

1 **Tobacco Eco-toxic Fallout: Organochlorine pesticides and polychlorinated
2 biphenyls residues in hookah wastewater**

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25 **Abstract**

26 Concerns about both flavored and traditional waterpipe smoking continue to grow because
27 of their considerable environmental and health impacts. This study aims to conduct a
28 comprehensive evaluation of the levels of polychlorinated biphenyls (PCBs) and organochlorine
29 pesticides (OCPs) present in wastewater generated from waterpipe use. Samples from four major
30 brands of flavored tobacco (Nakhla, Al fakher, Al tawareg, Tangiers) and traditional tobacco were
31 analyzed. The mean concentration levels of Σ OCPs in Nakhla, Al-Fakher, Al Tawareg and
32 Tangiers brands were 111.25, 125.51, 122.70, and 98.13 ng/L, respectively, and in traditional
33 tobacco samples was 132.23 ng/L. The PCBs concentrations in flavored tobacco samples were
34 10.36 -11.94 μ g/L, which exceeds the concentration in traditional tobacco at 10.26 μ g/L. β -HCH

35 was the most prevalent OCP, representing up to 51% in flavored tobacco wastewater and 45% in
36 traditional tobacco wastewater. PCB194 was the most common PCB congener, consistently
37 making up 24-25% of the entire PCB concentration. The risk quotient (RQ) for values traditional
38 and flavored hookah wastewater were ranged from 0.00 (δ -HCH) to 2.46 (endosulfan) and 0.00
39 (δ -HCH) to 3.50 (endosulfan), respectively. The environmental and health impacts of hookah
40 wastewater, particularly concerning PCBs and OCPs and other toxic compounds, are becoming
41 increasingly concerning. Despite the comparatively low toxic equivalent (TEQ) values associated
42 with hookah wastewater, the continuous discharge of such waste into aquatic environments present
43 considerable threats to the wellbeing of both natural habitats and people. Addressing this
44 contamination requires concerted efforts from policymakers, researchers, and communities
45 worldwide to develop effective solutions.

46 **Keywords:** Waterpipe, Wastewater, Tobacco, Organochlorine pesticide, Polychlorinated
47 biphenyls

48 **Introduction**

49 Tobacco smoking represents a significant global health challenge, as a major preventable
50 cause of mortality and morbidity (Danaei et al., 2017; De Silva et al., 2024; Masjedi et al., 2023d).
51 Tobacco consumption patterns have shifted in recent years, with a decline in cigarette smoking but
52 an increase in waterpipe tobacco smoking, which is one of the most traditional and widespread
53 methods worldwide (Dehvari and Babaei, 2022; Khodadost et al., 2020). This increased prevalence
54 of waterpipe tobacco smoking causes concern about both the health risks to smokers and the
55 potential adverse environmental impacts associated with the frequent disposal of concentrated
56 hazardous wastes from waterpipe smoking (Heydari et al., 2024a; Kassem et al., 2020a; Masjedi

57 et al., 2023a; Masjedi et al., 2023d; Maziak et al., 2015; Rashidi et al., 2024a; Soleimani et al.,
58 2024a; Soleimani et al., 2025b; Termeh-Zonoozi et al., 2023).

59 A waterpipe is made up of a water container with a bowl at the top filled with waterpipe
60 tobacco. The tobacco is ignited by burning charcoal placed on top, and the generated smoke flows
61 through the water before it is breathed in (Edwards et al., 2021; Termeh-Zonoozi et al., 2023).
62 After each use, the charcoal residues, aluminum foil used to cover the waterpipe tobacco during
63 smoking, and burnt or partially burnt tobacco residues are discarded as waste. Additionally,
64 approximately 94% of the smoked water from waterpipe is disposed of as wastewater in bathroom
65 or kitchen sinks, where it flows into onsite septic systems or municipal sewer systems, with some
66 also being discarded in toilet, backyard soil, or street storm drain (Edwards et al., 2021; Hsieh et
67 al., 2021; Kassem et al., 2020a).

68 Previous scientific reports confirmed high concentrations of various pollutants, including
69 BTEX (Heydari et al., 2020; Jafari et al., 2020; Masjedi et al., 2023e), PAHs (Masjedi et al.,
70 2023c; Rashidi et al., 2024b; Soleimani et al., 2025a), heavy metals (Masjedi et al., 2023b;
71 Masjedi et al., 2020), and aromatic amines (Heydari et al., 2024b; Soleimani et al., 2024b) in fresh
72 tobacco and tobacco smoke. However, these toxic chemicals may be present in the waterpipe
73 wastes and wastewater. As a result, releasing waterpipe wastewater into the environment can add
74 these pollutants to soil and water systems, leading to their buildup and contributing to overall
75 environmental contamination (Edwards et al., 2021). Few researches evaluated the pollutants, such
76 as toxic elements (Al-Kazwini et al., 2015; Jafari et al., 2020; Qamar et al., 2015), BTEX (Masjedi
77 et al., 2023d), aldehydes, nicotine (Edwards et al., 2021), furanic compounds (Schubert et al.,
78 2012), and primary aromatic amines (Heydari et al., 2024a; Schubert et al., 2011) in waterpipe
79 wastewater. Despite the detection of various chemicals in waterpipe wastewater, other toxic

80 compounds that may also be present, such as biphenyls, polychlorinated biphenyls (PCBs),
81 pesticides, and herbicides, have not been thoroughly investigated.

82 PCBs and organochlorine pesticides (OCPs) belong to the group of persistent pollutants
83 that can persist for long durations in the environment and build up in adipose tissue (Moon et al.,
84 2017). Exposure to PCBs and OCPs is associated with numerous harmful health outcomes,
85 including damage to immune, nervous and reproductive systems, an heightened risk of various
86 cancers—including breast cancer—and adverse effects on neurodevelopment (Dickerson et al.,
87 2019; Koual et al., 2019; Mouly and Toms, 2016; Rezek et al., 2008; Zhang et al., 2010). Despite
88 restrictions on their use, PCBs and several OCPs, including hexachlorocyclohexanes (HCHs),
89 hexachlorobenzene (HCB), and dichlorodiphenyltrichloroethane (DDT) have remained as
90 environmental concerns in some regions (Wang et al., 2016c). PCBs are widespread contaminants
91 found throughout the environment owing to their persistent chemical properties and affinity for
92 accumulating in fats (Dickerson et al., 2019). Some researchers have reported the negative impacts
93 of smoking on PCBs concentrations in human body, exhibiting higher levels in smokers than
94 nonsmokers (D'Errico et al., 2012; Dickerson et al., 2019; Moon et al., 2017; Oltramare et al.,
95 2025). OCPs were widely used for control of insect-borne epidemics, such as malaria, and
96 agricultural cultivation (Karimi et al., 2020; Qi et al., 2014; Taufeeq et al., 2021a), and may be
97 applied during the cultivation of tobacco products (Arfaeinia et al., 2024b). Previous studies
98 detected residues of OCP in present in tobacco and its derivatives (Arfaeinia et al., 2024b; Qi et
99 al., 2014; Taufeeq et al., 2021a). In a study, PCBs and OCPs were detected in leachate from
100 smoked cigarette butts, indicating that these compounds are released from discarded cigarette butts
101 into the aquatic ecosystem (Arfaeinia et al., 2024b). Exposure to these hazardous substances in

102 humans may occur through consuming contaminated fatty foods (Arisawa et al., 2011), inhalation
103 and/or dermal contact (Schettgen et al., 2012).

104 This study introduces novel insights by comprehensively measuring concentrations of
105 PCBs and OCPs—persistent organic pollutants—in waterpipe wastewater from both flavored and
106 traditional tobacco, an area previously underexplored compared to prior research on general
107 chemical toxicity, heavy metals, or solid waste. It tests hypotheses of potentially harmful levels,
108 quantifies ecological risks, and differentiates wastewater impacts, thereby highlighting new
109 contaminants from this emerging tobacco waste source and advancing environmental toxicology
110 beyond existing aquatic toxicity assessments. The primary objective of this work was to
111 comprehensively assess the concentration levels of PCBs and OCPs compounds in waterpipe
112 wastewater, with a particular focus on both flavored and traditional tobacco. We hypothesized that
113 wastewater from waterpipe may contain OCPs and PCBs at concentrations capable of posing
114 environmental harm. In addition, we evaluated the ecological risks associated with the detected
115 OCP and PCB compounds. This study seeks to provide meaningful insight into the levels of these
116 hazardous chemicals in waterpipe wastewater, thereby enhancing understanding of their
117 contribution to environmental pollution and supporting the development of improved waste
118 management practices.

119 **2. Material and Methods**

120 **2.1. Study protocol and sample collection**

121 In this study, the presence and concentrations of 11 PCBs and 12 OCPs were measured in
122 wastewater collected from hookah bowls using both flavored and traditional tobaccos. Four
123 commonly available flavored tobacco brands—Nakhla, Al-Fakher, Al Tawareg, and Tangiers—

124 were selected for analysis. After a typical smoking session at local cafés, the wastewater remaining
125 in the hookah bowls was immediately collected to preserve analyte integrity. For each flavored
126 tobacco brand, 10 wastewater samples were obtained. Additionally, 10 wastewater samples from
127 bowls using freshly smoked traditional (non-flavored) tobacco were collected for comparison and
128 analysis of the target contaminants. A total of 50 wastewater samples were collected immediately
129 following waterpipe use. Of these, 40 samples were derived from four distinct flavored tobacco
130 brands, while the remaining 10 originated from traditional (unflavored) tobacco. All samples were
131 placed in opaque, foil-wrapped glass bottles, transported to the laboratory within approximately 2
132 hours of collection in a chilled container containing ice packs, and subsequently stored at -4 °C in
133 the dark conditions until analysis. To preserve analyte stability and prevent volatilization, samples
134 were kept at this temperature without exposure to light during storage. Sample extraction was
135 carried out within a maximum holding time of 48 hours after collection for all samples.

136 **2.2. Sample preparation and extraction**

137 The target pollutants were extracted from waterpipe wastewater samples with using the
138 dispersive liquid-liquid microextraction (DLLME) method based on our previous study (Jorfi et
139 al., 2022; Soleimani et al., 2023). The extraction solvent was dichloromethane (DCM) and
140 dispersion solvent was acetone. The extraction process involved placing 10 ml of the waterpipe
141 wastewater sample in a 15 ml polypropylene tube and then adding 50 µl of triphenyl phosphate
142 (TPP) solution. A cloudy solution was formed through rapid injection of 1 ml of DLLME solution
143 composed of acetone and dichloromethane (9:1). Following one minute of agitation, the mixture
144 was centrifuged at 6500 rpm for five minutes, and the lower dichloromethane layer containing
145 PCBs and OCPs was extracted for further analysis and quantification.

146 To minimize contamination and guarantee methodological accuracy, all glassware and
147 polypropylene tubes were meticulously rinsed with methanol and DCM, and blank samples
148 (containing only solvents and internal standard, without wastewater) were processed together with
149 the real wastewater samples. The trace levels quantified in blank samples were applied to adjust
150 the samples results accordingly, ensuring that any background contamination was subtracted from
151 the sample measurements.

152 **2.3. OCPs and PCBs analysis**

153 The gas chromatograph-mass spectrometer (GC-MS) instrument comprising the Agilent
154 7890 GC and Agilent 5975 MS (Agilent Technologies, Palo Alto, CA) was utilized for OCPs and
155 PCBs analysis. This setup featured a split/splitless injection port and an ultra-inert column
156 measuring 30 meters long, millimeters in diameter, and 25 micrometers thick. The oven
157 temperature program was initiated at 55°C, held for one minute, subsequently rose at a rate of 1°C
158 per minute to 150°C for two min, and finished with a 20°C/min increase to 280°C for 15 min. For
159 OCPs, the oven was first heated to 80°C for 1 min, then ramped at 30°C/min to 175°C (hold for 4
160 min), and finally gradually increased at 3°C/min to 225°C, holding this temperature for 10 min to
161 ensure complete elution of analytes. The system was injected with one microliter of every extract,
162 and its pulse was maintained at 40 psi for 0.2 min at 300°C. To identify and quantify the analytes,
163 a selected ion monitoring (SIM) mode was employed, consisting of one quantitative ion and two
164 qualifier ions for each compound. Quality control and quality assurance (QA/QC) were carried out
165 according to our previous study, and information such as retention time, spiked concentration
166 (ppb), average of obtained concentration (ppb), average of spike recovery (%), acceptable range
167 for spike recovery (%), intraday RSD% of spike recovery, acceptable range for intraday RSD (%),

168 interday RSD% of spike recovery, acceptable range for interday RSD (%), LOD (ppb) and LOQ
169 (ppb) are provided in that study as well as in Table S1 (Jorfi et al., 2022; Soleimani et al., 2023).
170 For PCBs compounds, LODs were between 0.03 and 0.07 µg/L and LOQs were between 0.10 and
171 0.23 µg/L, For OCPs compounds, LODs were between 0.06 and 0.08 µg/L and LOQs were
172 between 0.18 and 0.26 µg/L. This indicated that the analytical method is capable of detecting and
173 reliably quantifying the target compounds at trace levels.

174 **2.4. Eco-toxicological risk assessments for OCPs and PCBs**

175 The toxic equivalent (TEQ) was calculated based on approach described by Van et al. (176 2006b). This involved applying the detected concentrations of PCBs in waterpipe wastewater
177 samples by the World Health Organization's (WHO, 2005) toxic equivalency factors (TEFs) for
178 humans and other mammals, as indicated in Equation (1):

179 Equation 1:
$$TEQ = \sum [C_i \times TEF_i]$$

180 The toxic equivalency of a mixture is computed by aggregating the concentrations of its
181 individual components (C_i) after each concentration has been weighted by a corresponding TEF.

182 The environmental hazard associated with the identified OCP compounds in waterpipe
183 wastewaters was assessed by employing the risk quotient (RQ) approach. The specific formula for
184 calculation of the RQ is as follow:

185 Equation 2:
$$RQ = \frac{MEC}{PNEC}$$

186 Where MEC is the quantified level of OCPs (ng/l) in waterpipe wastewater samples, while
187 PNEC is the predicted no-effect concentration values derived from the Guo et al. (2023) research.
188 The PNEC values obtained through division of the LC₅₀ or EC₅₀ by Assessment Factor (AF) set at
189 a constant value of 1000, utilizing a consistent Assessment Factor (AF) of 1000 for all substances.

190 The application of an AF = 1000 is in accordance with widely accepted ecological risk
191 assessment frameworks, including the European Union Technical Guidance Document (EU TGD),
192 Organization for Economic Co-operation and Development (OECD) guidelines (ECB-JRC, 2003),
193 and the European Chemicals Agency (ECHA) guidance under the European Union Registration,
194 Evaluation, Authorization and Restriction of Chemicals (REACH) (ECHA, 2008). This
195 conservative assessment factor is recommended when available toxicity data are limited to acute
196 laboratory tests and the lack of chronic toxicity data (ECHA, 2008; Arfaeinia et al., 2024a; ECB-
197 JRC, 2003). The use of a consistent AF across all compounds guarantees methodological
198 consistency and delivers a conservative estimate of ecological risk in complex matrices such as
199 wastewater (Arfaeinia et al., 2024a). Environmental risk is considered moderate when RQ values
200 fall between 0.1 and 1 and values less than 0.1 correspond to a low risk (Nie et al., 2015).

201 **2.5. Statistical analyzes**

202 Data analysis was conducted using SPSS (Version 27). Specifically, Independent Samples Test
203 was employed to identify significant differences in PCBs/OCPs concentrations across the two
204 fruit-flavored and traditional waterpipe wastewater samples. The p-value less than 0.05 was
205 considered the cutoff for statistical significance.

206 **3. Results and discussion**

207 **3.1. The OCPs concentration levels in waterpipe wastewater**

208 In this study, the concentrations of OCPs in wastewater produced from fruit-flavored and
 209 traditional waterpipe tobacco were measured, and the results are summarized in Table 1. As noted,
 210 the mean Σ OCP concentrations in waterpipe wastewater from fruit-flavored tobacco were 111.25,
 211 125.51, 122.70, and 98.13 ng/L for the Nakhla, Al-Fakher, Al Tawareg, and Tangiers brands,
 212 respectively. In comparison, traditional tobacco samples showed a higher average concentration
 213 of 132.23 ng/L. DDT isomers were not detected in the wastewater samples from fruit-flavored
 214 waterpipe tobacco. Fig. 1 presents a violin plot comparing the Σ OCP concentrations in wastewater
 215 from fruit-flavored versus traditional tobacco. The results of the Independent Samples Test
 216 evaluating differences in Σ OCP concentrations between the two wastewater types are summarized
 217 in Table S2. The concentration of Σ OCPs did not differ significantly between the two traditional
 218 and fruit-flavored waterpipe wastewater (p -value>0.05). Although higher concentrations were
 219 observed in traditional waterpipe wastewater. Among the OCPs compounds, the concentration
 220 levels of DDE (dichlorodiphenyldichloroethylene), DDD (dichlorodiphenyltrichloroethane), DDT
 221 (dichlorodiphenyltrichloroethane) and chlordane were significantly different between the two
 222 traditional and fruit-flavored waterpipe wastewater (p -value <0.05).

Table 1. The individual concentrations (mean \pm sd, ng/L) of OCPs in waterpipe wastewater from
 flavored and traditional tobacco

Pesticide	Flavored				Traditional
	Nakhla	Al-fakher	Al Tawareg	Tangiers	
Aldrin	1.01 \pm 0.73	1.77 \pm 1.03	1.74 \pm 1.40	1.7 \pm 1.21	2.39 \pm 1.29
Dieldrin	4.38 \pm 1.78	3.93 \pm 2.60	3.96 \pm 1.82	4.5 \pm 1.82	5.12 \pm 3.01
Heptachlor	9.12 \pm 4.61	10.55 \pm 6.883	11.21 \pm 2.35	7.51 \pm 4.18	13.06 \pm 7.83
Chlordane	2.14 \pm 1.46	3.60 \pm 2.74	1.74 \pm 1.59	2.35 \pm 2.20	1.05 \pm 0.59
Endosulfan	8.39 \pm 6.32	10.49 \pm 7.54	7.10 \pm 7.26	7.02 \pm 8.32	4.91 \pm 3.67
α -HCH	38.8 \pm 17.41	41.94 \pm 31.04	54.07 \pm 35.57	42.42 \pm 17.76	44.07 \pm 15.14
β -HCH	53.65 \pm 29.07	65.62 \pm 37.23	84.50 \pm 51.70	55.80 \pm 30.61	66.02 \pm 34.26
γ -HCH	0.357 \pm 0.31	0.42 \pm 0.26	0.33 \pm 0.31	0.84 \pm 0.78	0.66 \pm 0.63
δ -HCH	0.83 \pm 0.59	1.13 \pm 0.78	1.77 \pm 1.06	1.27 \pm 1.01	1.37 \pm 1.49
Σ HCH	89.36 \pm 33.85	102.2 \pm 53.42	103.92 \pm 60.43	79.98 \pm 40.47	102.91 \pm 43.77
p,p'-DDE	ND	ND	ND	ND	0.52 \pm 0.24
p,p'-DDD	ND	ND	ND	ND	4.18 \pm 2.41
p,p'-DDT	ND	ND	ND	ND	2.06 \pm 0.35
Σ DDT	ND	ND	ND	ND	5.83 \pm 2.53

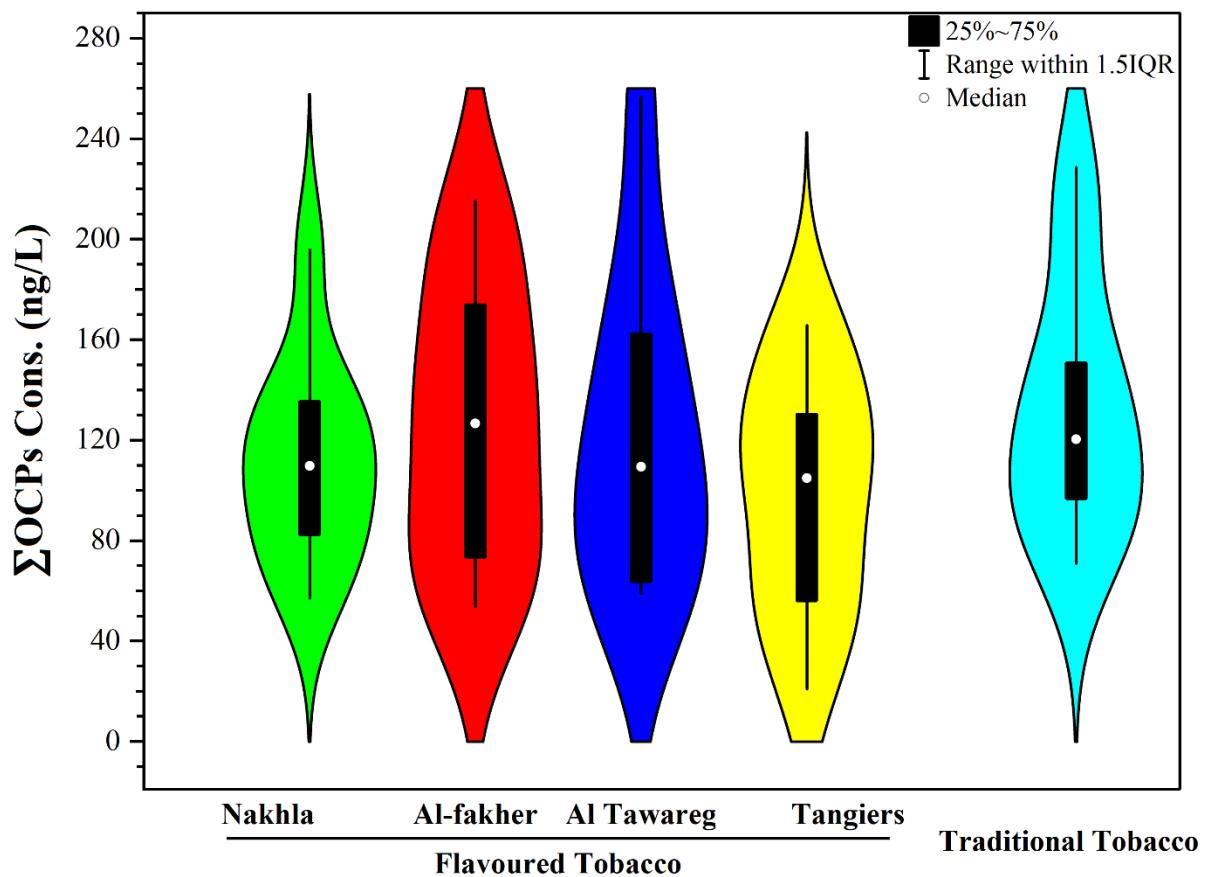
223 Due to its susceptibility to a wide range of diseases, tobacco cultivation often needs the
224 utilize of various chemical treatments, including organic pesticides (López Dávila et al., 2020).
225 OCPs are used as pesticides in agriculture, including tobacco farming. Residues from these
226 pesticides can remain on the crops and be present in final products (Kartalović et al., 2020a). As
227 well as, OCP residues can accumulate in soil and water over time and be absorbed by plants during
228 growth (Guo et al., 2019). In addition to these, there is a possibility that manufacturing equipment
229 or materials could introduce small amounts of OCP residues into tobacco products. Therefore, both
230 environmental factors (such as contamination during cultivation) and industrial processes (like
231 pesticide use or combustion) contribute to the presence of PCBs and OCPs in tobacco products.
232 The extensive application of pesticides in tobacco fields leads to their accumulation in the final
233 product, and when used with hookah, some of it is also trapped in the water in the hookah bowl,
234 creating a toxic wastewater (Quadroni and Bettinetti, 2019). The increased pesticide levels found
235 in waterpipe wastewater of traditional tobaccos may be because this type of tobaccos are
236 comprised entirely of tobacco, whereas flavored tobaccos are only 30% tobacco, with the rest
237 consisting of sweeteners and flavorings added during processing (Kassem et al., 2020b; Kassem
238 et al., 2018). Thus, during waterpipe use OCPs residues leach into wastewater, with higher
239 concentrations in traditional tobacco—composed entirely of tobacco—compared to flavored
240 varieties (only ~30% tobacco, diluted by additives), resulting in elevated pesticide-to-mass ratios
241 and greater trapping in hookah water.

242 Hexachlorocyclohexane (HCH) isomers had the maximum concentration level in both
243 fruit-flavored and traditional tobacco wastewater samples. The concentration of Σ HCH in
244 Nakhla, Al-Fakher, Al Tawareg and Tangiers brands were 89.36, 102.19, 103.91, and 79.98 ng/L,
245 respectively, and in traditional tobacco samples was 102.91 ng/L. The elevated concentrations of

246 HCH compounds in the waterpipe wastewater samples could result from their persistent and non-
247 volatile characteristics nature, combined with careless pesticide application in tobacco farming and
248 the considerable microbial breakdown resistance of HCHs (Abbas, 2021; Wang et al., 2016a). The
249 predominance of β -HCH comes from its higher chemical stability and lower biodegradability in
250 comparison with other HCH isomers. Unlike α - and γ -HCH, β -HCH shows greater resistance to
251 microbial decomposition and volatilization, leading to its accumulation preferentially in
252 environmental matrices such as wastewater (Mehboob et al., 2013; Qian et al., 2019). The presence
253 of HCHs, a type of insecticide, is frequently observed in agricultural areas, including rivers in
254 India (Chakraborty et al., 2016), Pakistan (Taufeeq et al., 2021b), Iran (Kafaei et al., 2020), Egypt
255 (Barakat et al., 2013), and China (Wang et al., 2016b), which are affected by activities such as
256 tobacco farming (Taufeeq et al., 2021b). Significant amounts of α - and β -HCH, by-product
257 substances in the making of lindane, were improperly discarded, posing environmental and health
258 risks (Ma et al., 2020; Sineli et al., 2016), particularly because of the elevated toxicity of HCHs
259 that are related to endocrine, neurological, renal, and gastrointestinal concerns, along with immune
260 system damage (Ali et al., 2020; Kong et al., 2014), with β -HCH being the most hazardous to
261 mammals (Jackovitz and Hebert, 2015; Kafaei et al., 2020). Subsequent to HCHs, heptachlor
262 exhibited the next highest concentration among the waterpipe wastewater samples analyzed. The
263 concentration of this pollutant in the samples from fruit-flavored tobacco in Nakhla, Al-Fakher, Al
264 Tawareg and Tangiers brands were 9.12, 10.55, 11.21, and 7.51 ng/L, respectively, and in
265 traditional tobacco samples was 13.05 ng/L. The International Agency for Research on Cancer
266 (IARC) has classified heptachlor as a substance that may cause cancer in humans (Vainio et al.,
267 1991). Because of their long-lasting nature and tendency to lipids, heptachlor residues persist in
268 the environment, affecting life forms in both land and water ecosystems (McManus et al., 2013).

269 Interestingly, DDT isomers were not found in waterpipe wastewater samples of fruit-flavored
270 tobacco, but were present in waterpipe wastewater samples of local tobacco samples at a ΣDDT
271 levels of 5.82 µg/L. In a 2019 research by Quadroni and Bettinetti (Bettinetti et al., 2012), DDT
272 pesticide was detected to be the most prevalent in 78.57% of in tobacco products samples, with
273 concentration levels of 9 ng/g of pp'-DDT and 13 ng/g of pp'-DDE. A research by Rahman et al.,
274 (Rahman et al., 2012) reported that the average DDT residue in tobacco leaf samples collected
275 from different areas in Kushtia, Bangladesh was 4000 ng/g. DDT and its by-products such as DDD
276 and DDE can adversely affect the liver as well as normal and cancerous tissues that respond to
277 estrogen (Liu et al., 2022; Wang et al., 2022).

278 These results underscore varietal differences driven by tobacco content and combustion
279 dynamics, with traditional types posing higher risks from undiluted pesticide legacies, while
280 HCH/heptachlor ubiquity reflects global agricultural bans' incomplete mitigation. Elevated β -HCH
281 toxicity to mammals further amplifies concerns for endocrine/neurological damage in exposed
282 ecosystems. This interpretation extends literature by mechanistically linking cultivation practices
283 to waterpipe-specific waste pollution, advocating refined monitoring in high-use regions.



284
 285 **Fig.1.** Violin plot of Σ OCPs concentrations levels in waterpipe wastewater from fruit-flavored and traditional
 286 tobacco.
 287

288 **3.2. The PCBs concentration levels in waterpipe wastewater**

289 The measured concentrations of Σ PCBs in wastewater samples generated from both
 290 flavored and traditional waterpipe tobacco are presented in Table 2. All tested waterpipe
 291 wastewater samples contained PCBs, indicating that waterpipe tobacco wastewater represents a
 292 significant source of these environmental pollutants. As shown in Table 2, the mean concentrations
 293 of Σ PCBs in wastewater from fruit-flavored tobacco brands—Nakhla, Al-Fakher, Al-Tawareg,
 294 and Tangiers—were 11.41, 11.05, 11.94, and 11.65 μ g/L, respectively. The mean concentration in
 295 traditional tobacco wastewater samples was 10.26 μ g/L. According to our findings, the average
 296 Σ PCB concentrations in tobacco brand wastewaters, ranked from highest to lowest, are: Al-

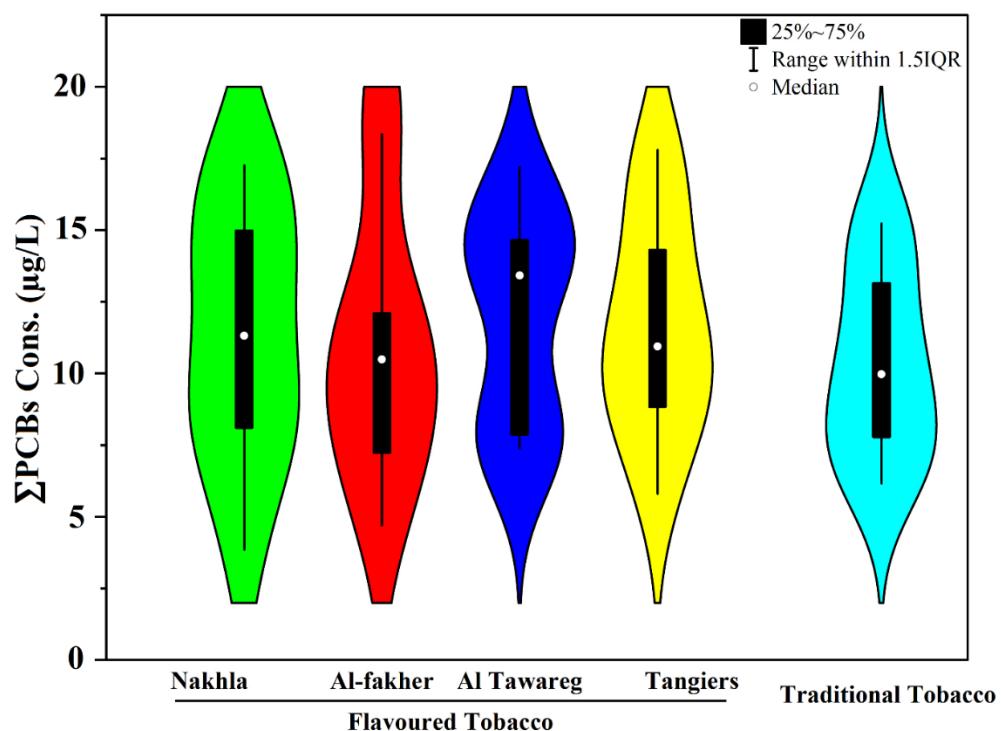
297 Tawareg, Tangiers, Nakhla, Al-Fakher, followed by traditional brands. The violin plot of Σ PCBs
298 concentrations levels in waterpipe wastewater from fruit-flavored and traditional tobacco are
299 shown in Fig. 2. The results of Independent Samples Test are presented in Table S2. The detection
300 of Σ PCBs in all waterpipe wastewater samples indicates that waterpipe tobacco—regardless of
301 flavor type—serves as a consistent source of these persistent organic pollutants. Although the
302 concentrations did not differ significantly between flavored and traditional tobacco (p -
303 value >0.05), the slightly elevated Σ PCB levels observed in flavored brands (11.05–11.94 μ g/L)
304 compared to traditional tobacco (10.26 μ g/L) may reflect compositional and processing differences
305 between the two product types. Elevated concentrations of PCBs in wastewater samples of fruit-
306 flavored can arise from the use of flavoring agents, substantial quantities of organic chemicals,
307 sweeteners, scents, and essential oils introduced during processing of these type of tobacco (Farley
308 et al., 2018; Masjedi et al., 2023b). Moreover, the slight variations in PCBs concentrations across
309 wastewaters from various brands may also be linked to environmental factors affecting leaf
310 contamination pathways: tobacco grown in soils impacted by historical PCB emissions, near
311 industrial areas, or irrigated with contaminated water can accumulate PCB residues that later
312 transfer into tobacco smoke and ultimately into the waterpipe bowl (Verma et al., 2010; Zhu et al.,
313 2014). The similar magnitude of PCB concentrations between flavored and traditional varieties
314 suggests that agricultural contamination pathways remain dominant; however, the slightly higher
315 levels in flavored products may reflect an additive effect of processing-related inputs. These
316 findings reinforce the hydrophobic and combustion-stable nature of PCBs, their ability to partition
317 into the water phase during smoking, and the potential role of both agricultural environments and
318 manufacturing practices in shaping PCB burdens in waterpipe wastewater. This mechanistic
319 understanding highlights why PCB pollution persists across tobacco types and supports the need

320 for greater monitoring of additive-rich flavored products, whose complex composition may
 321 enhance the mobilization or introduction of persistent pollutants.

Table 2. The individual concentrations (mean \pm sd, $\mu\text{g/L}$) of PCBs in waterpipe wastewater from flavored and traditional tobacco.

PCBs	Flavored				Traditional
	Nakhla	Al-fakher	Al Tawareg	Tangiers	
PCB77	2.14 \pm 1.15	2.17 \pm 1.21	1.84 \pm 1.10	2.03 \pm 1.29	1.84 \pm 1.06
PCB81	1.16 \pm 0.67	0.98 \pm 0.68	1.09 \pm 0.59	1.17 \pm 0.65	1.19 \pm 0.62
PCB114	0.78 \pm 0.46	0.74 \pm 0.30	0.82 \pm 0.46	0.86 \pm 0.46	0.74 \pm 0.4
PCB118	0.91 \pm 0.65	0.87 \pm 0.80	1.17 \pm 0.67	1.17 \pm 0.82	0.80 \pm 0.64
PCB123	0.41 \pm 0.27	0.34 \pm 0.25	0.42 \pm 0.27	0.43 \pm 0.27	0.34 \pm 0.18
PCB126	0.20 \pm 0.19	0.21 \pm 0.18	0.22 \pm 0.19	0.22 \pm 0.18	0.21 \pm 0.20
PCB156	0.59 \pm 0.23	0.56 \pm 0.19	0.58 \pm 0.21	0.69 \pm 0.24	0.60 \pm 0.25
PCB157	0.17 \pm 0.14	0.16 \pm 0.12	0.19 \pm 0.14	0.19 \pm 0.14	0.19 \pm 0.11
PCB167	2.01 \pm 1.12	1.76 \pm 1.23	2.28 \pm 1.31	2.05 \pm 1.22	1.79 \pm 1.00
PCB189	0.93 \pm 0.31	0.86 \pm 0.27	0.91 \pm 0.28	0.86 \pm 0.44	0.92 \pm 0.17
PCB194	3.08 \pm 1.65	2.72 \pm 1.60	3.20 \pm 1.72	3.06 \pm 1.55	2.74 \pm 1.47

322



323

324 **Fig.2.** Violin plot of Σ PCBs concentrations levels in waterpipe wastewater from fruit-flavored and traditional
 325 tobacco

326

327 The individual concentrations of PCBs in wastewaters samples from different fruit-
328 flavored tobaccos as well as traditional tobacco are also detailed in Table 2. As indicated, average
329 concentration of PCB77, PCB81, PCB114, PCB118, PCB123, PCB126, PCB156, PCB157,
330 PCB167, PCB189 and PCB194 in wastewater samples of waterpipe with fruit-flavoured tobacco
331 were 2.05 ± 1.19 , 1.10 ± 0.65 , 0.81 ± 0.43 , 1.03 ± 0.75 , 0.43 ± 0.29 , 0.22 ± 0.18 , 0.64 ± 0.28 , 0.27
332 ± 0.39 , 2.03 ± 1.23 , 0.92 ± 0.40 , and $3.05 \pm 1.61 \mu\text{g/L}$, respectively. The mean concentration levels
333 of PCB77, PCB81, PCB114, PCB118, PCB123, PCB126, PCB156, PCB157, PCB167, PCB189
334 and PCB194 in wastewater samples of waterpipe with traditional tobacco were also 1.84 ± 1.06 ,
335 1.19 ± 0.62 , 0.74 ± 0.40 , 0.80 ± 0.64 , 0.33 ± 0.18 , 0.21 ± 0.20 , 0.60 ± 0.25 , 0.19 ± 0.11 , $1.79 \pm$
336 1.00 , 0.92 ± 0.17 , and $2.74 \pm 1.47 \mu\text{g/L}$, respectively. As can be seen, PCB194 exhibited the
337 maximum concentration level among all quantified PCBs congeners. This observation could be
338 explained by the durable chemical structure and resistance to degradation of PCB194, which tends
339 to accumulate more easily in wastewater in relation to the other congeners (Beyer and Biziuk,
340 2009). Moreover, its higher lipid affinity may contribute to stronger adsorption to particulate
341 matter in the waterpipe residues, resulting in higher detected concentrations (Urbaniak et al.,
342 2017). A study quantified dioxin-like PCB congeners (e.g., PCB 77, PCB 105, PCB 114, PCB
343 118) with toxicity equivalent values ranging from 8.7×10^{-6} to 3.21×10^{-4} ng WHO-TEQ per
344 cigarette (Adesina et al., 2022). Inhalation of these pollutants was associated with non-
345 carcinogenic health risks, as HQ values exceeded safe limits (Adesina et al., 2022). It should be
346 noticed that industrial processes have caused the the emission of a significant amount of PCBs into
347 the ecosystem, especially, and the analogues readily build up in the environmental compartments
348 (e.g., atmosphere, water, soil, and sediments), particularly in the nearby regions because of their
349 persistence (Kim et al., 2017; Mao et al., 2021; Mila et al., 2022; Rivoira et al., 2022). Previous

350 researches across many countries has consistently reported that the PCBs level in surface soil were
351 closely associated with closeness to the source areas (Mao et al., 2021; Zhao et al., 2016).
352 Numerous studies have shown that the increased PCB levels in the environmental matrices are a
353 consequence of historical usage or improper disposal of PCBs-related goods (Meijer et al., 2003).
354 PCBs can contaminate soil, air, and water and tobacco plants may absorb these chemicals from
355 the environment during cultivation (Guo et al., 2019). The combustion of tobacco during smoking
356 can release PCBs into the mainstream smoke. Studies have identified various PCB congeners in
357 cigarette smoke, indicating that combustion processes contribute to their presence (Adesina et al.,
358 2022). Although less documented, manufacturing processes might also introduce trace amounts of
359 PCBs into tobacco products due to contamination or use of contaminated materials. Therefore,
360 during waterpipe smoking, some of PCBs enters the smoke and is inhaled by the smoker,
361 endangering his health. Additionally, some PCBs trapped in the waterpipe water, and the release
362 of this water into the environment can have various eco-toxicological effects.

363 **3.3. Environmental Toxicity of OCPs and PCBs**

364 Although direct evidence connecting wastewater from waterpipe to substantial PCB or
365 OCP contamination is limited compared with well-known sources such as industrial discharge or
366 agricultural runoff, the release of these pollutants into aquatic environments still presents serious
367 ecological and public-health risks due to their persistence, toxicity, and tendency to bio-
368 accumulate in living organisms. The ecological risks related with OCPs in waterpipe wastewater
369 for aquatic environment are provided in Table 3. The assessment of ecological risks posed by
370 individual OCPs in traditional tobacco waterpipe wastewater showed that the RQ values were
371 ranged from 0.00 (δ -HCH) to 2.46 (endosulfan). The RQ value of endosulfan was greater than 1,
372 with high ecological risk. As well as, the RQ values of β -HCH, δ -HCH, chlordan, p,p'-DDE, p,p'-

373 DDT and heptachlor were less than 0.1, with low ecological risks. Other compounds such as α -
 374 HCH, γ -HCH, aldrin and dieldrin have medium ecological risks (0<RQ<1). In the case of flavored
 375 tobacco, the RQ values were ranged from 0.00 (δ -HCH) to 3.50 (endosulfan). The RQ value of
 376 endosulfan was generally greater than 1, with high ecological risk. As well as, the RQ values of β -
 377 HCH, δ -HCH, chlordan, dieldrin and heptachlor were less than 0.1, with low ecological risks.
 378 Other compounds such as α -HCH, γ -HCH and aldrin have medium ecological risks (0<RQ<1).

379 **Table 3.** Ecological hazard metrics related to organochlorine pesticides (OCPs) in waterpipe wastewater
 380 for aquatic media

OCPs	Traditional Tobacco			Flavored Tobacco		
	MEC	PNEC	RQ	MEC	PNEC	RQ
α -HCH	44.07	370	0.12	38.51	370	0.11
β -HCH	66.02	3140	0.02	54.13	3140	0.02
γ -HCH	0.66	2.9	0.23	0.32	2.9	0.11
δ -HCH	1.37	1580	0.00	0.91	1580	0.00
Aldrin	2.39	10	0.24	1.03	10	0.11
Chlordan	1.05	90	0.01	1.87	90	0.02
Endosulfan	4.91	2	2.46	6.99	2	3.50
p,p'-DDE	0.52	15	0.03	<LOD	15	-
Dieldrin	5.12	50	0.11	3.05	50	0.06
p,p'-DDD	4.18	9	0.46	<LOD	9	-
p,p'-DDT	2.06	30	0.07	<LOD	30	-
Heptachlor	13.06	150	0.09	7.63	150	0.05

381 The TEQs of the PCBs in the in flavored and traditional waterpipe wastewater for aquatic
 382 media ranged from 8.1×10^{-6} (PCB157) to 0.02 (PCB126) and 5.7×10^{-6} (PCB157) to 0.02
 383 (PCB126) ng/L (Table 4). In a study, the TEQ values of dioxin-like PCBs in cigarette butts
 384 leachates were low, and it is reported that continuous discharge into water bodies could pose long-
 385 term environmental and health dangers (Arfaeinia et al., 2024a). The ecological impact of
 386 waterpipe wastewater is an increasing issue, particularly regarding its toxicological effects on
 387 aquatic ecosystems and human health. Despite the shallow TEQs observed in waterpipe
 388 wastewater, continuous discharge can lead to significant ecological and health risks. The TEF and

389 TEQ approach is indeed a well-established method for assessing the risk associated with exposure
 390 to PCBs and other dioxin-like substances (Van den Berg et al., 2006b), particularly in dietary
 391 contexts. However, its application in non-living environmental components (including soil, water,
 392 or air) presents several challenges (Arfaeinia et al., 2024b). Its application in abiotic environmental
 393 matrices requires careful consideration of bioavailability, transport mechanisms, and
 394 environmental fate. By addressing these challenges through targeted research and interdisciplinary
 395 collaboration, we can enhance our risk assessment frameworks and better protect human health
 396 and the environment. To accurately assess human risk for abiotic environments, it is suggested to
 397 utilize congener-targeted equations across the entire model rather than relying on the TEQ model.
 398 This approach is crucial because the fate and transfer properties of different congeners vary
 399 significantly (Van den Berg et al., 2006a), which can lead to inaccuracies if a generalized TEQ
 400 framework is applied. While the concentrations of PCBs and OCPs from waterpipe wastewater
 401 may be relatively low compared to other pollutants, their continuous release poses significant risks
 402 due to bioaccumulation effects on aquatic ecosystems.

403 **Table 4.** The toxicity equivalent (TEQ) and Toxic Equivalency Factors (TEFs) values of PCBs in
 404 waterpipe wastewater for aquatic media

PCBs	Concentrations		TEF (WHO 2005)	TEQs	
	Traditional tobacco	Flavored tobacco		Traditional tobacco	Flavored tobacco
PCB77*	1.84	2.05	0.0001	1.8E-04	2E-04
PCB81*	1.19	1.1	0.00001	1E-05	1.1E-05
PCB114**	0.74	0.8	0.00003	2.2E-05	2.4E-05
PCB118**	0.8	1.03	0.00003	2.4E-05	3.1E-05
PCB126*	0.21	0.22	0.01	0.02	0.02
PCB156**	0.6	0.64	0.00003	1.8E-05	1.9E-05
PCB157**	0.19	0.27	0.00003	5.7E-06	8.1E-06
PCB167**	1.79	2.03	0.00003	5.8E-05	6.1E-05
PCB189*	0.92	0.92	0.00003	2.4E-05	2.8E-05

405 *: non-ortho substituted PCBs; **: mono-ortho substituted PCBs
 406
 407

408 **4- Practical applications and future research prospects**

409 Both PCBs and OCPs are classified as POPs, known for their carcinogenic, immunotoxic,
410 and neurotoxic effects (Androutsopoulos et al., 2013; Lauby-Secretan et al., 2013). These
411 compounds can bio accumulate in human tissues through inhalation or environmental exposure
412 (Adesina et al., 2022; Kartalović et al., 2020b; Thakur and Pathania, 2020; Zhu et al., 2022). This
413 study showed that various hazardous pollutants including OCPs and PCBs can enter the
414 environment through waterpipe wastewater and/or tobacco waste and negatively impact the
415 terrestrial and aquatic ecosystems. To effectively diminish the ecological effect of waterpipe
416 tobacco wastewaters, it is suggested that multi-pronged approach be taken. Countries with high
417 rates of waterpipe use, particularly within the Middle East region, such as Iran, should prioritize
418 thorough tobacco waste-specific waste management policies. Moreover, it is essential to highlight
419 the duty of tobacco of tobacco manufacturers in handling their products not just during production,
420 but also after they are used and disposed. They must be forced to adopt Extended Producer
421 Responsibility (EPR) programs to fulfill this. Moreover, to prevent these pollutants from entering
422 the environment, specific actions are needed, such as public education and increasing smokers'
423 awareness of the serious consequences of discharging these pollutants into the environment. In
424 addition, while this study found that hookah wastewater can contain hazardous chemicals, its
425 effects on terrestrial organisms/plants were not assessed. Additional scientific research is needed
426 to understand the level of toxicity of this type of hazardous wastewater poses to both
427 aquatic/terrestrial organisms. Simultaneously, researches of smokers' behavior could explore
428 attitudes regarding the disposal of tobacco waste and highlights the significance of educational
429 initiatives.

431 **4. Conclusion**

432 This study evaluated the environmental health risks associated with wastewater generated
433 from waterpipe tobacco use, with special emphasis on PCBs and OCPs. The results showed that
434 flavored and traditional waterpipe tobacco products contribute to the contamination of aquatic and
435 terrestrial ecosystems, while flavored waterpipe tobacco products have higher concentrations of
436 PCBs, because of the addition of flavoring material. The analysis showed that PCB194 was the
437 most abundant PCBs in both flavored and traditional tobacco products, whereas β -HCH and α -
438 HCH were the most prevalent pesticides in all analyzed samples. In addition, waterpipe wastewater
439 demonstrated considerable detection of OCP residues, which might underline the urgent need to
440 control these toxic substances. The research put more focus on controlling the methods of disposal
441 of waterpipe waste so as to suppress the negative consequences on the environment and public
442 health. Proper management systems involving effective waste management strategies like
443 wastewater treatment and proper disposal methods could reduce the adverse effects of on both
444 aquatic and terrestrial ecosystems. Such these insights help to improve the understanding of the
445 toxic burden associated with waterpipe tobacco waste and set a foundation for further research and
446 policy initiatives aimed at mitigating pollutants and protecting both the environment and human
447 health. This would call for cooperation among policymakers and industry stakeholders in dealing
448 with such challenges effectively, reducing the ecological impact of tobacco products and
449 preserving human health.

450 **Credit author statement**

451 The study was planned and overseen by **Hossein Arfaeinia** and **Gholamreza Heydari**.
452 Samples were collected by **Farshid Soleimani** and **Mohammad Mahdi Hatami**. Experiments
453 and data collection were carried out by **Hossein Arfaeinia**, **Farshid Soleimani**, and **Niloufar**

454 **Borhani Yazdi**, **Ali Mouseli** was the advisor of the work. **Zohre Moeini** and **Masoumeh**
455 **Tahmasbizadeh** performed the statistical analysis. **Farshid Soleimani** and **Zohre Moeini**
456 prepared the initial draft of the manuscript. The completed manuscript was carefully reviewed and
457 confirmed by all the authors.

458 **Declaration**

459 All authors have read, understood, and have complied as applicable with the statement on
460 "Ethical responsibilities of Authors" as found in the Instructions for Authors.

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470 **References**

471 (ECHA), E.C.A., 2008. Guidance on information requirements and chemical safety assessment, Chapter
472 R.10: Characterisation of dose-response for the environment. Helsinki: ECHA.
473 Abbas, W.T., 2021. Advantages and prospective challenges of nanotechnology applications in fish
474 cultures: a comparative review. Environmental Science and Pollution Research 28, 7669-7690.
475 Adesina, O.A., Tosin, O., Mayowa, L., Ogundipe, K., Adeyemo, A.T., 2022. Concentrations of
476 Polychlorinated Biphenyl in Mainstream Cigarette Smoke and its Risk Assessments. J. Drug Alcohol Res.
477 11, 7.
478 Al-Kazwini, A.T., Said, A.J., Sdepanian, S., 2015. Compartmental analysis of metals in waterpipe smoking
479 technique. BMC Public Health 15, 1-7.
480 Ali, S.N., Baqar, M., Mumtaz, M., Ashraf, U., Anwar, M.N., Qadir, A., Ahmad, S.R., Nizami, A.-S., Jun,
481 H.J.E.S., Research, P., 2020. Organochlorine pesticides in the surrounding soils of POPs destruction
482 facility: source fingerprinting, human health, and ecological risks assessment. 27, 7328-7340.

483 Androutsopoulos, V.P., Hernandez, A.F., Liesivuori, J., Tsatsakis, A.M., 2013. A mechanistic overview of
484 health associated effects of low levels of organochlorine and organophosphorous pesticides. *Toxicology*
485 307, 89-94.

486 Arfaeinia, H., Masjedi, M.R., Asgarian, R., Soleimani, F., Alipour, V., Dadipoor, S., Saeedi, R., Jahantigh,
487 A., Maryamabadi, A., 2024a. Release of polychlorinated biphenyls (PCBs) and organochlorine pesticides
488 (OCPs) from cigarette butts into the aquatic environment: Levels and ecotoxicity. *Heliyon* 10, e39046.

489 Arfaeinia, H., Masjedi, M.R., Asgarian, R., Soleimani, F., Alipour, V., Dadipoor, S., Saeedi, R., Jahantigh,
490 A., Maryamabadi, A., 2024b. Release of polychlorinated biphenyls (PCBs) and organochlorine pesticides
491 (OCPs) from cigarette butts into the aquatic environment: Levels and ecotoxicity. *Heliyon* 10.

492 Arisawa, K., Uemura, H., Hiyoshi, M., Kitayama, A., Takami, H., Sawachika, F., Nishioka, Y., Hasegawa, M.,
493 Tanto, M., Satoh, H., 2011. Dietary patterns and blood levels of PCDDs, PCDFs, and dioxin-like PCBs in
494 1656 Japanese individuals. *Chemosphere* 82, 656-662.

495 Barakat, A.O., Khairy, M., Aukaily, I.J.C., 2013. Persistent organochlorine pesticide and PCB residues in
496 surface sediments of Lake Qarun, a protected area of Egypt. 90, 2467-2476.

497 Bettinetti, R., Quadroni, S., Manca, M., Piscia, R., Volta, P., Guzzella, L., Roscioli, C., Galassi, S.J.C., 2012.
498 Seasonal fluctuations of DDTs and PCBs in zooplankton and fish of Lake Maggiore (Northern Italy). 88,
499 344-351.

500 Beyer, A., Biziuk, M., 2009. Environmental fate and global distribution of polychlorinated biphenyls. *Rev
501 Environ Contam Toxicol* 201, 137-158.

502 Chakraborty, P., Khuman, S.N., Selvaraj, S., Sampath, S., Devi, N.L., Bang, J.J., Katsoyannis, A.J.E.P., 2016.
503 Polychlorinated biphenyls and organochlorine pesticides in River Brahmaputra from the outer
504 Himalayan Range and River Hooghly emptying into the Bay of Bengal: Occurrence, sources and
505 ecotoxicological risk assessment. 219, 998-1006.

506 D'Errico, M., De Tullio, G., Di Gioacchino, M., Lovreglio, P., Basso, A., Drago, I., Serra, R., Apostoli, P.,
507 Vacca, A., Soleo, L., 2012. Immune Effects and Polychlorinated Biphenyls, Smoking and Alcohol.
508 *International journal of immunopathology and pharmacology* 25, 1041-1054.

509 Danaei, M., Jabbarinejad-Kermani, A., Mohebbi, E., Momeni, M., 2017. Waterpipe tobacco smoking
510 prevalence and associated factors in the southeast of Iran. *Addiction & health* 9, 72.

511 De Silva, R., Silva, D., Piumika, L., Abeysekera, I., Jayathilaka, R., Rajamanthri, L., Wickramaarachchi, C.,
512 2024. Impact of global smoking prevalence on mortality: a study across income groups. *Bmc Public
513 Health* 24, 1786.

514 Dehvari, M., Babaei, A., 2022. Analysis of heavy metals and PAHs in the waste resulting from hookah
515 consumption: Ahvaz City, Iran. *Environmental Science and Pollution Research* 29, 33130-33137.

516 Dickerson, A.S., Ransome, Y., Karlsson, O., 2019. Human prenatal exposure to polychlorinated biphenyls
517 (PCBs) and risk behaviors in adolescence. *Environment International* 129, 247-255.

518 ECB-JRC, 2003. European Chemicals Bureau & Joint Research Centre (ECB & JRC). Technical Guidance
519 Document on risk assessment for existing and new notified substances (Parts II & III). Luxembourg:
520 Publications Office of the European Union.

521 Edwards, R.L., Venugopal, P.D., Hsieh, J.R., 2021. Aquatic toxicity of waterpipe wastewater chemicals.
522 *Environmental Research* 197, 111206.

523 Farley, S.M., Schroth, K.R., Grimshaw, V., Luo, W., DeGagne, J.L., Tierney, P.A., Kim, K., Pankow, J.F.J.T.c.,
524 2018. Flavour chemicals in a sample of non-cigarette tobacco products without explicit flavour names
525 sold in New York City in 2015. 27, 170-176.

526 Guo, J., Chen, W., Wu, M., Qu, C., Sun, H., Guo, J.J.T., 2023. Distribution, sources, and risk assessment of
527 organochlorine pesticides in water from Beiluo River, Loess Plateau, China. 11, 496.

528 Guo, W., Pan, B., Sakkiah, S., Yavas, G., Ge, W., Zou, W., Tong, W., Hong, H., 2019. Persistent Organic
529 Pollutants in Food: Contamination Sources, Health Effects and Detection Methods. *Int J Environ Res
530 Public Health* 16.

531 Heydari, G., Ranjbar Vakilabadi, D., Kermani, M., Rayani, M., Poureshgh, Y., Behroozi, M., Fanaei, F.,
532 Arfaeinia, H.J.E.P., Bioavailability, 2020. Load characteristics and inhalation risk assessment of benzene
533 series (BTEX) pollutant in indoor air of Ghalyan and/or cigarette cafes compared to smoking-free cafes.
534 32, 26-35.

535 Heydari, G., Tangestani, M., Soleimani, F., Ramavandi, B., Asl, F.B., Rashidi, R., Arfaeinia, H., 2024a.
536 Occurrence and eco-toxicological risk assessment of primary aromatic amines in hookah wastewater.
537 Environmental Progress & Sustainable Energy 43, e14466.

538 Heydari, G., Tangestani, M., Soleimani, F., Ramavandi, B., Asl, F.B., Rashidi, R., Arfaeinia, H.J.E.P., Energy,
539 S., 2024b. Occurrence and eco-toxicological risk assessment of primary aromatic amines in hookah
540 wastewater. 43, e14466.

541 Hsieh, J.R., Mekoli, M.L., Edwards Jr, R.L., 2021. Levels of chemical toxicants in waterpipe tobacco and
542 waterpipe charcoal solid waste. Journal of environmental protection 12, 913.

543 Jackovitz, A.M., Hebert, R.M., 2015. Wildlife toxicity assessment for hexachlorocyclohexane (HCH),
544 Wildlife Toxicity Assessments for Chemicals of Military Concern. Elsevier, pp. 473-497.

545 Jafari, A.J., Asl, Y.A., Momeniha, F., 2020. Determination of metals and BTEX in different components of
546 waterpipe: charcoal, tobacco, smoke and water. Journal of Environmental Health Science and
547 Engineering 18, 243-251.

548 Jorfi, S., Poormohammadi, A., Maraghi, E., Almasi, H., 2022. Monitoring and health risk assessment of
549 organochlorine pesticides in Karun River and drinking water Ahvaz city, South West of Iran. Toxin
550 Reviews 41, 361-369.

551 Kafaei, R., Arfaeinia, H., Savari, A., Mahmoodi, M., Rezaei, M., Rayani, M., Sorial, G.A., Fattahi, N.,
552 Ramavandi, B.J.C., 2020. Organochlorine pesticides contamination in agricultural soils of southern Iran.
553 240, 124983.

554 Karimi, B., Nabizadeh Nodehi, R., Yunesian, M., 2020. Serum level of PCBs and OCPs and leukocyte
555 telomere length among adults in Tehran, Iran. Chemosphere 248, 126092.

556 Kartalović, B., Mastanjević, K., Novakov, N., Vranešević, J., Ljubojević Pelić, D., Puljić, L., Habschied, K.,
557 2020a. Organochlorine Pesticides and PCBs in Traditionally and Industrially Smoked Pork Meat Products
558 from Bosnia and Herzegovina. Foods 9, 97.

559 Kartalović, B., Mastanjević, K., Novakov, N., Vranešević, J., Ljubojević Pelić, D., Puljić, L., Habschied, K.,
560 2020b. Organochlorine Pesticides and PCBs in Traditionally and Industrially Smoked Pork Meat Products
561 from Bosnia and Herzegovina. Foods 9.

562 Kassem, N.O., Kassem, N.O., Liles, S., Reilly, E., Kas-Petrus, F., Posis, A.I.B., Hovell, M.F., 2020a.
563 Waterpipe device cleaning practices and disposal of waste associated with waterpipe tobacco smoking
564 in homes in the USA. Tobacco control 29, s123-s130.

565 Kassem, N.O., Kassem, N.O., Liles, S., Reilly, E., Kas-Petrus, F., Posis, A.I.B., Hovell, M.F.J.T.c., 2020b.
566 Waterpipe device cleaning practices and disposal of waste associated with waterpipe tobacco smoking
567 in homes in the USA. 29, s123-s130.

568 Kassem, N.O., Kassem, N.O., Liles, S., Zarth, A.T., Jackson, S.R., Daffa, R.M., Chatfield, D.A., Carmella,
569 S.G., Hecht, S.S., Hovell, M.F.J.N., Research, T., 2018. Acrolein exposure in hookah smokers and non-
570 smokers exposed to hookah tobacco secondhand smoke: implications for regulating hookah tobacco
571 products. 20, 492-501.

572 Khodadost, M., Maajani, K., Abbasi-Ghahramanloo, A., Naserbakht, M., Ghodusi, E., Sarvi, F.,
573 Mohammadzadeh, A., Motevalian, S.A., Hajebi, A., 2020. Prevalence of hookah smoking among
574 university students in Iran: A meta-analysis of observational studies. Iranian Journal of Public Health 49,
575 1.

576 Kim, L., Jeon, J.-W., Son, J.-Y., Park, M.-K., Kim, C.-S., Jeon, H.-J., Nam, T.-H., Kim, K., Park, B.-J., Choi, S.-
577 D.J.E.g., health, 2017. Monitoring and risk assessment of polychlorinated biphenyls (PCBs) in agricultural
578 soil from two industrialized areas. 39, 279-291.

579 Kong, X., He, W., Qin, N., He, Q., Yang, B., Ouyang, H., Wang, Q., Yang, C., Jiang, Y., Xu, F.J.E.i., 2014.
580 Modeling the multimedia fate dynamics of γ -hexachlorocyclohexane in a large Chinese lake. 41, 65-74.
581 Koual, M., Cano-Sancho, G., Bats, A.-S., Tomkiewicz, C., Kaddouch-Amar, Y., Douay-Hauser, N., Ngo, C.,
582 Bonsang, H., Deloménie, M., Lecuru, F., 2019. Associations between persistent organic pollutants and
583 risk of breast cancer metastasis. *Environment International* 132, 105028.
584 Lauby-Secretan, B., Loomis, D., Grosse, Y., El Ghissassi, F., Bouvard, V., Benbrahim-Tallaa, L., Guha, N.,
585 Baan, R., Mattock, H., Straif, K., 2013. Carcinogenicity of polychlorinated biphenyls and polybrominated
586 biphenyls. *Lancet Oncology* 14, 287-288.
587 Liu, X., Song, L.J.F., Toxicology, C., 2022. Quercetin protects human liver cells from o, p'-DDT-induced
588 toxicity by suppressing Nrf2 and NADPH oxidase-regulated ROS production. 161, 112849.
589 López Dávila, E., Houbraken, M., De Rop, J., Wumbei, A., Du Laing, G., Romero Romero, O., Spanoghe,
590 P.J.E.M., Assessment, 2020. Pesticides residues in tobacco smoke: risk assessment study. 192, 1-15.
591 Ma, Y., Yun, X., Ruan, Z., Lu, C., Shi, Y., Qin, Q., Men, Z., Zou, D., Du, X., Xing, B.J.S.o.T.T.E., 2020. Review
592 of hexachlorocyclohexane (HCH) and dichlorodiphenyltrichloroethane (DDT) contamination in Chinese
593 soils. 749, 141212.
594 Mao, S., Liu, S., Zhou, Y., An, Q., Zhou, X., Mao, Z., Wu, Y., Liu, W.J.E.p., 2021. The occurrence and
595 sources of polychlorinated biphenyls (PCBs) in agricultural soils across China with an emphasis on
596 unintentionally produced PCBs. 271, 116171.
597 Masjedi, M.R., Arfaeinia, H., Dobaradaran, S., Keshtkar, M., Soleimani, F., Novotny, T.E., Torkshavand, Z.,
598 2023a. Post-consumption waterpipe tobacco waste as an unrecognized source of toxic metal (loid) s
599 leachates into aquatic environments. *Science of the total environment* 879, 163207.
600 Masjedi, M.R., Arfaeinia, H., Dobaradaran, S., Keshtkar, M., Soleimani, F., Novotny, T.E., Torkshavand,
601 Z.J.S.o.T.T.E., 2023b. Post-consumption waterpipe tobacco waste as an unrecognized source of toxic
602 metal (loid) s leachates into aquatic environments. 879, 163207.
603 Masjedi, M.R., Dobaradaran, S., Arfaeinia, H., Samaei, M.R., Novotny, T.E., Rashidi, N.J.E.P., 2023c.
604 Polycyclic aromatic hydrocarbon (PAH) leachates from post-consumption waterpipe tobacco waste
605 (PWTW) into aquatic environment-a primary study. 327, 121500.
606 Masjedi, M.R., Taghizadeh, F., HamzehAli, S., Ghaffari, S., Ahmadi, E., Dobaradaran, S., Ramavandi, B.,
607 Tahergorabi, M., Arfaeinia, H.J.E.P., Bioavailability, 2020. Load characteristics, in vitro bioaccessibility
608 and health risk assessment of PM2. 5-bounded heavy metals in indoor air of waterpipe and/or cigarette
609 cafes compared to smoking-free cafes. 32, 56-67.
610 Masjedi, M.R., Torkshavand, Z., Arfaeinia, H., Dobaradaran, S., Soleimani, F., Farhadi, A., Rashidi, R.,
611 Novotny, T.E., Dadipoor, S., Schmidt, T.C., 2023d. First report on BTEX leaching from waterpipe tobacco
612 wastes (WTWs) into aquatic environment. *Heliyon* 9.
613 Masjedi, M.R., Torkshavand, Z., Arfaeinia, H., Dobaradaran, S., Soleimani, F., Farhadi, A., Rashidi, R.,
614 Novotny, T.E., Dadipoor, S., Schmidt, T.C.J.H., 2023e. First report on BTEX leaching from waterpipe
615 tobacco wastes (WTWs) into aquatic environment. 9.
616 Maziak, W., Taleb, Z.B., Bahelah, R., Islam, F., Jaber, R., Auf, R., Salloum, R.G., 2015. The global
617 epidemiology of waterpipe smoking. *Tobacco control* 24, i3-i12.
618 McManus, S.-L., Coxon, C.E., Richards, K.G., Danaher, M.J.J.o.C.A., 2013. Quantitative solid phase
619 microextraction-Gas chromatography mass spectrometry analysis of the pesticides lindane, heptachlor
620 and two heptachlor transformation products in groundwater. 1284, 1-7.
621 Mehboob, F., Langenhoff, A.A., Schraa, G., Stams, A.J., 2013. Anaerobic degradation of lindane and other
622 HCH isomers, Management of microbial resources in the environment. Springer, pp. 495-521.
623 Meijer, S.N., Ockenden, W.A., Sweetman, A., Breivik, K., Grimalt, J.O., Jones, K.C., 2003. Global
624 Distribution and Budget of PCBs and HCB in Background Surface Soils: Implications for Sources and
625 Environmental Processes. *Environ Sci Technol* 37, 667-672.

626 Mila, A., Cao, R., Geng, N., Zhu, X., Chen, J.J.C., 2022. Characteristics of PAHs, PCDD/Fs, PCBs and PCNs in
627 atmospheric fine particulate matter in Dalian, China. 288, 132488.

628 Moon, H.J., Lim, J.-e., Jee, S.H., 2017. Association between serum concentrations of persistent organic
629 pollutants and smoking in Koreans: A cross-sectional study. *Journal of epidemiology* 27, 63-68.

630 Mouly, T.A., Toms, L.-M.L., 2016. Breast cancer and persistent organic pollutants (excluding DDT): a
631 systematic literature review. *Environmental Science and Pollution Research* 23, 22385-22407.

632 Nie, M., Yan, C., Dong, W., Liu, M., Zhou, J., Yang, Y., 2015. Occurrence, distribution and risk assessment
633 of estrogens in surface water, suspended particulate matter, and sediments of the Yangtze Estuary.
634 *Chemosphere* 127, 109-116.

635 Oltramare, C., Riou, J., Bochud, M., Zennegg, M., Vernez, D., Berthet, A., 2025. Human exposure to
636 persistent organic pollutants in Switzerland: The role of diet, age, smoking, and body composition. *Food*
637 and *Chemical Toxicology*, 115711.

638 Qamar, W., Al-Ghadeer, A.R., Ali, R., 2015. Analysis of toxic elements in smoked shisha waterwaste and
639 unburnt tobacco by inductively coupled plasma-mass spectrometry: probable role in environmental
640 contamination. *Research Journal of Environmental Toxicology* 9, 204.

641 Qi, D., Fei, T., Sha, Y., Wang, L., Li, G., Wu, D., Liu, B., 2014. A novel fully automated on-line coupled
642 liquid chromatography-gas chromatography technique used for the determination of organochlorine
643 pesticide residues in tobacco and tobacco products. *Journal of Chromatography A* 1374, 273-277.

644 Qian, Y., Chen, K., Liu, Y., Li, J., 2019. Assessment of hexachlorocyclohexane biodegradation in
645 contaminated soil by compound-specific stable isotope analysis. *Environmental Pollution* 254, 113008.

646 Quadroni, S., Bettinetti, R.J.C., 2019. An unnoticed issue: Organochlorine pesticides in tobacco products
647 around the world. 219, 54-57.

648 Rahman, M.A., Chowdhury, A.Z., Moniruzzaman, M., Gan, S.H., Islam, M.N., Fardous, Z., Alam,
649 M.K.J.B.o.E.C., Toxicology, 2012. Pesticide residues in tobacco leaves from the Kushtia district in
650 Bangladesh. 89, 658-663.

651 Rashidi, N., Masjedi, M.R., Arfaeinia, H., Dobaradaran, S., Hashemi, S.E., Ramavandi, B., Rashidi, R.,
652 Dadipoor, S., Soleimani, F., 2024a. Mono and polycyclic aromatic hydrocarbons in waterpipe
653 wastewater: Level and ecotoxicological risk assessment. *Heliyon* 10.

654 Rashidi, N., Masjedi, M.R., Arfaeinia, H., Dobaradaran, S., Hashemi, S.E., Ramavandi, B., Rashidi, R.,
655 Dadipoor, S., Soleimani, F.J.H., 2024b. Mono and polycyclic aromatic hydrocarbons in waterpipe
656 wastewater: Level and ecotoxicological risk assessment. 10.

657 Rezek, J., Macek, T., Mackova, M., Triska, J., Ruzickova, K., 2008. Hydroxy-PCBs, methoxy-PCBs and
658 hydroxy-methoxy-PCBs: metabolites of polychlorinated biphenyls formed in vitro by tobacco cells.
659 *Environmental science & technology* 42, 5746-5751.

660 Rivoira, L., Castiglioni, M., Nurra, N., Battuello, M., Sartor, R.M., Favaro, L., Bruzzoniti, M.C.J.A.S., 2022.
661 Polycyclic aromatic hydrocarbons and polychlorinated biphenyls in seawater, sediment and biota of
662 neritic ecosystems: occurrence and partition study in southern Ligurian Sea. 12, 2564.

663 Schettgen, T., Alt, A., Preim, D., Keller, D., Kraus, T., 2012. Biological monitoring of indoor-exposure to
664 dioxin-like and non-dioxin-like polychlorinated biphenyls (PCB) in a public building. *Toxicology letters*
665 213, 116-121.

666 Schubert, J., Bewersdorff, J., Luch, A., Schulz, T.G., 2012. Waterpipe smoke: a considerable source of
667 human exposure against furanic compounds. *Analytica Chimica Acta* 709, 105-112.

668 Schubert, J., Kappenstein, O., Luch, A., Schulz, T.G., 2011. Analysis of primary aromatic amines in the
669 mainstream waterpipe smoke using liquid chromatography-electrospray ionization tandem mass
670 spectrometry. *Journal of Chromatography A* 1218, 5628-5637.

671 Sineli, P.E., Tortella, G., Dávila Costa, J.S., Benimeli, C.S., Cuozzo, S.A.J.W.J.o.M., Biotechnology, 2016.
672 Evidence of α -, β -and γ -HCH mixture aerobic degradation by the native actinobacteria *Streptomyces* sp.
673 M7. 32, 1-9.

674 Soleimani, F., Alipour, V., Dadipoor, S., Lidón-Moyano, C., Vazirizadeh, A., Rashidi, R., Arfaeinia, H.,
675 Gaffari, H., Dobaradaran, S., 2024a. *Peronia peronii* as a bio-indicator to assess the toxicity of waterpipe
676 tobacco leachates in aquatic and sediment media. *Environmental Geochemistry and Health* 46, 323.
677 Soleimani, F., Mallaki, R., Arfaeinia, H., Ghaemi, M.J.S.R., 2025a. Bioaccumulation of polycyclic aromatic
678 hydrocarbons from leachates of waterpipe tobacco wastes on *Peronia peronii* species from the Persian
679 Gulf region. 15, 9227.
680 Soleimani, F., Masjedi, M.R., Alipour, V., Dadipoor, S., Rashidi, R., Asgariyan, R., Jahantigh, A.,
681 Maryamabadi, A., 2023. Release of polychlorinated biphenyls (PCBs) and organochlorine pesticides
682 (OCPs) from cigarette butts into the aquatic environment: Levels and ecotoxicity.
683 Soleimani, F., Masjedi, M.R., Tangestani, M., Arfaeinia, H., Dobaradaran, S., Farhadi, A., Afrashteh, S.,
684 Mallaki, R., Vakilabadi, D.R.J.A.J.o.C., 2024b. Primary aromatic amines (PAAs) in third-hand smoke
685 collected from waterpipe/cigarette cafés: Level and exposure assessment. 17, 105587.
686 Soleimani, F., Ranjbar Vakilabadi, D., Arfaeinia, H., Masjedi, M.R., Ashtari Mehrjardi, A., 2025b. Phthalate
687 acid esters (PAEs) in hookah tobacco and burnt wastes: levels and ecotoxicological risks. *International
688 Journal of Environmental Analytical Chemistry*, 1-16.
689 Taufeeq, A., Baqar, M., Sharif, F., Mumtaz, M., Ullah, S., Aslam, S., Qadir, A., Majid, M., Jun, H., 2021a.
690 Assessment of organochlorine pesticides and health risk in tobacco farming associated with River
691 Barandu of Pakistan. *Environmental Science and Pollution Research* 28, 38774-38791.
692 Taufeeq, A., Baqar, M., Sharif, F., Mumtaz, M., Ullah, S., Aslam, S., Qadir, A., Majid, M., Jun, H.J.E.S.,
693 Research, P., 2021b. Assessment of organochlorine pesticides and health risk in tobacco farming
694 associated with River Barandu of Pakistan. 28, 38774-38791.
695 Termeh-Zonoozi, Y., Dilip Venugopal, P., Patel, V., Gagliano, G., 2023. Seeing beyond the smoke:
696 Selecting waterpipe wastewater chemicals for risk assessments. *Journal of Hazardous Materials Letters*
697 4, 100074.
698 Thakur, M., Pathania, D., 2020. Environmental fate of organic pollutants and effect on human health,
699 Abatement of Environmental Pollutants. Elsevier, pp. 245-262.
700 Urbaniak, M., Wyrwicka, A.J.P.-C.W.T., Recovery, R., 2017. PCDDs/PCDFs and PCBs in wastewater and
701 sewage sludge. 109.
702 Vainio, H., Heseltine, E., Shuker, L., McGregor, D., Partensky, C.J.E.J.o.C., Oncology, C., 1991. Meeting
703 Report: Occupational exposures in insecticide application and some pesticides. 27, 284-289.
704 Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H.,
705 Hakansson, H., Hanberg, A., Haws, L., 2006a. The 2005 World Health Organization reevaluation of
706 human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological
707 sciences* 93, 223-241.
708 Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H.,
709 Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A.,
710 Tuomisto, J., Tysklind, M., Walker, N., Peterson, R.E., 2006b. The 2005 World Health Organization
711 reevaluation of human and Mammalian toxic equivalency factors for dioxins and dioxin-like compounds.
712 *Toxicol Sci* 93, 223-241.
713 Verma, S., Yadav, S., Singh, I., 2010. Trace metal concentration in different Indian tobacco products and
714 related health implications. *Food Chem Toxicol* 48, 2291-2297.
715 Wang, B., Wu, C., Liu, W., Teng, Y., Luo, Y., Christie, P., Guo, D.J.E.S., Research, P., 2016a. Levels and
716 patterns of organochlorine pesticides in agricultural soils in an area of extensive historical cotton
717 cultivation in Henan province, China. 23, 6680-6689.
718 Wang, D., ke Yang, S., Wang, G., Gao, L., Wang, Y., Jiang, Q., Chen, Y.J.P.J.o.E.S., 2016b. Residues and
719 Distributions of Organochlorine Pesticides in China's Weihe River. 25.

720 Wang, L., Qie, Y., Yang, Y., Zhao, Q.J.E.S., Technology, 2022. Binding and activation of estrogen-related
721 receptor γ : A novel molecular mechanism for the estrogenic disruption effects of DDT and its
722 metabolites. 56, 12358-12367.

723 Wang, W., Wang, Y., Zhang, R., Wang, S., Wei, C., Chaemfa, C., Li, J., Zhang, G., Yu, K., 2016c. Seasonal
724 characteristics and current sources of OCPs and PCBs and enantiomeric signatures of chiral OCPs in the
725 atmosphere of Vietnam. *Science of The Total Environment* 542, 777-786.

726 Zhang, J., Jiang, Y., Zhou, J., Wu, B., Liang, Y., Peng, Z., Fang, D., Liu, B., Huang, H., He, C., 2010. Elevated
727 body burdens of PBDEs, dioxins, and PCBs on thyroid hormone homeostasis at an electronic waste
728 recycling site in China. *Environmental science & technology* 44, 3956-3962.

729 Zhao, Q., Bai, J., Lu, Q., Gao, Z., Jia, J., Cui, B., Liu, X., 2016. Polychlorinated biphenyls (PCBs) in
730 sediments/soils of different wetlands along 100-year coastal reclamation chronosequence in the Pearl
731 River Estuary, China. *Environmental Pollution* 213, 860-869.

732 Zhu, M., Yuan, Y., Yin, H., Guo, Z., Wei, X., Qi, X., Liu, H., Dang, Z., 2022. Environmental contamination
733 and human exposure of polychlorinated biphenyls (PCBs) in China: A review. *Science of the total
734 environment* 805, 150270.

735 Zhu, Z.-C., Chen, S.-J., Zheng, J., Tian, M., Feng, A.-H., Luo, X.-J., Mai, B.-X.J.S.o.t.t.e., 2014. Occurrence of
736 brominated flame retardants (BFRs), organochlorine pesticides (OCPs), and polychlorinated biphenyls
737 (PCBs) in agricultural soils in a BFR-manufacturing region of North China. 481, 47-54.

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Supplementary Information

Table S1. Quality control and quality assurance of OCPs and PCBs quantitation analysis

Chemicals	Retention Time	Spiked Concentration (ppb)	Average of Obtained Concentration (ppb)	Average of Spike Recovery (%)	Acceptable range for Spike recovery (%)	Intraday RSD% of Spike Recovery	Acceptable range for Intraday RSD (%)	Interday RSD% of Spike Recovery	Acceptable range for Interday RSD (%)	LOD (ppb)	LOQ (ppb)
a-Lindane	13.87		1.85	92.48		7.84		23.95		0.06	0.18
b-Lindane	15.01		1.45	72.58		7.36		15.35		0.06	0.18
c-Lindane	15.35		1.87	93.41		14.75		18.14		0.06	0.18
d-Lindane	16.78		1.89	94.55		14.65		23.99		0.06	0.18
Aldrin	20.74		1.53	76.54		10.37		15.78		0.08	0.26
Chlordan	24.11		1.88	94.18		12.07		21.70		0.07	0.24
Endosulfan	24.64		1.91	95.70		14.24		18.80		0.07	0.23
DDE	25.77		1.42	70.84		11.27		19.63		0.06	0.21
Dieldrin	25.81		1.98	99.07		16.50		15.36		0.07	0.25
DDD	27.29	2	1.78	88.80		7.79		18.27		0.07	0.22
DDT	28.48		1.49	74.73		13.67		20.95		0.06	0.21
Metoxychlor	30.21		1.52	76.10		13.49		20.14		0.07	0.24
PCB18	9.23		1.97	98.35		7.91		21.24		0.04	0.12
PCB 28	11.89		1.99	99.51		13.43		16.65		0.04	0.12
PCB 52	12.55		1.91	95.53		16.38		22.63		0.03	0.11
PCB 44	13		1.97	98.55		7.07		15.19		0.03	0.10
PCB 77	15.84		1.97	98.63		7.35		20.91		0.04	0.14
PCB149	16.35		1.72	86.01		11.74		20.75		0.05	0.16
PCB 118	16.67		1.91	95.41		13.66		22.32		0.04	0.12

60-115 (González and Herrador, 2007)

21 (González and Herrador, 2007)

32 (González and Herrador, 2007)

PCB 114	17.09	1.62	81.10	11.06	19.80	0.04	0.14
PCB 153	17.5	1.80	90.06	15.81	22.16	0.05	0.16
PCB 105	17.7	1.67	83.73	7.91	20.57	0.04	0.14
PCB 138	18.69	1.73	86.41	11.83	18.79	0.06	0.21
PCB 180	22.19	1.50	74.83	11.31	16.47	0.07	0.23

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748 **Table S2.** The comparison of OCPs and PCBs compounds levels between the two traditional and fruit-flavored waterpipe wastewater

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
PCB77	Equal variances assumed	.141	.709	.911	47	.367	.39067	.42883	-.47204	1.25337
	Equal variances not assumed			.912	14.010	.377	.39067	.42833	-.52795	1.30928
PCB81	Equal variances assumed	.132	.718	.119	43	.906	.02881	.24158	-.45838	.51601
	Equal variances not assumed			.113	13.619	.911	.02881	.25401	-.51742	.57505
PCB11 4	Equal variances assumed	.116	.735	1.259	43	.215	.20107	.15969	-.12097	.52311
	Equal variances not assumed			1.174	13.286	.261	.20107	.17133	-.16825	.57039
PCB11 8	Equal variances assumed	1.144	.291	1.172	43	.248	.31424	.26811	-.22646	.85494
	Equal variances not assumed			1.239	15.835	.233	.31424	.25366	-.22394	.85243
PCB12 3	Equal variances assumed	1.534	.222	1.895	44	.065	.18972	.10011	-.01203	.39148
	Equal variances not assumed			2.154	17.681	.045	.18972	.08807	.00445	.37500
PCB12 6	Equal variances assumed	.028	.868	1.690	38	.099	.11423	.06758	-.02257	.25104
	Equal variances not assumed			1.695	15.543	.110	.11423	.06738	-.02895	.25742
PCB15 6	Equal variances assumed	.768	.387	1.418	37	.165	.15828	.11162	-.06788	.38444
	Equal variances not assumed			1.289	13.490	.219	.15828	.12276	-.10596	.42252
PCB15 7	Equal variances assumed	.574	.454	1.001	34	.324	.13028	.13009	-.13409	.39466
	Equal variances not assumed			1.467	33.662	.152	.13028	.08884	-.05033	.31089

PCB16	Equal variances assumed	1.075	.305	.577	47	.566	.24875	.43088	-.61808	1.11557
7	Equal variances not assumed			.639	16.136	.532	.24875	.38944	-.57626	1.07375
PCB18	Equal variances assumed	.047	.830	1.240	40	.222	.18457	.14885	-.11627	.48541
9	Equal variances not assumed			1.221	14.726	.241	.18457	.15114	-.13811	.50724
PCB19	Equal variances assumed	.258	.614	.547	48	.587	.31197	.57015	-.83440	1.45833
4	Equal variances not assumed			.564	14.387	.582	.31197	.55355	-.87228	1.49621
TPCBs	Equal variances assumed	.962	.332	.893	48	.376	1.25080	1.40054	-1.56518	4.06678
	Equal variances not assumed			1.010	16.486	.327	1.25080	1.23842	-1.36826	3.86986
Aldrin	Equal variances assumed	2.016	.162	-1.412	47	.164	-.64833	.45904	-1.57180	.27513
	Equal variances not assumed			-1.181	11.657	.261	-.64833	.54878	-1.84794	.55128
Dieldri	Equal variances assumed	.005	.942	-1.067	48	.292	-1.05075	.98522	-3.03167	.93017
n	Equal variances not assumed			-.876	11.449	.399	-1.05075	1.19922	-3.67766	1.57616
Heptac	Equal variances assumed	2.182	.146	-2.376	48	.022	-5.42975	2.28529	-10.02463	-.83487
hlor	Equal variances not assumed			-1.957	11.470	.075	-5.42975	2.77505	-11.50721	.64771
Chlorda	Equal variances assumed	9.746	.003	1.603	48	.116	1.14025	.71143	-.29017	2.57067
ne	Equal variances not assumed			2.729	44.065	.009	1.14025	.41789	.29808	1.98242
Endosul	Equal variances assumed	5.987	.018	1.220	48	.228	3.05937	2.50798	-1.98326	8.10200
fan	Equal variances not assumed			1.743	27.244	.093	3.05937	1.75569	-.54150	6.66024
alphaH	Equal variances assumed	.240	.626	.321	48	.750	3.25825	10.14786	-17.14540	23.66190
CH	Equal variances not assumed			.371	17.099	.715	3.25825	8.77935	-15.25642	21.77292
betaHC	Equal variances assumed	.800	.376	-.804	48	.425	-11.89675	14.80084	-41.65583	17.86233
H	Equal variances not assumed			-.895	16.073	.384	-11.89675	13.29740	-40.07553	16.28203
gamma	Equal variances assumed	1.664	.203	-1.185	48	.242	-.21325	.18001	-.57519	.14869
HCH	Equal variances not assumed			-.963	11.358	.356	-.21325	.22143	-.69874	.27224
deltaH	Equal variances assumed	1.303	.259	-.490	48	.626	-.19175	.39112	-.97815	.59465
CH	Equal variances not assumed			-.380	10.976	.711	-.19175	.50470	-1.30289	.91939
THCH	Equal variances assumed	.180	.673	-.521	48	.605	-9.04500	17.37225	-43.97424	25.88424
	Equal variances not assumed			-.546	14.718	.594	-9.04500	16.58032	-44.44427	26.35427

DDE	Equal variances assumed	90.717	.000	-8.685	48	.000	-.41600	.04790	-.51231	-.31969
	Equal variances not assumed			-4.205	9.000	.002	-.41600	.09894	-.63982	-.19218
DDD	Equal variances assumed	284.488	.000	-8.919	48	.000	-3.76000	.42155	-4.60758	-2.91242
	Equal variances not assumed			-4.318	9.000	.002	-3.76000	.87075	-5.72977	-1.79023
DDT	Equal variances assumed	76.347	.000	-11.578	48	.000	-1.65200	.14268	-1.93888	-1.36512
	Equal variances not assumed			-5.605	9.000	.000	-1.65200	.29472	-2.31870	-.98530
TDDT	Equal variances assumed	132.499	.000	-14.260	48	.000	-5.82800	.40870	-6.64974	-5.00626
	Equal variances not assumed			-6.904	9.000	.000	-5.82800	.84420	-7.73772	-3.91828
TOCPs	Equal variances assumed	.020	.889	-.973	48	.336	-17.82750	18.33090	-54.68424	19.02924
	Equal variances not assumed			-.981	14.012	.343	-17.82750	18.17147	-56.79836	21.14336

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