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1 **Drinking water quality in areas impacted by oil activities in Ecuador:**
2 **associated health risks and social perception of human exposure**

3

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29

30 **Highlights**

- 31 • A punctual enrichment in volatile hydrocarbons is observed in several private wells.
- 32 • Low mineralization of drinking waters is a special health issue in the Amazon
33 region.
- 34 • The bacterial contamination of waters needs more attention by public policy.
- 35 • Local stakeholders are unable to provide effective water supply and water treatment
36 systems.
- 37 • Social and economic constraints lead people to choose the risks they have to face.

38

39 **Abstract**

40 The unregulated oil exploitation in the Northern Ecuadorian Amazon Region (NEAR),
41 mainly from 1964 to the 90's, led to toxic compounds largely released into the
42 environment. A large majority of people living in the Amazon region have no access to
43 drinking water distribution systems and collects water from rain, wells or small streams.
44 The concentrations of major ions, trace elements, PAHs (polycyclic aromatic
45 hydrocarbons) and BTEX (benzene, toluene, ethylbenzene, xylenes) were analyzed in
46 different water sources to evaluate the impacts of oil extraction and refining. Samples were
47 taken from the NEAR and around the main refinery of the country (Esmeraldas Oil

48 Refinery/State Oil Company of Ecuador) and were compared with domestic waters from
49 the Southern region, not affected by petroleum activities. In most of the samples,
50 microbiological analysis revealed a high level of coliforms representing significant health
51 risks. All measured chemical compounds in waters were in line with national and
52 international guidelines, except for manganese, zinc and aluminium. In several deep-water
53 wells, close to oil camps, toluene concentrations were higher than the natural background
54 while PAHs concentrations never exceeded individually 2 ng.L⁻¹. Water ingestion
55 represented 99% of the total exposure pathways for carcinogenic and non-carcinogenic
56 elements (mainly zinc) in adults and children, while 20% to 49% of the Total Cancer Risk
57 was caused by arsenic concentrations. The health index (HI) indicates acceptable chronic
58 effects for domestic use according the US-EPA thresholds. Nevertheless, these limits do not
59 consider the cocktail effects of metallic and organic compounds. Furthermore, they do not
60 include the social determinants of human exposure, such as socio-economic living
61 conditions or vulnerability. Most (72%) of interviewed families knew sanitary risks but a
62 discrepancy was observed between knowledge and action: religious beliefs, cultural
63 patterns, information sources, experience and emotions play an important role front to
64 exposure.

65

66 **Graphical abstract**

67

68 **Keywords (max. 6)**

69 Oil activities; Domestic waters; Hydrocarbons; Metal(loid)s; Demineralized waters; Social
70 risk perception.

71 **1. Introduction**

72 Since decades, the petroleum industry has become a significant component of the global
73 economy, but with strong environmental and social impacts (WEC, 2016). A high record of
74 accidents occurring throughout the history of oil production demonstrates the devastating
75 effects and the risks involved for exposed populations (Amiard, 2017; Levy and Nassetta,
76 2011). In Ecuador, crude oil exportation represents the country's main source of income,
77 exceeding 50% of the total exportations from 2004 to 2014, and settling down at 37% in
78 2017 (Banco Central del Ecuador (BCE), 2010; Calderon et al., 2016; MCE, 2017). On the
79 other hand, Ecuadorian oil industry is characterized by a long-term history of social and
80 environmental conflicts (Fontaine, 2007).

81 The oil industry exerted with inadequate environmental standards is strongly suspected of
82 polluting surface and ground waters, particularly in Orellana and Sucumbíos provinces
83 where 80% of total oil spills and 97% of waste pits were recorded (MAE, 2015). During
84 the Texaco oil extraction period (1964-1992), formation waters were directly released into
85 the environment, in forests and rivers (Buccina et al., 2013; Narváez, 2000). However,
86 since the 2000's the Ecuadorian legislation prohibited these practices, binding oil
87 companies to redirect these waters into ancient oil wells (Decree 1215, 2001). Nevertheless,
88 local inhabitants testified that illegal polluting discharges are still released punctually and
89 mainly during the night.

90 Oil hydrocarbons, in particular PAHs and BTEX, are considered a high environmental and
91 health concern since most of them are persistent and carcinogenic (Amiard, 2017;
92 Jørgensen and Fath, 2010). Certain PAHs and their metabolites can induce leukemia,
93 hepatitis and immunotoxicity; they can also affect the reproductive system and cause

94 genotoxic and carcinogenic effects (IARC, 2010). Twelve PAHs and BTEX have been
95 classified as probable or suspected carcinogens in humans but only benzo(a)pyrene (BaP)
96 and benzene are confirmed as carcinogenic (ATSDR, 2007; IARC, 2018). Despite their
97 high toxicity, volatility and solubility in water, BTEX are not commonly studied; noting
98 that they are responsible for acute and chronic effects including eyes and throat irritation,
99 headaches, tachycardia, leukemia, affections to nervous system, cancer and death (Leusch
100 and Bartkow, 2010; Mitra and Roy, 2011; Neghab et al., 2015). Previous epidemiological
101 studies reported numerous chronic effects including psychological disorders, endocrine and
102 reproductive affections and cases of cancers (Hurtig and San Sebastián, 2002; Levy and
103 Nassetta, 2011; Ramirez et al., 2017; Clinica Ambiental, 2017; Webb et al., 2018).
104 Genotoxic analyses on individuals from the NEAR showed that the exposure to
105 hydrocarbons has caused DNA damage and increased the risk of developing cancer (Paz-y-
106 Miño et al., 2008).

107 Although hydrocarbons constitute the main fraction (75%) of crude oil, petroleum is a
108 complex mixture of elements, such as sulfur, major cations, anions, trace metal(oid)s
109 (TME) and organic molecules. Major elements (potassium (K), magnesium (Mg), sodium
110 (Na) and calcium (Ca)), and trace elements (nickel (Ni), vanadium (V), iron (Fe) and
111 cooper (Cu)), are naturally present as salts or organometallic compounds in crude and
112 formation waters, while barium (Ba), cobalt (Co), arsenic (As) and lead (Pb) salts are added
113 during the extraction, transportation or storage (Amiard, 2017). Though certain metallic
114 elements are essential for biological functions, most of them could be highly toxic, even at
115 low concentrations, and can cause hazardous effects due to their tendency to bio-
116 accumulate (Jørgensen and Fath, 2010). In 2017, IARC listed cadmium (Cd), As, Cr and Ni
117 as probed carcinogenic elements for humans (lungs, prostate, bladder, kidney, liver and

118 stomach cancers); they can also affect nervous, immune and reproductive systems and can
119 induce abortions, anemia, and teratogenic effects (Fry, 2015).

120 Released in the environment, hydrocarbons, metals and metalloids can reach aquifers and
121 surface waters throughout all the phases of petroleum production. These pollutants can
122 integrate the dissolved phase or be sorbed onto sediment and particles as their speciation
123 and distribution depend on the physicochemical characteristics of aquatic environments
124 (US-EPA, 2000; Amiard, 2017; Boehler et al., 2017).

125 Extensive information has been compiled in relation with the signs and symptoms of health
126 problems in oil extraction areas in Ecuador (Arana and Arellano, 2007; Hurtig and San
127 Sebastián, 2005; O’Callaghan-Gordo et al., 2016; San Sebastian, 2001). However, to our
128 knowledge, there is no quantitative determination of the risks involved by drinking water
129 exposure, nor epidemiological studies that connect water quality to suspected cancer and
130 non-cancer risks.

131 In Ecuador, access to a water supply network has increased in recent years but the
132 percentages of the supplied population are very heterogenous over the territory; in the
133 studied cantons, it varies from 26,6% in Aguarico, to 33,7% in Shushufindi, 41,6% in Joya
134 de Los Sachas and 57,5% in Orellana (SENPLADES, 2014). Nevertheless, in the NEAR,
135 the use of unreliable water sources for domestic purposes (drinking, cooking, bathing and
136 washing clothes) is still a high-risk factor of exposure to toxic pollutants either by dermal
137 contact or ingestion. In Esmeraldas city, along the Pacific coast, where refining activities
138 take place, the water distribution system reaches most of the households but is unreliable
139 supply and safety wise. Therefore, Amazonian and Esmeraldas inhabitants rely on different
140 water sources such as rivers, springs, streams, rainwater, or private wells; sources that are
141 not always safe. Most of the dug wells, in general deep wells (≥ 8 m), were drilled by oil

142 companies as compensation for the disturbance caused by their activities. However,
143 inhabitants dig private shallow wells (<8 m) given that they don't trust the groundwater
144 quality. Then, in this context of extended oil activities in a precarious environment, the
145 presence of pollutants can reach the groundwater, as well as superficial waters
146 (Wernersson, 2004; Webb et al., 2018), highlighting a serious health concern for local
147 populations of the NEAR and Esmeraldas areas. But, in Ecuador, similar to most of
148 countries, effective regulations for drinking waters do not exist or are still inadequate
149 (Kayser et al., 2015; Pinto et al., 2012), mainly because they define thresholds for
150 individual elements and not for the mixture of metallic and organic compounds present in
151 water.

152 Then, this study aims to measure the drinking water quality level (by determining trace
153 metal(loid)s and hydrocarbons contents) and the associated human health risk in areas
154 influenced by oil industry (production and refining activities) in Ecuador. The two major
155 questions that motivated our research were: i) are the punctual and local wastewater
156 discharges by oil companies in the Ecuadorian Amazon traceable by chemical analysis? and
157 ii) what are the social responses of local communities to face the perceived contamination
158 of drinking water?

159 **2. Materials and Methods**

160 **2.1 Study area**

161 Two oil areas were selected for this study (Fig. 1). The first area is located in the Northern
162 Ecuadorian Amazon Region (NEAR) between 76°30'20"-77°12'00"W and 00°05'01"N-
163 00°55'11"S covering the Orellana and Sucumbíos provinces. This area was defined by the

164 Ecuadorian Ministry of Environment (PRAS Program, 2010) as the most affected socially
165 and environmentally due to oil activities. The second area is located in the Northern
166 Ecuadorian Pacific Coast (NEPC) between 79°39'27"-79°42'18"W and 00°53'52.00"-
167 00°56'41"N in the Esmeraldas province where most of the crude oil refining is performed.
168 During four decades, these zones were associated to a historic record of oil production and
169 many environmental disasters (Buccina et al., 2013). Both regions were compared with two
170 control areas located in the Morona-Santiago province (77°53'12"-78°34'51"W; 2°58'48"-
171 3°31'20"S) in the Southern Ecuadorian Amazon Region (SEAR) and in the Manabí
172 province (80°19'59"-80°20'57"W; 1°12'57"S-1°13'32" S) Pacific Coast (SEPC), where
173 neither oil nor mining activities has taken place.

174

175 2.2 Water sample collection

176 From 2012 to 2016, we realized five sampling campaigns of surface and drinking waters in
177 the whole study area: two during the low water stage, two during the flood and one during
178 the falling water stage of the Napo River and tributaries. A total of 83 samples of domestic
179 water were collected from local communities from 7 different sources: 15 samples from
180 deep wells (≥ 8 m depth), 8 from shallow wells (< 8 m depth), 10 from rainwater stored in
181 plastic or concrete tanks, 18 from springs, 10 from rivers, 5 from streams, and 17 of
182 households tap water. Among these water samples, 15 were collected from the Pacific coast
183 coming mainly from the water distribution system.

184 Water sampling was performed in Teflon bottles, using ultra-clean procedures. River
185 waters were filtered (0.45 μm porosity) in the field on Teflon and cellulose acetate pre-
186 cleaned membranes. Each sample was conditioned by addition of nitric acid (for major and

187 trace elements analysis) and hydrochloric acid (for Hg analysis) and kept cooled (4°C) until
188 analysis. For PAHs determination, samples were collected in glass vials (10 and 20 mL)
189 previously calcined at 450°C overnight and kept frozen (-18°C) until analysis. Temperature
190 (T), potential Hydrogen (pH), electrical conductivity (EC), oxide reduction potential (ORP)
191 and dissolved oxygen (DO) were measured *in situ* by ®YSI probes.

192

193 2.3 Analytical methods

194 2.3.1 Major and trace elements concentrations

195 Analysis of fluorides, chlorides, sulfates and nitrates were performed by Ion
196 Chromatography (Dionex® ICS 200). The cations Ca, K, Mg, Na and Si were determined
197 by Optical Emission Spectrometry-Inductively Coupled Plasma (ICP-OES, Horiba® Jobin
198 Yvon Ultima2). The determination of trace metal(loid)s elements (TME) was performed by
199 Mass Spectrometry-Inductively Coupled Plasma (ICP-MS, Agilent 7500CE). Total Hg
200 analysis were performed according to the US EPA Methods 1631 (US Environmental
201 Protection Agency (US EPA), 2002) using oxidation-reduction with BrCl and SnCl₂, and
202 finally analyzed by cold-vapor atomic fluorescence spectrometer (CV-AFS, Brooks
203 Rand®). The quantification limits were calculated as 10 times the reagent blanks standard
204 deviation (SD) and listed in the table SI_1. The recoveries were calculated from different
205 River Water Certified Reference Standards; the percentages obtained for anions, trace
206 metal(loid)s and cations were 104±5% (ION-915), 96±10 % (SLRS-5) and 105±4 %
207 (SLRS-5 and EPOND) respectively. The average recovery for total Hg analysis reached
208 92±9 % (ORMS-5).

209 2.3.2 PAHs and BTEX concentrations

210 Solid-phase microextraction (SPME) was used in immersion mode in combination with gas
211 chromatography-mass spectrometry (SPME-GC/MS) for the analysis of parent and
212 alkylated PAHs and BTEX in water samples (8 mL and 10 mL for PAHs and BTEX,
213 respectively).

214 An Agilent Technologies 7890A/5975C GC/MS (Palo Alto, CA, USA) was used for the
215 analysis of BTEX. A MPS2XL autosampler (Gerstel®) was used to hold the 65 µm
216 PDMS/DVB SPME fibre (Supelco) during extraction and injection. After the addition of
217 perdeuterated surrogate standards, the fibre was immersed into the 10 mL water sample
218 with agitation (250 rpm) at 40 °C during 30 min. After extraction, the fiber was thermally
219 desorbed for 3 min into the liner of the GC injector port at 220°C in pulsed splitless mode
220 (25 psi, 1.5 min). Helium (6.0) was used as the carrier gas at a flow rate of 2 mL.min⁻¹.

221 Analytes were separated on a DB-624 column (30 m x 0.32 mm, 1.8 µm film thickness;
222 Agilent Technologies, J&W Scientific). The column oven program was as follows: 0°C (5
223 min) (liquid nitrogen) to 150°C (1 min) at 5°C.min⁻¹ and then to 260°C (8 min) at
224 30°C.min⁻¹. The MSD was operated with electron impact ionization (70 eV) in selected ion
225 monitoring (SIM) mode. The transfer line, source and quadrupole temperatures were 260,
226 230 and 150°C, respectively. Parent and alkylated PAHs were analyzed using an Agilent
227 Technologies 7890A/5973 GC/MS (Palo Alto, CA, USA) (Kanan et al., 2012). A GC
228 Sampler 120 (Agilent Technologies) was used to hold the 100 µm PDMS SPME fibre fibre
229 (Supelco) during extraction and injection. After the addition of perdeuterated surrogate
230 standards, the fibre was immersed into the 8 mL water sample with agitation (250 rpm) at
231 40 °C during 60 min. After extraction, the fiber was thermally desorbed for 3 min into the
232 liner of the GC injector port at 270°C in pulsed splitless mode (25 psi, 1 min). Helium (6.0)

233 was used as the carrier gas at a flow rate of 1.3 mL.min⁻¹. Analytes were separated on a HP-
234 5MS-UI column (30 m x 0.25 mm, 0.25 μm film thickness; Agilent Technologies, J&W
235 Scientific). The column oven program was as follows: 50°C (2 min) to 300°C (5 min) at
236 10°C.min⁻¹. The MSD was operated with electron impact ionization (70 eV) in selected ion
237 monitoring (SIM) mode. The transfer line, source and quadrupole temperatures were 280,
238 300 and 180°C, respectively.

239 PAHs and BTEX were quantified by their perdeuterated surrogate standards using their
240 molecular ions (SIM mode). Analyzed compounds (and acronyms) and their limits of
241 quantification (LQs) are listed in Table SI_2 and Table SI_4, respectively. A fiber blank
242 was measured before each water sample by exposing the SPME fiber in an empty vial
243 under the same conditions as the samples. A blank sample (reagents and surrogate
244 standards) and a control sample (blank sample spiked with model compounds) were
245 performed for each batch of experiments in order to check the background contamination
246 and the analytical performance. Whole-method accuracy was determined on spiked water
247 samples (at 10 ng.L⁻¹ in Milli-Q water and 50 ng.L⁻¹ in Vittel water for PAHs and BTEX,
248 respectively) and remained between 100-105% (CV < 10%) for parent and alkylated PAHs
249 and 89-98% (CV < 10%) for BTEX. Limits of quantification (LQs) were determined from a
250 10 signal to noise ratio (SNR) observed in low-spiked samples (Table SI_4), except for
251 compounds present in blanks. For these latter compounds, LQs were determined using
252 blank levels, assuming at least a factor three between the analyte mass in the sample and
253 that found in the blank. LQs are in the range 0.3 – 5.0 ng.L⁻¹ for parent and alkylated PAHs,
254 and 2 – 9 ng.L⁻¹ for BTEX, except for benzene (100 ng.L⁻¹).

255 2.3.3 Microbiological analysis

256 Water samples were collected in sterile flasks, refrigerated and analyzed within 12 hours of
257 collection. One mL of raw sample was plated onto selective 3M™ Petrifilm™
258 6404/6414/6444 plates (3M Microbiology Products, St. Paul, MN) and incubated following
259 manufacturer instructions. The concentrations of total coliforms and *E. coli* were
260 determined within 24-48 h of incubation time at 30°C. Confirmed coliforms are red or blue
261 colonies with associated gas bubbles. Confirmed *E. coli* are blue colonies with associated
262 gas bubbles. Results are accurate between 25-250 colonies of total coliforms per plate.

263

264 2.4 Sociological methods

265 “Risk culture” refers to the oil contamination risks awareness, behaviours and social
266 practices to cope with it in everyday life, considering another set of risks (social,
267 economic), and the capacity to think the building of future projects at both individual and
268 territorial scale (Becerra et al., 2015). The sociological study was centred on two rural
269 parishes of the NEAR, Dayuma (Orellana Province) and Pacayacu (Sucumbíos Province).
270 We studied how people perceived and managed their environment and the associated
271 contamination risks. Water resources were not the only issue considered in the interviews,
272 while it appeared as the main concern. We focused on both mestizo¹ and indigenous
273 communities. Primary sociological data were collected during five field surveys between
274 2012 and 2016, most of them during the water sampling campaigns. Our study is novel in
275 interdisciplinary scope, from inception through application, combining faster environmental
276 monitoring with slower-paced sociological studies that facilitate trust-based relationships
277 with study participants. Were realized 160 qualitative interviews, according various levels

¹ In other words, the individuals who consider that they don't belong to any ethnic group or native nationality because their parents have different geographical and cultural characteristics.

278 of exposure, living next to possible sources of contamination. Various generations as well
279 as both genders were represented. Around 30 interviews were conducted with elected
280 officials and community leaders. Interviews were built around 4 general topics: 1) History
281 of life; 2) Living conditions (economic incomes), perceptions of oil activities impacts
282 (positive and/or negative), perception of their regulation by local or national authorities; 3)
283 Attitude towards the future (quality of life, future projects); and 4) Biographical data (age,
284 nationality, education level, etc.).

285

286 2.5 Health risk assessment

287 Risk assessments were carried out according risk management measures proposed by the
288 WHO (2014). Since human exposure to multiple chemical mixtures is ubiquitous (polluted
289 air, soil and water), we used US-EPA guidelines (Callahan and Sexton, 2007) for assessing
290 the cumulative risk related to these chemical cocktails and considering different pathways
291 for toxic compounds into the body, with ingestion and dermal contact as main exposure
292 routes (Barraza et al., 2018; US EPA, 2015a,b).

293 Mathematical equations of the Probabilistic Risk Assessment (as published by Barraza et
294 al., 2018) allow us to evaluate the Hazard Index (HI) and the Total Cancer Risk (TCR),
295 which are defined as the addition of individual quotients of non-carcinogenic (HQ) and
296 carcinogenic (CR) elements respectively, obtained from the average daily dose (ADD), the
297 lifetime average daily dose (LADD) and the references doses (RfD) (US Environmental
298 Protection Agency (US EPA), 2015a, 2015b). For drinking water, we supposed a daily
299 consumption rate of 3 L and 1.5 L for adults and children, respectively and an annual
300 exposure frequency of 350 days per year, assuming that people moved 15 days every year

301 in the Amazon region. Values of HI higher than 1 means that adverse health effects can
302 occur. The TCR is the accumulation of cancer risk values (CR) calculated for carcinogenic
303 elements (As, Cd, Cr, Ni) and PAHs by the product of slope factor (SF) and LADD. The
304 TCR is then compared with the guidelines given by the US EPA meaning the probability of
305 providing cancer risks of 10^{-4} (1 in 10 000) or 10^{-6} (1 in 1 000 000).

306

307 2.6 Statistical analysis

308 Software ©Rstudio (Version 3.5.1) was used for statistical analysis and box plots figures.
309 One sample t-test was used when data showed a normal distribution (Shapiro-Wilcoxon
310 test). In other cases, variables were log-transformed to follow a normal distribution. A
311 confidence level of 0.95 was chosen. Pearson coefficient correlations were calculated to
312 check the significance of the correlations between the parameters.

313

314 3. Results

315 3.1 Physico-chemical parameters

316 Physico-chemical parameters of drinking waters (Table 1) were compared with the
317 different water quality guidelines (WQGs) reported in the Supplementary Information
318 (Table SI_3).

319 In the drinking water sources of the Amazon region, the pH values ranged from 3.5 to 8.7
320 (average of 5.8 ± 1.3) with an extreme minimum value of 2.5 in a forest spring (Shuara 09 oil
321 camp). Most pH values (73%) were in the range of the Ecuadorian quality guidelines.
322 Several water sources were found to be acidic: the river water from the SEAR (4.80 ± 1.47),

323 and the rainwater (pH of 4.84 ± 1.02). The only neutral sources were stream and distribution
324 system waters (7.02 ± 1.38 and 7.16 ± 0.51 , respectively).

325 The EC range ($3-1479 \mu\text{S}\cdot\text{cm}^{-1}$; average: $122 \pm 204 \mu\text{S}\cdot\text{cm}^{-1}$) showed that all the samples
326 were lower than the maximum recommended value ($1100 \mu\text{S}\cdot\text{cm}^{-1}$), except in a deep well
327 (26 m) in Pacayacu (NEAR). Only 19% of the samples were in line with the WQG used in
328 France ($200-1100 \mu\text{S}\cdot\text{cm}^{-1}$): most of the water samples (78%) showed conductivity lower
329 than $200 \mu\text{S}\cdot\text{cm}^{-1}$, and can be considered as demineralized waters. In the Amazon Region,
330 rainwaters showed the lowest conductivity in both, the oil ($11.9 \pm 12.9 \mu\text{S}\cdot\text{cm}^{-1}$) and control
331 area ($5.21 \mu\text{S}\cdot\text{cm}^{-1}$). Only the deep wells ($272.2 \pm 348.5 \mu\text{S}\cdot\text{cm}^{-1}$) and system waters
332 ($224.3 \pm 152.2 \mu\text{S}\cdot\text{cm}^{-1}$) in the NEAR, and river surface water ($237.7 \pm 139.2 \mu\text{S}\cdot\text{cm}^{-1}$) in the
333 SEAR showed conductivity higher than the recommended value ($200 \mu\text{S}\cdot\text{cm}^{-1}$). However,
334 in Esmeraldas, the tap water conductivity never reached the minimum WQG ($200 \mu\text{S}\cdot\text{cm}^{-1}$).
335 Concerning the total dissolved salts (TDS) content of the samples, it was found to be very
336 low falling below the minimum concentration of $100 \text{ mg}\cdot\text{L}^{-1}$ and the optimal range of 250-
337 $500 \text{ mg}\cdot\text{L}^{-1}$ set by WHO. Only water from deep wells and the distribution system met the
338 minimum recommended value.

339

340 3.2 Major and TME concentrations

341 The analyzed anions (Table 1) are present in concentrations compliant to the local and
342 international standards but lower than the recommended WHO guidelines. For example, all
343 analyzed sources were deficient in fluoride based on the minimum level of $0.5 \text{ mg}\cdot\text{L}^{-1}$
344 recommended by WHO (2005) for dental health. Similarly, most of the major cations'

345 concentrations (for example Ca and Mg) were lower than the minimum 2005 WHO
346 guidelines (Fig. 2).

347 Regarding Al concentrations, all the water sources sampled in the Amazon region (SEAR
348 and NEAR) showed values in a similar and acceptable range (WHO, 2005). While in the
349 public water system (Fig. 3), these concentrations exceeded regularly 200 $\mu\text{g.L}^{-1}$, explained
350 by the utilization of aluminum sulfate as flocculent during the water treatment. A similar
351 behavior was observed with Fe concentrations, both elements presenting a common origin
352 from the soil weathering; tropical, ferralitic soils are characterized by elevated Al and Fe
353 contents (Mainville et al., 2006).

354 Manganese concentrations in drinking water sources ranged between 0 and 2373 $\mu\text{g.L}^{-1}$,
355 and averaged 72 $\mu\text{g.L}^{-1}$; the highest concentrations being measured in a deep well close to
356 Pacayacu village in a private property (Pichincha 11, Libertador oil camp). In the majority
357 of private water wells, Mn concentrations exceeded the recommended values by Ecuador
358 (100 $\mu\text{g.L}^{-1}$), and *a fortiori* France and Canada (50 $\mu\text{g.L}^{-1}$), while in rivers, springs and
359 water systems, they were acceptable (Fig. 3).

360 The Zn concentrations in samples collected from rainwater tanks were significantly higher
361 than other sources (Fig. 3). Even though high concentrations of this element are not of
362 health concern, a limit of 500 $\mu\text{g/L}$ was considered as WQG in France, being the most
363 restrictive value among the legislations consulted; all rain waters exceeded this limit. In
364 isolated areas of the Amazon basin, people collect rainwater from their home's roof. The
365 acidic rain water passing through the roofs leached, dissolved and transported dissolved Zn
366 to water tanks.

367 The elements As, Cd, Cr, Ni and Pb and Co are considered carcinogenic (group 1 and 2A),
368 while oxides of Sb, V and Mo are defined as possibly carcinogenic (2B) by the IARC.

369 System water and (deep and shallow) wells presented the highest values of As, Ni, Cr, Pb,
370 Sb, and V without exceeding the WQGs. Chromium concentrations were very low (average
371 of $0.56 \pm 5.44 \mu\text{g.L}^{-1}$) and the maximum value ($10.57 \mu\text{g.L}^{-1}$), lower than the WQGs, was
372 measured in the Dayuma tap water. The increase of these carcinogenic elements may come
373 from the pipework quality of the water distribution system. Antimony in rainwater
374 presented also a mean concentration ($0.087 \pm 0.097 \mu\text{g.L}^{-1}$) higher than in the other sources,
375 but lower than the recommended limits.

376

377 3.3 PAHs concentrations

378 All aromatic organic compounds (PAHs and BTEX) concentrations measured in the
379 analyzed drinking waters (Table SI_4) were in line with the WQGs, even in the NEAR. The
380 benzo(a)pyrene considered as carcinogenic (group 1) was under the quantification limit in
381 all the samples. However, high values of toluene (2000 to 6000 ng.L^{-1}) were measured in
382 deep wells of the “12 de Febrero” community in San Carlos village located on the Sacha oil
383 field. Benzene (also classified as carcinogenic group 1) was present in the water from the
384 distribution system in Esmeraldas (NEPC) and Portoviejo (SEPC) sampled in 2016 but
385 these significant concentrations (490 to 710 ng.L^{-1}) close to the WQG (1000 ng.L^{-1}), were
386 not detected in 2017. The results of 2016 can be due to the contamination of the water
387 stored by residents in plastic or metallic tanks as a solution for the frequent water network
388 shortages. Our results show that there is a risk of accidental and local contamination of
389 drinking water by benzene in collection tanks from traffic or industrial emissions in
390 Esmeraldas city.

391

392 3.4 Bacteriological results

393 One of the main health concerns was the presence of *Escherichia Coli* and total coliforms
394 in water sources sampled in the Amazon region which could reach in deep wells up to 40
395 and 700 CFU.100 mL⁻¹, respectively, except in the public water distribution systems.
396 According to international regulations on drinking water quality, *Escherichia Coli* and total
397 coliforms must be absent in drinking water. Untreated wastewaters, agricultural runoffs,
398 migration and development of microorganisms in wells and shallow surface waters exposed
399 to light and high temperatures can contribute to the development of coliforms. Therefore, it
400 would be crucial to disinfect (e.g. boiling, chlorination) any kind of water sources in the
401 Amazon region prior to consumption to prevent any risk of water-borne diseases.

402

403 3.5 Human health risks assessment

404 For both adults and children (Table 2), the ingestion hazard index (HI_{ing}) showed a
405 contribution of 99 to 100% to the non-carcinogenic total health risk (THI). Compared to the
406 reference value (US EPA, 2015), 7% and 27% of the THI obtained for deep well water
407 sources was higher for adults and children, respectively.

408 For adults, the HI values ranged from 3.4×10^{-02} to 2.6 and from 1.4×10^{-04} to 2.0×10^{-02} for
409 ingestion and dermal routes, respectively. From the sites that shows HQ values > 1 (Table
410 SI_5), two samples came from the NEAR, with the highest value (THI=2.6) in Dayuma due
411 to high aluminum concentrations (HQ=1.8) in the system water, and in a deep well
412 (HI=1.1) with an elevated hazard quotient in Mn (HQ=0.75). Along the Pacific coast
413 (NEPC), only one sample showed a HQ value > 1, corresponding to a tap water collected

414 from a pumping and storage station in front of the discharge channel of the main refinery of
415 the country; this elevated HI (1.8) is mainly explained by the Cd content (HQ=1.5).

416 For children, no contribution of dermal exposure was found in the total hazard index. The
417 ingestion route in the THI ranged from 7.5×10^{-02} to 5.5. From all the samples, 9 (11%) were
418 higher than the reference value (US EPA, 2015). The highest THI values were found in
419 deep wells waters of the NEAR, two in Pacayacu (HI =1.6 and 0.61 due to Mn
420 concentrations), and two in Dayuma (HI=1.32 and 1.38 explained by As concentrations), in
421 a private well and in the stadium, respectively. Individually, hazard quotients >1 in
422 rainwater were found in the whole Amazon region, being Zn the element that contributed to
423 most of the total hazard index (HQ of Zn=1.01 and 1.06, in the NEAR and SEAR
424 respectively). Finally, in the system water from Dayuma (NEAR), we found one point with
425 a high concentration of Al in Auca 09 field corresponding to THI equal to 3.9. In the
426 NEPC, the highest risk explained by Cd (HI=3.13) and As (HI=0.38) concentrations were
427 found in Esmeraldas, in the potable water pumping station and in a particular house,
428 respectively.

429 For both, adults and children, water from a deep well located in the stadium of Dayuma
430 (NEAR) presented the highest contribution (93%) of carcinogenic molecules in the dermal-
431 HI, while regarding the ingestion risk contribution, system water from the pumping station
432 close to the refinery exhibited a contribution of 88% to the total HI.

433 It is interesting to notice that, the hazard quotient of arsenic represents between 20% and
434 49% of the total ingestion HI (Fig. 4), while As concentrations never exceeded $3 \mu\text{g.L}^{-1}$. In
435 the Total Cancer Risk (TCR) calculated for carcinogenic elements (As, Cd, Cr and Ni),
436 arsenic contributes with 51% to 100% in 65 points (78% of the total sampling points). In
437 Esmeraldas, Cd contributes with 56% to 94% of the TCR in 4 system water samples.

438

439 **4. Discussion**

440 **4.1 Impacts of oil activities on drinking water quality**

441 Vanadium, Ba, Ni, Co, Mo and PAHs (except AC, IP, and Pe) are the main elements and
442 compounds that can trace oil activities impacts in the hydrological system, due to their high
443 contents in the Ecuadorian Amazon crude oil (Table SI_6). High concentrations of V
444 (305 ± 36 mg.kg⁻¹), Ba (133 ± 5 mg.kg⁻¹), Ni (99 ± 11 mg.kg⁻¹), Co (1.82 ± 0.04 mg.kg⁻¹), and
445 Mo (0.93 ± 0.02 mg.kg⁻¹) were measured in a topsoil sampled in a waste pool (from the
446 Auca 08 oil well, NEAR). These values were slightly higher than the concentrations
447 measured in fresh crude oil from the same oil camp (Auca 03), except for barium (7 ± 1
448 mg.kg⁻¹). However, the crude from the national oil pipeline showed slightly lower values of
449 toxic compounds than these in the waste pool soil except for PAHs (Table SI_6). Barium is
450 then considered as a relevant element to trace oil activities since barite (barium sulfate) is
451 commonly used in drilling activities. This element in surface and groundwaters mainly
452 comes from the soil drainage, as in Ecuador these sources are defined as calcium
453 bicarbonate waters where barium salts may precipitate easily (Kabata-Pendias and Szteke,
454 2015). All the Ba values measured in the study drinking waters were in line with the
455 WQGs. The only elements that exceeded the WQGs thresholds were Al, Fe, Mn, Cu and
456 Ba; these elements mainly originate from the natural soil erosion and are not of health
457 concern at observed concentrations except for Mn. The water sample from Pacayacu
458 (Pichincha 11 oil camp) presented concentrations in most of the analyzed elements and
459 compounds 10 to 100 times higher than the sampling points average. Manganese

460 concentrations were higher than 50, 100 and 500 $\mu\text{g}\cdot\text{L}^{-1}$ in 11%, 9% and 4% of the samples,
461 respectively. The highest concentrations were all observed in private or public deep wells.
462 Manganese can be related with agriculture practices, as it is one of the main components in
463 fertilizers, animal food, and pesticides. As proposed by Van Wendel de Joode et al. (2016),
464 drinking water risk assessment should consider Mn as a health hazard. Several studies have
465 shown a negative association between elevated Mn concentrations in drinking waters and
466 children's neurodevelopment, behavior and academic achievement (Bouchard et al., 2011;
467 Van Wendel de Joode et al., 2016).

468 Regarding organic toxic compounds, no pollution by hydrocarbons was found in the study
469 water samples. The unique concern highlighted in drinking water sources which can
470 originate from the oil activities, was the toluene and the sum of methylnaphthalene
471 concentrations measured in several deep wells in the San Carlos community (located on oil
472 camps managed by the Rio Napo Company), nevertheless without exceeding individually,
473 national and international guidelines. Individual alkylated PAHs have been observed to
474 have potentially mutagenic, tumor-promoting, or carcinogenic activity and their toxic
475 potential may easily surpass that of the parent compounds (Andersson and Achten, 2015).
476 However, the concentrations of di- and tri-methylnaphthalenes were very low, but except
477 for 1- and 2-methylnaphthalene, insufficient toxicity data is available to quantify cancer
478 risk from chronic exposure to individual or mixtures of alkylated PAHs. Considering the
479 concentrations ranges of carcinogenic PAHs, we may suppose that direct ingestion of water
480 and dermal contact are probably not the main exposure routes. This hypothesis was
481 confirmed by the Total Cancer Risk indexes calculated for parents and alkylated-PAHs
482 (section 3.5).

483 On the other hand, we observed just two significant correlations between toxic compounds
484 and oil activities impacts. These moderate and positive correlations were found between the
485 number of pits in the vicinity area of the sampling points and MA (2-methylanthracene;
486 $r=0.43$) and total dissolved Hg ($r=0.47$) concentrations. However, no correlation was found
487 with the oil spills frequency, nor with the number of flares or oil waste pools.

488

489 4.2 Drinking water risks due to low mineralization

490 In the whole Ecuadorian Amazon Region and along the Pacific Coast, the study water
491 sources presented very low mineralization levels, till 10 to 100 times lower than the
492 WHO's minimum recommended concentrations (WHO, 2006), with certain exceptions in
493 deep wells. Although high concentrations of certain major elements can affect the human
494 health (Nerbrand et al., 2003), it is very important to pay attention to acid and low
495 mineralized water sources as well. Acid pH water can accelerate the leaching of toxic
496 metals and other compounds from roofs or distribution pipes and modify the taste. Acidic
497 pH is characteristic of rainwaters which feed spring and shallow groundwater and is the
498 main source of drinking water for local people. The percolation of rain waters in tropical
499 soils of the Amazonian plain does not change the water pH as these soils are acidic and
500 highly weathered. Additionally, the lack of minerals can cause direct health effects like
501 tooth caries due to the lack of fluoride, malfunction of the intestines, reduction of calcium
502 and magnesium intake and other essential elements as well as an increase of intake of toxic
503 elements, due to their dissolution in acid waters during the cooking for example (WHO,
504 2006). For about 50 years, epidemiological studies in many countries all over the world
505 have reported that soft water (i.e., water low in Ca and Mg) is associated with increased

506 morbidity and mortality from cardiovascular disease (CVD) compared to hard water and
507 water high in Mg (Kozisek, 2005). Epidemiological studies of an ecologic design among
508 Russian populations supplied with water varying in TDS suggested that low-mineral
509 drinking water may be a risk factor for hypertension and coronary heart disease, gastric and
510 duodenal ulcers, chronic gastritis, goiter, pregnancy complications and several
511 complications in newborns and infants, including jaundice, anemia, fractures and growth
512 disorders (Turnlund, 2002). The intake of low water-content in Ca, is associated with a
513 higher risk of fracture in children, certain neurodegenerative diseases, pre-term birth and
514 low weight at birth and some types of cancer (Kozisek, 2005). The WHO established in
515 1980 minimum and optimum levels of minerals and recommended that demineralized water
516 contains: for Mg and Ca, a minimum of 10 and 20 mg.L⁻¹, respectively, and an optimum
517 range of 20-30 and 40-80 mg.L⁻¹, respectively. For total water hardness, the sum of Ca and
518 Mg should be 2 to 4 mmol.L⁻¹ (Kozisek, 2005). In rainwater, the most important drinking
519 water source for Amazonian communities, the Mg and Ca average concentrations were less
520 than 0.01 and 1.28 mg.L⁻¹, respectively. Average concentration of Na in rainwater was 0.12
521 mg.L⁻¹, 2000 less than the minimum recommended value (WHO, 1980).

522 Another issue caused by the regular domestic use of low mineralized water is the loss of
523 essential minerals from food during the cooking, mainly of Mg and Ca and in a less extent
524 of essential microelements (Cu, Mn and Co). A low diversified diet due to precarious living
525 conditions coupled to the domestic use of demineralized water reduce the nutrients intake
526 by local populations and participate to the child undernutrition.

527 It appears that the health risk tied to the chronic exposure to low mineralized water can be
528 as important or in some cases, more important than the health risk related with current oil
529 activities. Though, it is necessary to pay attention to specific sampling points (deep wells)

530 were the total hazard index and total cancer risk denote that inorganic elements related with
531 oil production (as V or Mo in surface water, Table SI_5) can contribute significantly to the
532 sanitary risk.

533 However, the quality of rainwater may subsequently deteriorate during harvesting, storage
534 and household use (WHO, 2011). In the Amazon region, many families collect rainwater
535 from their house' roof, explaining the very high concentrations of Zn measured in this
536 water source. Later, they store it in large plastic or metallic tanks without any cover where
537 wind-blown dirt, leaves, insects, fecal particles, or particles from the atmosphere or from
538 burning materials (e.g. trash or oil flares) can contaminate the stored rainwater.

539

540 4.3 Limits of Ecuadorian Regulations

541 We suggest three types of limits in the National environmental regulations: legal, technical
542 and political.

543 4.3.1 Legal limits

544 In Ecuador, two regulations have been set up: the INEN 1-108 and the TULSMA (Texto
545 Unificado de Legislación Secundaria del Ministerio del Ambiente). The Ecuadorian
546 regulation INEN 1-108 is related to treated water for human consumption, and certain
547 parameters, such as pH, conductivity or oxygen percentage were omitted from the 2014
548 latest version compared to the 2006 version (Table SI_3). Regarding the inorganic
549 compounds, from 34 parameters considered in the 2006, only 18 were proposed in 2014.
550 For example the Mn threshold values increased from 0.1 mg.L⁻¹ in 2006 to 0.4 mg.L⁻¹ in
551 2011, to completely be removed in 2014. From 5 PAHs regulated in 2006, INEN reduced
552 to one molecule in 2014, the Benzo(a)Pyrene, with a maximum permissible value (MPV)

553 higher than in the 2006 version. For BTEX molecules, toluene MPV became more
554 permissive, and ethylbenzene regulation disappeared. A restriction of the maximum
555 permissible limit for microbiological parameters was also observed, reducing the MPV for
556 fecal coliforms from 2 NMP.100 ml⁻¹ in 2006 to 1.1 NMP.100 ml⁻¹ currently, and
557 eliminating total coliforms guidelines.

558 The second Ecuadorian regulation, TULSMA, is applicable to natural water sources for
559 human consumption prior to any treatment. In its last version (November 2015), this
560 regulation only considered treated-clean waters and raw water that needed a physical
561 treatment and presented a lower number of parameters than the former text. The MPV of
562 some elements, such as Cd, increased from 0.003 mg.L⁻¹ in February, 2015 to 0.02 mg.L⁻¹
563 in November, 2015. Concentrations of PAHs and BTEX in drinking water sources are not
564 regulated. The current version for fecal coliforms set up a lower concentration (1000
565 NMP.100 ml⁻¹) than the previous ones (2000 NMP/100 ml) but it still remains very high.

566 Then, during the last decade, both Ecuadorian regulations, INEN and TULSMA, have not
567 just reduced the number of control parameters but also proposed less restrictive values
568 without considering international recommendations. Since international regulations (Santé-
569 Canada, WHO, US-EPA and European Union) are based on epidemiological and risk
570 assessment studies, we considered them in this study as more adequate water quality
571 references for the health risk assessment discussion. Nevertheless, concentrations
572 thresholds are related to individual elements or molecules, or for groups of specific metal or
573 organic contaminants but not for chronic exposure to cocktails of both categories of toxic
574 elements and compounds.

575 *4.3.2. Technical limits*

576 These limits are mainly due to the weakness of technical capacities of local stakeholders. In
577 the different visited communities, we found collective water supply systems installed by
578 local autonomous governments that were often ineffective. Many of these systems were
579 abandoned because of the lack of water availability, and/or of pump maintenance. This
580 ineffectiveness reflects two realities combined in the Amazon region: i) the lack of
581 technical ability of the projects managers and ii) lack of proper management of public
582 resources (Juteau-Martineau, 2019). Sometimes, under the pretext of public utility projects,
583 public funds can be redirected to non-public matters.

584 *4.3.3. Political limits: political ability to relay the social demands*

585 People in charge of community relationships between public oil companies and local
586 inhabitants have always negated the link between river's contamination and oil activities.
587 According to them and policy makers, water quality degradation is mainly due to the
588 presence of total and fecal coliforms, given that wastewater treatment is not available in the
589 country, except in big cities. They don't constitute any opposition force that would set up a
590 water quality monitoring or at least the compliance of safety regulations. The latter does not
591 reflect the social experience of inhabitants of the oil region, with what they observed in
592 their own farm or in the close river, this experience leads them to ask for remediation,
593 compensation and indemnity. The local political ability to relay the social demands varies
594 from place to place. For example, in the Management Plan of Pacayacu, oil activities are
595 not accounted as responsible for the poor water quality, in contrast to the Dayuma Plan that
596 holds oil companies responsible for the contamination of water resources, even during
597 environmental remediation activities.

598

599 4.4 Social perception of the risk and human exposure

600 *Perceived environment and perceived exposure to health risks*

601 In the Amazon basin, traditionally, indigenous and mestizo use water sources close to their
602 home, from rivers, streams, rainwater or shallow wells. But in the oil Amazon basin, the
603 lack of access to drinking water is the major concern expressed by communities living close
604 to oil infrastructures (Fig. 5), not only for inhabitants but also for cattle. The social
605 experience of the environmental pollution is stable with time and the general resentment is
606 that “everything is polluted and oil companies are lying”. Contamination is mainly
607 perceived empirically, directly from the farms or indirectly from a decrease in aquatic
608 biodiversity.

609 The interviews conducted in the NEAR showed 2 main social responses to perceived
610 contamination of local water resources, *Exit* and *Voice* (as proposed by Hirschman, 2011):
611 *Exit* means leaving the current water supply. At the household level, harvesting rainwater is
612 today perceived as the safest and most effective way to collect water even if in fact various
613 sources are combined (rainwater, wells, rivers or spring). Harvesting rainwater has
614 undergone a rapid development thanks to the social compensation programs systematically
615 implemented by the National oil Company, Petroecuador, since the 2000's. During oil
616 exploration campaigns or when opening new platforms, the public company offered zinc
617 plates to cover the roofs of many communities' houses and water tanks to store the clean
618 water. Later filtration systems were offered by NGOs to specific families involved in the
619 protestation against oil activities. At the community scale, collective action took place: for
620 instance, two communities close to the urban centre of Pacayacu developed their own
621 drinking water supply system within a "*minga*", an indigenous practice of cooperative and

622 voluntary work for the common good. One of them has failed due to the lack of technical
623 and financial maintenance.

624 *Voice:* In the centre of Pacayacu village, most of the inhabitants contrary to the position of
625 the leaders, do not trust the quality of the drinking water system and choose the « voice »
626 thanks to the help of the NGO “Acción Ecológica”. The mobilization, coordinated by this
627 same NGO, operates in different ways: creation in 2009 of the “environmental clinic” as an
628 alternative program to restore the environment and livelihoods of about 30 families living
629 in the oil impacted area; in 2011, opening of a defense committee of families that perceived
630 a local contamination of their water resources, and organization of “Toxic-tours” in Atacapi
631 and Libertador oil camps.

632 *Facing the risk but to which risk high priority is given?*

633 The perception of the contamination risk was largely shared in the interviewed families as
634 72% of them knew about sanitary risks linked to bad water quality. But there was a
635 discrepancy between knowledge and action, as social investigations underlined for other
636 risks (Weiss et al., 2011): existence of the first (knowledge) does not guarantee the second
637 (action). It is important to distinguish between the drinking water supplies: primarily public
638 water system in urban centres and rain, river or private wells in rural areas. Paradoxically to
639 the perceived sanitary risk, the adopted strategy is not always to reduce the exposure. An
640 oil spill in a private farm is generally conserved as a proof of oil activities damages and
641 used to ask for material compensation (job or material good) or money (Becerra et al.,
642 2016). Similarly, a riparian who saw his water resource damaged by an oil spill for
643 example, won't necessary look for other water sources for domestic use.

644 The role of religious beliefs, cultural ideals, experience and emotions were evaluated in
645 order to understand why people resist to change their practices to face supposed polluted
646 water sources.

647 *Religious beliefs.* Data collected from interviews with mestizo people showed that culture
648 risk is highly influenced by religious beliefs in at least two ways. First, faith can bring a
649 certain form of fatalism towards one's own existence. Some individuals could also stop
650 worrying about the future since God decides for them. Data collected gave numerous
651 references to biblical scriptures.

652 *Cultural ideals and practices.* Change to prevent sanitary risk depends first on social
653 perceptions of the risks, and secondly on a cultural process, but also depends on the
654 existence of other available alternative ways and on adequate financial resources. In the
655 Amazon forest, Shuar and Kishwa communities have a strong reliance on nature and
656 surface waters because of their ancestral culture. Their spirituality is based on the principle
657 of Mother Earth as well as deities of the jungle, the agricultural garden "*chacra*" and the
658 water. They usually leave far from towns or oil infrastructures. Even if these groups tend to
659 evolve toward a cultural hybridism (for instance integrating modern food to their diet), they
660 prefer natural food and water from the farm, rivers or mountains (Beguet, 2015).
661 Furthermore, in indigenous groups, environmental pollution is unequally perceived. We
662 observed in Shuar and Kischwa groups that generally, this perception by women is less
663 noticeable than by men: maybe because women usually don't work for oil company
664 (Racines, 2017).

665 *Sensitive experience.* Danger is learned by sensitive experiences which could be traduced
666 by: "*the kick warns you and the damage teaches you*". Since health effects of
667 environmental exposure are not immediate, people tend not to change their practices and

668 the collective action stops to the suspicion or denunciation. Social determinants such as the
669 high rates of unemployment and poverty (Larrea and Camacho, 2013) explain the difficulty
670 to get out from this situation of “environmental suffering”. People respond to the
671 contamination of water in a confused way. As explained by Auyero and Swistun (2007)
672 often people under these conditions have “toxic confusion”, as awareness of their situation
673 is distorted by lack of knowledge of the real causes which leads to inappropriate behaviors.
674 *Chronic and historical distrust of oil companies.*

675 Due to numerous social liabilities between oil companies and Amazonian communities,
676 health issues related to water contamination are attributed by inhabitants to the impact of oil
677 activities which obscure the complexity of the causes neglecting all the historical and
678 political context that is responsible for poor human health, limits the perception of their
679 own responsibilities and inhibits practices changes. Because of this situation that despite
680 the awareness of rivers and water being contaminated, people are not changing their daily
681 practices based on the hope that finally, there will be some recognition and retribution due
682 to the damage caused by the oil companies during the last decades. Each emergence of
683 cancer cases, whatever its origins, nourished the proofs list against oil companies’
684 activities. The social liability acts as a psychological lock that convinces inhabitants and
685 NGOs that only oil companies are responsible of the environmental and sanitary hazards of
686 the region.

687 **5. Conclusion and recommendations**

688 Contrarily to the common prejudices, this study showed for the first time that the health
689 risks due to drinking water exposure could be more impacted by the precarious living
690 conditions than by the oil activities in the Ecuadorian Amazon region. Local people

691 routinely chose the water sources based on the end-use, availability and some of them
692 regarding their perception of contamination risks especially after an accident (oil spill).

693 International and national regulations are generally based on maximum acceptable
694 concentrations of inorganic and organic compounds because water may contain elements
695 and molecules that are undesirable. Main of the different water sources sampled in Ecuador
696 can be considered as suitable for human consumption. It is important to control the quantity
697 of aluminum sulfate in the system during the water treatment as well as the way of
698 collecting and storing rainwater. Regarding Mn, a well-known neurotoxin, the high
699 concentrations observed in private wells can also be related to agriculture (use of
700 pesticides; van Wendel de Joode et al., 2016). Arsenic which contributes from 20% to 49%
701 to the ingestion health index, is naturally present in high concentrations in soils and waters
702 of most of Latin America regions (Bundschuh et al., 2012). But the novelty of this study is
703 the low mineralization of the drinking water sources which could be an important health
704 issue due to the deficiency in essential minerals like Ca, Mg and F. The addition of salt
705 enriched with fluoride and iodine into the cooking water is a common practice, but not used
706 everywhere in Ecuador, especially in remote areas. Most of the symptoms as fatigue,
707 stomachaches or dizziness, often signaled by the population can be related with the low
708 concentrations of minerals in their domestic water.

709 In Ecuador, agricultural runoffs and discharges of household effluents into water bodies
710 without previous waste treatment seems to be the main source of microbiological pollution,
711 confirmed by the presence of fecal coliforms in almost all the drinking water samples. It
712 appears primordial before consumption, to disinfect or boil any kind of water sources
713 before use in areas where there is no access to treated clean water. At the national level,
714 public policies should address this problem by extending rural potable water supply and

715 waste water treatment systems to the communities living in remote areas of the Amazon
716 region.

717 Although no toxic compounds in drinking water samples exceeded the international water
718 quality guidelines, human co-exposure to low mineralized water and volatile organic
719 molecules needs more attention in oil impacted areas. Local people living in these areas
720 still endure the insufficient recognition of historical impacts of oil exploitation by the
721 Ecuadorian government, confirming that information can be considered as a sort of power
722 that should be shared. Till now, without any satisfactory processing of the historical
723 impacts of the oil activities in the country, inhabitants of the NEAR focus their problems on
724 oil companies ignoring other possible sources, such as agriculture practices or the lack of
725 water treatment. The belief held by many of the inhabitants that oil companies are the only
726 reason for water pollution is part of a symbolic process by which water pollution
727 crystallizes the set of social and environmental claims in front of oil industry. Water quality
728 preservation is the most shared argument that can become a symbol of the oil companies'
729 environmental debt and of the government to solve this issue.

730

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743

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Figures captions

Figure 1. Hazards description (flares, oil spills, pools and pits, refinery, oil fields and pipelines) and sampling points of drinking waters (from various sources: rainfall, river, spring, stream, well) in four study areas: A) Northern Ecuadorian Pacific Coast (NEPC), B) Northern Ecuadorian Amazon Region (NEAR) and C) in two control zones (Southern Ecuadorian Amazon Region (SEAR) and Southern Ecuadorian Pacific Coast (SEPC)).

Figure 2. Major element concentrations in drinking water sampled during the 2012-2016 period, in (A) the Northern Ecuadorian Amazon Region (NEAR) and in (B) the control zone in the Southern Ecuadorian Amazon Region (SEAR); the red and blue lines report maximum and minimum values recommended by the World Health Organization for drinking water (2005) respectively; international water quality guidelines (WQG) are reported.

Figure 3. Al, Fe, Mn, Zn and Ba concentrations in drinking water sampled during the 2012-2016 period, in (A) the Northern Ecuadorian Amazon Region (NEAR) and in (B) the control zone in the Southern Ecuadorian Amazon Region (SEAR). The red and blue lines report maximum and minimum values recommended by the World Health Organization for drinking water (2005), respectively; international quality guidelines (WQG) are reported.

Figure 4. Distribution of ingestion and dermal contact Hazard Index (HI) for the Amazon and Pacific Ecuadorian regions, followed by the percentage of samples that overcome the Total HI reference value (US EPA, 2015b) in children and adults.

Figure 5. The 20 most cited words in Spanish by local people living in Dayuma and Pacayacu villages (©NVivo simulation).

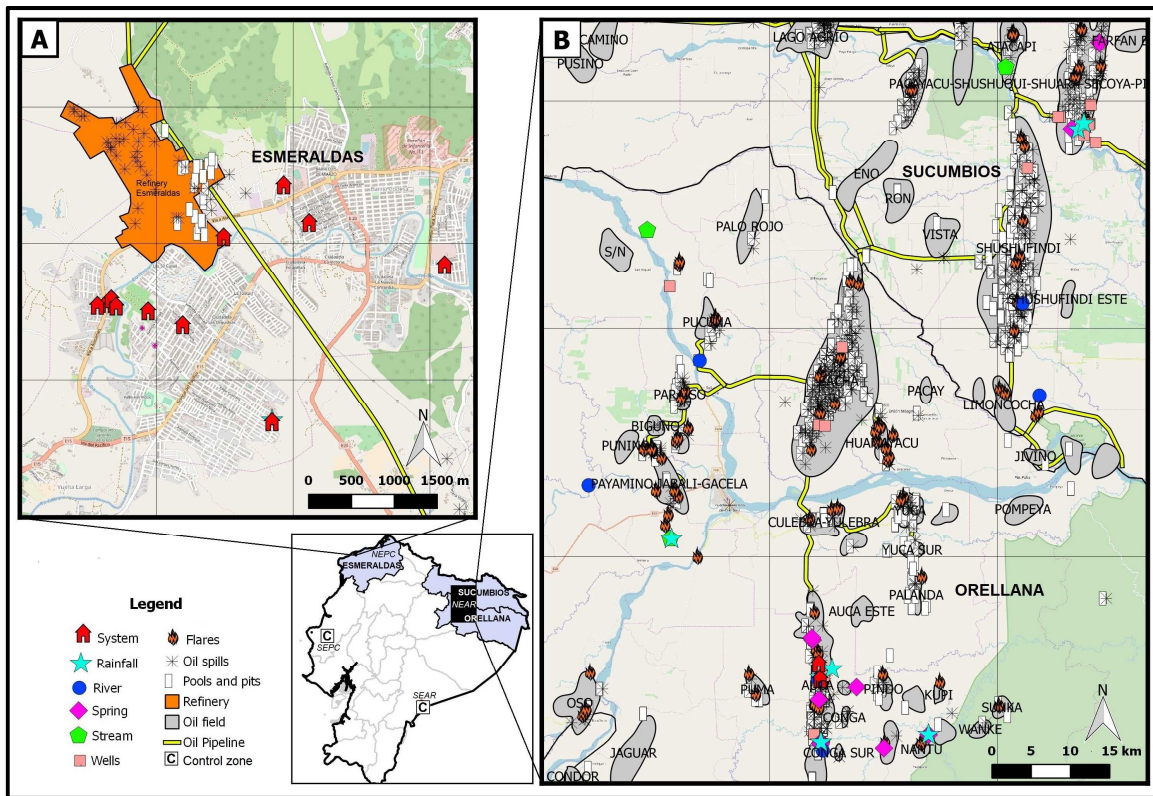


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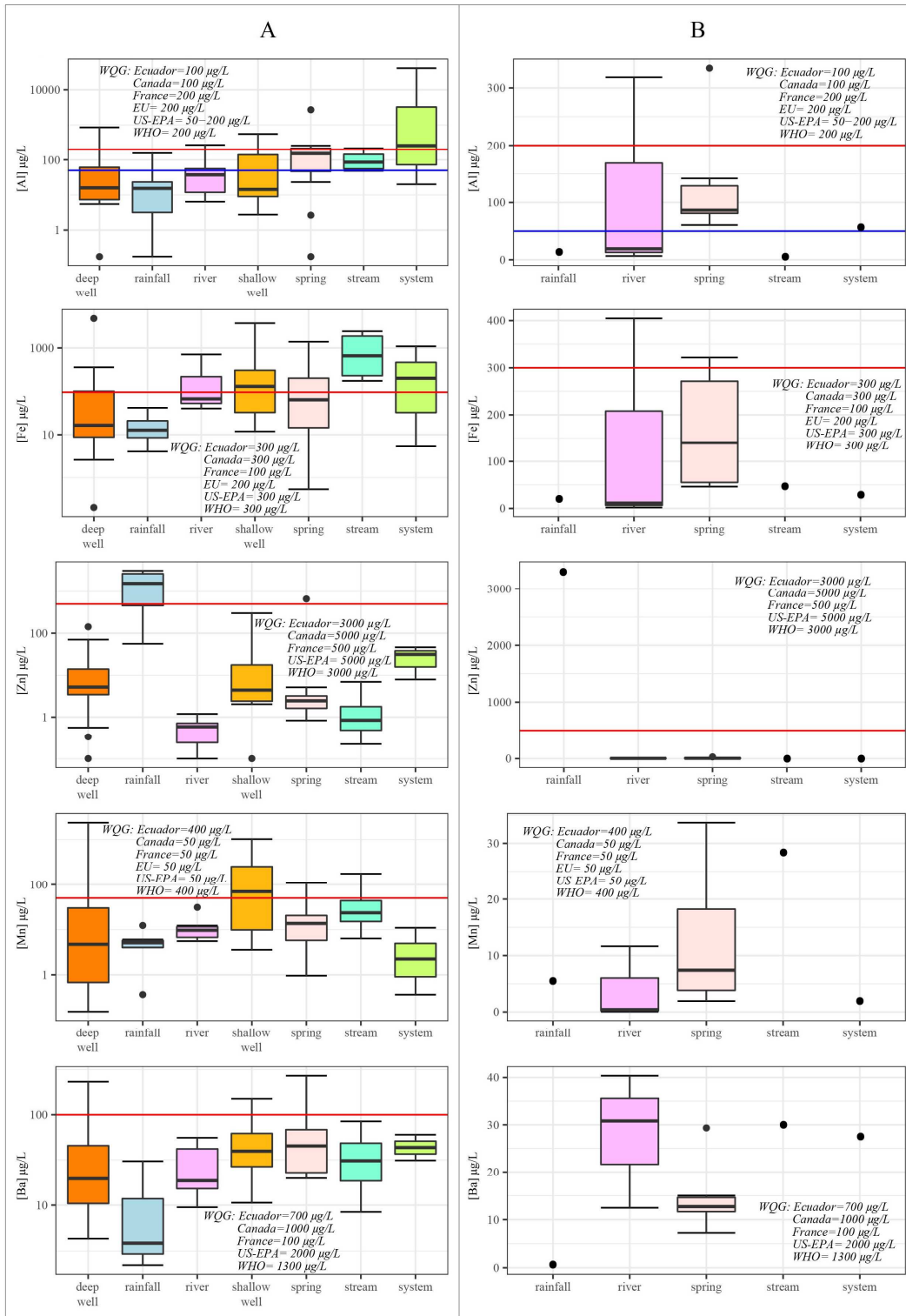


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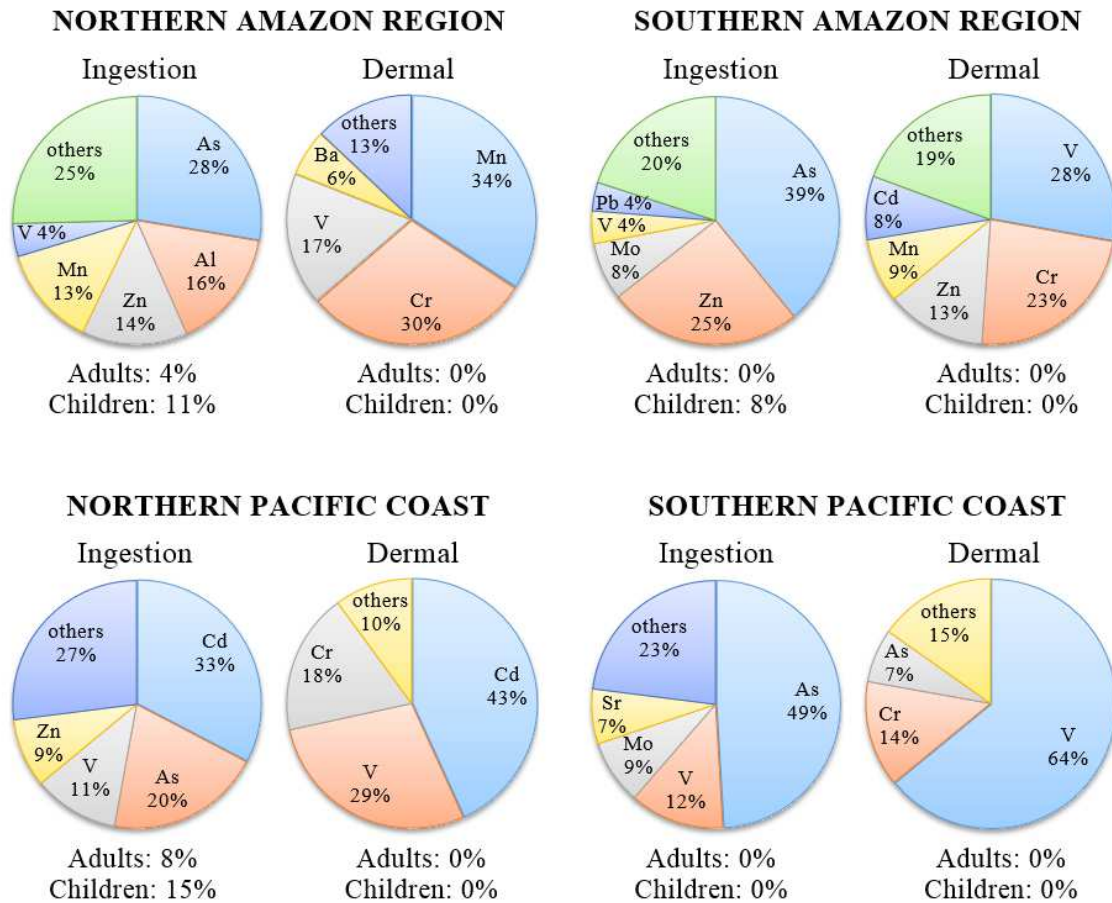


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Start-----Table 1

Table 1. Local metrics^{#,##,b,c}, inorganic major element ^b and metal(oid)s average concentrations (\pm Standard Deviation)^{d,e} in different sources of domestic water in the Northern and Southern Ecuadorian Amazon Region (NEAR and SEAR, respectively) and in the Northern and Southern Ecuadorian Pacific Coast (NEPC and SEPC, respectively).

PARAMETER	NEAR							SEAR					NEPC		SEPC	
	deep well	rainfall	river	shallow well	spring	stream	system	rainfall	river	spring	stream	system	rainfall	system	system	shallow well
Elevation [#]	281±17	276±18	264±10	264±6	283±12	293±36	266±6	321*	301±22	497±278	850*	303*	108*	32±25	65*	74*
T ^{##}	27±3	28±4	25*	26±1	26±2	27±1	29±3	24*	25±1	25±2	23*	25*	23*	27±2	29*	29*
EC ^a	272±349	12±13	82±91	156±59	60±67	86±66	224±152	5*	238±139	31±28	60*	49*	17*	144±63	210*	1319*
pH	6.11±1.03	4.84±1.02	6.12±2.06	5.61±0.42	5.2±1.43	7.02±1.38	7.16±0.51	7.11*	4.80±1.47	5.64±1.17	7.26*	6.69*	7.11*	7.01±0.19	6.82*	6.7*
OD ^b	3.25±2.42	4.89±2.34	5.37±1.99	3.33±2.68	5.24±1.9	5.97±2.78	5.96±1.76	2.56*	5.57±1.87	2.82±2.13	2.02*	2.05*	--	3.62±0.92	4.34*	3.12*
OD ^c	43.9±27	63±28	68.4±17.6	42.4±33.7	66.8±22.3	71.5±28.5	77.9±19.4	29.9*	66.6±22.6	33.6±24.8	23.8*	24.8*	--	46.9±10.9	57.5*	42.9*
CaCO ₃ ^b	75.5±49.7	5.76±7.69	29.2±22.2	45.7±14.8	23.9±27.2	34.2±24.5	46.1±21.7	4.42*	47.2±29.3	13.9±13.2	28*	23.3*	2.14*	30.9±18.5	66*	239.2*
Bicarbonates ^b	92.1±60.7	7.03±9.38	35.7±27.1	55.7±18.1	29.2±33.2	41.8±29.9	56.2±26.5	5.4*	57.6±35.8	16.9±16.1	34.2*	28.5*	2.61*	37.8±22.6	80.5*	291.8*
Fluorides ^b	0.12±0.17	<0.02	0.04±0.04	0.03±0.02	0.03±0.04	0.06±0.04	0.07±0.04	<0.02*	0.08±0.02	0.04±0.03	0.07*	0.07*	<0.02*	0.08±0.03	0.17*	0.36*
Chlorides ^b	25.28±83.48	0.19±0.11	0.96±0.83	10.65±11.29	0.92±1.39	0.55±0.43	36.61±32.95	0.19*	1.64±1.74	0.09±0.03	0.65*	0.09*	3.18*	4.22±2.06	6.09*	18.6*
Sulfates ^b	1.13±1.26	0.62±0.33	1.88±3.06	2.5±2.67	0.46±0.75	0.36±0.11	2.56±3.32	0.11*	7.38±7.35	0.27±0.25	0.34*	0.19*	2.07*	20.99±6.12	14.76*	253.81*
Nitrates ^b	5.38±4.71	0.81±0.52	1.32±1.23	5.18±5.51	1.69±2.2	0.31±0.22	0.74±1.13	0.17*	0.13±0.19	0.35±0.19	0.16*	0.47*	0.06*	2.3±1.61	0.56*	22.17*
Ca ^b	15.27±12.22	1.28±2.81	6.1±4.34	10.55±3.79	4.53±5.8	5.71±4.52	10.30±4.69	0.06*	16.42±16.63	2.71±2.45	5.53*	3.94*	0.56*	12.02±7.76	21.19*	104.13*
K ^b	1.99±1.73	0.18±0.11	1.41±0.96	1.77±1.48	0.86±0.81	2.17±0.43	1.93±0.1	<0.08*	0.79±0.07	0.58±0.33	1.34*	0.81*	0.5*	2.18±0.54	3.57*	7.6*
Mg ^b	6.04±9.23	<0.01	2.1±1.99	4.83±2.49	1.38±2.32	2.66±2.15	0.95±0.5	<0.01*	2.3±0.52	1.02±1.11	1.55*	1.76*	0.08*	2.87±0.84	5.61*	34.9*
Na ^b	24.05±35.88	0.12±0.05	3.25±2.08	8.75±7.81	3.09±2.86	4.07±2.07	31.68±26.85	<0.12*	3.68±1.17	1.54±1.33	3.27*	2.74*	0.64*	7.37±3.13	8.48*	68.79*
Si ^b	18.65±8.18	0.44±0.72	13.85±11.25	11.88±3.85	11.47±7.63	19.79±12.14	7.46±3.87	0.02*	8.45±4.53	6.19±4.66	10.69*	9.44*	0.10*	13.74±0.55	15.64*	39.73*
SiO ₂ ^b	39.90±17.50	0.95±1.54	29.64±24.07	25.41±8.23	24.54±16.32	42.35±25.98	15.96±8.29	0.04*	18.07±9.7	13.23±9.98	22.87*	20.2*	0.21*	29.4±1.18	33.45*	85.01*
Hardness ^{**}	0.63±0.62	0.03±0.07	0.24±0.19	0.46±0.10	0.17±0.24	0.25±0.20	0.30±0.11	<0.01*	0.51±0.39	0.11±0.10	0.20*	0.17*	0.02*	0.42±0.19	0.76*	4.03*
TDS ^b	211±155	8±12	82±58	125±33	64±62	100±64	157±94	6*	108±50	37±31	70*	59*	7*	119±43	174*	887*
Hg ^d	2.1±3.5	1.9±1.1	1.7±0.7	0.8±0.7	2.6±2.5	1.5±1.5	8.0*	--	--	--	1.6*	--	--	--	--	--
Al ^e	110±230	32±55	64±93	126±202	340±755	113±79	13693±23475	14*	115±177	132±103	5.43*	55*	129*	318±249	168*	6.93*
Ti ^e	0.91±1.26	0.27±0.26	1.17±1.53	5.84±10.65	10.71±32.78	4.15±3.96	29.47±50.68	0.11*	0.32±0.35	1.11±0.56	0.03*	0.30*	0.23*	2.31±2.64	1.82*	<0.02
V ^e	1.79±2.25	0.35±0.34	2.37±2.68	0.84±0.71	1.26±1.44	3.11±2.89	4.87±6.95	0.06*	2.06±0.4	0.9±0.95	0.49*	1.12*	19.8*	4.96±3.14	4.9*	9.13*
Cr ^e	0.62±1.42	0.23±0.18	0.26±0.34	0.14±0.2	0.61±0.7	0.21±0.1	3.67±5.98	0.05*	0.32±0.21	0.18±0.1	0.06*	0.11*	2.14*	0.7±1.47	0.16*	0.46*
Mn ^e	230.4±635.1	5.3±3.6	11.9±8.8	231.8±366.7	21.8±29.5	57.2±79.1	4.5±5.6	5.3*	4±6.6	12.5±12.5	28.3*	1.8*	6.7*	7±9.7	11*	0.7*
Fe ^e	392±1223	17±13	208±258	669±1362	255±430	1146±1115	432±579	18*	139±230	165±127	47*	30*	69*	290±630	64*	10*
Co ^e	0.23±0.5	0.04±0.04	0.11±0.13	0.6±0.53	0.32±0.31	0.38±0.32	0.09±0.09	0.03*	0.09±0.14	0.13±0.1	0.19*	0.03*	0.1*	0.1±0.09	0.06*	0.01*

Ni^e	0.57±0.93	0.26±0.1	0.18±0.13	0.38±0.54	0.77±0.6	0.54±0.68	0.82±0.56	0.78*	0.26±0.4	0.25±0.21	0.2*	0.18*	6.55*	0.92±1.04	0.57*	6.78*
Cu^e	7.76±12.63	1.52±1.62	0.36±0.29	8.87±15.31	1.07±1.28	0.71±0.86	6.82±9.15	0.61*	2.56±2.8	8.66±13.34	0.51*	2.01*	0.65*	3.9±2.86	15.42*	7.76*
Zn^e	20.3±38.1	1629±1249	0.5±0.4	49.9±111.5	57.5±190.9	2.2±3.2	28.5±19.3	3316.8*	3.5±1.2	8.5±11	0.2*	4*	999.3*	144.7±338	14.3*	25.5*
As^e	0.87±1.46	0.03±0.03	0.22±0.11	0.41±0.56	0.17±0.13	0.62±0.6	1.19±1.51	<0.02*	0.61±0.55	0.34±0.28	0.5*	0.85*	0.04*	0.51±0.3	1.03*	1.36*
Se^e	1.66±5.61	0.27±0.36	0.36±0.44	1.23±1.96	0.44±0.42	0.3±0.45	0.21±0.19	<0.06*	0.08±0.09	<0.06	0.07*	<0.06*	0.07*	0.21±0.14	0.31*	2.06*
Sr^e	206.6±197.1	3.8±5.3	70.9±52.8	125.6±62.5	73.7±96.4	75.5±50.3	67.6±27.4	0.3*	56.5±18.8	24.2±21.2	58.7*	26.4*	2.3*	80.4±33.8	126.6*	569.9*
Mo^e	2.59±5.48	0.03±0.03	0.55±1.04	0.07±0.05	0.07±0.19	0.19±0.13	0.32±0.39	<0.02*	5.5±9.42	0.02±0.02	0.12*	<0.02*	0.14*	1.25±1.08	0.27*	6.59*
Cd^e	0.036±0.046	0.022±0.014	0.019±0.023	0.085±0.078	0.042±0.035	0.040±0.064	0.015±0.012	0.036*	0.089±0.147	0.039±0.076	0.003*	0.001*	0.02*	1.381±4.711	0.006*	0.071*
Sb^e	0.024±0.029	0.087±0.097	0.013±0.009	0.028±0.028	<0.011	0.023±0.022	0.055±0.03	0.23*	0.028±0.026	0.017±0.013	0.033*	<0.011*	0.163*	0.279±0.312	0.152*	0.076*
Ba^e	54.7±74.2	9.4±10.2	28.4±18.3	54.1±46.6	62.7±68.4	39.3±32.9	44.9±14.6	0.5*	27.9±14.2	14.8±7.6	29.8*	27.5*	0.5*	23.9±7.9	33.1*	24.2*
Pb^e	0.509±0.639	1.169±1.994	0.084±0.15	1.536±2.796	0.247±0.293	0.129±0.117	0.948±0.846	0.151*	0.246±0.101	0.808±1.023	0.003*	0.090*	0.146*	0.453±0.684	0.768*	0.451*
U^e	0.071±0.116	0.004±0.009	0.027±0.021	0.022±0.019	0.068±0.077	0.069±0.089	0.396±0.639	0.001*	0.042±0.068	0.008±0.004	0.009*	0.004*	0.001*	0.052±0.092	0.083*	0.977*

NEAR=North Ecuadorian Amazon Region; SEAR= South Ecuadorian Amazon Region; NEPC= North Ecuadorian Pacific Coast; SEPC= South Ecuadorian Pacific Coast; #=masl (meters above sea level); ##=°C;
* single value (n=1); **Ca+Mg (mmol.L⁻¹); a=μS.cm⁻¹; b= mg.L⁻¹; c=%saturation; d=ng.L⁻¹; e= μg.L⁻¹.

End-----Table 1

Start---Table 2

Table 2. Health Index for ingestion and dermal exposure pathways (HI_{ing} and HI_{der}), Total Hazard Index (THI), Cancer Risk for ingestion and dermal exposure pathways (CR_{ing} and CR_{der}), Total Cancer Risk (TCR), and percentage of samples (%) higher than the reference value for non-cancer risk (THI:1) and for cancer risk (TCR:10⁻⁶-10⁻⁴).

POPULATION	RISK INDEX	NEAR							SEAR					NEPC		SEPC	
		deep well	rainfall	river	shallow well	spring	stream	system	rainfall	river	spring	stream	system	rainfall	system	system	shallow well
ADULTS	HI_{ing}	3.17x10 ⁻¹	2.88x10 ⁻¹	8.34x10 ⁻²	2.29x10 ⁻¹	1.09x10 ⁻¹	1.69x10 ⁻¹	9.27x10 ⁻¹	5.27x10 ⁻¹	1.92x10 ⁻¹	1.01x10 ⁻¹	1.05x10 ⁻¹	1.51x10 ⁻¹	3.58x10 ⁻¹	3.45x10 ⁻¹	4.52x10 ⁻¹	2.67x10 ⁻¹
	HI_{der}	2.16x10 ⁻³	8.03x10 ⁻⁴	7.23x10 ⁻⁴	1.69x10 ⁻³	9.79x10 ⁻⁴	1.12x10 ⁻³	3.77x10 ⁻³	1.15x10 ⁻³	8.05x10 ⁻⁴	4.77x10 ⁻⁴	3.94x10 ⁻⁴	4.14x10 ⁻⁴	5.06x10 ⁻³	3.13x10 ⁻³	2.13x10 ⁻³	1.21x10 ⁻³
	THI	3.20x10 ⁻¹	2.89x10 ⁻¹	8.41x10 ⁻²	2.31x10 ⁻¹	1.10x10 ⁻¹	1.70x10 ⁻¹	9.30x10 ⁻¹	5.29x10 ⁻¹	1.93x10 ⁻¹	1.02x10 ⁻¹	1.06x10 ⁻¹	1.51x10 ⁻¹	3.63x10 ⁻¹	3.48x10 ⁻¹	4.54x10 ⁻¹	2.68x10 ⁻¹
	> 1	7%	0%	0%	0%	0%	0%	33%	0%	0%	0%	0%	0%	0%	8%	0%	0%
	CR_{ing}	2.46x10 ⁻⁵	9.53x10 ⁻⁷	6.28x10 ⁻⁶	1.17x10 ⁻⁵	4.83x10 ⁻⁶	1.77x10 ⁻⁵	3.38x10 ⁻⁵	2.35x10 ⁻⁷	1.72x10 ⁻⁵	9.71x10 ⁻⁶	1.42x10 ⁻⁵	2.42x10 ⁻⁵	1.27x10 ⁻⁶	1.45x10 ⁻⁵	3.87x10 ⁻⁵	2.93x10 ⁻⁵
	CR_{der}	6.52x10 ⁻⁹	2.52x10 ⁻¹⁰	1.66x10 ⁻⁹	3.10x10 ⁻⁹	1.33x10 ⁻⁹	4.70x10 ⁻⁹	8.95x10 ⁻⁹	6.22x10 ⁻¹¹	4.56x10 ⁻⁹	2.57x10 ⁻⁹	3.76x10 ⁻⁹	6.40x10 ⁻⁹	3.35x10 ⁻¹⁰	3.84x10 ⁻⁹	1.02x10 ⁻⁸	7.75x10 ⁻⁹
	TCR	2.46x10 ⁻⁵	9.53x10 ⁻⁷	6.28x10 ⁻⁶	1.17x10 ⁻⁵	4.83x10 ⁻⁶	1.77x10 ⁻⁵	3.38x10 ⁻⁵	2.35x10 ⁻⁷	1.72x10 ⁻⁵	9.71x10 ⁻⁶	1.42x10 ⁻⁵	2.42x10 ⁻⁵	1.27x10 ⁻⁶	1.45x10 ⁻⁵	3.87x10 ⁻⁵	2.93x10 ⁻⁵
	>10⁻⁴	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	10⁻⁶-10⁻⁴	73%	29%	100%	86%	100%	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%
	<10⁻⁶	13%	71%	0%	14%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
CHILDREN	HI_{ing}	6.88x10 ⁻¹	6.24x10 ⁻¹	1.81x10 ⁻¹	4.97x10 ⁻¹	2.37x10 ⁻¹	3.65x10 ⁻¹	2.01x10 ⁰	1.14 x10 ⁰	4.16x10 ⁻¹	2.19x10 ⁻¹	2.28x10 ⁻¹	3.27x10 ⁻¹	7.75x10 ⁻¹	7.47x10 ⁻¹	9.79x10 ⁻¹	5.78x10 ⁻¹
	HI_{der}	3.75x10 ⁻⁴	1.39x10 ⁻⁴	1.25x10 ⁻⁴	2.93x10 ⁻⁴	1.70x10 ⁻⁴	1.94x10 ⁻⁴	6.53x10 ⁻⁴	1.99x10 ⁻⁴	1.40x10 ⁻⁴	8.27x10 ⁻⁵	6.82x10 ⁻⁵	7.18x10 ⁻⁵	8.78x10 ⁻⁴	5.42x10 ⁻⁴	3.69x10 ⁻⁴	2.10x10 ⁻⁴
	THI	6.88x10 ⁻¹	6.24x10 ⁻¹	1.81x10 ⁻¹	4.97x10 ⁻¹	2.37x10 ⁻¹	3.65x10 ⁻¹	2.01x10 ⁰	1.14x10 ⁰	4.16x10 ⁻¹	2.20x10 ⁻¹	2.28x10 ⁻¹	3.27x10 ⁻¹	7.76x10 ⁻¹	7.48x10 ⁻¹	9.79x10 ⁻¹	5.78x10 ⁻¹
	> 1	27%	14%	0%	0%	0%	0%	33%	100%	0%	0%	0%	0%	0%	17%	0%	0%
	CR_{ing}	1.07x10 ⁻⁵	4.13x10 ⁻⁷	2.72x10 ⁻⁶	5.08x10 ⁻⁶	2.09x10 ⁻⁶	7.69x10 ⁻⁶	1.47x10 ⁻⁵	1.02x10 ⁻⁷	7.46x10 ⁻⁶	4.21x10 ⁻⁶	6.16x10 ⁻⁶	1.05x10 ⁻⁵	5.49x10 ⁻⁷	6.28x10 ⁻⁶	1.68x10 ⁻⁵	1.27x10 ⁻⁵
	CR_{der}	2.82x10 ⁻⁹	1.09x10 ⁻¹⁰	7.19x10 ⁻¹⁰	1.34x10 ⁻⁹	5.53x10 ⁻¹⁰	2.03x10 ⁻⁹	3.87x10 ⁻⁹	2.69x10 ⁻¹¹	1.97x10 ⁻⁹	1.11x10 ⁻⁹	1.63x10 ⁻⁹	2.77x10 ⁻⁹	1.45x10 ⁻¹⁰	1.66x10 ⁻⁹	4.42x10 ⁻⁹	3.35x10 ⁻⁹
	TCR	1.07x10 ⁻⁵	4.13x10 ⁻⁷	2.72x10 ⁻⁶	5.08x10 ⁻⁶	2.09x10 ⁻⁶	7.69x10 ⁻⁶	1.47x10 ⁻⁵	1.02x10 ⁻⁷	7.46x10 ⁻⁶	4.21x10 ⁻⁶	6.16x10 ⁻⁶	1.05x10 ⁻⁵	5.49x10 ⁻⁷	6.28x10 ⁻⁶	1.68x10 ⁻⁵	1.27x10 ⁻⁵
	>10⁻⁴	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	10⁻⁶-10⁻⁴	53%	0%	100%	71%	75%	100%	100%	0%	100%	100%	100%	100%	0%	100%	100%	100%
	<10⁻⁶	47%	100%	0%	29%	25%	0%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%

NEAR=North Ecuadorian Amazon Region; SEAR= South Ecuadorian Amazon Region; NEPC= North Ecuadorian Pacific Coast; SEPC= South Ecuadorian Pacific Coast; HI_{ing}=hazard index for ingestion exposition; HI_{der}= hazard index for dermal exposition; THI=total hazard index.

End-----Table 2

