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Seasonal Concentrations of Insecticide Residues, Ecological and Health Risks of Waters from Déganobo Lake System in San-Pedro, Cote D'Ivoire

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ABSTRACT: The objective of this paper was to evaluate the seasonal concentrations of insecticide residues, ecological and health risks of waters from Déganobo Lake System in San-Pedro, Cote D' Ivoire using appropriate standard methods. For this study, waters samples from this aquatic ecosystem were collected over a year (from August 2022 to July 2023). The concentrations of these insecticide residues were obtained according to the MA. 403-Pest 3.1 standard (CEAEQ, 2011) with minor modifications. Generally, the seasonal concentrations of these residues were significant in these waters, especially those of methyl parathion, except for acetamiprid and deltamethrin, which were undetectable throughout the study period. This situation is related to their extensive use in agricultural practices in the watershed of this aquatic ecosystem. Most of these insecticide residues showed high concentrations in these waters during the small and great dry seasons, while their lowest concentrations were observed during the small rainy season. This high presence of insecticide residues in these waters presents significant ecological and health risks, particularly due to the residues of bifenthrin, chlorfenvinphos, ethyl parathion, methyl parathion, and vinclozolin. This study highlights the need to implement effective management practices to safeguard and protect this lake system to ensure its impressive biodiversity in the long term.

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Insecticides play crucial roles in enhancing the quality of life for humans, domestic animals, and livestock as essential tools for controlling harmful insects (Kho *et al.*, 2024). Their usage has increased significantly, particularly with the development and modernization of agriculture. Like all pesticides, insecticides help improve agricultural yields to support a rapidly growing human population (Darwesh *et al.*, 2024; Zhang et *al.*, 2025). The global insecticide market, estimated at USD 17.23 billion, is expected to grow to USD 34.32 billion (databridgemarketresearch.com, 2024). However, the intensive use of these compounds poses environmental risks. Insecticides are highly persistent in the environment, especially synthetic ones. The ecological impacts depend on their efficacy, toxicity, and persistence. These compounds disrupt trophic networks by killing the natural predators of target species. They can also degrade ecosystem services and paradoxically promote the proliferation of resistant parasitic insects (Punniyakotti *et al.*, 2024; Cui *et al.*, 2023; Khelfi e*t al.*, 2023). Furthermore,

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they have the potential to bioaccumulate in biota (Ajermoun *et al.*, 2022), particularly in aquatic organisms (Cui et *al.*, 2023). Consequently, they are likely to heavily contaminate surface waters, posing significant risks to humans through the ingestion of contaminated biota and water (Khelfi et *al.*, 2023; Punniyakotti et *al.*, 2024).

In general, the modes of action of insecticides are based on neurotoxicity, impact on cellular respiration, formation of chitinous cuticle, and disruption of molting (Misiewicz *et al.*, 2024; Hecker *et al.*, 2024). There are numerous families of insecticides, including carbamates, synthetic pyrethroids, organophosphates, and neonicotinoids. Organophosphates and carbamates are semi-systemic insecticides with low persistence. They are cholinesterase inhibitors, which account for their high toxicity to humans and warm-blooded animals (Bai et *al.*, 2023; Stevens *et al.*, 2024). Synthetic pyrethroids act through a neurotoxic shock effect. Although biodegradable, they are highly toxic to humans and fish (Khelfi *et al.*, 2023). Neonicotinoids are also neurotoxic and exhibit long persistence in the environment. They are highly toxic to humans (Cartereau *et al.*, 2024).

As one of the major tourist sites in the Southwest of Côte d'Ivoire in general, and a characteristic feature of the city of San-Pedro in particular, the Déganobo Lake System faces a bleak ecological future. The recent studies by Konan and Yao (2023a) have highlighted significant organic contamination of its waters, a consequence of heavy anthropogenic pressures on its watershed.

Similarly, the recent studies by Konan and Yao (2023b) have revealed notable contamination of these waters by herbicides, with significant health risk implications. This ecosystem hosts an impressive biodiversity, making it the second most important site globally for hosting numerous migratory birds under the DIOE program (Konan *et al*.,2023a). Thus, the objective of tis paper is to evaluate the seasonal concentrations of insecticide residues, ecological and health risks of waters from Déganobo Lake System San-Pedro, Cote D' Ivoire

MATERIAL AND METHODS

Presentation of the study area: The Déganobo Lake System consists of two lakes: "Lac Ouest" and "Lac Est". Lac Ouest, the larger of the two, covers a current open water surface area of 49.05 hectares. It is located between longitudes 6.637115W and 6.544196W and latitudes 4.748951N and 4.755580N. For Lac Est, it covers a current open water surface area of 28.87 hectares (PRICI, 2016; Konan and Yao, 2023a; 2023b). It spans longitudes 6.628952W and 6.639512W and latitudes 4.749382N and 4.760087N (Figure 1). These two lakes are connected by a tunnel (Konan and Yao, 2023 a;b).

The lake experiences various water seasons linked to a subequatorial climate specific to the San-Pedro Department. These include: a Great Dry Season (GDS) from December to March; a Great Rainy Season (GRS) from April to July, a Small Dry Season (SDS) from August to September, coinciding with the major upwelling season, a Small Rainy season (SRS) from October to November (N'go *et al*., 2017; Konan and Yao, 2023a;b).

The major activity in the watershed of this ecosystem is agriculture with intensive use of pesticides, followed by industrial activities (Konan and Yao, 2023 a;b). The hydrography of this lake system comprises the San-Pedro River and the Digboué Lagoon, interconnected by numerous swampy (Doumbia *et al*., 2021). This ecosystem boasts remarkable biodiversity. It serves as a receptacle for all kinds of wastes, especially from two industrial areas, a general hospital, domestic discharges nearby, as well as agricultural residues (Konan and Yao, 2023 a;b).

Water samples collection and their preservation in situ: This study was conducted in the same period as that of Konan and Yao (2023), namely from August 2021 to July 2022. The water samples collection was carried out on the same sampling site as theirs, namely to sample sites S1 to S8 (Figure 2). The water column samples were collected using a 1 L capacity Niskin bottle. So, eight water samples were collected monthly, resulting in a total of ninety-six samples.

The waters samples are treated *in situ* according the recommendation of MA. 403-Pest 3.1 standard (CEAEQ, 2011) and were preserved in accordance with NF EN ISO 5667-3 standard (2013).

Analytical procedure: The concentrations of 9 nine insecticide residues were determined in these waters, namely ADC, AMP, BFT, CVP, DMT, IMD, PTE, PTM, and VCZ. The analytical procedure used to determine the concentrations of these ten insecticide residues in water samples was identical to the method used by Konan and Yao (2023b) for determining the concentrations of some herbicide residues in the waters of this lake system. It follows MA. 403-Pest 3.1 standard (CEAEQ, 2011) with some modifications. Throughout all operations, Milli-Q water from Merk was used.

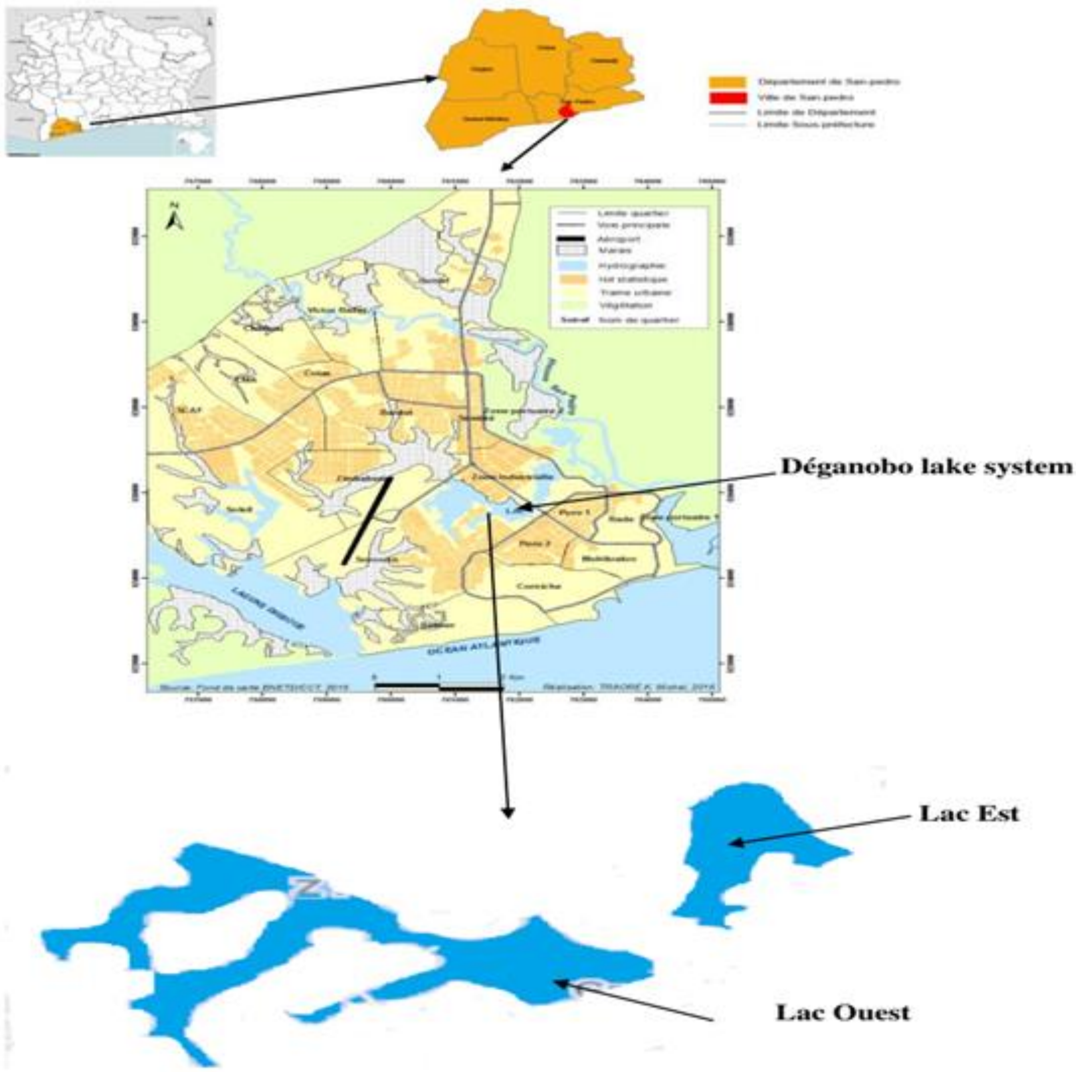

Fig. 1: The localization of the Déganobo Lake System (Konan and Yao, 2023 a;b).

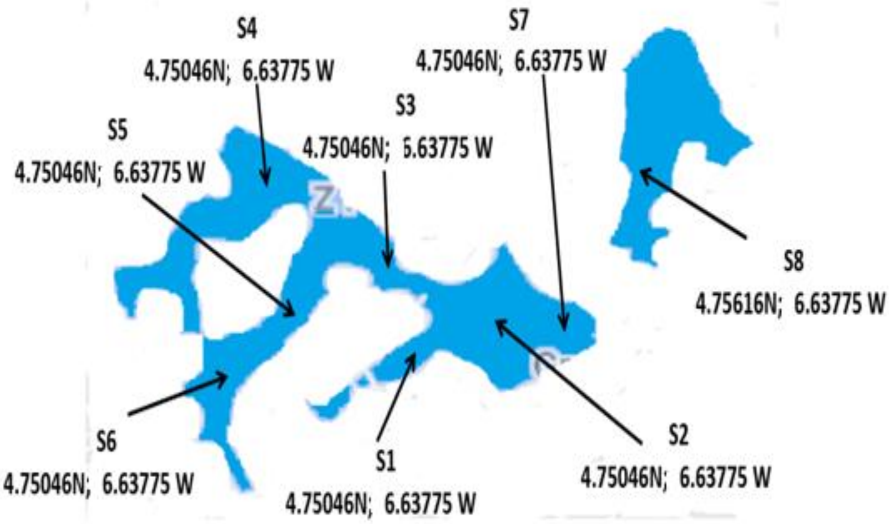

Fig. 2: Geolocation of sample sites used in this study (Konan and Yao, 2023a,b).

The various other solutions were prepared using analytical grade standards of these insecticides certified by Dr. Erhenstorfer Laboratories (GmbH Germany) in pure isooctane. During the solid-phase extraction and purification of the eluates, the extraction solution was pure isooctane containing the target insecticides at a concentration of 300 ng/l. Blanks consisted of 150 ml of Milli-Q water, to which extraction control solutions of each insecticide were added to achieve an individual concentration of 500 ng/l. During the testing and assay phase, the injection solution was pure isooctane containing these insecticides at concentrations ranging from 100 to 600 ng/l. The calibration solution used was prepared from standards of these insecticides in isooctane, with concentrations ranging from 0.01 to 3500 ng/l. The standard solutions for testing and internal control were obtained from 250 µl of the calibration solution, 50 ml of the injection solution, and 150 µl of pure isooctane.

The purified extracts were analyzed by GC-MS using the Shimadzu 2010 spectrophotometer (Japan). The helium used had a purity of 99.999%. The gas flow rate was maintained at 1 ml/min. The injection volume was 1 µl. Thermal decomposition began at 70°C for 2 minutes, followed by a temperature increase at a rate of 20°C per minute until reaching 320°C, and finally maintaining this temperature for 5 minutes. The vaporization temperatures of the injector and the ion source were maintained at 250°C. The injector operated in "splitless" mode for 2 minutes, followed by "split" mode with a ratio of 50:1. The electron energy was 70 eV, and the transfer line temperature was set to 250°C. Insecticide residue concentrations were obtained by comparing peak areas between the spectra of the purified extracts and the standards and were normalized to the sample volume.
The accuracy of the analytical procedure used was verified in accordance with the criteria chosen by Konan and Yao (2023b). For a better estimation of the accuracy of the analytical procedure used, the experiments were performed in triplicate. The analytical procedure is considered accurate if both of the following conditions are met simultaneously:
- the coefficients of determination (R^2) of the calibration curves must be greater than 0.98 (International Organization Standard, 2005).
- the Relative Standard Deviation (RSD) of the analytical procedure and the intermediate RSDs must be less than 15% (Rahman *et al*., 2021).

The Limit Of Detection (LOD) and the Limit Of Quantification (LOQ) of the analytical procedure for these insecticides were determined according to the method of US-EPA (1991) and that of PAM (1994).

Ecological and health risk assessment: Ecological and health risk assessment related to the presence of these insecticide residues in these waters over the study period were conducted using the SEQ-Eau V2 water quality guidelines (MEDD and Agence de l'Eau, 2003). This also includes the Risk Quotient (RQ), which is expressed as follows:

$$\mathrm{RQ} = \frac{\mathrm{MEC}}{\mathrm{PNEC}} \qquad (1)$$

With: MEC, the Measurement Environmental Concentration (µg/l); PNEC, the Probable; No Effect Concentration (µg/l)

This index was evaluated for ADC, BFT, CPP, CVP, IMD, PTM, and VCZ, which have PNEC values (µg/l) of 0.46, 2.10^-5, 4, 0.1, 0.1, 0.2, 1.66.10^-2, and 3.65, respectively. According to the European Commission (2003), the ecotoxicity risks of an insecticide residue for biota are low for $0.01 \leq RQ < 0.1$, moderate for $0.1 \leq RQ < 1$, and high for $RQ > 1$.

Statistical analysis: The study employed standard statistical techniques, including mean (m), standard deviation (s), coefficient of variation (CV), minimum mean value (Min), and maximum mean value (Max), along with one-way ANOVA and Student’s t-test. One-way ANOVA was used to identify significant differences between seasonal means for various parameters. If differences were found, three post hoc tests (Fisher LSD, Tukey HSD, and Dunnett test) were applied to determine which seasonal means differed and to identify homogeneous subgroups. Student's t-test was used to verify if the ecotoxicity risks of insecticide residues for biota, determined by their RQ values, are statistically significant relative to the conditions established by the European Commission (2003). Results were considered statistically significant for $p < 0.05$.

RESULTS AND DISCUSSION

The calibration curves for the target herbicides in this study showed R^2 values between 0.9910 and 0.9956, indicating good linearity and efficiency based on the International Organization Standard (2005) condition of $R^2 > 0.98$. This strong correlation suggests a high probability of linearity between herbicide concentration and peak size, as per Durak et *al.* (2021) and Konan Yao (2023b). The recovery rate for control solutions of the target herbicides ranged from 90% to 105%. The relative standard deviation (RSD) of protocol precision was between 1.5% and 7.130% (below 10%), and for intermediate precisions, it was between 1.75% and 11.466% (below 15%). Therefore, the quantification method for these insecticide residues in water samples is deemed satisfactory and reproducible. The limits of detection (LOD) and limits of quantification (LOQ) values for the different herbicides are provided in Table 1.

Table 1: LOD and LOQ of target insecticides obtained in this study

Target insecticides	LOD (ng/L)	LOQ (ng/L)
ADC	0.05	0.7
AMP	0.02	0.5
BFT	0.04	1.5
CVP	0.05	0.7
DMT	0.08	1.0
IMD	0.06	0.9
PTE	0.02	0.8
PTM	0.03	0.4
VCZ	0.03	0.5

Table 2 give the seasonal concentrations of the ten insecticide residues in the waters from the Déganobo system in the study period. The seasonal concentrations of CVP, PTE, and PTM in these waters were high during the study period. PTE showed the highest seasonal concentrations, while PTM exhibited the lowest concentrations among the three organophosphates. Maximum concentrations of PTE and CVP were observed during SDS, and the lowest during SRS. For PTM, concentrations were very high during GDS and relatively low during SDS. The intra-seasonal variations of these concentrations were low, indicating near stability within each season. One-way ANOVA revealed an overall statistically significant difference between the mean concentrations of these organophosphates ($p < 0.05$). Post-hoc tests showed no significant difference between the concentration of CVP during GDS and that during GSP ($p > 0.05$), but a significant difference for the concentration of PTM during SDS and that during SRS, and similarly, a significant difference for the concentration of PTM during SDS and that during SRS, as well as between the concentration of PTM during GDS and that during GRS ($p < 0.05$).

The concentrations of ADC were high in all seasons, particularly during the GRS, except during the SRS. The highest concentration of CPP was observed during GDS, and the lowest during PSP. The intra-seasonal variations in concentrations of these two insecticides were low, except for ADC during the SDS. One-way ANOVA showed a statistically significant difference between the seasonal concentrations of this carbamate ($p < 0.05$). Post-hoc tests revealed that only the concentration of ADC during SDS was significantly different from that during SRS ($p < 0.05$). Similarly, the concentration of ADC during GRS was different from that during GRS ($p < 0.05$).

Among the two pyrethroid insecticides investigated in these waters, only BFT was significant. The highest seasonal concentration of BFT was observed during SDS, and the lowest during SRS in this period. The intra-seasonal variations in the concentrations of BFT were low throughout the study. One-way ANOVA revealed a significant overall difference in the seasonal concentrations of BFT ($p < 0.05$). Post-hoc tests indicated that the concentration of BFT during SDS was statistically different from that during SRS ($p < 0.05$). Similarly, the concentration of BFT during SDS was significantly different from that during GRS ($p < 0.05$).

All seasonal concentrations of AMP in these waters were below their LOD obtained with the implemented protocol. As for the seasonal concentration of IMD, it was relatively high in GRS and relatively low in SDS. The intra-seasonal variations in the concentrations of IMD were low, except during SRS. One-way ANOVA highlighted a significant overall difference between the seasonal concentrations of IMD ($p < 0.05$). Post-hoc tests showed that only the concentration of IMD during GDS was not statistically different from that during GRS ($p > 0.05$).

The seasonal concentrations of VCZ in these waters were relatively very high during the study period. The highest seasonal concentration of VCZ was observed during the GDS, and the lowest during the SRS. The concentration of this dicarboxamide fungicide remained relatively stable throughout all seasons, as indicated by the low coefficients of variation (CV) over the study period. One-way ANOVA highlighted that the differences between the mean seasonal concentrations of VCZ were not statistically significant ($p > 0.05$).

These waters were unsuitable for any biological activity, posing serious health risks to aquatic biota (inadequate for biological and aquaculture use) and for any anthropogenic use (inadequate for drinking water production, water sports, and recreational activities, etc.) in all seasons, according to SEQ-Eau V2 (MEED and Agence de l'eau, 2003). This is due to the mean seasonal concentrations of CVP, PTE, PTM, and VCZ throughout the study period and those of BTR in the last three seasons in these waters.

Table 2: Seasonal concentrations of insecticide residues in waters from Deganobo Lake System in the study period.

Seasons		ADC	AMP	BFT	CVP	DMT	IMD	PTM	PTE	VCZ
SDS	m±s	0.020±0.011	< LOD	0.653±0.016	0.798±0.071	< LOD	0.024±0.006	0.044±0.004	1.433±0.006	0.745±0.060
	CV (%)	54.250		2.439	8.853		24.025	10.023	0.384	8.050
	Min	0.010		0.380	0.590		0.010	0.020	1.130	0.490
	Max	0.060		0.880	1.010		0.050	0.090	1.850	0.950
SRS	m±s	0.018±0.001	< LOD	0.552±0.014	0.586±0.005	< LOD	0.064±0.052	0.046±0.001	1.258±0.033	0.721±0.008
	CV (%)	6.978		2.581	0.845		82.057	2.174	2.642	1.103
	Min	0.010		0.310	0.530		0.010	0.010	0.950	0.520
	Max	0.030		0.720	0.630		0.320	0.100	1.530	0.860
GDS	m±s	0.031±0.003	< LOD	0.573±0.026	0.676±0.007	< LOD	0.138±0.005	0.071±0.002	1.359±0.005	0.774±0.037
	CV (%)	9.102		4.594	1.076		3.972	2.788	0.371	4.833
	Min	0.020		0.410	0.600		0.090	0.030	1.180	0.560
	Max	0.050		0.710	0.730		0.190	0.100	1.520	0.850
GRS	m±s	0.031±0.006	< LOD	0.556±0.013	0.660±0.055	< LOD	0.136±0.007	0.069±0.001	1.327±0.028	0.754±0.042
	CV (%)	20.661		0.227	8.357		5.138	0.965	2.101	5.510
	Min	0.010		0.330	0.400		0.070	0.030	0.740	0.460
	Max	0.060		0.800	1.030		0.210	0.120	2.040	1.190
Annual	m±s	0.025±0.006	< LOD	0.583±0.043	0.680±0.074	< LOD	0.090±0.027	0.057±0.005	1.344±0.108	0.749±0.076
	CV (%)	22.027		7.332	10,888		29.764	8.308	8.002	10.087
	Min	0.010		0.310	0,400		0.010	0.020	0.740	0.460
	Max	0.060		0.880	1,030		0.320	0.120	2.040	1.190

Table 3: Ecological and health risks of waters from Déganobo Lake System related to some insecticide residues according to SEQ-Eau V2 (MEED and Agence de l'Eau, 2003) during the Study Period.

Insecticide residues	Reference values (µg/L)	Mean seasonal and annual concentrations obtained in this study		Ecological and health risks	Insecticide residues	Reference values (µg/L)	Mean seasonal and annual concentrations obtained in this study		Ecological and health risks
		SDS	0.020±0.011			Very good quality (< 0.1)	SDS	0.024±0.006	Très faibles
	Good quality (between 0.005 and 0.05)	SRS	0.018±0.001				SRS	0.064±0.052	
ADC		GDS	0.031±0.003	Low	IMD	Good quality (between 0.1 and 0.7)	GDS	0.138±0.005	Faibles
		GRS	0.031±0.006				GRS	0.136±0.007	
		Annual	0.025±0.006			Very good quality (< 0,1)	Annual	0.090±0.027	Très faibles
		SDS	0.011±0.003				SDS	1.433±0.006	
		SRS	0.026±0.010			Very poor quality (> 0,03 µg/L)	SRS	1.258±0.033	
BFT	Very good quality (< 0.1)	GDS	0.044±0.005	Faibles	PTE		GDS	1.359±0.005	Very high
		GRS	0.045±0.001				GRS	1.327±0.028	
		Annual	0.031±0.011				Annual	1.344±0.108	
	Medium quality (between 0.7 and 4)	SDS	1.114±0.062	Medium			SDS	0.044±0.004	
BTR		SRS	1.502±0.021		PTM	Poor quality (between 0.02 and 2)	SRS	0.046±0.001	High
	Poor quality (between 1.4 and 2)	GDS	1.681±0.052				GDS	0.071±0.002	
		GRS	1.641±0.213	High			GRS	0.069±0.001	
		Annual	1.484±0.184				Annual	0.057±0.005	
		SDS	0,798±0,071				SDS	0.774±0.037	
	Médiocre qualité (comprise entre 0,03 et 2 µg/L)	SRS	0,586±0,005			Poor quality (between 0.7 and 1.4)	SRS	0.754±0.042	
CVP		GDS	0,676±0,007	Élevés	VCZ		GDS	0.749±0.076	High
		GRS	0,660±0,055				GRS	0.745±0.060	
		Annual	0,680±0,074				Annual	0.721±0.008	

The other insecticide residues indicate good water quality relative to their concentrations in these waters in all seasons according this water quality guidelines (Table 2). All these observations were highlighted by Student's t-test ($p < 0.05$).

According to the QR index, the ecotoxicological risks associated with ADC were low during all seasons ($0.01 \leq QR < 0.1$). The ecotoxicological risks associated with IMD and VCZ were moderate during all seasons ($0.1 \leq QR < 1$). The ecotoxicological risks due to CVP, BFT, and PTM were significant in all seasons ($QR \geq 1$). The risks associated with CVP generally decreased from SDS to GRS, whereas those associated with PTM and BFT increased from SDS to GRS (Table 3). These results were illustrated by the Student's t-test

Table 4 : RQ values of some insecticide residues in waters from Déganobo Lake System during the Study Period.

Insecticide residues	SDS	SRS	GDS	GRS	Annual
ADC	0,043±0,032	0,039±0,015	0,066±0,018	0,067±0,027	0,054±0,011
BFT	34342,11 ±9038,29	29046,05 ±6549,77	30164,47 ±4166,66	29243,42 ±7574,06	30699,01 ±5292,94
CVP	7,981±1,217	5,831±0,304	6,756±0,365	6,600±1,720	6,792±0,514
IMD	0,118±0,062	0,319±0,380	0,691±0,162	0,681±0,233	0,452±0,146
PTM	2,636±1,122	2,786±1,822	4,255±1,092	4,142±1,573	3,454±0,896
VCZ	0,204±0,034	0,197±0,023	0,212±0,020	0,207±0,058	0,205±0,018

The relatively high presence of these insecticide residues in the waters from this lake system is linked to the intensive agricultural practices in its watershed, as highlighted by Konan and Yao (2023b) for the presence of herbicides. These residues originate from vegetable farming practices (Soro *et al.*, 2018), cocoa farming (Atto and Monde, 2020), horticulture (Soro *et al.*, 2019), and some food crop cultivation (N'Guessan *et al.*, 2019). This usage is mainly limited to the reduced swampy areas in the GDS. It could be more widespread in the PSC, on the mainland and the expanded swampy areas during the PSP. This also applies to the insecticides used in the treatment and preservation of cocoa beans in the packaging factories near this lake sytem (Ogou and Bidi, 2019) during the GDS and SDS. The relatively high temperature of these waters during the study period (Konan and Yao, 2023a) would have favored the microbial degradation of these insecticide residues (Chang *et al.*, 2022), except for BFT, which is not very sensitive to microbial degradation in water (ESFA, 2010). Due to its hypereutrophication, these waters are anoxic during the day and oversaturated with oxygen at night (Qin *et al.*, 2023). Thus, the aerobic microbial degradation of these pesticide residues would be slowed down during the day but increased at night (Wang *et al.*, 2021). The hydrolysis of ADC (CCME, 1999), CVP (Lewis *et al.*, 2016), PTE (US-EPA, 2000a), PTM (Castrejón-Godínez *et al.*, 2022), and VCZ (US-EPA, 2000b), facilitated by microbial activities, contributes to their degradation during this period. However, the very high turbidity of these waters would have limited their degradation by photolysis during the study period.

During GDS, the intensive use of active substances in the watershed of this aquatic ecosystem would result in the relatively high presence of their residues in its waters, especially those of ADC, PTM, IMD, and VCZ. This contradicts the highest temperature of these waters during this season (Konan and Yao, 2023a), as temperature activates the microbial degradation of these insecticide residues (Chang *et al.*, 2022). This suggests their inputs would be greater than those observed in this season. During GRS, the significant washing of the watershed of this aquatic ecosystem by meteoric waters would contribute to this situation, but to a lesser extent due to the dilution effects caused by rising waters as well as their renewal. These processes would generally manifest in slight decreases in the concentrations of these insecticide residues in these waters compared to those observed during GDS. The intensive use of insecticides in its basin during SDS would lead to a relatively high presence of all target insecticide residues in its waters, especially those of CVP, PTE, and BFT. The inputs of meteoric waters during SRS would generally very slightly enrich these waters with all insecticide residues, as a consequence of the meteoric inputs during GRS and their low usage in the watershed of this ecosystem during this season. This is particularly the case for ADC residues. Ultimately, meteoric inputs would have significantly impacted the seasonal presence of these pesticide residues, as highlighted by one-way ANOVA and post-hoc tests used in this study.

The presence of pesticide residues in these waters is due to a prolonged period of discharge associated with their intensive use in agricultural practices in the watershed of this lake system. The residence time of each residue depends on their frequency of use, retention, and degradation rate in the soils and waters of this ecosystem (Konan and Yao, 2023b). This explains the relatively low concentrations of some insecticide residues, with the exception of CVP, PPZ, PTE, PTM, and VCZ, and consequently their low ecotoxicity to the biota from this aquatic ecosystem, as highlighted by SEQ-Eau V2 (MEED and Agence de l'Eau, 2003) and confirmed by the Student's t-test. The seasonal QR values for IMD and ADC (<1) over the study period (European Commission, 2003) also corroborate these observations, highlighted by Student's t-test.

PTE, PTM, and CVP are among the most effective insecticides for protecting agricultural crops in the watershed of this aquatic site, particularly in vegetable farming, as well as for protecting dried cocoa beans in packaging factories (Lewis *et al.*, 2016). The same applies to VCZ, which is one of the most commonly used fungicides for this purpose. This is reflected in the relatively high concentrations of these insecticide residues in these waters. As a result, these waters would be completely unsuitable for biological activities and human health-related uses due to their significant presence, according to SEQ-Eau V2 (MEED and Agence de l'eau, 2003), highlighted by Student's t-test. These three organophosphates (CVP, PTE, and PTM) pose risks of acute toxicity (UTZ, 2015) through endocrine disruption, neurotoxicity, and cholinesterase inhibition in the short and/or long term (Cingotti *et al.*, 2018). They are highly toxic to aquatic invertebrates but moderately toxic to fish and other aquatic fauna (Lewis *et al.*, 2016). Regarding VCZ, it is likely to cause severe ecotoxic effects on the aquatic fauna and flora from this site, as well as genotoxic and carcinogenic effects on the population in this area using these waters (Yang *et al.*, 2011). In contrast to VCZ, the ecotoxicity of CVP, PTE, and PTM for the aquatic flora of this ecosystem, and consequently for the living organisms that depend on it, has been shown by the seasonal QR values, well above 1.2 (Nyström *et al.*, 2002; Durak *et al.*, 2021) and highlighted by the Student's t-test.

Conclusion: This year-long study highlighted significant contamination of waters from Déganobo Lake System by insecticide residues, using a highly precise analytical method. This situation is primarily due to intensive agricultural practices in the watershed, with extensive pesticide use. The resulting implications are high ecological and health risks during the study period, mainly due to the residues of BFT, CVP, PTE, PTM, and VCZ. So, this study underscores the urgent need to implement a management policy to safeguard, protect, and ensure the long-term ecological state of this ecosystem, so it can continue to fulfil its important socio-economic and Eco-touristic roles for San-Pedro Department.

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Data availability statement: Data are available upon request from the corresponding author.

REFERENCES

Ajermoun, N; Aghris, S; Ettadili, F; Alaoui, OT; Laghrib, F; Farahi, A; Lahrich, S; Bakasse, M; Saqrane, S; El Mhammedi, MA. (2022). Phytotoxic effect of the insecticide imidacloprid in *Phaseolus vulgaris* L. plant and evaluation of its bioaccumulation and translocation by electrochemical methods. *Environ. Res.*, 214(1), 113794. https://doi.org/10.1016/j.envres.2022.113794

Atto, Y ; Monde, S. (2020). Évaluation du niveau de contamination du lac d'Adaou (est de la côte d'ivoire) par les produits phytosanitaires. *Dynamiques environ.*, 45, 56-60. https://doi.org/10.4000/dynenviron.3924

Bai, Y ; Hou, Y ; Wang, Q ; Lu, C ; Ma, X ; Wang, Z ; Xu, H. (2023). Analysis of the binding modes and resistance mechanism of four methyl benzimidazole carbamates inhibitors fungicides with *Monilinia fructicola* β2-tubulin protein. *J. Mol. Struct.*, 1291, 136057. https://doi.org/10.1016/j.molstruc.2023.136057

Castrejón-Godínez, ML ; Tovar-Sánchez, E ; Ortiz-Hernández, ML ; Encarnación-Guevara, S ; Martínez-Batallar, ÁG ; Hernández-Ortiz, M ; Sánchez-Salinas, E ; Rodríguez, A ; Mussali-Galante, P. (2022). Proteomic analysis of *Burkholderia zhejiangensis* CEIB S4–3 during the methyl parathion degradation process. *Pestic. Biochem. Physiol.*, 187, 105197. https://doi.org/10.1016/j.pestbp.2022.105197

Cartereau, A ; Bouchouireb, Z ; Kaaki, S ; Héricourt, F ; Taillebois, E ; Le Questel, J-Y ; Thany, SH. (2024). Pharmacology and molecular modeling studies of sulfoxaflor, flupyradifurone and neonicotinoids on the human neuronal α7 nicotinic acetylcholine receptor. *Toxicol. Appl. Pharmacol.*, 492, 117123. DOI: 10.1016/j.taap.2024.117123

CCME (Canadian Council of Ministers of the Environment) (1999). Canadian water quality guidelines for the protection of aquatic life: Metribuzin. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CEAEQ (Centre d'Expertise en Analyse Environnementale du Québec) (2011).

Détermination des pesticides de type organophosphoré, triazine, carbamate et urée substituée dans l'eau : extraction avec C-18 ; dosage par chromatographie en phase gazeuse couplée à un spectromètre de masse. MA. 403-Pest.

Chang, J ; Fang, W ; Chen, L ; Zhang, P ; Zhang, G ; Zhang, H ; Liang, J ; Wang, Q ; Ma, W. (2022). Toxicological effects, environmental behaviors and remediation technologies of herbicide atrazine in soil and sediment: A comprehensive review. *Chemosphere*, 307(3), 136006. **https://doi.org/10.1016/j.chemosphere.2022.136006**

Cingotti ; N ; Broekstra, N ; Jensen, G. (2018). L'Union européenne devrait interdire le chlorpyriphos, dangereux pour le cerveau. Note de synthèse. EDS: Health and Environment Alliance (HEAL).

Cui, J ; Wei, Y ; Jiang, J ; Xiao, S ; Liu, X ; Zhou, Z ; Liu, D ; Wang, P. (2023). Bioaccumulation, metabolism and toxicological effects of chiral insecticide malathion and its metabolites in zebrafish (*Danio rerio*). *Chemosphere*, 318, 137898. https://doi.org/10.1016/j.chemosphere.2023.137898

Durak, J; Rokoszak, T; Skiba, A; Furman, P; Styszko, K. (2021). Environmental risk assessment of priority biocidal substances on Polish surface water sample. *Environ. Sci. Pollut. Res*., 28, 1254–1266. https://doi.org/10.1007/s11356-020-11581-7

Doumbia, MY ; Tchakam, MG; Terric, JM. (2021). DINIYO À SAN PEDRO de la cité portuaire à la métropole côtière. Document contexte. Atelier international de maîtrise d'œuvre urbaine de San Pedro 2021.

EFSA (2010). Draft Assessment Report (DAR) - public version-. Initial risk assessment provided by the rapporteur Member State France for the existing active substance Bifenthrin upon resubmission in the framework of the accelerated procedure in accordance with Commission Regulation (EC) No 33/2008.

European Commission (2003). Technical guidance document on risk assessment part II.

Hecker, F A; Leggio, B; König, T; Kim, V; Osterland, M; Gnutt, D; Niehaus, K; Sven Geibel, S. (2024). Cell Painting unravels insecticidal modes of action on Spodoptera frugiperda insect cells. *Pestic. Biochem. Physiol*., 203, 105983. https://doi.org/10.1016/j.pestbp.2024.105983

International Organization for Standardization (2005). General requirements for the competence of testing and calibration laboratories with later amendments ISO/IEC 17025, 1–44.

Khelfi, A; Djemili, I; Bellouard, M-M; Hedhili, A; Nebbali, M; Hoummani, H; Smaoui, O; Achour, S; Fabresse, N; Nisse, P; Kerrouchi, AN; Brousse, G; Nouioui, MA; Céline Eiden, C; Herireche, M; Lemaire-Hurtel, A-S; Laribi, M; Leveau, P; Darrouzain, F; Chaouali, N; Cazaubon, Y; Maalem, O; Ougrine, M; Moslah, B; Aroud, M; Amira, D; Issam Serghini, I. (2023). CHAPITRE 6 - Toxicologie des pesticides, Tout-En-un de Toxicologie, Elsevier Masson, 471-572. https://doi.org/10.1016/B978-2-294-77821-6.00006-5

Kho, J-W; Kim, J-Y; Jung, M; Lee, YS; Doo-Hyung Lee, D-H. (2024). Control efficacy of eight insecticides on *Myzus persicae* (*Hemiptera: Aphididae*) and insecticide resistance development of aphid populations collected from kimchi cabbage in South Korea. J. Asia-Pacific Entomol., 27(4), 102340. https://doi.org/10.1016/j.aspen.2024.102340

Lewis, KA; Tzilivakis, J; Warner, D; Green, A. (2016). An international database for pesticide risk assessments and management. Human and Ecological Risk Assessment: *Inter. J*., 22(4), 1050-1064. https://doi.org/10.1080/10807039.2015.1133242

MEDD and Agence de l'eau (2003). Système d'Évaluation de la Qualité des Eaux (SEQ-Eaux), grilles d'évaluation, version 2, France.

Misiewicz, A ; Filipiak, ZM ; Kadyrova, K., Bednarska, A. (2024). Combined effects of three insecticides with different modes of action on biochemical responses of the solitary bee *Osmia bicornis*. *Chemosphere*, 359, 142233. https://doi.org/10.1016/j.chemosphere.2024.142233 Get rights and content

NF EN ISO 5667-3 (2013). Qualité de l'eau - Échantillonnage - Partie 3 : conservation et manipulation des échantillons d'eau. Boutique AFNOR, France.

N'go, YA ; Kouassi, KH ; Soro, GE ; Meledje, H ; Goula Bi, TA ; Savané, I. (2017). Dynamique et impact de du climat sur les ressources hydriques et agricoles du Sud-Ouest de la Côte d'Ivoire. *Inter. J. Innov. Appl. Stud.*, 19(2), 304-314.

N'guessan, BR ; Adingra, KBC ; Komena, BK; Ipou, IJ. (2019). Les facteurs de risques de la modernisation de l'agriculture à base de pesticides dans la Sous-Prefecture de Tapeguia. *Eur. Sci. J.*, 15(15), 378-400.

Nyström, B; Becker-Van, SK; Bérard, A; Grandjean, D; Druart, JC; Leboulanger, C. (2002). Toxic effects of Irgarol 1051 on phytoplankton and macrophytes in Lake Geneva. *Water Res.*, 36, 2020–2028. https://doi.org/10.1016/S0043-1354(01)00404-3

Ogou, AWA; Bidi, J.T. (2019). Port, Aménagement et Développement Durable À San-Pedro (Sud-ouest de la Côte d'Ivoire). *Eur. Sci. J.*, 15(8) : 110-131.

PAM (Pesticide Analytical Manual) (1994). U.S. Food and Drug Administration, U.S. Department of Health and Human Service, Washington, DC, USA. https://www.fda.gov/food/laboratory-methods-food/pesticide-analytical-manual-volume-i-pam-3rdedition

PRICI (Projet de Renaissance des Infrastructures en Côte d'Ivoire) (2016). Étude d'impact environnemental et social relative au projet d'aménagement des collecteurs primaires de la ville San-Pedro. Rapport final. Ed. Ministère de la Construction, du Logement, de l'Assainissement et de l'Urnabisme (MCLAU), Côte d'Ivoire,

Punniyakotti, P ; Vinayagam, S ; Rajamohan, R; Priya, SD; Moovendhan, M; Sundaram, T. (2024). Environmental fate and ecotoxicological behaviour of pesticides and insecticides in non-target environments: Nanotechnology-based mitigation strategies. *J. Environ. Chem. Eng.*, 12(5), 113349. https://doi.org/10.1016/j.jece.2024.113349

Qin, B ; Zhang, Y ; Zhu, G ; Gao, G. (2023). Eutrophication control of large shallow lakes in China. *Sci. Tot. Environ*., 881, 163494. https://doi.org/10.1016/j.scitotenv.2023.163494

Rahman, M ; Hoque, MdS; Bhowmik, S ; Ferdousi, S ; Kabiraz, MP; Brake, MLv. (2021). Monitoring of pesticide residues from fish feed, fish and vegetables in Bangladesh by GC-MS using the QuEChERS method. *Heliyon*, e06390. https://doi.org/10.1016/j.heliyon.2021.e06390

Soro, G ; Koffi, NM ; Koné, B ; Kouakou, YE ; M'Bra, KR ; Soro, PD ; Soro, N. (2018). Utilisation de produits phytosanitaires dans le maraîchage autour du barrage d'alimentation en eau potable de la ville de Korhogo (nord de la Côte d'Ivoire) : risques pour la santé publique. *Environ. Risques Santé*, 17(2), 155-163.

Soro, G ; Wahabi, SA ; Adjiri, OA ; Soro, N. (2019). Risques sanitaires et environnementaux liés à l'usage des produits phytosanitaires dans l'horticulture à Azaguié (Sud Côte d'Ivoire). *J. Appl. Biosci.*, 138, 14072 – 14081. DOI: 10.4314/jab.v138i1.7

Stevens, DR ;. Blaauwendraad, SM ;. Bommarito, PA ; Dries, Mvd ; Trasande, L ; Spaan, S; Pronk, A; Tiemeier, H; Gaillard, R; Jaddoe, VWV;. Ferguson, KK. (2024). Gestational organophosphate pesticide exposure and childhood cardiovascular outcomes. Environ. Inter., 193, 109082. DOI: 10.1016/j.envint.2024.109082

US-EPA (1991). Method 525.1, revision 2.2. Method for the determination of organic compounds in drinking water. Federal Register 56:30272. https://www.epa. gov/sites/production/files/2015-09/documents/method_525-1_rev-2-2_1991.pdf

US-EPA (2000a). Ethyl parathion RED. Report EPA-738-F00-009.

US-EPA (2000b). Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures - EPA/630/R-00/002 August 2000.

UTZ (2015). Liste des substances prohibés et liste des pesticides sous surveillance, version 1.0. Editeur UTZ, Amsterdam, Pays-Bas.

Wang, F ; Gao, J ; Zhai, W ; Cui, J ; Hua, Y ; Zhou, Z ; Liu, D ; Wang, P ; Zhang, H. (2021). Accumulation, distribution and removal of triazine pesticides by *Eichhornia crassipes* in water-sediment microcosm. *Ecotoxicol. Environ. Saf.*, 219, 112236. https://doi.org/10.1016/j.ecoenv.2021.112236

Zhang, Y-b; Li, H; Han, P; Tian, X-c; Wang, H; Geng, L-l; Zhang, J; Liu, W-x; Wan, F-h; Guedes, R-N; Nicolas, D; Zhang, G-f. (2025). Monitoring the insecticide susceptibility of a newly introduced invasive species, *Tuta absoluta* (Meyrick), in China. *Crop Protect*., 189, 107041. https://doi.org/10.1016/j.cropro.2024.107041

www.databridgemarketresearch.com/fr/reports/global-insecticides-market