.

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### Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jhazmat.2023.132119](https://doi.org/10.1016/j.jhazmat.2023.132119).

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