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Physico-chemistry of urban wet weather discharges in the Riviera Palmeraie catchment, Abidjan (Ivory Coast)

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ABSTRACT: A physico-chemical characterisation of urban wet weather discharges (UWWDs) was carried out on a residential catchment of Riviera Palmeraie in the Abidjan District. This neighborhood is characterised by periodic drainage channel overflows, which have caused several floods in recent years. In order to determine the temporal variability of pollutant concentrations and their transfer dynamics, 5 floods were sampled between November 2021 and April 2023. Physico-chemical parameters such as pH, electrical conductivity (EC), total suspended solids (TSS), chemical oxygen demand (COD), ammonium, nitrite, nitrate, total nitrogen (TN), total phosphorus (TP), and phosphate were determined. Descriptive analysis of these parameters and the associated statistical tests showed that urban wet weather discharges are alkaline (pH 9.92), highly loaded with TSS (19.3 $g.L^{-1}$) and moderately mineralised (EC 698 $\mu S\ cm^{-1}$). While construction sites and soil erosion in the catchment are the main sources of TSS, the high values for electrical conductivity and concentrations of ammonium, total nitrogen and total phosphorus are directly related to wastewater discharges into the drainage system and leaching from the urban areas as a whole. Nitrogen and phosphorus pollution is predominantly in particulate form and is strongly correlated with TSS ($r = 0.86$) for most floods. For all the sampled floods, discharge and electrical conductivity appear to be good descriptors of ammonium dynamics. Suspended solids also appear to be good descriptors of total nitrogen and total phosphorus dynamics.

KEYWORDS: wastewater, suspended solids, nitrogen and phosphorus nutrients, drainage system, pollution, water quality guidelines.

1 INTRODUCTION

Over the years, the sealing and artificialisation of urban surfaces has resulted in the collection of increasingly polluted rainwater due to atmospheric deposition and leaching from sealed surfaces and roofs [1]. In developing countries, these problems are exacerbated by the lack of infrastructure to collect and treat wastewater, which is often discharged directly into the drainage system or into natural watercourses running through urbanised areas.

Urban stormwater management is one of the major challenges facing cities worldwide in the 21st century. Urban wet weather discharges are likely to have an impact not only on the physico-chemical quality of the receiving water, but also on its ecological quality. These discharges contain loads of organic and inorganic pollutants that are directly related to the anthropisation of the catchment area and land use, but also depend on water use and the characteristics of the sewage network (presence or absence, separate or combined). UWWDs pose a threat to both freshwater and marine aquatic ecosystems [2], [3], [4]. Their impact on receiving aquatic ecosystems is a key issue of the European Water Framework Directive (WFD, 60/2000/EC) [5], [6]. In response to these issues, numerous studies have focused on amount, composition and variability of

UWWDS. To give just a few examples, [3] assessed the impact of UWWDs on the algal compartment in a retention/infiltration basin in Chassieu (Rhône, France), [7] studied the first flush in a combined sewer system located in Pavia (Italy), [5] assessed the impact of urban discharges from the Grenoble agglomeration (France), with 500,000 equivalent-inhabitants, on the receiving waters of the Isère and Drac rivers.

In Africa, few studies have assessed pollution associated with UWWDs. In Côte d'Ivoire, the city of Abidjan faces some difficulties in terms of water and urban sanitation management [8], [9]. Households not connected to the sewage system, poor maintenance of sanitation facilities in informal neighborhoods, and the limited data available in these areas slow down the implementation of sanitation systems [9], [10], [11], [12]. Domestic wastewater, rainwater and industrial effluents are often discharged into the environment without prior treatment. In particular, the Ébrié lagoon becomes a receptor for various urban discharges that are difficult to identify [13]. In order to understand the pollution generated by UWWDs, the urban catchment area of Riviera Palmeraie (9.24 Km2) was chosen as study site. The aim of our work is to characterise the temporal variability of pollutant concentrations in UWWDs and their transfer dynamics during some rainfall events.

2 MATERIEL AND METHODS

The study site, sampling method, analysis protocol and statistical analyses are presented in this section.

2.1 SITE DESCRIPTION AND SAMPLING PROCEDURE

Riviera Palmeraie is a residential area of almost 17,000 inhabitants [14], located in the central-western part of Cocody in the District of Abidjan (Ivory Coast). It has been urbanised recently, over the last fifteen years, and wastewater is evacuated through a sewer system [15], [16].

The catchment area covers 9.24 km^2 and includes a drainage system into which, however, domestic wastewater or wastewater from washing stations is discharged. The sampling station is located after the confluence of the two main collectors (Fig. 1). Several construction and public works sites are currently underway (Fig. 2-A).

Riviera Palmeraie faces recurrent flooding caused by high rainfall events. These events present high rainfall depths and intensities [17]. Soil impermeabilization due to urbanization can contribute to brief, intense and frequent floodings by overflowing drainage channels [16]. These flash floods occur during both rainy seasons, mainly from April to July, but also from September to November.

2.2 SAMPLING AND ANALYSIS METHODS

Water sampling was carried out using a HACH SIGMA AS 950 automatic sampler (Fig. 2-B). An initial sampling phase (every 5 minutes – 6 samples) was carried out from a water level of 20 cm to better sample the flood rise, followed by a second phase (every 20 minutes – 6 samples) to ensure that the sampling was evenly distributed during the flood recession. Water samples were collected in two 1 litre-polyethylene bottles.

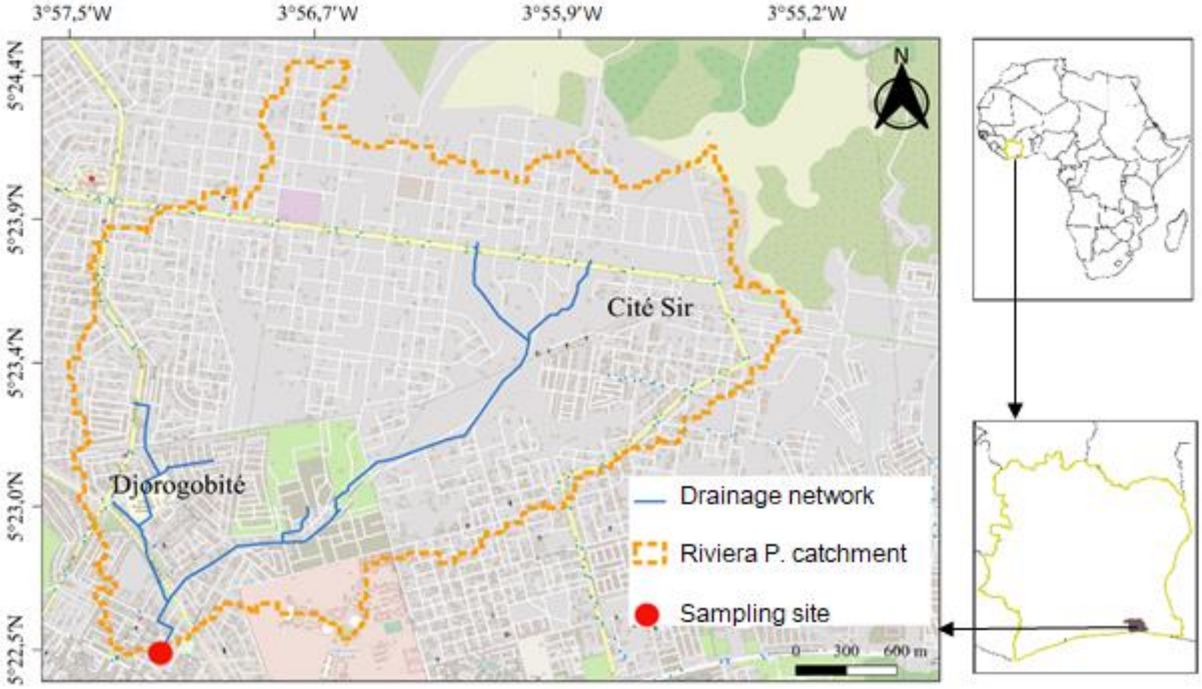

Fig. 1. Riviera Palmeraie catchment

The sampling site is located at a gauging station, which was used to record the water levels; discharges were calculated using the rating curve available for this station. Five floods were sampled during the study period: May 2022, July 2022, September 2022, November 2022 and March 2023.

Samples were also collected during low flow periods, in June, July, August and September 2022. Electrical conductivity and pH were measured using specific HACH probes (CDC 40105 and pHC 101); total suspended solids (TSS) were quantified by differential weighing on cellulose filters with a porosity of 0.45 µm; ammonium, nitrites, nitrates and phosphate were analysed using Hach LCK 304, LCK 341, LCK 339 and LCK 350 cuvette tests respectively; total nitrogen, total phosphorus and chemical oxygen demand (COD) were determined using Hach LCK LATON 238, LCK 350 and LCI 400 cuvette tests after mineralisation.

2.3 DATA PROCESSING

Statistical analysis was used to determine whether the distribution of the concentrations of the parameters studied was homogeneous across all floods, or whether there was a significant difference, and to identify possible relationships between the parameters. The collected data were subjected to univariate analysis, and Shapiro-Wilk test was used to test the hypothesis of normal distribution. The Kruskal-Wallis test was used when the data were not normally distributed, and a threshold of 5% was used to determine the level of significance. When a significant difference ($p < 0.05$) was found between parameters, a pairwise comparison was made using the Mann-Whitney test. Spearman's rank correlation was used to assess relationships between parameters and their degree of dependence. These statistical tests were performed using R 3.0.2 [18].

Fig. 2. Public works on site (A) and automatic sampler (B) at the gauging station

3 RESULTS

This section presents the different sampling campaigns and the hydrological characteristics of the sampled floods. It deals with the main components of the physico-chemical quality of the UWWDs at Palmeraie and the distribution between dissolved and particulate fractions of the transferred pollutants

3.1 HYDROLOGICAL CONDITIONS

Four sampling campaigns and in-situ measurements were carried out during low flow periods: on 30 June 2022, 26 July 2022, 26 August 2022 and 16 September 2022. For these dates, channel flow was generated by wastewater discharges ranging from 0.013 $m^3.s^{-1}$ to 0.05 $m^3.s^{-1}$. Floods were sampled in both dry and wet seasons, with antecedent dry weather period varying from a few days to over 2 months (Table 1).

- The small flood of 05/31/2022 occurred during the long rainy season. This flood was preceded by a relatively short dry weather period (6 days) and its maximum discharge was 8.5 $m^3.s^{-1}$. This peak discharge was relatively low.
- The high flood of 07/07/2022 was also recorded during the long rainy season. The antecedent dry weather period of the flood was relatively short (8 days) and the maximum discharge reached 40 $m^3.s^{-1}$. This high peak discharge was the most significant of all the floods sampled.
- The mean flood of 16/09/2022 occurred during the short dry season. This flood was preceded by the longest dry weather period between floods (2 months) and had a peak discharge of 17 $m^3.s^{-1}$. This peak discharge was relatively high.
- The small flood of 11/24/2022, occurred during the short rainy season. The antecedent dry weather period of the flood was moderately longer (1 month) and the peak discharge was 11 $m^3.s^{-1}$. This peak discharge was relatively low.
- The high flood of 03/29/2023 occurred during the long dry season. This flood was preceded by a short dry weather period (24 days) and its maximum discharge was 22 $m^3.s^{-1}$. This peak discharge was relatively high (Fig. 3). The characteristics of the five sampled floods are given in Table 1.

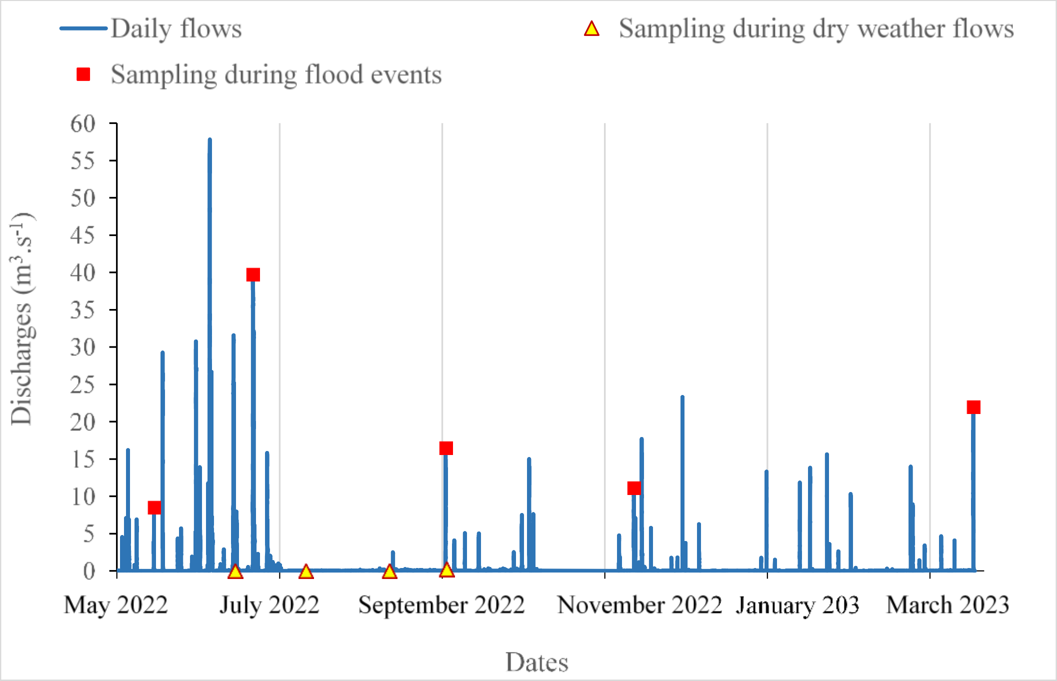

Fig. 3. Sampling during low flow period and flood events

Tableau 1. Main characteristics of rainfall events

Sampling site	Rainfall event date (dd/mm/yy)	Flood duration(hh:mm)	Antecedent dry weather period	Flood volume (m^3)
Riviera Palmeraie	31/05/2022	5:50	6 d	30500
	07/07/2022	2:30	8 d	473000
	16/09/2022	4:00	2 months 4 d	35700
	24/11/2022	3:10	1 month 6 d	52400
	29/03/2023	3:30	24 d	70400

3.2 ANALYSIS OF THE PHYSICO-CHEMICAL QUALITY OF URBAN WET WEATHER DISCHARGES

The quality of urban wet weather discharges (UWWDs) is estimated using some physico-chemical parameters, which are used to characterise the level of pollution in the discharges and to assess the temporal dynamics of concentrations during floods. Mean values (μ), standard deviations (σ), minimum and maximum values of the measured parameters are presented in Table 2 for both low flow and flood sampling campaigns.

- Hydrogen potential (pH) and electrical conductivity (EC)

During both the dry and flood periods, urban discharges runoff has an alkaline pH ($\mu = 9.3$). The pH decreases during the rising part of the flood, reaching a value of 8.7, and remains slightly below the average pH (9.3) during dry weather flows (Fig. 4-A). Its variability between events is not significant (Mann-Withney test ($p > 0.05$), Table 2). The alkalinity of these urban wet weather discharges is related to the effluent discharged into the drainage system. The pH does not exceed the Ivorian guideline for liquid discharges (5.5-9.5) into the receiving waters [19].

The mineralisation of urban wet weather discharges is moderately high at the beginning of the flood (698 $\mu S.cm^{-1}$) and then decreases with increasing flow (110 $\mu S.cm^{-1}$) (Fig. 4-B). Similarly, the electrical conductivity of urban discharges runoff decreases from low flow conditions ($\mu = 470$ $\mu S.cm^{-1}$) to floods period ($\mu = 265$ $\mu S.cm^{-1}$). Overall, this parameter varies little from flood to flood (Mann-Withney test ($p > 0.05$), Table 2).

- Total suspended solids (TSS) and chemical oxygen demand (COD)

The highest concentrations of total suspended solids (TSS) from UWWDs at Riviera Palmeraie were recorded during high flow periods ($\mu = 13.6$ $g.L^{-1}$ for the flood of 11/24/2022), compared to low flow periods ($\mu = 6.2$ $g.L^{-1}$). This TSS concentration peak occurs when the rate flow reaches its maximum amplitude (11 $m^3.s^{-1}$) (Fig. 4-C). The high TSS concentrations of the UWWDs did not differ significantly from one flood to another (Mann-Withney test ($p > 0.05$), Table 2). The highest mass of TSS discharged was observed for the 07/07/2022 event in the long rainy season (i.e. 2500 T), compared to the 24/11/2022 event (i.e. 570 T).

In terms of chemical oxygen demand (COD), the value is high at the beginning of the flood on 07/07/2022 (with a maximum of 1330 mg $O_2.L^{-1}$) and remains relatively higher than the average value during periods of low flow (286 mg $O_2.L^{-1}$) (Fig. 4-D). This result reflects the contamination of the UWWD with organic matter. This parameter varies significantly from low flow periods to flood events, and for different floods (Mann-Withney test, $p < 0.05$).These values exceed the Ivorian guideline for liquid discharge (500 mg $O_2.L^{-1}$) [19].

- Ammonium, nitrite, nitrate and phosphate

High ammonium concentrations were recorded, ranging from 1.22 to 24.8 mg $N\text{-}NH_4^+.L^{-1}$ for all floods. The dynamics of ammonium transfer are characterised by high concentration at the beginning of the floods (24.8 mg $N\text{-}NH_4^+.L^{-1}$), which decreases with increasing flow to reach the average concentration observed during low flow periods (1.28 mg $N\text{-}NH_4^+.L^{-1}$) (Fig. 5-A). These UWWDs show high ammonium concentrations only during the rising part of the 09/16/2022 flood.

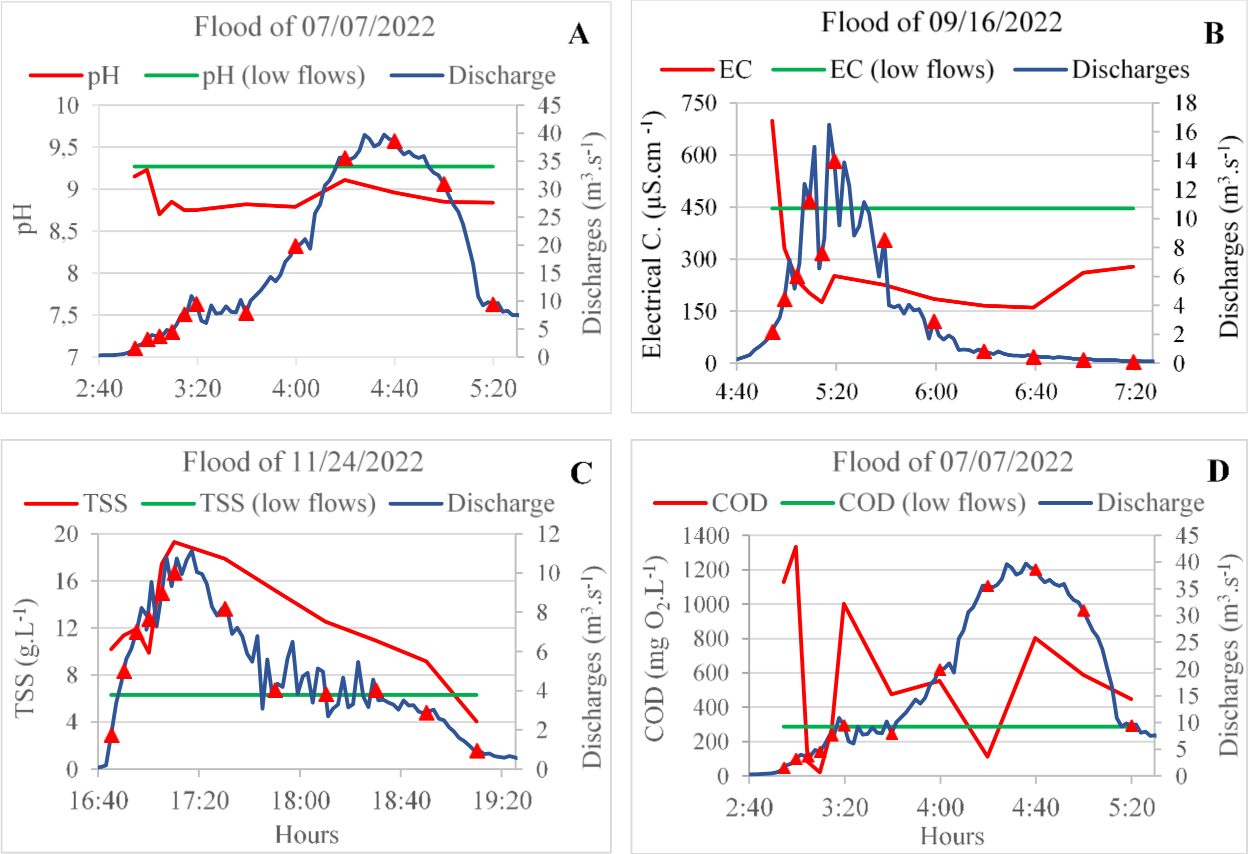

Fig. 4. Dynamics of pH, electrical conductivity (E C), total suspended solids (TSS), chemical oxygen demand (COD) during low flows and flood events

The mass of nitrogen discharged in the form of ammonium was highest during the event of 11/24/2022 in the short rainy season, i.e. 219 Kg $N\text{-}NH_4^+$.

Nitrate concentration is low during flood events, but remains higher than the average concentration in low flow conditions (0.74 mg $N\text{-}NO_3^-.L^{-1}$), with a maximum of 3.1 mg $N\text{-}NO_3^-.L^{-1}$ recorded as the rising part of the flood of 09/16/2022 (Fig. 5-B). The nitrate concentration varies little from flood to flood (Mann-Withney test ($p > 0.05$) and does not exceed the Ivorian guideline for liquid discharges (i.e. mg 11 $N\text{-}NO_3^-$) [19]. The highest mass of nitrates discharged was observed for the event of 07/07/2022 during the long rainy season (i.e. 220 Kg $N\text{-}NO_3^-$).

In addition, the urban wet weather discharges show low concentrations of nitrites and orthophosphates. The maximum values are, 1.5 mg N-NO_2^-.L^{-1} and 0.73 mg P-PO_4^{3-}.L^{-1} respectively, and the concentrations did not vary significantly for different floods (Mann-Withney test ($p > 0.05$). Orthophosphate concentrations do not exceed the Ivorian guideline for liquid discharges (i.e. 16 mg P-PO_4^{3-}.L^{-1}) [19].

Tableau 2. Physico-chemical parameters of UWWDs during flood events, median values with a letter: a, b, c or d in common do not differ significantly (Mann-Withney test; p > 0,05)

Parameters	Unity	Statistics	Low flows n = 4	Flood of 05/31/2022 n = 12	Flood of 07/07/2022 n = 12	Flood of 09/16/2022 n = 12	Flood of 11/24/2022 n = 12	Flood of 03/29/2023 n = 11
TSS	mg.L^{-1}	Mean ± SD	6230^a ± 3330	12940^b ± 3360	13580^b ± 1420	10630^b ± 3220	12480^b ± 3320	12120^b ± 2010
		Range	2030 - 10650	3660 - 18050	9660 - 16920	2460 - 16610	4040 - 19290	8900 - 16160
COD	mg O_2.L^{-1}	Mean ± SD	286.3^a ± 181.7	38.61^b ± 28.02	568.2^a ± 335.46	257.8^a ± 221.93	948.3^c ± 139.42	505.55^a ± 188.69
		Range	91.20 - 520	6.18 - 162	20.12 - 1333	54.30 - 1042	689 - 1204	211 - 1106
pH		Mean ± SD	9.27^a ± 0.32	8.83^a ±0.18	8.9^a ± 0.14	9.31^a ± 0.25	9.11^a ± 0.13	9.32^a ± 0.24
		Range	8.95 – 9.61	8.50 - 9.40	8.7 - 9.23	8.79 - 9.92	8.60 - 9.3	9.02 - 10.10
E C	µS.cm-^{1}	Mean ± SD	470^a ± 171	257.25^a ± 39.33	159.42^b ± 37.42	264.83^a ± 85.58	233.42^a ± 34.19	238.05^a ± 40.69
		Range	282 - 812	187 - 390	110 - 235	161 - 698	196 - 412	178 - 422
NH_4^+	mg N-NH_4^+.L^{-1}	Mean ± SD	1.28^a ± 0.69	2.48^a ± 0.54	2.34^a ± 1.45	5.79^a ± 4.56	5.36^a ± 4.81	2.63^a ± 1.5
		Range	0.16 - 2.04	1.22 - 4.22	0.68 - 6.21	0.15 - 24.8	0.22 - 23.8	0.76 - 10.6
NO_3^-	mg N-NO_3^-.L^{-1}	Mean ± SD	0.65^a ± 0..06	1.0^a ± 0..44	1.35^a ± 0.41	1.44^a ± 0.57	0.86^a ± 0.49	1.35^a ± 0.41
		Range	0.57 - 0.742	0.37 - 1.48	0.7 - 2.46	0.34 - 3.1	0.12 - 1.50	0.55 - 1.88
NO_2^-	mg N-NO_2^-.L^{-1}	Mean ± SD	0.07^a ± 0.07	0.27^a ± 0.30	0.08^a ± 0.02	0.08^a ± 0.03	0.08^a ± 0.07	0.05^a ± 0.02
		Range	0.02 - 0.21	0.02 - 1.50	0.02 - 0.13	0.02 - 0.14	0.002 - 0.33	0.0 - 0.1
TN	mg N.L^{-1}	Mean ± SD	3.03^a ± 1.38	66.8^b ± 19.87	97.25^b ± 35.23	7.95^a ± 4.86	69.27^b ± 22.93	229.73^c ± 65.07
		Range	0.84 - 5.62	31.8 - 105.8	57 - 177.6	1.14 - 26.0	32 - 117	118 - 350
PO_4^{3-}	mg P-PO_4^{3-}.L^{-1}	Mean ± SD	0.09^a ±0.14	…_	…_	0.36^a ± 0.11	…_	0.25^a ± 0. 28
		Range	0.00 - 0.38	…_	…_	0.12 - 0.73	…_	0.01 – 0.68
TP	mg P.L^{-1}	Mean ± SD	4.15^a ± 2.65	1.51^a ± 0.53	2.85^a ±0.45	9.96^b ± 3.77	19.33^c ± 3.52	10.97^b ± 2.6
		Range	1.50 - 8.18	0.63 - 2.32	1.97 - 3.79	2.71 - 20.2	15.21 - 31.1	6.50 - 19.5

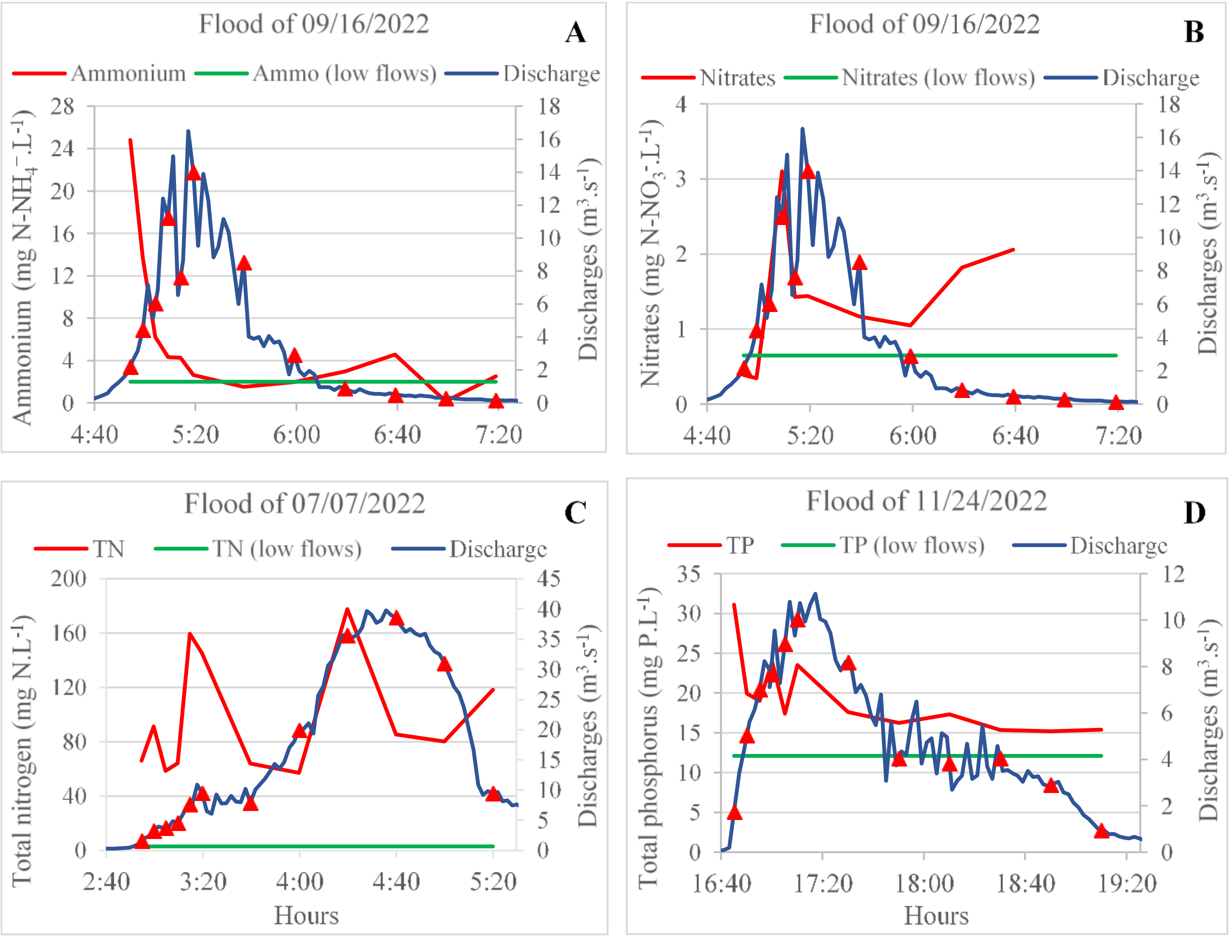

Fig. 5. Dynamics of ammonium, nitrates, total nitrogen and total phosphorus concentrations during low flows and flood events

- Total nitrogen (TN) and total phosphorus (TP)

Total nitrogen concentrations in UWWDs are high, higher than the average concentration in dry weather flows (3 mg N.L^{-1}). Overall, they ranged from 32 to 350 mg N.L^{-1} for all floods (Table 2) and exceeded the Ivorian guideline for liquid discharge (50 mg N.L^{-1}) [19], as well as the discharge standard of the WFD (2000/60/EC) (15 mg N.L^{-1}). The dynamic of the total nitrogen transfer during the high flood of 07/07/2022 shows a significant peak of 180 mg N.L$^{-1,}$ which coincides with the peak discharge (39.7 m^3.s^{-1}) (Fig. 5-C). This parameter varies significantly from low flow periods to flood events and for different floods (Mann-Withney test ($p < 0.05$)). The highest mass of nitrogen discharged was observed for the 07/07/2022 event during the long rainy season (i.e. 19 T N).

Total phosphorus concentrations in UWWDs are also high, ranging from 0.6 mg P.L^{-1} to 31 mg P.L^{-1} for all flood events. Concentrations during floods (19.3 mg P.L^{-1}) are higher than the average concentration during low flow periods (4.2 mg P.L^{-1}) and exceed the discharge standard of the WFD (2000/60/EC) (2 mg P.L^{-1}). The dynamic of total phosphorus transfer during the flood of 11/24/2022 is characterised by a decrease of the total phosphorus concentrations at the beginning of the flood (a maximum of 31 mg P.L^{-1}) (Fig. 5-D). This parameter varies significantly from low flow periods to flood events and for different floods (Mann-Withney test ($p < 0.05$)). The highest mass of total phosphorus discharged was observed for the event of 11/24/2022 in the long rainy season (i.e. 1300 Kg P).

Concerning the distribution of nitrogen and phosphorus pollutants, Fig. 6 shows the proportions of the different forms of nitrogen: on the one hand during the flood of 07/07/2022 (representative for the floods of 05/31/2022, 11/24/2022 and 03/29/2023) and on the other hand during the flood of 09/16/2022. For all floods, nitrogen and phosphorus loads were mainly in particulate form, exept for the flood of 09/16/2022. On 09/16/2022, most of the nitrogen was in ammoniacal form (over 75%), compared to 10% in organic form. However, the other floods had less than 15% dissolved nitrogen, compared to 85% organic nitrogen (Fig. 6-A and B).

For phosphorus, the particulate form predominated (95%) over phosphates (less than 5% of total phosphorus) in all floods sampled (Fig. 6-C).

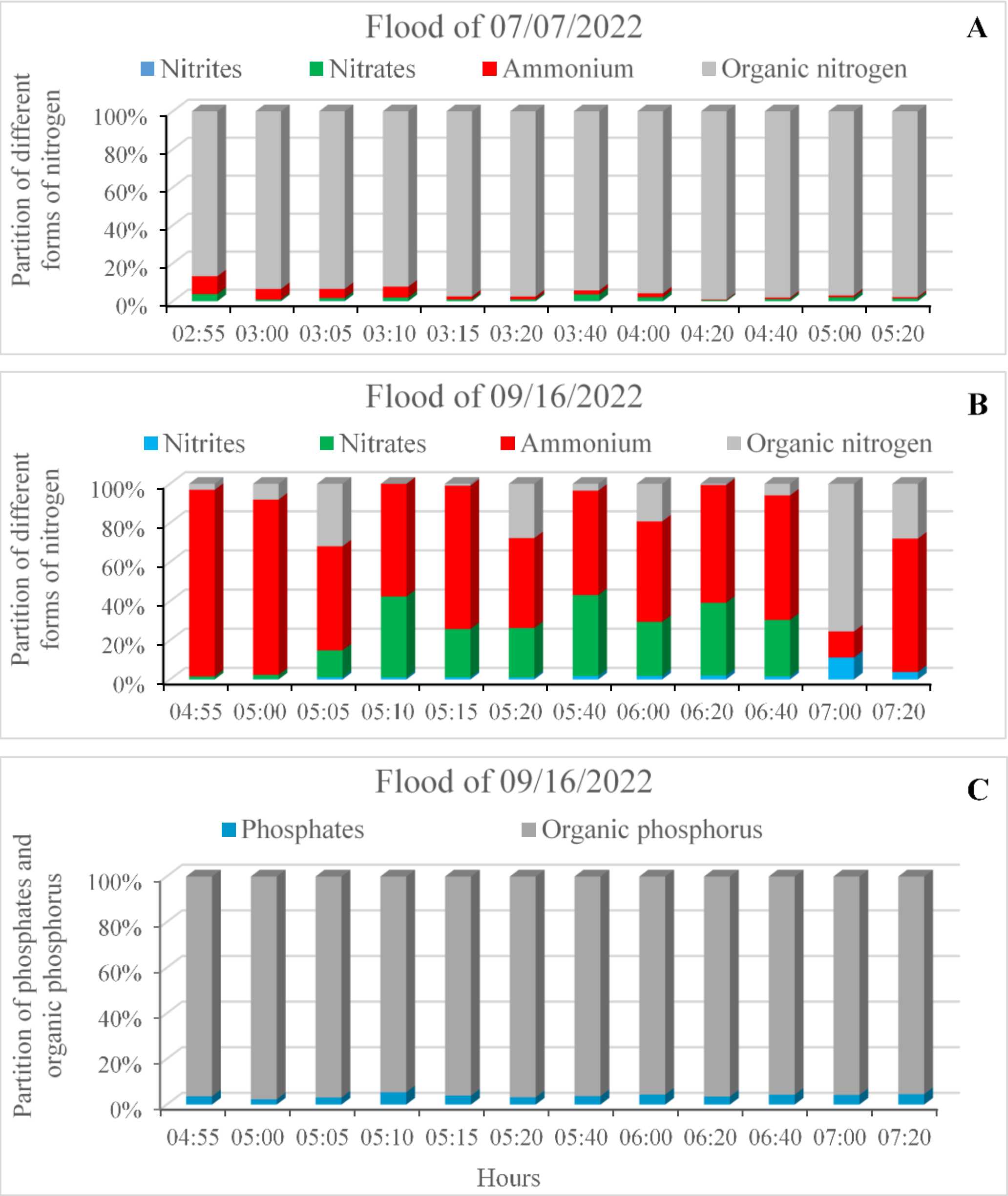

Fig. 6. Proportions of dissolved and particulate forms of nitrogen and phosphorus

3.3 RELATIONSHIP BETWEEN PHYSICO-CHEMICAL PARAMETERS

The joint analysis of the dynamics of discharge, conductivity, TSS and nutrient concentrations, and the determination of the correlation between these parameters allows us to compare their dynamics and to assess the relationship between one parameter and another. Fig. 7 shows the dynamics of dissolved (in this case, ammonium and conductivity) and particulate (total nitrogen, total phosphorus and suspended solids) compounds during floods.

For comparison purposes, the different concentrations have been transformed into reduced centred variables for each element. The dynamics of electrical conductivity and ammonium concentrations were quite similar, with a rapid decrease in concentration as discharge increased (Fig. 7-A). Spearman's test showed a strong positive correlation between ammonium and electrical conductivity: r = 0.93 for the 07/07/2022 flood (Table 3). However, there was no similarity between the dynamics of discharge and those of conductivity and ammonium concentrations. Electrical conductivity seems to be a good descriptor of ammonium dynamic.

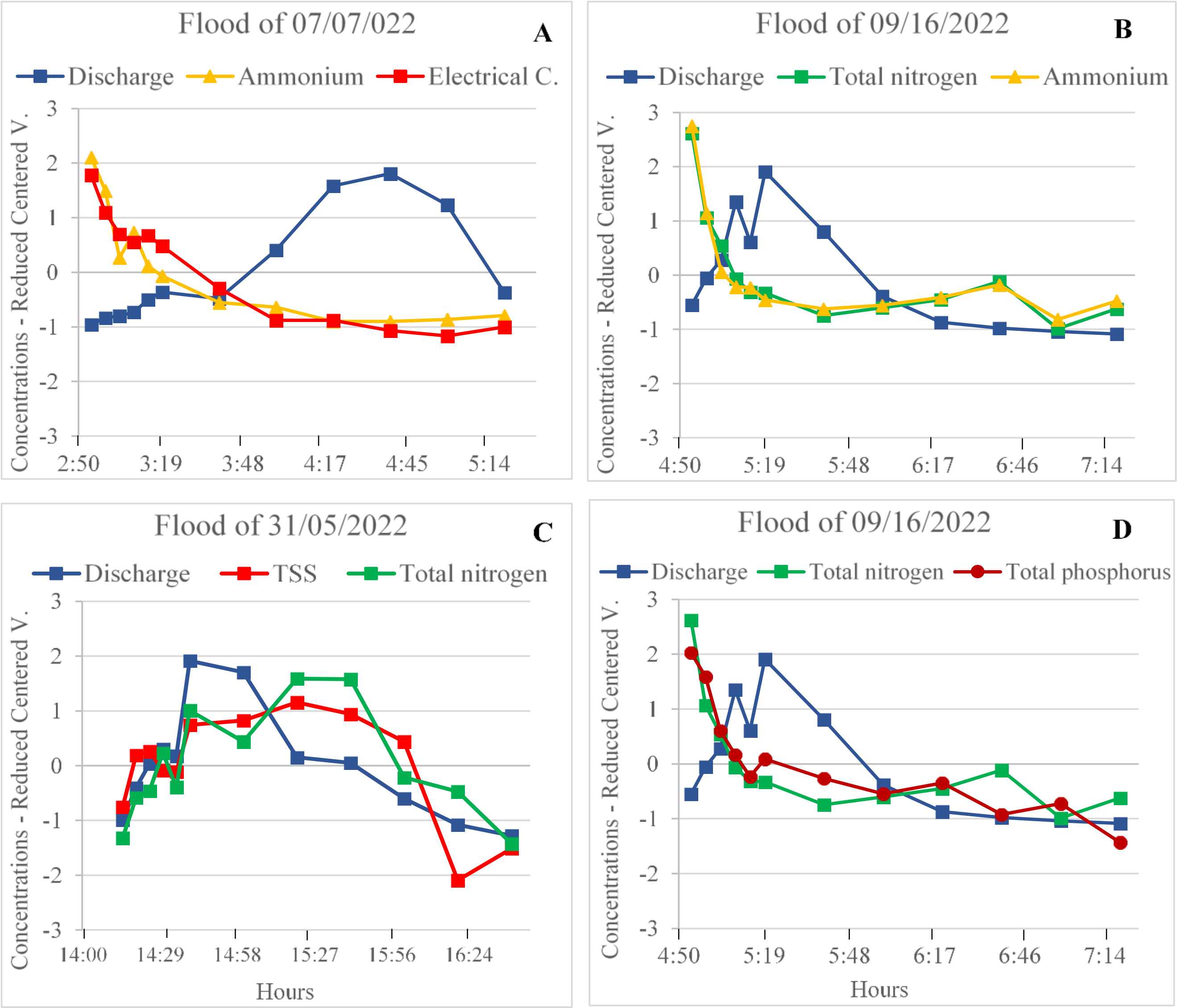

Fig. 7. ***Dynamics of discharge, electrical conductivity, total suspended solids (TSS), total nitrogen and total phosphorus evaluated together***

During the flood of 05/31/2022, there was a simultaneous increase in TSS and total nitrogen with the increase in discharge (Fig. 7-C). There was a significant positive correlation between discharge and TSS (r = 0.61) and a significant positive correlation between TSS and total nitrogen (r = 0.86). Discharge would therefore be a good descriptor of TSS dynamics during the flood of 05/31/2022. In particular, the flood of 09/16/2022 show significant transfers of ammonium between the different forms of nitrogen, and dynamic of total phosphorus tends to be similar to the dynamic of total nitrogen (Fig, 7-D), and their correlation was positive and significant (r = 0.776). (Fig. 7-B and D).

4 DISCUSSION

Analysis of the physico-chemical quality of urban wet weather discharges (UWWDs) revealed an alkaline pH (9.23) and moderately high electrical conductivity (265 µS.cm^{-1}). Furthermore, in a retention/infiltration basin in Chassieu, [20] showed that during the rainy event of 05/05/2015, discharges from the drainage system had an average pH of 8.49 and an average electrical conductivity of 340 µS.cm^{-1}. The high electrical conductivity at the beginning of the flooding in Riviera Palmeraie reflects the effects of constant volume of domestic effluents discharged into the drainage system. The results of the study [4] showed that the conductivity varied from 692 to 1652 µS.cm^{-1} in dry weather, compared with 152 to 974 µS.cm^{-1} in wet weather at the outlet of a drainage system.

The UWWDs at Palmeraie are highly contaminated with TSS. In particular, the peak of TSS (19.3 g.L^{-1}) in phase with the peak flow is due to dust and mineral solids from earthworks, unpaved roads and cleared areas, which are very large in the catchment [21] and [22]. Numerous studies have also reported an increase in TSS concentrations during rainfall events, and the mass of TSS discharged exceeds (10 times) that discharged by wastewater on a dry day [23], [24], [25], [26] and [27].

Contamination of UWWDs by oxidisable organics is directly related to wastewater discharges and the use of various chemical components, which are discharged without any treatment in the drainage system. Our results compare well with COD concentrations reported by several authors, which ranged from70 to 1600 mg O_2.L^{-1} in similar studied sites studied [28], [29] and [30].

Concerning nutrients, the high concentrations of ammonium, total nitrogen and total phosphorus during the rising part of the flood can also be directly related to wastewater discharges. Several authors have shown that wastewater is loaded with amino acids, faeces, and urine which contain 88% of nitrogen and 66% of phosphorus in human waste [31], [32], [33], [34] and [8]).

With regard to the total nitrogen concentration, a significant peak (178 mg N.L^{-1}) is recorded with the flood peak could be caused by rainfall leaching of pollutants from the endogenous deposits of the city. According to [35], [36], [37], this consists of a leaching nitrogen from the soil, organic matter from vegetated surfaces, solid waste and animal excreta as sources of nitrogen.

The distribution of nitrogen forms showed a dominance of dissolved nitrogen for most floods at the catchment outlet. For example, the predominance of ammoniacal nitrogen during a rainy event such as that of 16/09/2022 would be associated with to the long duration of dry weather period (2 months) preceding the flood in the dry seasons [38] and [39].

[29] and [36] showed that it should be noted that pollution from urban runoff may contain a higher proportion of ammonia salts. Furthermore, the fraction of non-nitrified ammoniacal nitrogen can become highly toxic to the receiving environment at alkaline pH (above 9) [3], [40], [38] and [41].

However, nitrite (0.27 mg N-NO_2^-.L^{-1}) and nitrate (1.4 mg N-NO_3^-.L^{-1}) concentrations are relatively low and compare well with nitrite (0.1 mg.L^{-1}) and nitrate (1.6 mg.L^{-1}) concentrations in rainwater [42]. In fact, the lack of oxygen in the effluent, the small size of the catchment and the relatively fast flow velocities leave little time for a complete nitrogen degradation. Anthropogenic contamination in the form of nitrites and nitrates is therefore low. These negligible proportions of nitrates, nitrites and orthophosphates indicate that the Palmeraie catchment is not affected by chemical fertilizers and agricultural activities.

For total phosphorus, the concentration reaches a significant peak (24 mg P.L^{-1}) as the peak flood approaches. According to [43] the lack of phosphorus retention on impervious surfaces, combined with construction sites could be a cause of the high total phosphorus concentration in stream water. Furthermore, the distribution of phosphorus forms showed a dominance of particulate phosphorus for most floods.

Compared to the negligible fraction of phosphates, particulate phosphorus dominates with 95% in UWWDs. This predominance of particulate phosphorus could be explained by the leaching of phosphorus accumulated in biomass from the soil surface of the urban area. In fact, there is a high affinity of phosphorus for the solid and biological phases in terrestrial environments, i.e. a ratio of 1000/1 [44]. In addition, the lack of oxygen in liquid effluents limits the production of dissolved phosphorus (phosphates) during phosphorus degradation.

In summary, nitrogen and phosphorus concentrations were highest during floods sampled during the rainy seasons. It can be seen that the total nitrogen concentration (350 mg N.L^{-1}) exceeds the WFD (2000/60/EC) discharge standard (15 mg N.L^{-1}). Similarly, according to SEQ-Eau, urban wet weather discharges have a very poor quality in terms of ammonium concentration (24.8 mg N-NH_4^+.L^{-1}) [45]. In the same way, the total phosphorus concentration (19.3 mg P.L^{-1}) exceeds the discharge standard of the WFD (2000/60/EC) (2 mg P.L^{-1}), thus indicating a risk of eutrophication of receiving waters would be conceivable during rainy periods [46], [47] and [48].

With regard to the dynamics of discharge and conductivity: the joint observation of a rapid decrease of conductivity and an increase of discharge makes it possible to determine the beginning of a rainfall event and, conversely, the end of the event [49].

It should be note that ammonium dynamics are systematically identical to those of conductivity and characterises the important leaching of dissolved pollutants.

[25] and [35] showed that this result is consistent with the dilution phenomenon observed during floods due to the large quantities of rainwater with low mineral content and low organic matter content mixing with wastewater. The decrease in

conductivity observed during floods can be explained by the dilution phenomenon: rainwater runoff generally has lower conductivity than wastewater.

These phenomena are quite common in urban hydrology [49]. In contrast to biological processes, dilution affects the change in conductivity of UWWDs. There is a pronounced "flushing effect" of the wastewater load at the beginning of a rain event [50] and [24].

The significant correlation between discharge and TSS reflects the ability of stormwater volumes to mobilise solid particles accumulated on the urban fabric. If the fraction of TSS accumulated in the drainage network during dry weather is negligible, this result is consistent with the significant erosion of areas under construction [51]. Also, the similar dynamics of total nitrogen and total phosphorus during each type of flood highlight a stock of nitrogen and phosphorus pollutants of diffuse origin that can increase nitrogen and phosphorus concentrations in UWWDs [48].

5 CONCLUSION

At the end of this study, which focused on the physico-chemical composition of urban wet weather discharges and the dynamics of pollutants in the Riviera Palmeraie catchment, it was found that these discharges are highly concentrated in TSS, with an average of 13 $g.L^{-1}$.

There is also pollution from domestic sources connected to the drainage network. As a result, there is considerable pollution of oxidisable organic matter, ammoniacal nitrogen, total nitrogen and, to a lesser extent, total phosphorus. Their concentrations far exceeded the WFD standards (2000/60/EC) and Ivorian guideline for liquid discharges.

A high COD of 1330 $mg\ O_2.L^{-1}$ was recorded at the beginning of the flood (07/07/2022) during the long rainy season, and a high concentration of ammoniacal nitrogen at the beginning of the flood during the short dry season (09/16/2022). Furthermore, the wet weather urban discharges were characterised by a high concentration of total nitrogen (180 $mg\ N.L^{-1}$) at the peak of discharge and a high concentration of total phosphorus at the beginning of the flood.

However, nitrite, nitrate and phosphate concentrations were low and varied little from flood to flood. In addition, significant dilution phenomena were observed after the start of the flood.

Although the Palmeraie catchment is not affected by agricultural activity and chemical fertilisers, there is a risk of eutrophication of the receiving waters during the main and short rainy seasons. To this end, the total nitrogen and total phosphorus discharged during the flood event (flood duration of 3 to 4 hours) were 18652 Kg N and 1290 Kg P, respectively, during the rainy seasons.

Thus, the joint analysis of the discharge and the dynamics of these two nutrients showed a contribution of pollutants of diffuse origin to the increase in nitrogen and phosphorus masses.

According to the SEQ-Eau, the UWWDs of the Riviera Palmeraie would have a negative impact on the turbidity, biological functions and fish fauna in the waters of the Ebrié lagoon, due to excessive inputs of suspended solids, oxidisable organic matter, nitrogen and phosphorus.

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