



# Impacts of the 2024 flash flood on water quality, pathogenic bacteria and organic contaminant risks in the Albufera Natural Park (Valencia, Spain)

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## ARTICLE INFO

### Keywords:

Extreme weather events  
PFAS  
PAHs  
Pharmaceuticals  
Ecological risk assessment

## ABSTRACT

Climate change is increasing flash flood frequency and intensity around the globe, which can contribute to the mobilization of urban and agricultural contaminants into aquatic ecosystems. In October 2024, a massive flash flood affected the Valencia region (Spain), which discharged contaminated water into the Albufera Natural Park (ANP), a protected Mediterranean wetland. In this study we provide one of the most comprehensive assessments to characterize the contamination footprint produced by a flash flood event in downstream aquatic ecosystems. We evaluated physical-chemical parameters, pathogenic bacteria, and 241 organic contaminants, including pesticides (PEST), pharmaceuticals and personal care products (PPCPs), perfluoroalkyl substances (PFAS), organophosphorus flame retardants (OPFRs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs), in 15 sampling sites along the ANP. Our study reveals an increase of pathogenic bacteria and chemical exposure concentrations in the north-west areas of the ANP, correlating with elevated ammonia and reduced oxygen levels. Comparison with pre-flood data revealed significant concentration increases for PPCPs, PFAS, PAHs, and OPFRs, attributed to wastewater treatment failures and urban/industrial chemical mobilization. Several pollutants were found to significantly exceed established ecological protection thresholds (risk quotients > 10), with the most significant risks identified for ibuprofen, PFOS, and fluoranthene in water samples, along with 13 sediment-associated contaminants (including PFOS and several PESTs and PPCPs). This study provides a basis for guiding future monitoring and interventions designed to assess and prevent contamination risks from flash floods in freshwater ecosystems.

## 1. Introduction

Flood events are becoming more frequent and severe due to climate change, with projections indicating further increases in the coming decades (IPCC, 2023; UNEP, 2025). According to the European Environment Agency (EEA, 2024), approximately 12 % of the EU population currently resides in areas that are vulnerable to river flooding. Between 1980 and 2024, floods in Europe accounted for € billions of economic losses and caused at least 4500 fatalities, with flash floods accounting for most of these incidents (WMO, 2025). Flash floods can be defined as

rapid, extreme flows of water into normally dry areas, typically occurring within minutes to hours of intense rainfall, and are particularly prevalent in the Mediterranean region due to a combination of climatic, topographic, and anthropogenic factors (Ropero et al., 2024).

Beyond their human and economic burden, flash floods have severe environmental consequences. They can transport soils, erode riverbanks, scour riverbeds, and discharge large quantities of suspended sediments and organic matter into aquatic systems (Vericat and Batalla, 2010; Soria et al., 2025). Additionally, they may transport urban debris and increase chemical pollutant concentrations in downstream

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<https://doi.org/10.1016/j.envres.2025.123515>

Received 1 October 2025; Received in revised form 19 November 2025; Accepted 4 December 2025

Available online 4 December 2025

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freshwater ecosystems, by washing off from impervious surfaces, the collapse of sanitation networks, and the resuspension of legacy pollutants (Quesada et al., 2014; Crawford et al., 2022). Studies conducted in Mediterranean coastal ecosystems, like the Mar Menor Lagoon (Murcia, Spain), have documented elevated water concentrations of persistent organic pollutants, such as pesticides, hydrocarbons or polychlorinated biphenyls, as well as pharmaceuticals after massive flash flood events (León et al., 2017; Castaño-Ortiz et al., 2023). However, despite these preliminary investigations, our understanding of the contaminant footprint produced by extreme flood events and their impact on aquatic ecosystems remains limited (Crawford et al., 2022).

On the 29th of October of 2024, the Valencia region (Spain) experienced one of its most intense rainstorms in 200 years. The extreme rainfall event, triggered by an isolated depression at high levels (DANA = “Depresión Aislada en Niveles Altos” in Spanish) or cut-off low, delivered up to 200–700 L/m<sup>2</sup> of precipitation within 24 h in some upstream areas (AEMET, 2024). This resulted in a catastrophic flash flood that affected over 200,000 residents, which inundated urban, industrial, and agricultural areas, and caused 230 deaths (Soria et al., 2025; Mas-Coma et al., 2025). A significant proportion of the floodwaters and sediments generated by such event were discharged into the Albufera Natural Park (ANP) - a Ramsar-listed wetland and a critical ecological and economic resource for the region. During the flood, the ANP received over 120 hm<sup>3</sup> of water from the Barranco del Poyo ravine located in the northwestern sector and the overflow of the Magro River in the southwestern sector (Soria et al., 2025), which contributed to an almost 4-fold renovation of the Albufera Lake’s volume. The flash flood carried a wide range of urban and industrial residues into the ANP, and produced the collapse of the sewage network, contributing to the release of various types of organic contaminants and pathogenic bacteria, amongst other contaminants.

This study aimed to characterize the contaminant footprint of the massive flash flood that impacted the ANP and to assess its ecological risks. A monitoring campaign was conducted after the flash flood event, which involved the collection of water and sediment samples from 15 locations across the park. The specific objectives of this study were (1) to characterize the flood’s impacts on water quality and pathogenic bacteria, (2) to assess the flood’s contaminant profile through the comparison of exposure concentrations in water and sediment samples with exposure levels measured prior to the flooding event, and (3) to assess the risks posed by the measured contaminants to aquatic organisms. The study included the assessment of a wide range of physical-chemical parameters, potentially pathogenic bacteria, and 241 organic contaminants in water and sediment samples, including pesticides (PEST), pharmaceuticals and personal care products (PPCPs), perfluoroalkyl substances (PFAS), organophosphorus flame retardants (OPFRs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs). This work provides the most comprehensive dataset to date on post-flood organic pollution in downstream aquatic ecosystems, which supports the development of future monitoring campaigns and enhanced international management strategies.

## 2. Materials and methods

### 2.1. Study area and sampling

The ANP comprises rice fields, a complex network of irrigation/drainage channels, and the Albufera Lake. The Albufera Lake is a shallow, polymictic coastal lagoon characterized by a hypereutrophic status (Vicente and Miracle, 1992; Doña et al., 2015; Martín et al., 2020; Amador et al., 2024). Fifteen sampling sites were selected as part of this study, including nine irrigation channels and ravines (sites 1, 2, 3, 4, 5, 7, 8, 9, 11), three sites in the Albufera Lake (sites 13, 14, 15), and three sites in the lake outlets that transport water into the Mediterranean sea

(sites 18, 19, 20; Fig. 1). The sampling site codes are not in sequential order, as they were assigned based on the study design of a broader monitoring campaign.

The sampling campaign was performed between the 11th and the 15th of November of 2024 (14–17 days after the flash flood; Table S1). Before those dates, the area was inaccessible due to the hazardous conditions caused by the moving waters and the ongoing search for victims. During the sampling days, the collapse of the sanitation networks was still widespread, leading to the inflow of wastewater from the northwest part of the Barranco del Poyo. However, the water depth in Albufera Lake had returned to pre-flood levels (Soria et al., 2025), indicating that the contaminant levels measured here represent the new baseline that persisted for weeks after the event.

Water and sediment sampling were conducted from the side or from bridges in the channels, ravines and lake outlets, or from a small boat in the Albufera Lake. Grab water samples were collected and introduced into sterile plastic bottles for the analysis of physical-chemical parameters and bacteria. Water samples for the analysis of organic contaminants were taken in pre-cleaned amber glass bottles. Sediment samples of the top 5 cm were taken with a core sampler and introduced into zip log plastic bags. Water and sediment samples for contaminant analyses were frozen (−20 °C) until further processing.

### 2.2. Analysis of physical-chemical parameters

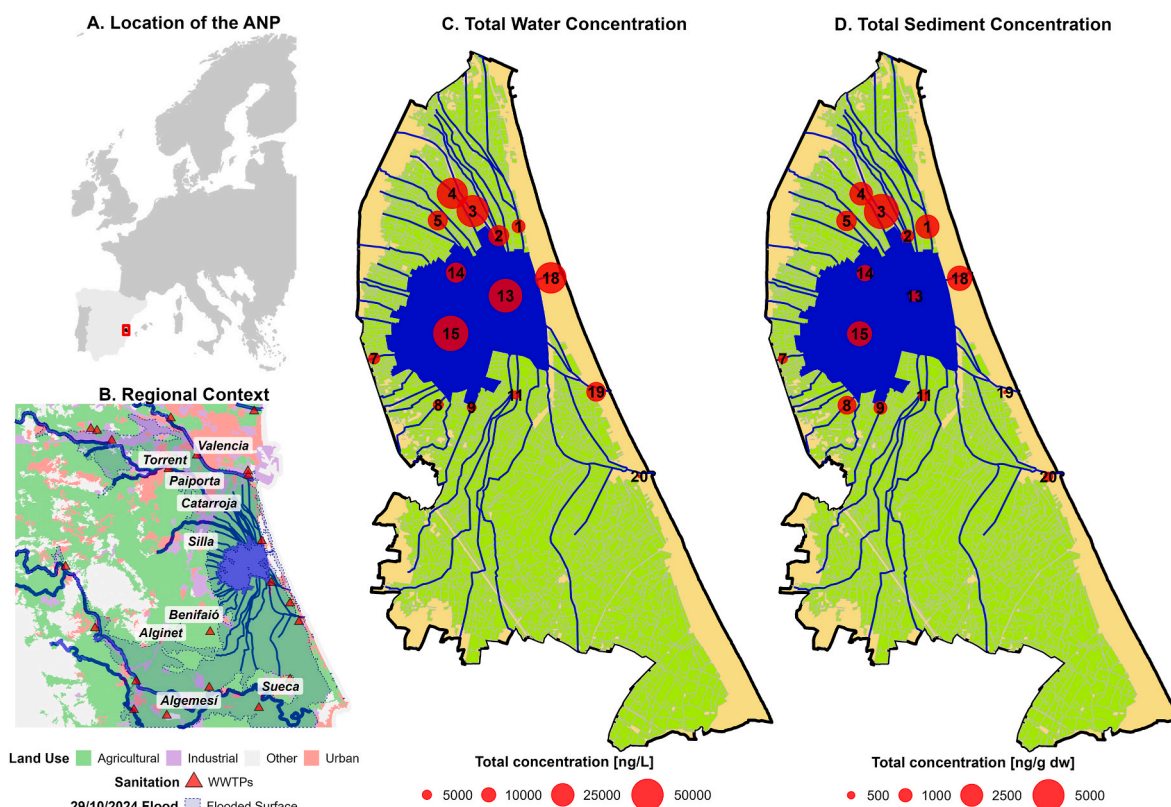
Basic water physical-chemical parameters were measured *in-situ* (i. e., temperature, pH, dissolved oxygen, conductivity) using a portable multiparameter device (HANNA HI0194). Furthermore, several water (alkalinity, nitrate, ammonium, total nitrogen, soluble reactive phosphorus, total phosphorus, chlorophyll-a, total suspended solids and loss of ignition (LOI) of suspended solids) and sediment (pH, conductivity, humidity, LOI of sediment, total nitrogen and total phosphorus) variables were measured in the laboratory. These parameters were analyzed following standard test protocols (e.g. APHA, 2005) as described in the Supporting Information (Text S1).

### 2.3. Analysis of pathogenic bacteria

Quantification of the abundance of total heterotrophic bacteria in the water samples was performed by flow cytometry (see Text S2 for details). Amplicon sequencing of the 16S rRNA and clustering of filtered sequences in zero-radius Operational Taxonomic Units (ZOTUs) was performed following the methods described in Text S2. Next, identification and quantification of potentially pathogenic genera in water was carried out. For this, the taxonomic assignment of the identified ZOTUs was performed using SINA (<https://github.com/epruesse/SINA>) with the SILVA 138.2 (<https://www.arb-silva.de/documentation/release-1381/>) database. The relative abundances of the main genera with potentially pathogenic species for humans present in the analyzed samples were selected, extracted from the ZOTUs dataset, and quantified. The selection of these genera was made based on the ePATHogen database published by the Public Health Agency of Canada (PHAC) (<https://health.canada.ca/en/epathogen>), which contains a searchable list of nearly 8000 pathogens with their associated human and animal risk group classifications. Pathogenic bacteria were classified based on public health risk as RG1 (lowest), RG2 (medium) and RG3 (highest). All genera belonging to the RG2 and RG3 groups (264 genera) were selected for our study (see Text S2 for a complete list). For each of these genera, the associated taxa (ZOTUs) and the relative abundances in each sample were calculated.

### 2.4. Analysis of organic contaminants

PEST (excluding organochlorine pesticides), PPCPs, PFAS and OPFRs in water (dissolved fraction) and sediment samples were assessed using a multiresidue method by reversed-phase liquid chromatography coupled



**Fig. 1.** (A) Location of the Albufera Natural Park (ANP). (B) Map showing the area affected by the flooding and the land use distribution in the region. (C) Total chemical concentrations in the water samples taken after the flooding in the ANP. (D) Total chemical concentrations in sediment samples taken after the flooding in the ANP. Sampling sites: 1. Carrera del Saler; 2. Ravisanxo; 3. Barranco del Poyo; 4. Port de Catarroja; 5. Barranco de Beniparrell; 7. La Foia; 8. Alqueresia; 9. Campets; 11. Dreta; 13. Lake-B2; 14. Lake-A1; 15. Lake-B1; 18. Gola del Pujol; 19. Gola del Perellonet; 20. Gola del Perelló. In sampling sites 2 and 19, some sediment samples were lost and only PAHs could be measured in sediment.

with high-resolution mass spectrometry (HPLC–HRMS; see **Text S3**). The list of PEST contained a list of commonly used agricultural pesticides and several legacy, organochlorine pesticides (OCPs): pentachlorobenzene (PeCB), hexachlorobenzene (HCB), hexachlorocyclohexane (HCH, alpha, beta, and gamma isomers), the six p,p'- and o,p'-chloro-substituted isomers of DDT and its derivatives (DDE and DDD), endosulfan (alpha and beta isomers), endosulfan sulfate and mirex, which are classified as persistent organic pollutants. This group also contained dechlorane plus (DP, syn- and -anti isomers), which is a chlorinated flame retardant. OCPs along with DP were analyzed by gas chromatography coupled to tandem mass spectrometry (GC-MS/MS; see **Text S4**). The list of PPCPs was primarily populated with active ingredients used in pharmaceutical products (e.g. analgesics, betablockers, antiepileptics, anxiolytics, antibiotics), personal care products, and stimulant drugs such as caffeine. The PFAS group included short-chain perfluorinated acids (C2-C6) and long-chain perfluorinated acids (C7-C18), some of which are included in the Stockholm convention and the list of priority substances of the Water Framework Directive (WFD), e.g., perfluorooctane sulfonic acid, perfluorooctanoic acid (ECEuropean Commission, 2013). The list of OPFRs contained compounds used as plasticizers and antifoaming agents in a variety of industries including plastics, furniture, textiles, electronics, construction, vehicles, and the petroleum industry.

The list of PAHs included short and long chain priority substances listed by the US EPA, some of which are also included in the priority list of the European Water Framework Directive, WFD (ECEuropean Commission, 2013). Total PAH concentrations (including the dissolved and sorbed fraction) were analyzed in the study samples, by GC-MS (see **Text S5**). Due to the low resolution of some chromatographic peaks, for some compounds the concentrations found in the samples were expressed as

the sum of two isomers (i.e., Benzo[a]anthracene + Chrysene; Benzo[b]fluoranthene + Benzo[k]fluoranthene; Indeno[1,2,3-cd]pyrene + Benzo[ghi]perylene; Phenanthrene + Anthracene).

The list of PCBs, PBDEs, PCDDs and PCDFs included 6 indicator PCBs, 12 dioxin-like PCBs, 26 PBDEs and 17 PCDD/Fs (all 2,3,7,8-substituted congeners). As for the PAHs and the OCPs, the dissolved and sorbed fractions of the water samples were analyzed separately. The method used for the analysis was based on gas chromatography coupled to high resolution mass spectrometry (GC-HRMS, see **Text S4**). The number of compounds in each group, together with the analytical method used and the limits of quantification (LOQ) are summarized in **Table S2**.

### 2.5. Data analyses

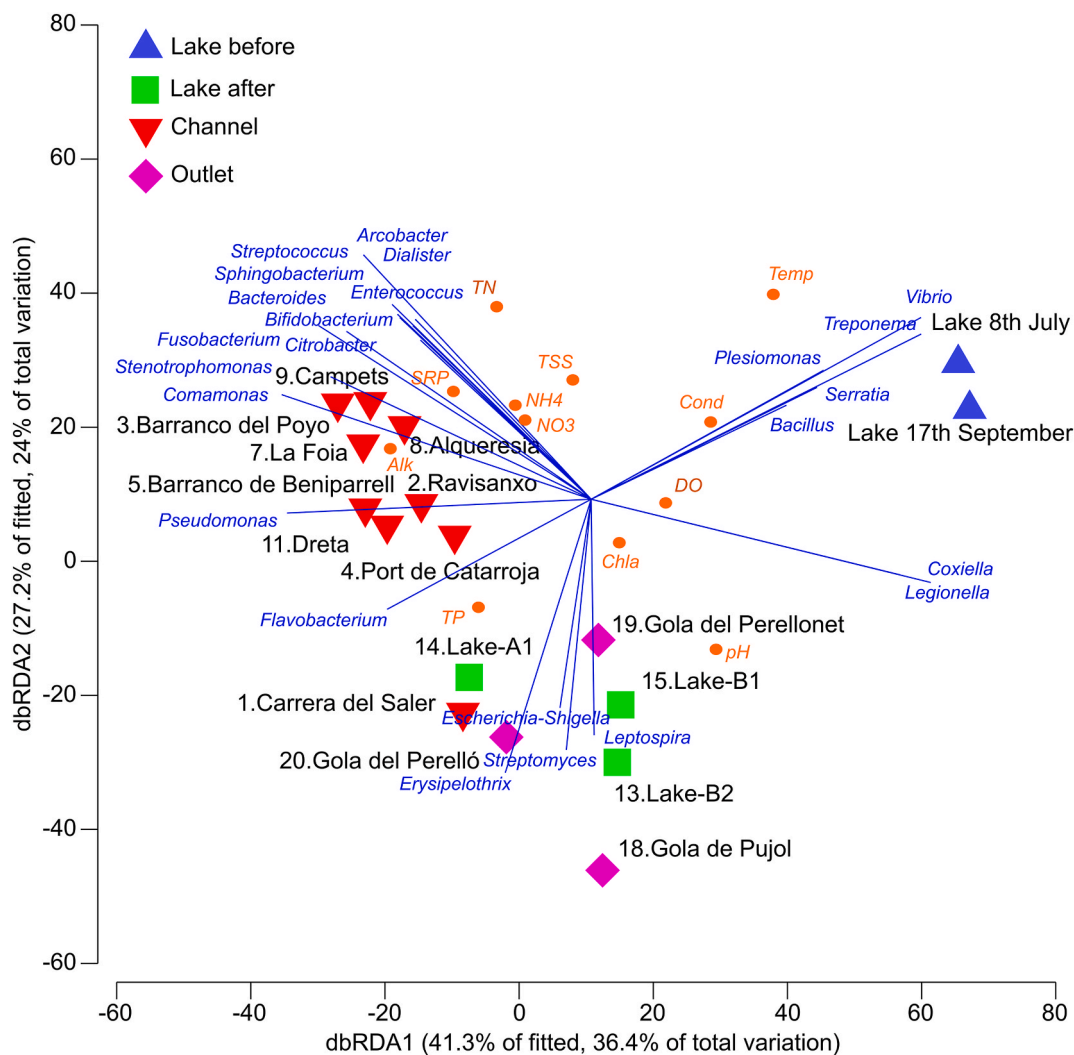
A distance-based Redundancy Analysis (dbrDA; Legendre and Anderson, 1999) was performed with the water physico-chemical parameters and the potentially pathogenic bacteria in water to visualize the relationship between these variables and the different sampling site groups (i.e., channels/ravines, lake, outlets). The analysis included two samples taken by our team in the Albufera Lake (Embarcadero Gola Pujol), near site 13, before the flash flood event (on the 8th July and 17th September of 2024) to assess the relative changes in water quality parameters and bacteria abundance after the flash flood. Furthermore, a PERMANOVA analysis with 999 Monte Carlo permutations was done to assess statistically significant differences regarding potentially pathogenic bacteria composition in the different sample groups. Finally, a HeatMap workflow was carried out to describe pathogenic bacteria dissimilarity in water before and after the flash flood event and among sampling site groups in unconstrained space. For this, the ZOTUs table

was Hellinger-transformed to calculate ordination based on Bray-Curtis distances. This transformation method helps to down-weight the importance of abundant species and eliminates the issue where shared absences of species inflate similarity between sites (Legendre and Gallagher, 2001). The dbRDA, the PERMANOVA and the HeatMap analysis were performed using the Primer version 7 software (PRIMER-E Ltd, Plymouth, UK).

The exposure concentration for the different organic contaminant groups in water (ng/L) and sediment (ng/kg dry weight) was calculated. The sum of the organic contaminant exposure concentrations after the flash flood event were compared with data for PEST (excluding OCPs), PPCPs, PFAS and OPFRs obtained from previous monitoring campaigns conducted in the ANP that had used similar sampling and analytical techniques (Soriano et al. 2023, 2024a, 2024b), and PAH samples that had been taken in the ANP during April and October of 2022 (see Text S5). To assess the effect of the flash flood event on contaminant concentrations, generalized linear mixed models (GLMMs) were fitted using the *glmmTMB* package in R (Brooks et al., 2017) for each contaminant group and environmental matrix (i.e., water, sediment). The initial

model included sampling date as a fixed factor, which was used to assess statistically significant differences between the samples analyzed before and after the flash flood event. Furthermore, additional terms were incrementally tested, including sampling site groups, the interaction between date and sampling site group, a random intercept based on the sampling event, and a random intercept for sampling site group. In cases where the normality assumption was violated or strong skewness was detected, the response variable was transformed as  $\log(x + 1)$ . Additionally, different families and link functions were tested to ensure the best model fit. Model selection was performed using the Akaike's Information Criterion (AIC) and likelihood ratio tests (LRT) to compare nested models. When more than two sampling events were available, Tukey post-hoc contrasts were applied using the *emmeans* package in R (Lenth, 2025) to assess pairwise differences between sampling dates.

Ecological risks for single contaminants were calculated by comparing the measured water and sediment concentrations with safe environmental concentrations. When the substance was included as part of the WFD priority list (ECEuropean Commission, 2013), the water annual average Environmental Quality Standard (EQS) was taken for



**Fig. 2.** Distance based Redundancy Analysis (dbRDA) biplot showing the differences in potentially pathogenic bacteria and water quality parameters between the different samples taken in the Albufera Natural Park after the flash flood event (i.e., Lake after, Channel, Outlet) and the samples taken in the Albufera Lake before the flash flood event (i.e., Lake before; Lake July 8, 2024, Lake September 17, 2024). Each symbol represents one sample (classified by sample groups as described in the legend), the bacterial genera are represented by lines, and the small dots indicate the water quality parameters added as supplementary variables. The percentage on each axis indicates the proportion of the constrained and total variation displayed on that axis. Samples close to each other represent samples with very similar community compositions and the direction of the line indicates the axis of increasing values for that bacterial genus. The abbreviations of the physical-chemical parameters are shown in Table S3 together with the parameter values. The relative abundance of potential pathogenic bacteria used to make this analysis is shown in Table S4.

risk characterization. For the rest of compounds, the water and sediment Predicted No Effect Concentrations (PNECs) stored in the ecotoxicology database of the NORMAN network (<https://www.norman-network.com/nds/ecotox/lowestPnecsIndex.php>) were used for risk characterization. Ecological risks were calculated using the Risk Quotient (RQ) approach (unitless), which were calculated dividing the measured exposure concentration by the corresponding EQS or PNEC for each contaminant. Substances with RQs <1 were considered to pose low-to-insignificant risks for aquatic ecosystems. Substances with RQs between 1 and 10 were considered to pose moderate risks, and substances with RQs larger than 10 were considered to pose high risks. For the latter, the potential to produce acute toxic effects was investigated based on an analysis of the existing literature. Finally, cumulative risk quotients (RQ<sub>total</sub>) for water and sediment in the different sampling sites were calculated as the sum of the individual compound's RQs.

### 3. Results

#### 3.1. Physical-chemical parameters

Water samples collected from the Albufera Lake prior to the flash flood exhibited higher temperature (as expected given the time of the year) and electrical conductivity compared to those collected afterwards (with a drop from 2290 to 2430  $\mu\text{S}/\text{cm}$  to 908–1288  $\mu\text{S}/\text{cm}$ ; Table S3; Fig. 2). Dissolved oxygen saturation levels were particularly low after the flash flood, with values below 40 % at sampling sites 1 (Carrera del Saler) and 4 (Port de Catarroja), and between 40 % and 60 % at sites 2 (Ravisanxo), 3 (Barranco del Poyo), 8 (Alqueresia), 9 (Campets), and 20 (Gola del Perelló). In contrast, oxygen saturation in the Albufera Lake ranged from 96 % to 126 %, similar to pre-flood values (102%–115 %). Ammonia concentrations exceeded 1 mg N-NH<sub>4</sub>/L at sites 3 (Barranco del Poyo) and 4 (Port de Catarroja). In the Albufera Lake, the maximum ammonia concentration was 0.48 mg N-NH<sub>4</sub>/L, recorded at site 14 (Lake-A1), which is located near the discharge area of Barranco del Poyo. Nitrate concentrations varied widely in the channels and ravines, from 0.9 to 93 mg N/L, and were maintained rather homogenous in the Albufera Lake and outlets, with values ranging from 0.84 to 1.81 mg N/L. The nitrate values measured in the lake were about 3–4 times larger than the values measured prior to the flash flood event. Total phosphorus concentrations ranged from 0.14 to 0.37 mg P/L in the channels and ravines, and from 0.18 to 0.20 mg P/L in the lake—slightly higher than pre-flood measurements (0.06–0.14 mg P/L). Chlorophyll-a concentrations in the Albufera Lake taken two weeks after the flood reached 99–127  $\mu\text{g}/\text{L}$ , compared to 43–68  $\mu\text{g}/\text{L}$  before the event, suggesting enhanced phytoplankton activity after the lake's flushing event. Meanwhile, total suspended solids concentrations in the lake post-flood (50–76 mg/L, with 16–40 % organic matter) remained like pre-flood levels (47–116 mg/L). The relationships among these variables are depicted in Fig. 2, which shows an overall trend towards a decrease of oxygen and conductivity after the flood event, and a higher concentration of soluble reactive phosphorus and nitrogen compounds after the flood, particularly in the channels and ravines.

Regarding sediments, little variation was observed between the samples taken in the different sampling site groups except for the conductivity and the nitrogen and phosphorus concentrations. Sediment conductivity was higher in lake samples (440–480  $\mu\text{S}/\text{cm}$ ), moderate in outlets (320–380  $\mu\text{S}/\text{cm}$ ), and lower in irrigation channels and ravines (265–360  $\mu\text{S}/\text{cm}$ ). Total nitrogen concentrations in irrigation channels and ravine sediments varied widely (80–5099 mg-N/kg dry weight), with two notably high values (in sites 4 and 5). In contrast, lake sediments showed consistently high total nitrogen levels (908–1177 mg-N/kg), while outlet sediments exhibited moderate values (191–674 mg-N/kg). A similar trend was observed for total phosphorus content. Total P concentrations in channel sediments were highly variable (9.0–118 mg-P/kg), with a prominent maximum in site 8. Lake (17–77 mg-P/kg) and outlet (9.6–84 mg-P/kg) sediment samples also exhibited wide

concentration ranges. LOI values, indicating sediment organic matter content, were variable in irrigation channels and ravines (3.3–15.6 %). In comparison, LOI values in lake sediments ranged from 4.3 to 5.7 %, and in outlets from 4.3 to 7.3 %, showing lower dispersion (Table S3).

#### 3.2. Pathogenic bacteria

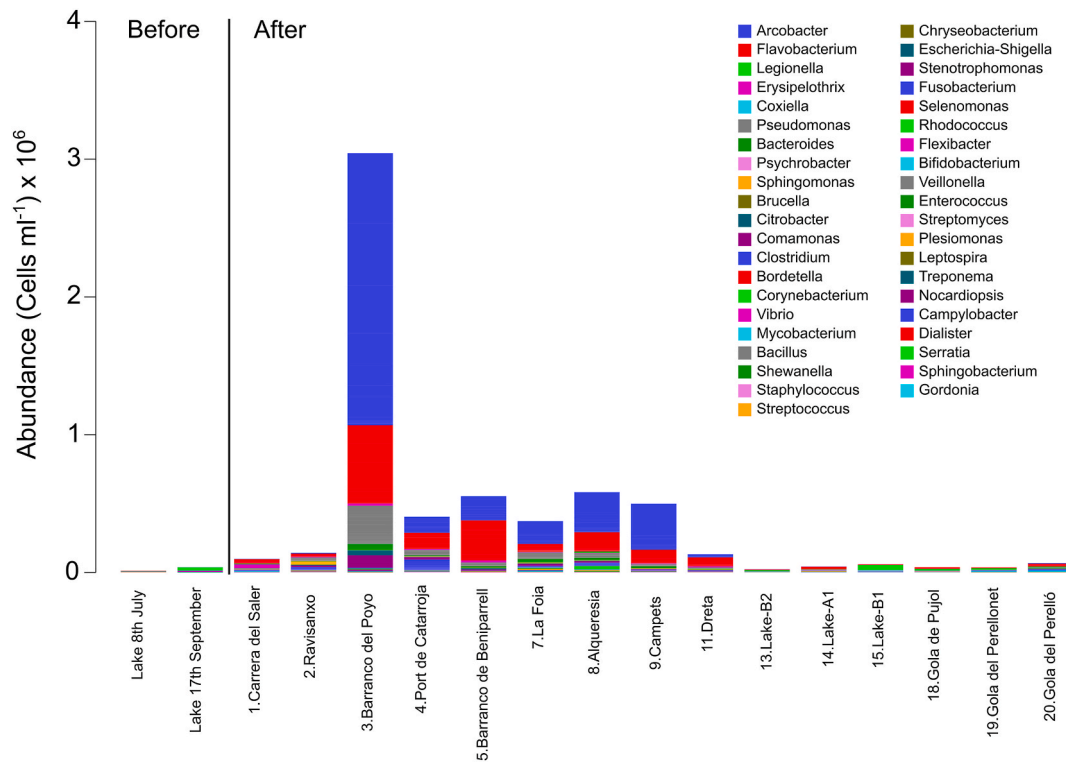
Fig. 3 shows the absolute abundance of bacterial genera with potentially pathogenic species (hereafter potentially pathogenic bacteria) in water samples collected in the ANP during the sampling campaign. A markedly higher total abundance of potentially pathogenic bacteria was detected in the irrigation channels and ravines, especially at sampling site 3 (Barranco del Poyo), which reached values of approximately  $3 \times 10^6$  cells/mL—about 2.5 to 3 times higher than those recorded in other channels/ravines and in the Albufera Lake (Fig. 3; Table S4). Similarly, elevated values were observed at sampling sites 4 to 8 (Port of Catarroja, Barranco de Beniparrell, La Foia, Alqueresia, and Campets). In these samples, a greater prevalence of bacteria belonging to the genera *Arcobacter* and *Flavobacterium* was detected, and to a lower extent *Pseudomonas* (Fig. 3; Fig. S1). *Arcobacter* and other genera related to untreated wastewater (*Streptococcus*, *Enterococcus*, *Bacteroides*) showed a positive relationship with samples that contained a higher concentration of soluble reactive phosphorous and nitrogen compounds (ammonia, nitrate), while *Flavobacterium* (and to a lower extent *Pseudomonas*) showed a larger abundance in samples that contained a larger total phosphorous concentration (Fig. 2).

The total abundance of potentially pathogenic bacteria in the Albufera Lake prior to the flash flood was similar to that observed in the samples taken after the flood event. However, in the samples taken prior to the flash flood the community was dominated by *Vibrio*, *Treponema*, *Plesiomonas*, and *Serratia*, while after the flash flood it was dominated by *Legionella*, *Coxiella*, and especially *Arcobacter*, indicating a shift in the structure of the community (Fig. 2; Fig. S1). Such differences in community structure among sample groups were confirmed by the PERMANOVA test (p-value: 0.001). The pair-wise PERMANOVA test showed significant differences in the community structure of potentially pathogenic bacteria in the lake before and after the flash flood (p-value: 0.016); and between the channels/ravines and the lake after the flood (p-value: 0.004), indicating different influences by urban wastewater. However, the statistical test did not reveal significant differences between the Albufera lake samples, and the samples taken in the outlets after the flood (p-value: 0.56; Table S5), suggesting similar bacterial composition at the moment of sampling.

#### 3.3. Chemical exposure

Our study detected the presence of 38 PEST (excluding OCPs), PPCPs, PFAS and OPFRs in the water samples, and 40 in the sediment samples collected in the ANP. Furthermore, the use of highly sensitive analytical methods enabled the identification of trace levels of a wide range of hydrophobic substances (OCPs, PAHs, PCBs, PBDEs, DP, PCDDs, PCDFs) both in water and sediment samples. Altogether, results revealed approximately 130 distinct organic compounds across all samples, with a mean of 109 and 93 compounds being detected per water and sediment sample, respectively.

Fig. 1 shows the total concentration of contaminants in the water and sediment samples taken after the flood event, while detailed information on concentrations per chemical group are shown in Table 1 (and per compound in Table S6–S15). Regarding water samples, the total concentration was dominated by PPCPs, followed by OPFRs. The highest total concentration was found in the northern part of the ANP, in sampling sites 3 (Barranco del Poyo) and 4 (Port de Catarroja), and in the lake (site 13 Lake B-2, and site 15 Lake B-1), and in the northern outlet (site 18 Gola del Pujol). The contamination by PPCPs was dominated by ibuprofen (detected in all water samples) with concentrations ranging between 796 and 58,588 ng/L, and paracetamol, which was detected in



**Fig. 3.** Total and relative abundance of potential pathogenic bacteria (genera) in the samples taken in the Albufera Lake before the flash flood event (8th July, 17th September) and after the flash flood event. The relative abundance of potential pathogenic bacteria used to make this figure is shown in Table S4.

**Table 1**

Concentration of the different chemical classes in the water (A) and sediment (B) samples taken in the different sampling sites and total concentration (sum of all chemical classes). PEST: pesticides; PPCPs: pharmaceuticals and personal care products; PFAS: perfluoroalkyl substances; OPFRs: organophosphorus flame retardants; PAHs: polycyclic aromatic hydrocarbons; PCBs: polychlorinated biphenyls; PBDEs: polybrominated diphenyl ethers; PCDDs: polychlorinated dibenzodioxins; PCDFs: polychlorinated dibenzofurans. The water concentrations for PEST (excluding OCPs), PPCPs, PFAS and OPFRs correspond to the dissolved fraction, while the rest are expressed as the total concentration. n.m.: not measured; n.c.: not calculated. Detailed information on individual compound concentrations is provided in Tables S6-S15.

A. Water (ng/L)	Channel/ravine										Lake			Outlet		
	1	2	3	4	5	7	8	9	11	13	14	15	18	19	20	
PEST	84	84	74	69	87	16	48	9	79	29	71	28	23	24	27	
PPCPs	7846	18,725	48,770	45,316	13,978	3062	3300	2251	922	52,100	15,847	58,679	45,567	15,808	1587	
PFAS	108	225	62	44	45	47	39	31	19	88	79	59	57	79	188	
OPFRs	369	357	466	572	3140	3106	1874	2068	3135	1160	1497	1063	1059	1427	733	
PAHs	280	260	196	405	310	273	260	346	159	177	241	144	243	194	220	
PCBs	10	11	11	21	42	14	128	49	15	34	30	34	23	33	9	
PBDEs	2.2	1.6	25	2.0	10	0.32	23	1.4	1.02	20	2.5	1.4	0.91	2.4	1.3	
PBDDs	0.07	0.05	0.08	0.07	0.08	0.03	0.05	0.03	0.04	0.44	0.06	0.04	0.06	0.10	0.06	
PCDFs	0.01	0.01	0.02	0.01	0.03	0.02	0.03	0.01	0.01	0.02	0.05	0.02	0.01	0.05	0.02	
<b>Total</b>	<b>8699</b>	<b>19,664</b>	<b>49,604</b>	<b>46,429</b>	<b>17,613</b>	<b>6518</b>	<b>5672</b>	<b>4755</b>	<b>4330</b>	<b>53,609</b>	<b>17,769</b>	<b>60,008</b>	<b>46,973</b>	<b>17,566</b>	<b>2764</b>	
B. Sediment (ng/g dw)	Channel/ravine										Lake			Outlet		
	1	2	3	4	5	7	8	9	11	13	14	15	18	19	20	
PEST	88	n.m.	65	738	63	63	77	137	98	72	59	71	44	n.m.	88	
PPCPs	2111	n.m.	5315	1421	1363	25	22	211	158	95	280	2649	2439	n.m.	2111	
PFAS	134	n.m.	32	30	29	5	25	17	51	35	51	59	106	n.m.	134	
OPFRs	<0.02	n.m.	<0.02	<0.02	28	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	n.m.	<0.02	
PAHs	466	926	650	428	465	508	1536	596	462	438	855	125	458	396	466	
PCBs	0.90	n.m.	0.66	3.65	4.20	6.03	8.89	0.93	2.65	6.23	14	3.30	0.53	n.m.	0.90	
PBDEs	0.65	n.m.	0.02	13	5.62	1.73	1.32	4.80	5.10	9.45	11	4.93	0.92	n.m.	0.65	
PBDDs	0.04	n.m.	0.19	0.09	0.13	0.01	0.04	0.04	0.11	0.33	0.75	0.26	0.03	n.m.	0.04	
PCDFs	0.00	n.m.	0.02	0.01	0.01	0.001	0.002	0.002	0.01	0.02	0.03	0.01	0.002	n.m.	0.00	
<b>Total</b>	<b>2801</b>	<b>n.c.</b>	<b>6062</b>	<b>2634</b>	<b>1958</b>	<b>609</b>	<b>1670</b>	<b>966</b>	<b>777</b>	<b>655</b>	<b>1271</b>	<b>2912</b>	<b>3049</b>	<b>n.c.</b>	<b>2801</b>	

53 % of the water samples with concentrations up to 11,292 ng/L in sampling site 3 (Barranco del Poyo). Regarding PPCPs, the contamination of methylparaben and caffeine was also relevant in sampling sites 3 and 4, and in the north-west part of the Albufera Lake, with

concentrations exceeding 100 ng/L (Table S7). As for OPFRs, the contamination was dominated by tris(2-chloroisopropyl)phosphate, with concentrations ranging between 2015 and 2733 ng/L in sampling sites 5 to 18, and tributyl phosphate, which was detected in all water

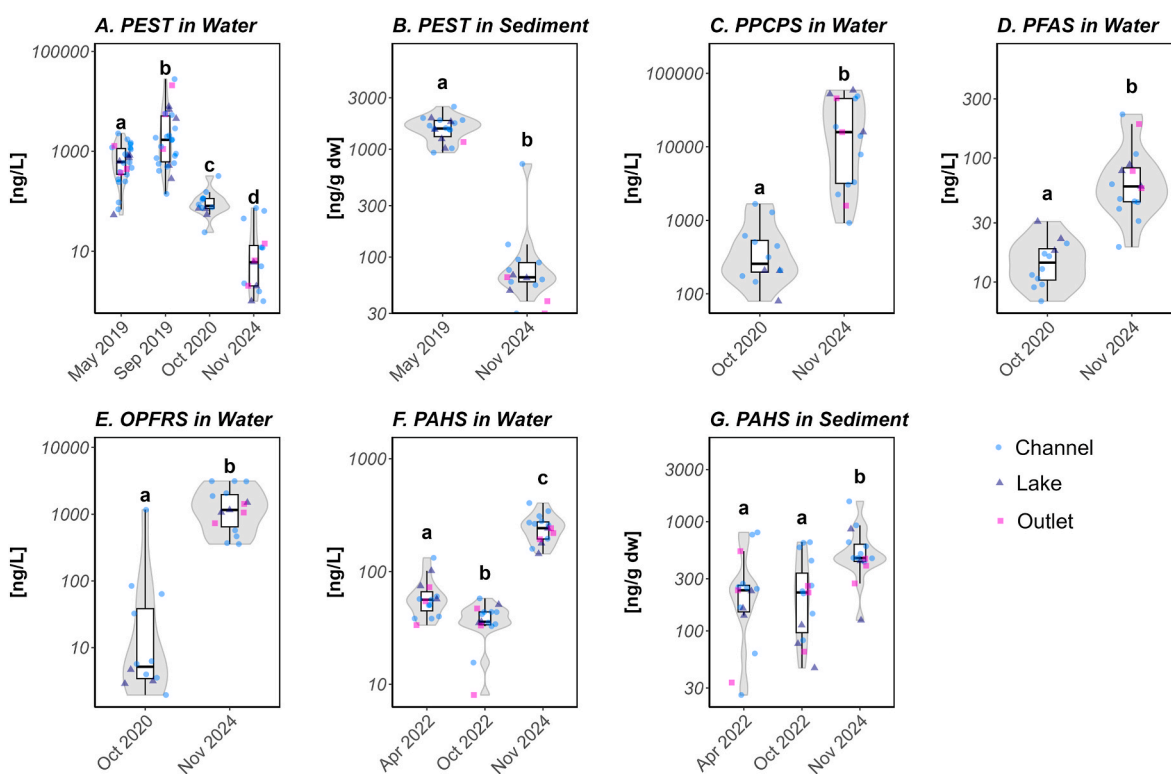
samples in concentrations ranging between 357 and 1427 ng/L (Table S9). Other compounds that showed concentrations above 100 ng/L were PFOS (perfluorooctane sulfonate), in sampling sites 2 (Ravisanxo) and 20 (Gola del Perelló; Table S8), and the PAH naphthalene in sampling site 9 (Campets; Table S10).

Regarding sediment exposure, the total concentration was dominated by PPCPs, followed by PAHs and PEST (Table 1). The highest total concentration was found in sampling site 3 (Barranco del Poyo), followed by sites 1 (Carrera del Saler), 4 (Port de Catarroja), 15 (Lake-B1), and 18 (Gola del Pujol; Fig. 1). PPCP contamination was dominated by paracetamol, with a concentration of 4,617 ng/g dw in site 3, and concentrations exceeding 1,000 ng/g dw in the aforementioned sites. It is also relevant the presence of atenolol, caffeine, methylparaben and thiamphenicol, all with concentrations above 100 ng/g dw in several sampling sites (Table S12). Regarding PAHs, it is noteworthy the contamination by acenaphthene, fluorene, naphthalene, and phenanthrene + anthracene, which were detected in all samples collected in the ANP, with maximum concentrations ranging between 100 and 300 ng/g dw, and higher exposure levels in sites 2 (Ravisanxo), 3 (Barranco del Poyo), 8 (Alqueresia), 9 (Campets), and 14 (Lake-A1; Table S15). Sediment contamination by PEST was dominated by the insecticide parathion-ethyl at Site 4 (Port de Catarroja), with a concentration of 661 ng/g dw. The fungicides difenoconazole, propiconazole, and tebuconazole were detected in all sediments analyzed, with concentrations ranging from 2 to 63 ng/g dw across the entire ANP (Table S11).

The GLMMs analysis done to assess statistical differences between chemical monitoring campaigns before and after the flash flood event shows that the sampling date significantly affected the chemical exposure distribution for all contaminant groups (Table S19). In all cases,

except for PEST, the exposure concentrations in the samples taken after the flash flood event showed a notable increase. The most significant increase was found for PPCPs and OPFRs in water, with median exposure concentrations increasing about two orders of magnitude as compared to the samples taken in former sampling campaigns (Fig. 4). The best fitting model for PAHs in sediment, also showed a significant influence of the sampling site groups besides sampling date. For these, the GLMM indicated a slightly higher exposure level in sediments collected in channels and ravines, as compared to sediments collected in the Albufera Lake (Table S19). The GLMM analysis and the Tukey post-hoc test for PEST in water showed a significant temporal trend in pesticide exposure concentrations not related to the flash flood event. Such trend highlights higher total exposure concentrations in September (after the pesticide applications in the rice fields) as compared to sampling done in spring and late autumn, and a slightly higher total pesticide concentration in channels and ravines as compared to the Albufera Lake. Notably, the water exposure concentrations measured after the flash flood event were about an order of magnitude lower than those measured in October 2020 (Fig. 4). A similar trend was observed for sediments, with median exposure concentrations that were about an order of magnitude lower than those found in the monitoring campaign conducted in May 2019 (Fig. 4).

The contamination profile of highly hydrophobic compounds measured in water, sediment, and particulate matter was dominated by PAHs, followed by PCBs, OCPs, PBDEs, and, to a lesser extent PCDDs (Fig. S2). Dissolved concentrations were negligible across all chemical classes. In contrast, concentrations sorbed to particulate matter were substantially higher for all contaminants, exceeding those in sediments. Among PAHs, naphthalene, acenaphthene, and phenanthrene +



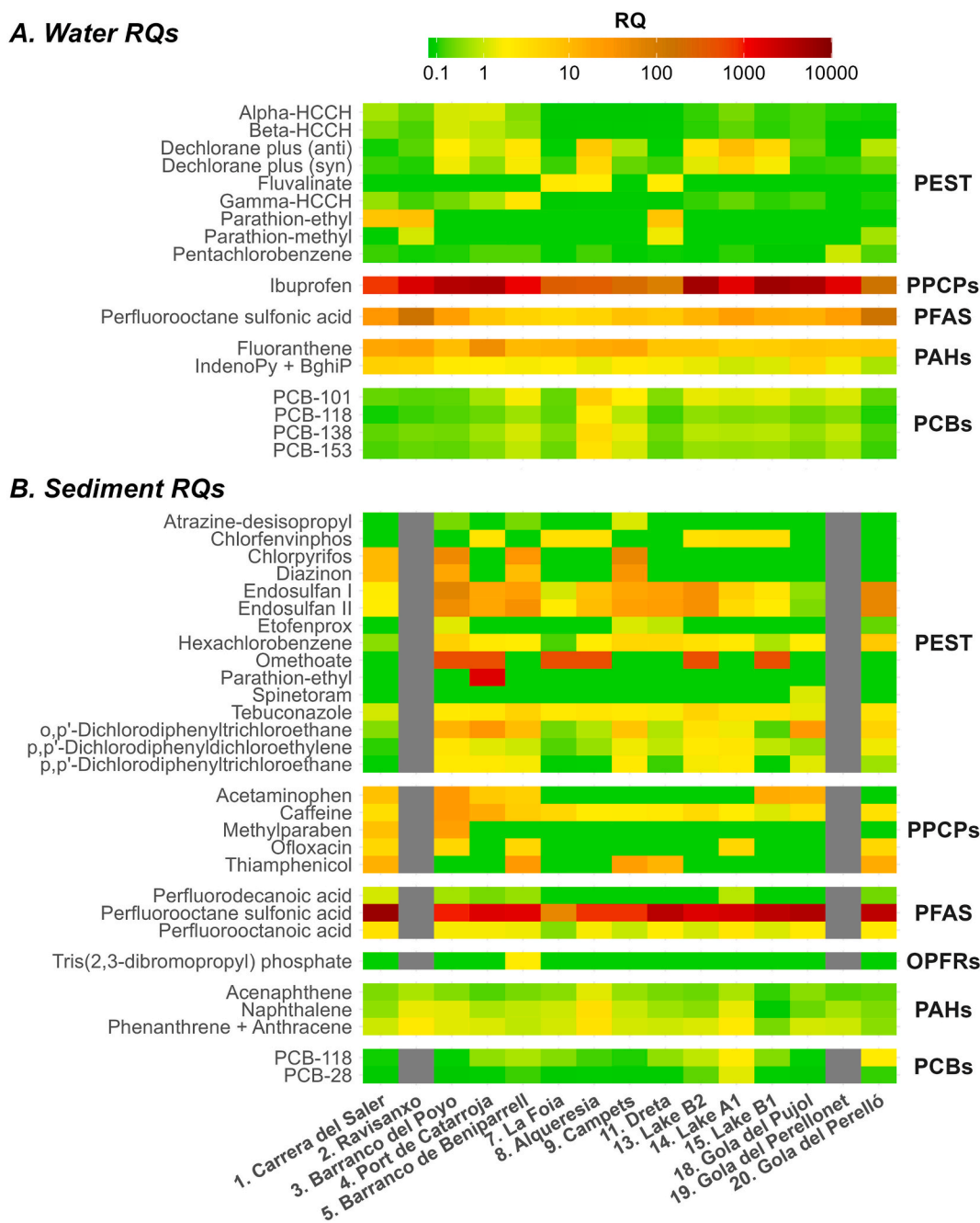
**Fig. 4.** Distribution of contaminant concentrations measured in previous monitoring campaigns (2019–2022) and after the flash flood event (2024). Different letters indicate significant differences among sampling events as indicated by the GLMM or the Tukey post-hoc test (when there were more than two sampling events). Colors and shapes indicate different sampling site groups (channel/ravines, lake, outlets). Boxplots show the median and interquartile range, while violin plots depict data distribution. Chemical concentrations measured after the flash flood (November 2024) in the 15 sampling sites ( $n = 15$ ) are provided in Table S6–S15. Data from the previous monitoring campaigns correspond to: PEST water (excluding OCPs): May 2019 and September 2019 (Soriano et al., 2024a;  $n = 26$ ), October 2020 (Soriano et al., 2023;  $n = 12$ ); PEST sediment (excluding OCPs): May 2019 (Soriano et al., 2024a;  $n = 18$ ); PPCPs water: October 2020 (Soriano et al., 2023;  $n = 12$ ); PFAS water: October 2020 (Soriano et al., 2023;  $n = 12$ ); OPFRs water: October 2020 (Soriano et al., 2023;  $n = 12$ ); PAHs water and sediment: April 2022 and October 2022 (collected in a previous monitoring campaign and analyzed as part of this study;  $n = 15$ ), and are provided in Tables S16–S18.

anthracene showed the highest contamination in particulate matter. For PCBs, PCB-101 and PCB-52 were predominant. Regarding the chemical group that contained OCPs and DP, we found that the flame retardant DP (anti and syn isomers) was the most abundant, and pentachlorobenzene, hexachlorobenzene and p,p'-DDE (Dichlorodiphenyldichloroethylene) dominated amongst the OCPs. PBDEs were primarily represented by BDE-209 in both particulate matter and sediments, whereas OCDD (octachlorodibenzo-p-dioxin) dominated the PCDD fraction in these matrices. The relative abundance of each compound varied across the three matrices (Fig. S2). The spatial evaluation showed that hydrophobic compounds were uniformly distributed in the particulate matter of the water samples taken across the ANP, except for PCBs, which exhibited markedly higher concentrations at sampling site 8

(Alqueresia). Sediment contamination was also relatively homogeneous, though PAH levels were elevated at sites 8 (Alqueria), 3 (Barranco del Poyo), and 2 (Ravisanxo). Overall, the highest concentrations of hydrophobic compounds in the Albufera Lake were consistently detected at sampling site 14 (Lake-A1), north-west region, both for water and sediments (Tables S10 and S15).

### 3.4. Ecological risk assessment

Seventeen substances exceeded the concentration proposed for the protection of aquatic life in at least one water sample (Fig. 5). These substances included seven PEST (i.e., alpha, beta and gamma hexachlorobenzene, fluralinate, parathion-ethyl, parathion-methyl, and



**Fig. 5.** Calculated Risk Quotients (RQs) for the compounds that showed a RQ > 1 in at least one of the water (A) and sediment (B) samples. RQs between 1 and 10 indicate moderate ecological risks, and RQs larger than 10 indicate high ecological risks. Please note that the category PEST includes dechlorane plus, which had been used as pesticide in the past but nowadays is considered a chlorinated flame retardant. The raw data used to build this figure are provided in Tables S20 and S21.

pentachlorobenzene), DP (anti and syn isomers), one PPCP (ibuprofen), one PFAS (PFOS), three PAHs (fluoranthene, and the sum of indeno [1,2,3-cd]pyrene and Benzo[g,h,i]perylene isomers), and four PCBs (PCB-101, PCB-118, PCB-138, PCB-153). Among these, the highest potential risk was associated with ibuprofen, with RQs exceeding 10 in all sampling sites, and exceeding 1000 in the northern channels and ravines (sites 2–5) and in all three samples collected in the Albufera Lake. The second highest risk was calculated for PFOS, with RQs ranging between 3 and 161, exceeding 10 in sampling sites 1–3, and in all samples taken in the Albufera Lake and outlets. RQs for fluoranthene ranged between 5 and 45, with the highest values being found in channels and ravines. For the rest of the compounds, maximum RQs ranged between 1 and 10, indicating only moderate risks (Fig. 5). The highest cumulative risks (based on the  $RQ_{total}$  for water exposure) were found for sites 15 (Lake-B1) > 13 (Lake-B2) > 18 (Gola de Pujol) > 4 (Port de Catarroja) > 3 (Barranco del Poyo; Table S20).

Regarding sediment samples, ecological risks (RQs >1) were identified for thirty compounds (Fig. 5). These included fifteen PEST (atrazine-desisopropyl, chlorfenvinphos, chlorpyrifos, diazinon, endosulfan I and II, etofenprox, hexachlorobenzene, o,p'-dichlorodiphenyltrichloroethane, omethoate, p,p'-dichlorodiphenyldichloroethylene, p,p'-dichlorodiphenyltrichloroethane, parathion ethyl, spinetoram, tebuconazole); five PPCPs (paracetamol, caffeine, methylparaben, ofloxacin, thiamphenicol); three PFAS (perfluorodecanoic acid, PFOS, and perfluorooctanoic acid); one OPFR (tris(2,3-dibromopropyl)phosphate); four PAHs (acenaphthene, naphthalene, and the sum of phenanthrene and anthracene isomers); and two PCBs (PCB-118 and PCB-28). The highest sediment risk was identified for PFOS, with calculated RQs above 100 in several channels and ravines (sites 1, 3, 5, 7, 11), and in all samples taken in the Albufera Lake and outlets. Other compounds that showed high sediment risks (RQs >10) were: parathion-ethyl >> omethoate >> endosulfan I > endosulfan II > chlorpyrifos > diazinon > o,p'-Dichlorodiphenyltrichloroethane > thiamphenicol > ofloxacin > paracetamol > caffeine > methylparaben (Fig. 5). The highest cumulative risks (based on the  $RQ_{total}$  for sediment exposure) were found for sites 1 (Carrera del Saler) > 18 (Gola de Pujol) > 4 (Port de Catarroja) > 11 (Dreta) > 15 (Lake-B1) > 20 (Gola del Perelló) > 13 (Lake-B2; Table S21).

## 4. Discussion

### 4.1. Flash flood impacts on physico-chemical parameters

This study demonstrates that the intense flash flood event affecting the Albufera Lake caused a marked reduction in conductivity levels due to the inflow of low-salinity floodwaters, while simultaneously increasing nitrogen concentrations - particularly ammonium - as a result of runoff from agricultural fields, urban areas, and the discharge of wastewater during and after the flooding period. These observations align with the monitoring data reported by Soria et al. (2025), which documented an 82 % decrease in water conductivity and a concurrent rise in nitrate levels after the flash flood. Soria et al. (2025) also noted a sharp increase in suspended solids and a decline in chlorophyll-a immediately after flooding. However, these trends were less evident in our study, as most inorganic suspended solids had either settled or been flushed from the lake by the time of sampling. These were subsequently replaced by phytoplankton biomass, whose rapid growth was stimulated by the substantial influx of fresh inorganic nutrients into the system, re-establishing the system towards its original hypereutrophic state (Sòria-Perpinyà et al., 2020). Additionally, our measurements detected critically low dissolved oxygen levels and elevated ammonia concentrations in the northwest channels and ravines (Barranco del Poyo), likely due to the continued discharge of untreated wastewater and the decomposition of reeds and other organic matter debris. These conditions may have posed high risks of hypoxia and ammonia-driven toxic stress to aquatic organisms a few days after the flash flood (Partani et al.,

2024; Zhang et al., 2023a).

### 4.2. Flash flood impacts on pathogenic bacteria

The wastewater discharges resulting from the flash flood event led to a significant increase in bacterial abundance in areas where sewage infrastructure had collapsed, consistent with observations from post-flood urban monitoring studies (Taylor et al., 2011; Lim and Foo, 2021). While total bacterial abundance in the Albufera Lake remained relatively unchanged, the community composition underwent a clear transformation. The flood event produced a shift from a stable, eutrophication-adapted bacterial community (similar to that described by Ghai et al., 2012) to an allochthonous assemblage of terrestrial and sewage-derived potentially pathogenic bacteria, dominated by *Flavobacterium*, *Escherichia sp.* and *Arcobacter* (Zhang et al., 2023b), which have been associated with gastroenteritis, bacteremia, and antimicrobial resistance in humans (Ferreira et al., 2016).

Although allochthonous bacteria in the Albufera Lake's channels and ravines are expected to show low persistence due to their poor competitive fitness against native ANP-adapted taxa (Zhang et al., 2023b), their temporal dynamics require rigorous monitoring to assess potential infection risks for both aquatic fauna and human populations reliant on ANP resources (e.g., fishermen, rice farmers; Mas-Coma et al., 2025). Furthermore, exposure of environmental bacteria to elevated pollutant loads may exacerbate public health concerns by potentially promoting antibiotic resistance development (Auguet et al., 2017; Buelow et al., 2020), particularly for antibiotic compounds whose concentration increased due to flood-induced runoff (e.g. thiamphenicol).

### 4.3. Flash flood impacts on chemical exposure

Previous studies showed that the ANP was contaminated with baseline levels of agricultural PEST, PPCPs, and industrial compounds (Amador et al., 2024; Martínez-Megías et al., 2024; Soriano et al., 2024a, 2024b). However, our study demonstrates significant post-flood increases in the total concentration of several contaminant classes (PPCPs, PFAS, OPFRs, and PAHs), likely resulting from urban pollutant remobilization and the discharge of untreated wastewater through northwestern and southern areas. Of particular concern were the markedly elevated total PPCP concentrations, with median levels in water reaching 60 times higher than those reported in former studies conducted in the ANP (Soriano et al., 2023). Moreover, these concentrations substantially exceeded those documented after analogous flood events in comparable ecosystems, such as Mar Menor (Castaño-Ortiz et al., 2023). Among these, ibuprofen levels exceeded 58,000 ng/L - representing a 50-fold increase over pre-flood measurements (Soriano et al., 2023) and the highest concentration ever documented in a freshwater lake (UBA, Umweltbundesamt, 2023). Similarly concerning were the paracetamol concentrations in water and sediment, which approached those found in poorly sanitized rivers of Asia and Latin America (Wilkinson et al., 2022). In addition to sewage inputs, the flash flood severely impacted pharmaceutical storage facilities in the vicinity of the ANP, resulting in extensive dispersion of pharmaceutical compounds throughout the northwestern sector. Nevertheless, the quantitative contribution of this source to the observed PPCP concentrations necessitates additional verification through comprehensive inventory data analysis.

PEST are among the most extensively studied contaminant groups in the ANP (Martínez-Megías and Rico, 2022; Martínez-Megías et al., 2023). Their temporal exposure patterns in water and sediment align with agricultural management practices in the surrounding rice paddies, as demonstrated by Amador et al. (2025). Interestingly, this study shows that the intense flushing that experienced the ANP significantly reduced the total concentration of PEST residues both in the water and the sediment compartments. However, our monitoring study revealed homogeneous spatial distribution of azole pesticides across the lake. These

fungicides are used in citrus and rice production (Martínez-Megías et al., 2023; Soriano et al., 2024a) and their distribution is likely attributable to the large-scale erosion and runoff from agricultural soils.

This study constitutes one of the first reports on the contamination produced by PFAS and OPFRs after a flash flood event. The predominant PFAS detected, PFOS - banned under the Stockholm Convention and strictly regulated worldwide (ECEuropean Commission, 2025) - reached a maximum concentration of 161 ng/L, exceeding previously reported levels in the ANP (Lorenzo et al., 2019). Among OPFRs, tris (2-chloroisopropyl)phosphate, a widely used flame retardant and plasticizer in foams, plastics, and automotive materials, was detected at eightfold higher concentrations than earlier records (Lorenzo et al., 2019; Soriano et al., 2023).

The median PAH concentration in waters (243 ng/L) and sediments (465 ng/gr dw) was nine times higher than the PAH concentrations obtained for previous monitoring campaigns and are notably higher than the PAH concentrations reported by León et al. (2017) for Mar Menor after a flash flood. The PAH profiling of the ANP after the flash flood revealed a dominance of low-molecular-weight (LMW) compounds (acenaphthene, fluorene, naphthalene, and phenanthrene + anthracene; 2 to 4 carbon rings), in line with previous reports of PAH contamination in the area (Soriano et al., 2024b). The ratio of high-molecular-weight (HMW) to low-molecular-weight (LMW) PAHs ranged from 0.07 to 0.23 in our study, which indicates petrogenic contamination (Zheng et al., 2016), with higher prevalence in the ANP channels and ravines. This may have originated from the remobilization of sediments, which contained residues of PAHs emitted by boat traffic (Soriano et al., 2024b), but also by spills produced by the more than 100,000 cars that were lost due to the flooding event.

Unfortunately, historical records for most OCPs analyzed in this study are limited for the ANP. The sediment concentrations of hexachlorobenzene and the DDT congeners and its by-products (DDE, DDD) are similar to the values reported by Peris et al. (2005) in the Albufera Lake twenty years ago, indicating that the flash flood may have contributed to their (partial) remobilization, but not to their elimination.

This is the first study that evaluated the contamination profile by PCBs, PBDEs, DP and PCDD/Fs in the ANP. Their concentration in particulate matter compared to sediments suggests that the flash flood event likely contributed to their transport from upstream urban and industrial areas. This interpretation is supported by the distinct distribution of individual compounds/congeners in sediments versus particulate matter. These findings are in line with previous investigations that demonstrate substantial persistent organic pollutant transport associated to particulate material after floodings in the Mediterranean region (David et al., 2012; León et al., 2017; Herrero et al., 2018), as well as in other parts of Europe (Schwanen et al., 2023) or Africa (Tesi et al., 2016; Iwegbue et al., 2020).

#### 4.4. Ecological risk assessment

Forty-four compounds exceeded threshold concentrations for the long-term protection of aquatic ecosystems in at least one sample. The highest-risk compounds (risk quotient, RQ > 10) in water were ibuprofen, PFOS, and fluoranthene. Ibuprofen is a widely used non-steroidal anti-inflammatory drug (NSAID). It induces endocrine disruption, reproductive impairment, and behavioral alterations in fish and macroinvertebrates at concentrations comparable to those measured in the ANP (Xia et al., 2017; Mathias et al., 2018), though lethal effects require concentrations an order of magnitude higher (>800,000 ng/L; Trombini et al., 2020). Long-term exposure to PFOS can disrupt thyroid hormone transport, causing developmental and neurotoxic effects (Chen et al., 2018; Yang et al., 2023). Fluoranthene, like other PAHs, may trigger behavioral and developmental toxicity in aquatic organisms, with UV exposure potentiating its effects (Hatch and Burton, 1999; Yang et al., 2023). The five WFD priority substances

( $\alpha$ -, $\beta$ -, $\gamma$ -hexachlorocyclohexane, pentachlorobenzene, and PFOS) exceeded the long-term quality standards but remained below maximum allowable concentrations.

Therefore, we conclude that the samples taken two weeks after the flash flood presented low-to-insignificant acute (mortality) risks to aquatic organisms due to water exposure. However, persistent post-flood pollution could still cause chronic effects, such as behavioral impairments, reduced growth, and developmental or reproductive issues to aquatic organisms. Notably, most high-risk compounds (e.g., hydrophobic PEST, PFAS, PAHs, PCBs) exhibit high sediment persistence and significant bioaccumulation potential in higher trophic levels (e.g., fish, birds; Cunha et al., 2012; Hu et al., 2024; Kowalska et al., 2024), which may threaten human activities like fishing and hunting. Therefore, continuous monitoring of contaminant levels in the ANP is needed, as well as in fish and other top predators. This should be coupled with a periodic assessment of the structure and functioning of aquatic communities, to assess any potential long-term consequences produced by the flash flood event in the ANP.

## 5. Conclusions

The study shows that the 2024 flash flood event that affected the ANP altered some physico-chemical parameters (dissolved oxygen concentrations, electric conductivity and nutrient conditions) and resulted in a shift in the structure of the potentially pathogenic bacterial community. Moreover, the combined effect of the massive flooding and the sewage system collapse led to a surge in contaminants—particularly PPCPs, OPFRs and PAHs—and the widespread remobilization of other hydrophobic compounds. While acute lethal effects on aquatic life were unlikely, we identified 44 compounds that surpassed the long-term aquatic toxicity thresholds. The most significant exceedances in water included ibuprofen, PFOS, and fluoranthene, while sediments contained 13 high-risk compounds (PFOS, PESTs and PPCPs). Spatially, the highest ecotoxicological risks from water exposure were concentrated in the Albufera Lake and the northwest sector (near Barranco del Poyo), whereas sediment-related risks were more uniformly distributed. This study presents one of the first detailed investigations of extreme flood impacts on aquatic ecosystems in Europe, highlighting key water quality parameters and contaminant mixtures that are likely emitted into the environment following such extreme events. The findings offer critical insights for guiding ecosystem management in the ANP by identifying vulnerable areas and environmental compartments at risk of contamination due to flooding. Additionally, the study underscores the need for restoration strategies—such as nature-based solutions and bioremediation—to partially eliminate chemical pollutants and restore the ANP to a good ecological condition, moving beyond its current hyper-eutrophic state.

## CRedit authorship contribution statement

**Andreu Rico:** Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Antonio Picazo:** Writing – review & editing, Methodology, Investigation. **Jhesibel Chavez:** Writing – review & editing, Methodology, Investigation. **Julian Campo:** Writing – review & editing, Methodology, Investigation. **Pere Colomer-Vidal:** Writing – review & editing, Methodology, Investigation. **Juan Muñoz-Arnanz:** Writing – review & editing, Methodology, Investigation. **Begoña Jiménez:** Writing – review & editing, Methodology, Investigation. **Cristiana Rizzi:** Writing – review & editing, Methodology, Investigation. **Lorenzo Federico:** Writing – review & editing, Methodology, Investigation. **Sara Villa:** Writing – review & editing, Methodology, Investigation. **Jose Francisco Palacios:** Writing – review & editing, Methodology, Investigation. **Carlos Roquera:** Writing – review & editing, Methodology, Investigation. **Pablo Amador:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Antonio Camacho:** Writing – review & editing, Supervision,

Methodology, Investigation, Conceptualization.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgements

This work has received funding from the Department of Environment of the Valencian Regional Government (Conselleria de Medi Ambient, Infraestructures i Territori de la Generalitat Valenciana), under the contract titled "Analytical assessment of the impact of the October 2024 DANA (Isolated High-Level Depression) event on the Albufera Natural Park of Valencia and the necessary actions for its comprehensive restoration", granted to A. Rico and A. Camacho. This organism delivered the corresponding permissions for publication of the data generated thereby. A. Rico also thanks the Talented Researcher Support Programme Plan GenT (CIDEAGENT/2020/043) of the Generalitat Valenciana. A. Camacho, A. Picazo and C. Rochera also got funding from the project Interreg Euro-MED Programme Wetland4Change - Project number Euro-MED0200309, granted to A. Camacho. This study is dedicated to the memory of Yolanda Picó, whose pioneering work laid the foundation for assessing chemical pollution in the Albufera Natural Park.

### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envres.2025.123515>.

### Data availability

The data supporting this study are published as Supplementary Material.

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