JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# Hydraulic Propagation and Ecological Risk of Cypermethrin in the Lower Mekong River System, Cambodia

**[1]Chin Ech, [2]Phoeurng Tork, [3]Koe Sambath, [4] Khy Eam Eang, [4] Paul Baudron**

[1] WAE Student, [2]Lecturer of ME Department of SRU, [3]WAE student
[4] Cambodia Development Resource Institute, P.O. Box 622, Phnom Penh, Cambodia
[4] UMR G-EAU, French National Research Institute for Sustainable Development, Montpellier, France

*Abstract:* Pesticide contamination poses a significant risk to the critical Tonle Sap–Mekong River (TS-MR) system, which sustains aquatic ecosystems and human livelihoods in Cambodia. This study investigated the spatial and seasonal hydraulic propagation of pesticides across the Tonle Sap River (TSR), Mekong River (MKR), and Bassac River (BSR) during the dry (March 2025) and rainy (June 2025) seasons. Water samples from sixteen sites were analyzed using Solid Phase Extraction (SPE) followed by Gas Chromatography-Mass Spectrometry (GC-MS) screening for 451 pesticide compounds. The analysis revealed a stark seasonal contrast: no pesticides were detected during the rainy season. Conversely, the highly restricted pyrethroid insecticide, Cypermethrin, was the only pesticide quantified during the dry season, exhibiting extreme localized concentrations up to 26.21 μg/L at a site along the MKR (S10-MK). Seasonal electrical conductivity (EC) data further confirmed significant water quality differences between the TSR and the MKR/BSR, with higher values suggesting localized pollutant inputs in the BSR during the dry period. The calculated maximum Risk Quotient (RQ) for Cypermethrin was approximately 0.01, indicating a low overall ecological risk to the aquatic environment. However, the extreme localized concentration highlights the presence of distinct point source pollution, likely from unchecked agricultural runoff or direct discharge. This research underscores the critical role of river hydrodynamics in pollutant distribution and provides essential data for targeted water management strategies, emphasizing the need for stricter control over restricted pesticide use in high-risk zones.

**Index Terms – Cypermethrin, Hydraulic Propagation, Mekong River, Water quality, Risk Assessment**

## I. Introduction

The global imperative to maximize crop yields continues to necessitate the widespread application of synthetic pesticides [1]. This dependency has resulted in agricultural runoff becoming a leading global source of water contamination, posing significant environmental crises[2] . Within Southeast Asia, the Mekong River Basin is a crucial economic and hydrological resource, supporting millions through irrigation, fisheries, and domestic consumption [3]. Cambodia, situated centrally, relies heavily on rice production, which is closely linked to the annual Mekong flood pulse [4]. Consequently, the nation has seen an acceleration in the use of imported agrochemicals, often with insufficient regulatory oversight or farmer training [5]. This situation renders Cambodia's interconnected surface waters the Tonle Sap River (TSR), Mekong River (MKR), and Bassac River (BSR) highly susceptible to contamination.

The introduction of modern pesticides has simultaneously enhanced productivity and introduced toxic compounds into aquatic environments [6]. Of particular concern in Cambodia is the continued, illicit use of highly restricted insecticides, such as the synthetic pyrethroid Cypermethrin. This compound is acutely toxic to aquatic fauna, characterized by a low water solubility (hydrophobicity) that promotes strong binding to suspended particulate matter and organic debris [7], [8]. While this partitioning can result in a low immediate Risk Quotient (RQ) in the water column, it facilitates long-range transport via sediments, which can lead to bioaccumulation and chronic ecological exposure [9]. The fate and spatial spread of these pollutants are fundamentally determined by hydraulic propagation the mechanical processes that govern pollutant mixing, dilution, and transport influenced by water flow and connectivity [10]. Understanding this process is vital because pollution directly impacts human health via water and fisheries[9], threatens vital aquatic biodiversity, and is uniquely governed by the system's dynamic, seasonally reversing flow regime.

The Tonle Sap system is hydrodynamically unique due to its seasonal flow reversal [3]. This creates two highly differentiated hydraulic states for contaminant distribution. During the dry season (low flow), minimal river volume and low flow velocity restrict dilution, leading to the concentration and accumulation of pollutants. This condition magnifies the local impact of point sources and makes physicochemical properties like Electrical Conductivity (EC) sensitive indicators of localized inputs and mixing [11]. Conversely, during the rainy season (high flow), high river discharge provides massive dilution capacity, generally resulting in low or non-detectable concentrations in the water phase as contaminants are flushed or adsorbed to mobilized sediments [12]. Despite this direct linkage between hydrodynamics and pollutant fate, a robust, quantitative, and spatial-temporal analysis of pesticide residues across the three major, interconnected river channels (TSR, MKR, and BSR) is critically limited. Existing Cambodian research has tended to focus on localized soil or irrigation canal contamination [11]. A crucial gap remains in linking observed contaminant distribution directly to seasonal hydraulic propagation dynamics across the entire watershed network [11]. This study provides necessary baseline data by concentrating on the influence of the TSR, MKR and BSR connectivity on pesticide transport.

To address this crucial data gap, this study investigates the hydraulic propagation of pesticides across the major river systems of Cambodia. The primary objectives are to quantify the spatial and seasonal occurrence of Cypermethrin and other target pesticide compounds in the TSR, MKR, and BSR during the dry and rainy seasons; to examine the influence of hydraulic factors (flow rate, EC) on the spatial distribution and transport patterns of detected contaminants; and to assess the potential Ecological Risk (RQ) posed by Cypermethrin concentrations to the aquatic ecosystems of the study area.

## II. RESEARCH METHODOLOGY

The methodological framework of this study followed a structured sequence starting from conceptualization to result interpretation (Figure 1). The process included seven key stages: identifying the research idea, defining objectives, reviewing background data, developing the methodology, conducting field sampling, performing laboratory analysis, and finally, data analysis and interpretation.

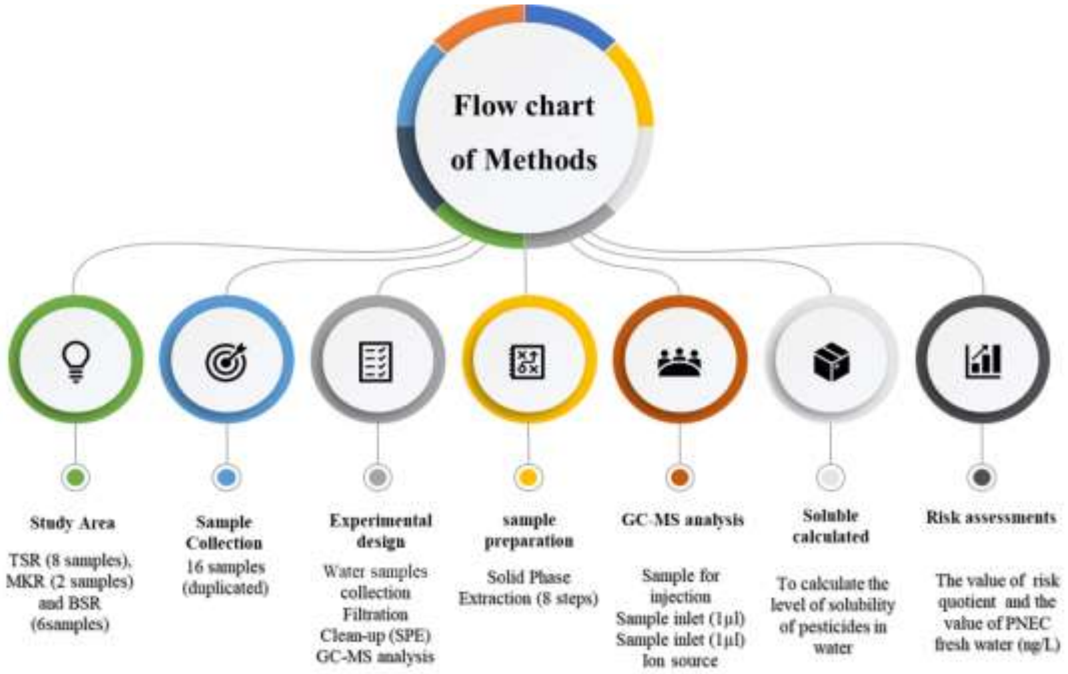


Figure 1. Study Design and Process Flow

### 2.1 Study Area

The study was carried out along the Tonle Sap River (TSR), Mekong River (MKR), and Bassac River (BSR), three hydraulically connected watercourses forming Cambodia's central aquatic system [3]. Sixteen representative sampling sites were chosen: S1-S8 (TSR), S9-S10 (MKR), and S11-S16 (BSR). Site selection was guided by the rivers' flow connectivity, land-use intensity, and accessibility for repeated sampling. These rivers experience two contrasting hydrological phases: a dry season with low discharge and a rainy season characterized by strong flow reversal from the Mekong into the Tonle Sap Lake.

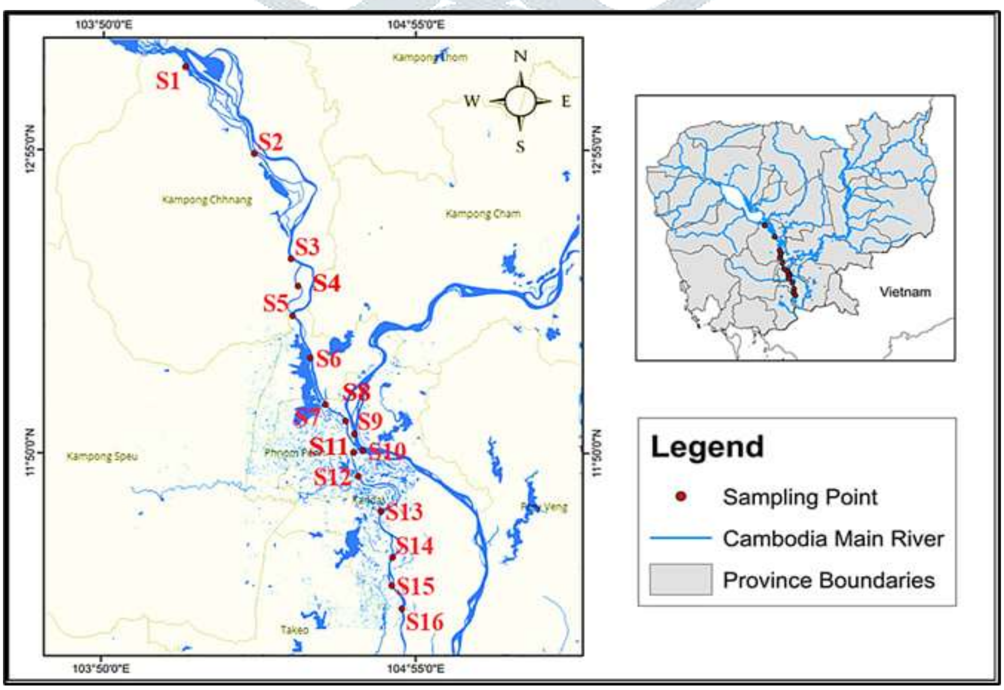


Figure 2. Map of the Tonle Sap, Mekong, Bassac River system showing the sixteen sampling sites

### 2.2 Field Sampling and on-site Measurements

After defining the study sites, field sampling was conducted sequentially in both seasons to capture temporal variations. At each station, surface water samples were collected approximately 3 m from the riverbank at a depth of 50 cm, representing the main mixing layer of the river.

Immediately before sampling, in-situ parameters temperature, pH, and electrical conductivity (EC), were measured using a WTW Cond 3110 meter. These parameters provided baseline water-quality indicators for interpreting pesticide transport under different hydraulic conditions. Flow rate and discharge data were obtained from the Mekong River Commission (MRC) to link contaminant concentration with hydrodynamic behavior.

Each site was sampled in duplicate using pre-cleaned 1 L high-density polyethylene bottles. Samples were labeled, stored in ice boxes at 4 °C, and transported within 24 h to the SATREPS Laboratory at the Institute of Technology of Cambodia (ITC) for further analysis [11].

### 2.3 Laboratory Analysis

Upon arrival at the laboratory, water samples were first filtered through 2 µm glass microfiber filters to remove suspended solids and prevent instrument interference. The filtered water was then subjected to Solid Phase Extraction (SPE) using PLS3-AC cartridges to isolate and pre-concentrate pesticide residues.

Extracted compounds were eluted, evaporated under nitrogen, and re-dissolved in acetone for quantification using gas chromatography mass spectrometry (GC-MS), [13]. The analytical was capable of detecting 451 pesticides compounds at trace levels. All analyses followed the EU SANTE (2021) guidelines for calibration, recovery, and reproducibility. Quality control included blanks, duplicates, and spiked samples for every ten analyses to verify precision and accuracy.

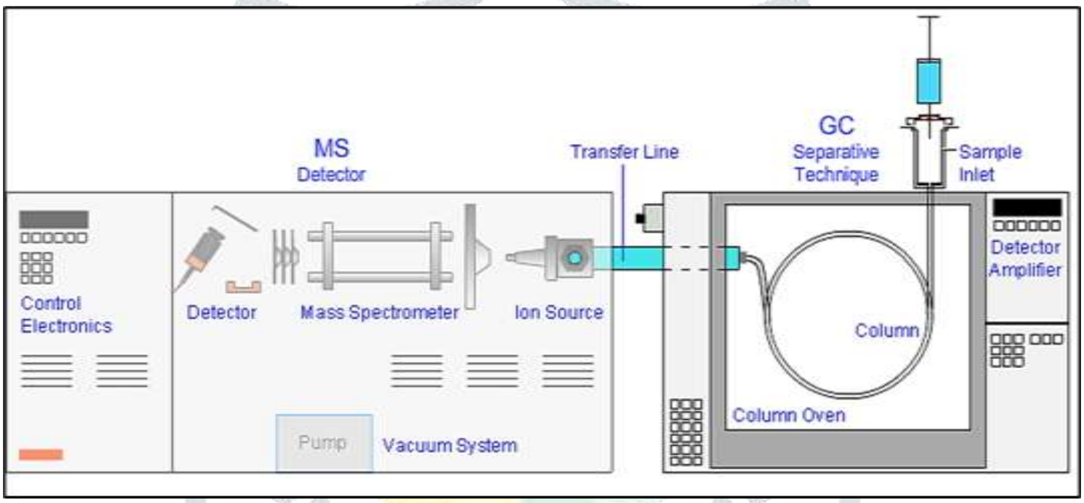


Figure 4. Analytical workflow for pesticide extraction and quantification using SPE and GC-MS.

### 2.4 Data Processing

Quantified concentrations were organized by river and season using Microsoft Excel and R Studio. Statistical analysis focused on identifying spatial differences (TSR vs MKR vs BSR) and seasonal contrasts (dry vs rainy). Correlations between pesticide concentration, EC, and flow velocity were used to explain hydraulic propagation patterns [11].

### 2.5 Ecological Risk Assessment

The final step involved evaluating potential ecological risk using the Risk Quotient (RQ) approach [13]:

$$RQ = \frac{MEC}{PNEC} \quad \textbf{(Eq.2.1)}$$

where MEC = measured environmental concentration (µg/L) and PNEC = predicted no-effect concentration (µg/L). An $RQ > 1$ indicates high risk, $0.1 \leq RQ \leq 1$ moderate risk, and $RQ < 0.1$ low risk.

For Cypermethrin, PNEC = 2.6 µg/L [13]. Calculated RQ values were mapped spatially to highlight potential hotspots and compared between the two seasons.

## III. RESULTS AND DISCUSSION

### 3.1 Physicochemical Characteristics

Water temperature ranged from 25-31 degrees, and pH values were stable from 6.5-8.5 across all sites. The EC exhibited strong spatial variation (Figure 4). The TSR had lower EC (50-150 µS/cm) than the MKR and BSR (160-600 µS/cm), consistent with reduced dilution and pollution inputs in the latter two rivers during the dry season [11]. Flow rate data also confirmed significantly lower discharge rates during the dry season, promoting contaminant accumulation (Figure 5).

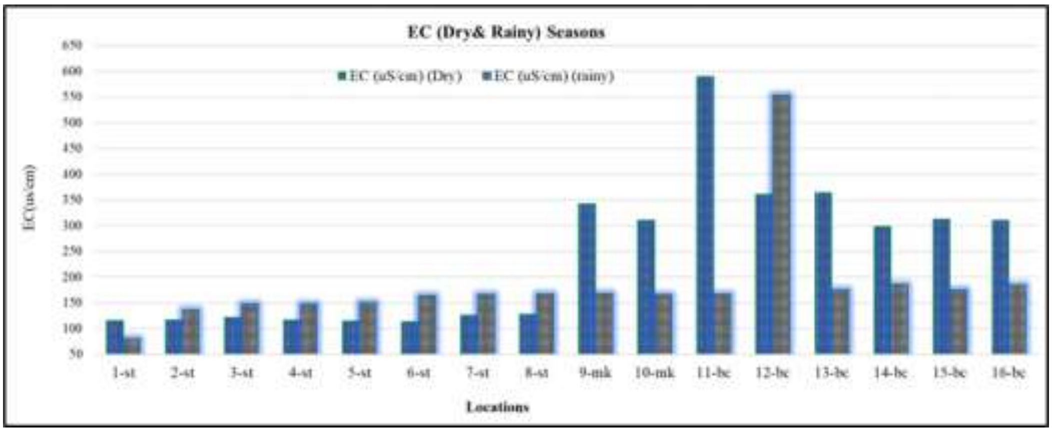


Figure 5. Electrical conductivity variation across TSR, MKR, and BSR during dry and rainy seasons.

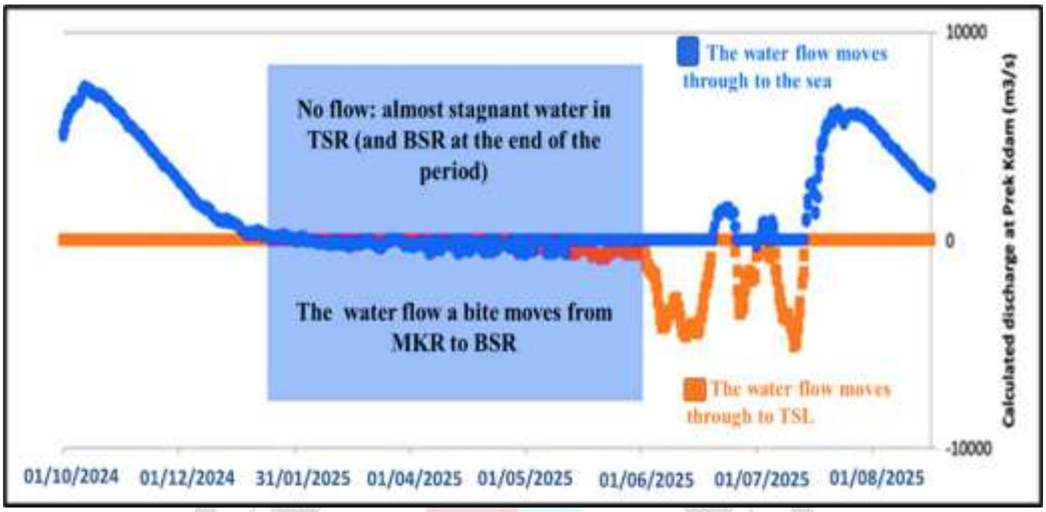


Figure 6. Comparison of river discharge (flow rate) between dry and rainy seasons.

### 3.2 Seasonal Pesticide Detection

Out of 451 pesticides screened, only Cypermethrin was detected exclusively during the dry season. Concentrations ranged from 2.95 µg/L (S9-MK) to an extreme localized peak of 26.21 µg/L (S10-MK) (Figure 7). No pesticide residues were detected in any samples during the rainy season, suggesting the dominance of hydraulic dilution over contaminant loading during the high-flow period [14].

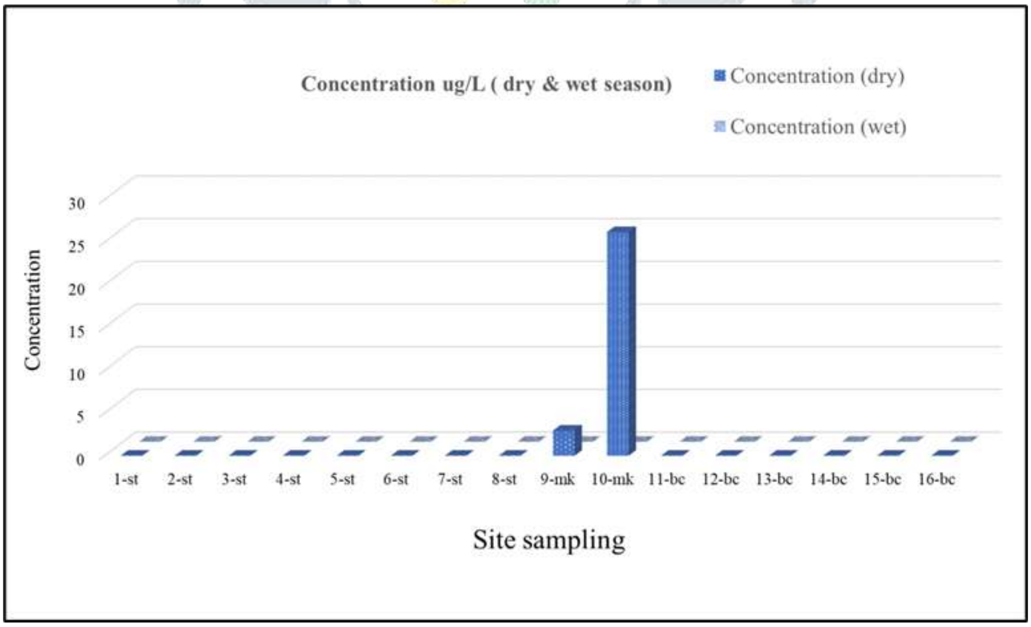


Figure 7. Seasonal Cypermethrin concentration across 16 sites

### 3.3 Ecological Risk of Cypermethrin

The calculated maximum RQ was approximately 0.01, indicating low overall ecological risk to the aquatic environment (Figure 8). This low RQ, despite the high concentration at S10-MK, is attributed to the low water solubility of Cypermethrin, which favors rapid partitioning onto sediments rather than remaining bioavailable in the water column [14]. However, the extreme localized peak still suggests potential for localized ecological stress.

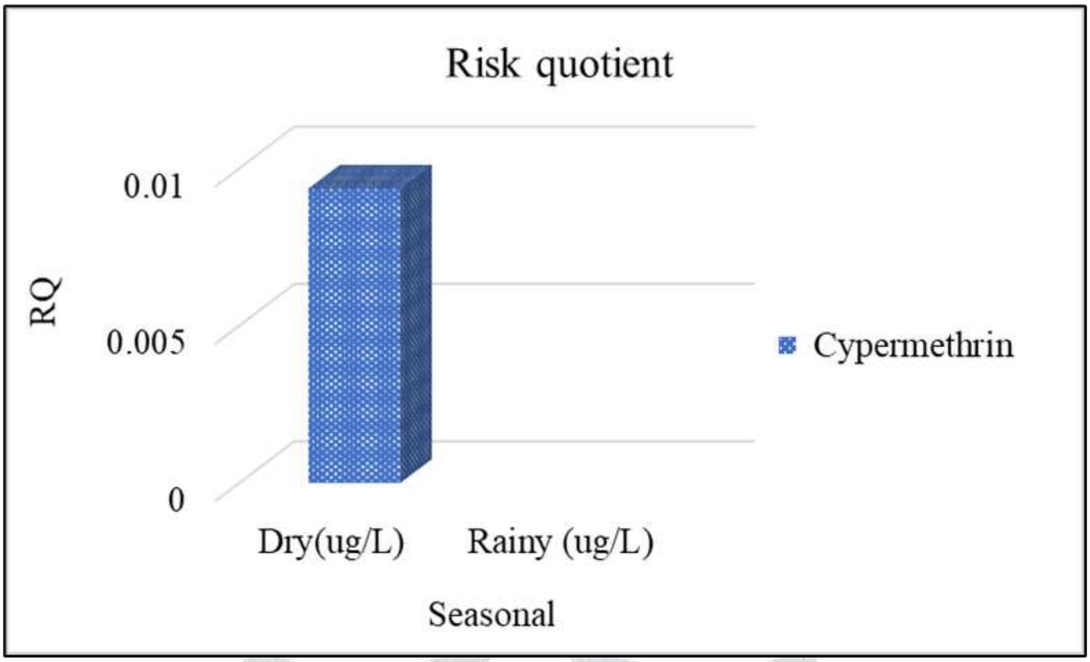


Figure 8. Risk Quotient (RQ) distribution for Cypermethrin across the study sites.

### 3.4 Discussion

The detection of Cypermethrin exclusively in the dry season highlights the strong seasonal and hydraulic dependence of pesticide mobility [14]. The low-flow conditions allow for the accumulation and concentration of contaminants, whereas the high flow and increased dilution during the rainy season rapidly flush the system. This confirms that monitoring during the low-flow period is crucial for identifying critical contamination events.

The high concentration detected at S10-MK strongly suggests a localized point-source pollution event, likely from direct discharge or runoff from an immediately adjacent intensive agricultural area, rather than widespread diffuse pollution [11]. Although the RQ indicates a low overall risk to the general ecosystem, the concentration of 26.21 µg/L far exceeds drinking water limits and poses a direct threat to aquatic organisms residing in that specific high-exposure zone.

The persistent use of Cypermethrin, a restricted pyrethroid, underscores the challenges in regulating agrochemical use in rural Cambodia [15]. These findings emphasize the urgent need for enhanced water management and stricter regulatory enforcement, as similar contamination patterns are reported across the wider Mekong Basin [11].

## IV. CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that hydrological dynamics govern pesticide distribution in Cambodia's major river system.

- Cypermethrin was the only compound detected, occurring exclusively in the dry season.
- The highest concentration (26.21 µg/L) suggests localized point-source pollution near the Mekong River.
- The overall ecological risk (RQ ≈0.01) is low, but the extreme localized peak demands regulatory attention.

Recommendations:

- Enforce stricter control of restricted pesticides.
- Implement hydrology-linked spatial temporal monitoring programs.
- Promote Integrated Pest Management (IPM) to reduce chemical dependence.

This research provides critical baseline information for managing pesticide pollution and safeguarding aquatic ecosystems in Cambodia and the broader Mekong Basin.

## V. Acknowledgment

This research was funded by the projects FEF-R Inversap and FEF-R Healthy Rice, two initiatives supported by the French Embassy in Cambodia, and funded by the French Ministry for Europe and Foreign Affairs.

### References

[1] P. Sharma *et al.*, "Emerging trends in the novel drug delivery approaches for the treatment of lung cancer," *Chem. Biol. Interact.*, vol. 309, p. 108720, 2019.

[2] M. Gavrilescu, "Fate of pesticides in the environment and its bioremediation," *Eng. Life Sci.*, vol. 5, no. 6, pp. 497–526, 2005.

[3] M. Kummu *et al.*, "Water balance analysis for the Tonle Sap Lake–floodplain system," *Hydrol. Process.*, vol. 28, no. 4, pp. 1722–1733, 2014.

[4] P. Ngin, P. Haglund, S. Proum, and J. Fick, "Pesticide screening of surface water and soil along the Mekong River in Cambodia," *Sci. Total Environ.*, vol. 912, no. September 2023, p. 169312, 2024, doi: 10.1016/j.scitotenv.2023.169312.

[5] V. M. Pathak *et al.*, "Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review," *Front. Microbiol.*, vol. 13, p. 962619, 2022.

[6] J. A. Rivera-Jaimes, C. Postigo, R. M. Melgoza-Alemán, J. Aceña, D. Barceló, and M. L. de Alda, "Study of pharmaceuticals in surface and wastewater from Cuernavaca, Morelos, Mexico: occurrence and environmental risk assessment," *Sci. Total Environ.*, vol. 613, pp. 1263–1274, 2018.

[7] I. C. Yadav *et al.*, "Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect

on neighboring countries: A comprehensive review of India," *Sci. Total Environ.*, vol. 511, pp. 123–137, 2015.
[8] W. H. Organization, *The WHO recommended classification of pesticides by hazard and guidelines to classification 2019*. World Health Organization, 2020.
[9] W. H. M. W. Mohtar, K. N. A. Maulud, N. S. Muhammad, S. Sharil, and Z. M. Yaseen, "Spatial and temporal risk quotient based river assessment for water resources management," *Environ. Pollut.*, vol. 248, pp. 133–144, 2019.
[10] M. Kah, S. Beulke, and C. D. Brown, "Factors influencing degradation of pesticides in soil," *J. Agric. Food Chem.*, vol. 55, no. 11, pp. 4487–4492, 2007.
[11] S. Keo *et al.*, "Detection of Pesticide Residues in The Canal Irrigation System of The Upper Mekong Delta, Cambodia," *Indones. J. Limnol.*, vol. 3, no. 1, pp. 10–17, 2022.
[12] Y. Shi, Y. Wan, Y. Wang, Y. Li, S. Xu, and W. Xia, "Fipronil and its transformation products in the Yangtze River: assessment for ecological risk and human exposure," *Chemosphere*, vol. 320, p. 138092, 2023.
[13] J. Hassan and A. Farahani, "GC–MS determination of PAHs in fish samples following salting-out-assisted solvent extraction-gel permeation chromatography," *Chromatographia*, vol. 74, no. 5, pp. 477–482, 2011.
[14] S. Hintze, G. Glauser, and D. Hunkeler, "Influence of surface water–groundwater interactions on the spatial distribution of pesticide metabolites in groundwater," *Sci. Total Environ.*, vol. 733, p. 139109, 2020.
[15] H. Q. Pham, A. T. Bui, and S. T. Le, "Spatial Distribution of Dioxins and Furans in Surface Sediments in Dau Tieng Reservoir, Vietnam," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2023, p. 12009.