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Simultaneous determination of traditional and emerging illicit drugs in sediments, sludges and particulate matter[☆]

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ABSTRACT

An analytical method for determining traditional and emerging drugs of abuse in particulate matter, sewage sludge and sediment has been developed and validated. A total of 41 drugs of abuse and metabolites including cocainics, tryptamines, amphetamines, arylcyclohexylamines, cathinones, morphine derivatives, pyrrolidifenones derivatives, entactogens, piperazines and other psychostimulants were selected. Samples were ultrasound extracted with McIlvaine buffer and methanol, and the extracts were cleaned up by solid phase extraction (SPE) using Strata-X cartridges. Drugs were eluted using methanol and methanol–dichloromethane and determined by liquid chromatography tandem mass spectrometry. The optimum solid–liquid extraction (SLE) conditions were: weight 1 g of sample and ultrasound assisted extraction (UAE) with 10 mL of methanol–McIlvain buffer (1:1, v/v, pH 4.5) for 10 min. Recoveries for all compounds were $\geq$50% in the three matrices with the exception of ephedrine (EPHE), 2-ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine (EDDP), ecgonine methyester (ECME), heroin (HER), 3,4-methylendioxyamphetamine (MDA) and 4-acetoxy N,N′-dimethyltryptamine (4-AcO-DIPT) and methadone (MET). Data acquisition was done by selective reaction monitoring (SRM), and the two most abundant product ions were used for confirmation. Limits of detection were lower than 1.32 ng g^{-1} dry weight (d.w.) and limits of quantification were between 0.12 and 3.96 ng g^{-1} (d.w.). The method was applied to the analysis of particulate matter, where cocaine (COC), benzoylecgonine (BECG), ecgoninemethylester (ECME), cocaethylene (COCET), methadone (MET) and codeine (COD) were mostly detected. In the case of dehydrated sludge, opioids are at higher concentration than cocainics and some emerging drugs such as 4-methoxyamphetamine (PMA), ketamine (KET) and bufotenine (BUF) were detected. In sediment COC, 4-methoxyphencyclidine (4-MeO-PCP), MET and BECG were most relevant compounds.

1. Introduction

Drugs are chemical agents that alter the biochemical or physiological processes of tissues or organisms [1], particularly, drugs of abuse are those whose use does not pursue a medical purpose. At present, they are separated into “emerging” and “traditional” drugs of abuse. The former includes those that were not listed in the 1961 United Nations Single Convention on Narcotic Drugs and in the 1971 United Nations Convention on Psychotropic Substances [2–4]. Although some of them, as tobacco and alcohol, are legal in Spain and other countries, most of these drugs are illegal. These drugs are metabolized by the body and both, unchanged compounds and their metabolites, are primarily excreted in the urine [5–9].

Some studies of drugs at the influents and effluents of wastewater treatment plants (WWTP) demonstrate a variable elimination rate (between 45 and 95%) depending on the drug [10]. For compounds such as cocaine (COC) and amphetamine (AMP) elimination efficiency is over 90%, while for other drugs or metabolites such as ecstasy, methamphetamine (MAMP), 11-nor-9-carboxy tetrahydrocannabinol or LSD is much less [11]. Further research is needed to determine the illicit drugs released to the environment and their possible impact on it. Part of these drugs could become deposited in fluvial sediments, which are not renewed as quickly as the water causing a possible long-term accumulation depending on their stability. The particulate matter present in wastewater influent has scarcely been studied [12,13]. These studies show that a significant

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fraction of illicit drugs ends in the particulate matter. The sludges generated by WWTP are often used as agricultural fertilizer, in some instances, after composting processes. Numerous studies have confirmed the presence of contaminants, including illicit drugs in sludge [14–17] that could pose a risk to agricultural soils and plants. The composition and quantity of sludge generated depends on the treatments applied in the WWTP and the wastewater composition. Even within the same WWTP, their characteristics may change annually, seasonally or daily due to variations in the composition of the influent wastewater and daily variations in treatment processes [18]. Monitoring of particulate matter and sludge from the WWTP and sediments in the receiving waters is crucial.

Table 1 outlines the methods published up to now, to extract and quantify illicit drugs in solid matrices including soil, sediment, sewage sludge and particulate matter. The study of illicit drugs in these matrices is very recent, the oldest method back to 2006 but the next was published in 2010. It is necessary to develop methods that provide a large percentage of recovery and high sensitivity. Most common extraction techniques are pressurized liquid extraction (PLE) [13,14,16,17,19] or solid–liquid extraction (SLE) [12,15,20] followed by a solid phase extraction (SPE) clean-up [12,13,15,17,19,20]. PLE is the preferred approach because this technique has as advantage that high pressure solvents remain in the liquid state above their boiling points. Therefore, these conditions enhance the solubility of target compounds in the solvent and the desorption kinetics from solid matrices providing shorter extraction times and great reproducibility [13,16,19,21]. However, this technique (i) requires special instrumentation to reach simultaneously high pressure and temperature, (ii) is expensive (several g of sorbents and mL of solvents, N_2 stream, and energy consumption) and (iii) matrix compounds are also frequently co-extracted. Furthermore, a number of studies reports similar recoveries using more conventional SLE by shaking or sonication for moderate and polar analytes, as illicit drugs [12,14,21].

The aim of this research was to develop and optimize analytical methods to determine 41 illicit drugs in sediments, sludges and particulate matter (see Table S1 in the supplementary material for the detailed list of compounds and their physico-chemical properties [22]). These compounds include traditionally consumed drugs of abuse (some of them as morphine (MOR) and codeine (COD) nowadays have mostly a medical use) and emerging psychoactive drugs. The method is based on traditional SLE favored by ultrasonication, followed by SPE clean-up and liquid chromatography tandem mass spectrometry (LC–MS/MS) determination. To the best of our knowledge there is not extraction method reported for determining ethylamphetamine (ETAMINE), ethylone (ETONE), methylphenidate (MEPHEN), mephedrone (MEP), methylone (METONE), dibuthylone (bk-MMBDB), 4-bromo-2,5-dimethoxyphenethylamine (2C-B), naphyrone (NAPH), methylenedioxypyrovalerone (MDPV), p-methoxyamphetamine (PMA), 4-acetoxy N,N′-diisopropyltryptamine (4-AcO-DIPT), bufotenine (BUF), 1-(3-chlorophenil)piperazine (mCPP), α-pyrrolidinopropiophenone (PPP), α-pyrrolidinopentiophenone (α-PVP), 3,4-methylendioxy-α-pyrrolidinopropiophenone (MDPPP), 4-methyl-α-pyrrolidinopropiophenone (4-MePPP), 4′-methyl-α-pyrrolidinohexanophenone (4′-MePHP), 4′-methyl-α-pyrrolidinobutiophenone (MPBP), 3-methoxyphencyclidine (3-MeO-PCP) and 4-methoxyphencyclidine (4-MeO-PCP) in sediments, sludges and particulate matter. The method was applied to determine these substances in sewage sludge and particulate matter from the WWTP Pinedo I and II, and Quart-Benàger, and in sediments taken from the Turia river (Valencia, Spain). The incidence of many of these compounds in sediment and particulate matter is assessed for the first time providing information on their presence in environmental matrices.

2. Experimental

2.1. Reagents and materials

The methanol used was LC–MS PAI 99.9% purity distributed by Panreac (Barcelona, Spain). The dichloromethane was 99.8% pure, stabilized with 0.1% ethanol and distributed by VWR® BDH Prolabo® (Barcelona, Spain). Formic acid was from AMRESCO® (Solon, OH, USA), citric acid from PROBUS S.A. (Badalona, Spain), and Na_2HPO_4 from Panreac. All of them were analytical grade.

AMP, MAMP, Ephedrone (EPHED), ETONE, MEPHEN, MEP, METONE, 3,4-methylenedioxymethamphetamine (MDMA), 3,4-methylendioxyamphetamine (MDA), 3,4-methylenedioxy-N-ethylamphetamine (MDEA), N-Methyl-1-(3,4-methylenedioxyphenyl)-2-butanamine (MBDB), bk-MMBDB, NAPH, PMA, 4-AcO-DIPT, BUF, 1-(3-trifluoromethylphenyl)piperazine (TFMPP), PPP, α-PVP, MDPPP, 4-MePPP, 4′-MePHP, MPBP, 3-MeO-PCP, 4-MeO-PCP, ketamine (KET), COC, benzoylecgonine (BECG), cocaethylene (COCET), ecgoninemethylester (ECME), COD, heroin (HER), methadone (MET) and MOR were distributed by LoGiCal® Standards (Barcelona, Spain). 6-monoacetylmorphine (6-MAM), ETAMINE, ephedrine (EPH), 2-ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine (EDDP), 2C-B and mCPP were distributed by Cerilliant® (Round Rock, TX, USA). MDPV was distributed by Toronto Research Chemicals Inc. (Toronto, Canada). BECG-d3, COC-d3, COCET-d3, EDDP-d3, MET-d3, MAMP-d5, MDMA-d5, MDEA-d5, METONE-d3 were distributed by LoGiCal® Standards. AMP-d5, MDA-d5, KET-d4, ECME-d3, 6-MAM-d3, HER-d9 and MOR-d3 were from Cerilliant®. Analytical standards and isotopically labeled internal standards were stored at −20 °C in dark (Table S1 of the supplementary material).

Water samples were filtered through GA-55 filters 90 mm and 0.45 μm pore diameter from ADVANTEC (Toyo Roshi Kaisha, Ltd. Tokyo, Japan) and deionized water through hydrophilic membrane propylene filters, with a diameter of 47 mm and a pore size of 0.2 μm manufactured by PALL Corporation (Mexico DF, Mexico). McIlvaine buffer pH 4.5 was prepared mixing 90.85 mL of 0.062 M Na_2HPO_4 solution and 9.5 mL of Citric acid 0.091 M and dilution to 1 L with distilled water. The lyophilizer used was a 4KBTXL-75 by VirTis SP Scientific of industries (Philadelphia, PA, USA). The equipment used for SPE was a VISIPREP™ from Supelco (Madrid, Spain). SPE was carried out on Strata-X Polymeric Reversed phase cartridges 200 mg/6 mL Phenomenex (Torrance, CA, USA). Samples were evaporated using a combined sample concentrator and a heating plate, the concentrator model was SBHCONC/1 and the heating plate model SBH130D/3 both manufactured by Stuart® (Stafford, UK). The vials used to inject the sample in the chromatograph were 2 mL amber vials with stoppers 99 mm + Septum Sil/PTFE, both manufactured by Análisis Vínicos S.L. (Tomelloso, Spain). Finally, syringe filters were Teflon (PTFE) hydrophobic with a pore size of 0.22 μm and manufactured by MS® (Ontario, Canada).

2.2. Sampling

Sludge and particulate matter samples were collected from three WWTPs that treat the sewage waters of Valencia and its orbital cities with a project flow rate of 60,000 m^3 day^{-1} (Quart-Benàger) [23] and 325,000 m^3 day^{-1} (the complex Pinedo I and II) [24]. Samples of WWTP were taken daily for seventeen consecutive days from 4th March to 20th of 2014. Influent wastewater samples (250 mL) were filtered under vacuum using the ADVANTEC® filters to retain the particulate matter. Then, filters were dried at room temperature for 24 h, weighted to compare the result with the mass of unused filters and determine the particulate matter weight (ranging from 2 to 5 g) and then frozen at −20 °C until the particulates were extracted.

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