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Analysis of Pesticide Residues in Groundwater of Agriculturally Intensive Regions of Cambodia

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Abstract: *Pesticides are substances used to prevent, control, or eliminate pests, weeds, and other harmful organisms in agricultural and non-agricultural settings. The use of pesticides in intensive agricultural areas of Cambodia poses significant risks of pollution of groundwater resources. This study investigates pesticide residues in groundwater from Koh Thum district, Kandal Province, and Kanghot area, Battambang Province. Five groundwater sampling sites in Koh Thum and five in Kanghot were collected from existingtube wells and push points with the water level ranges from 0.16 m to 20 m and shallow to intermediate-depth groundwater systems. The groundwater samples were processed using solid-phase extraction and analyzed by gas chromatography-mass spectrometry equipped with an automated system (451-compound database) to identify and quantify pesticide residues in groundwater samples. The results revealed detectable residues of atrazine, parathion chlorfenapyr, metalaxyl and azoxystrobin in the groundwater samples from Koh Thum while metalaxyl, chlorfenapyr and spirodiclofen were detected in the groundwater samples from Kanghot. Several groundwater samples from Koh Thum district exceeded the European Union guideline value of 0.1 µg/L for individual pesticides, and one sample exceeded the guideline limit of 0.5 µg/L for total pesticide concentration. In contrast, a few groundwater samples from the Kanghot area also exceeded this guideline of individual compound. Chlorfenapyr was the most frequently detected pesticide and showed the highest concentration. The detection of atrazine at a water level of 20 m and other pesticides at water levels ranging from 0.16 to 17.2 m suggests the transport of pesticide residues from agricultural soils to groundwater. The concentration of these pesticides highlights potential contamination from agricultural runoff, raising concerns about chronic exposure risks for communities. Overall, the findings highlight the urgent need for systematic groundwater monitoring, stricter pesticide regulation, and improved management practices to support sustainable agriculture and protect human health in Cambodia's intensively farmed regions.*

Keywords: Gas chromatography-mass spectrometry; Intensive agriculture; Pesticides; Solid phase extraction

1. INTRODUCTION

Pesticides are defined as chemical substances that are mainly used in agriculture in order to protect, control, reduce, destroy, eliminate or mitigate any insects, weeds, fungi, or other diseases that cause damage to crops, their application contributes to increased agricultural productivity and food security [1]. Pesticides are classified in many ways by their toxicity, what pests they target, how they work, and their chemical structure. The toxicity of pesticide was classified into extremely hazardous (Ia), highly hazardous (Ib), moderately hazardous (II), slightly hazardous (III), and unlikely to present acute hazard (U) [2]. Pesticides are a class of pollutants which are often referred to as micropollutants due to the low concentrations at which they are typically found in the environment, after application, pesticide residues in soil, groundwater and air [3,4]. Additionally, groundwater has long been utilized as a readily accessible and reliable source of water for domestic, industrial, and agricultural purposes. However, despite its importance as a vital water resource, groundwater contamination has become a common occurrence, when people utilized as a source of drinking

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water, contamination may pose significant risks to human health [5]. Pesticides are mobile because they drift to new regions in the form of aerosols, through surface runoff, leaching, and infiltration processes, to reach waterways and cause contamination in groundwater. Leaching is one of the primary mechanisms of groundwater contamination, and its extent is influenced by soil texture, permeability, organic matter content, pesticide physicochemical properties, and climatic factors such as rainfall and temperature [6] and preferential flow is a major pathway for pesticide transport to deeper soil layers and groundwater [7]. Water contaminated with pesticides is known to cause a range of other illnesses like asthma, dermatitis, as well as vomiting, coma, and even death [8]. A early study suggests that pesticide self-poisoning by ingestion accounts for approximately 150,000 deaths annually worldwide [9].

Pesticides were used in many countries in the world especially, it was the most useful in developing country including Cambodia [10]. In Cambodia, pesticides are widely used in crop, fruit, and vegetable production to enhance agricultural productivity and protect crops from pests, weeds, and diseases. During the growing season, farmers apply a variety of pesticides, including insecticides, herbicides, fungicides, and rodenticides, to protect crops and maintain productivity [11,12]. To support agricultural productivity, more than 3.2 million liters of pesticides, comprising over 100 different chemical compounds, are applied annually in agriculture of Cambodia. The extensive use of these agrochemicals has raised concerns regarding their potential impacts on the environment, particularly on surface water and groundwater resources [13]. Despite the widespread use of pesticides in Cambodia, information on pesticide contamination of groundwater remains limited, particularly in intensive agricultural areas where groundwater is used for domestic purposes. Therefore, monitoring pesticide residues in groundwater is essential for assessing potential risks to human health and water resources [14,15,16]. Therefore, this study aimed to assess pesticide residues in groundwater from selected agricultural regions of Cambodia, specifically Koh Thum District, Kandal Province, and the Kanghot area, Battambang Province, by quantifying pesticide concentrations and evaluating their relationships with groundwater physicochemical parameters.

2. METHODOLOGY

2.1 Site description and sample collection

This study was conducted in two agricultural regions of Cambodia: Koh Thum district in Kandal province and the Kanghot area in Battambang province. These regions were selected due to their intensive agricultural practices and increasing reliance on pesticides. In both areas, groundwater is used for domestic consumption and irrigation, making it particularly vulnerable to contamination from agricultural activities. In Koh Thum, farmers cultivate rice, fruits (e.g., mango plantations), and vegetables, and commonly is applied a variety of pesticides, most of which were classified as moderately hazardous [15]. In contrast, Kanghot is a rice-growing region, where pesticide application is widely practiced to control pests in rice fields [17].

Groundwater sampling was conducted on 23–24 November 2024. A total of ten sampling sites (W01.1–W09). All samples were collected from water table zone through existing tube wells or push-points. In Koh Thum, five sampling sites were selected and collected. Two sites (W01.1 and W01.2) are located in a mango farm across from Prek touch, representing a push-point and a tube well, respectively, the distance between W01.1 and W01.2 is 4 m. Another push-point (W02) is situated behind the same farm and near a pond. These three sites were installed in previous studies. Additionally, samples were collected from tube wells in a rice field (W03) and a vegetable farm (W04). In Kanghot, five groundwater sampling sites (W05–W09) were collected from household tube wells located near agricultural fields (**Fig.1)**. At each site, groundwater samples were collected in duplicated, using 1 L polypropylene bottles and labeled with location and date. Next, the measurements of physicochemical parameters, including temperature, pH, and electrical conductivity (EC), were performed using a WTW Cond 3110 meter. Water level and total well depth were measured using a sound water level meter. The samples were immediately stored in an icebox at approximately 4 °C and added 1ml of sodium phosphate buffer solution when arrived at the laboratory.

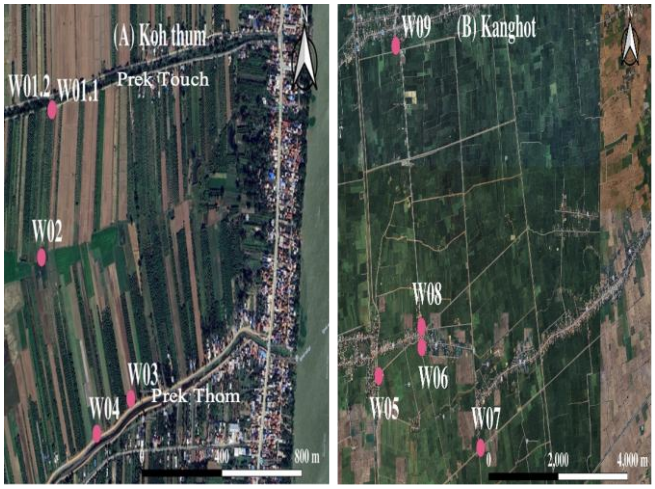

Fig. 1. Mapping of 10 sampling sites in (A) Koh Thum and (B) Kanghot. The red dots showed 10 specific sampling sites.

2.2 Chemical reagents and consumables

The sodium phosphate buffer solution (pH=7.0, 1 mol/L), dichloromethane (ACS BASIC), acetone, n-hexane, and acetonitrile were HPLC grade purchasing from RCI Labscane Limited. Pure water was extracted from Puric-α ultra-pure water Technology (Organo, Japan). Sodium sulfate anhydrous was purchased from Sigma-aldrich, Inc. InertSep (PLS-3) and InertSep Slim-J (AC-2) were purchased from GL Sciences, Japan. Pesticide standards, aldrin, azoxystrobin, biphenyl, buprofezin, carbofuran, chlorfenapyr, chloroneb, chlorothalonil, chlorpyrifos, cyhalofop butyl, dieldrin, difenoconazole, dimethametryn, fenobucarb, fipronil, hexaconazole, isazofos, isoxathion, malathion, metalaxyl, methyl parathion, metolachlor, mevinphos, o,p-ddt, paclobutrazol, permethrin, phenthoate, pretilachlor, propanil, propiconazole, pyroquilon, triadimefon were purchased from LGC Ltd and Fujifilm Wako Pure Chemical Corporation. The purity of pesticide standards are in the range of 96.3%- 99.9%.

2.3 Sample preparation and method validation

The solid-phase extraction was performed after filtration of groundwater samples (fiberglass filter, 0.45 µm). The SPE first started from the sorbent PLS-3 cartridge attached with AC-2 cartridge. They were activated by conditioning with adding 5 mL of dichloromethane, 5 mL of acetone, and 5 mL of purified water, two times subsequently. The purpose of the conditioning step was to ensure that the cartridge was wet and clean. Then, the samples were passed through the cartridges by a vacuum pump at a flow rate of approximately 15 mL/min. The set of cartridges were dried under evaporation with a nitrogen gas stream for 30-40 minutes. The dried cartridges were subsequently disassembled, and the PLS-3 cartridge was eluted with 2 mL of acetone followed by 3 mL of dichloromethane. In addition, the AC-2 cartridge was eluted with 3 mL of acetone while the vacuum pump was turned on at the end of the process. The mixed eluted solution in the glass tube was concentrated with a nitrogen gas stream until 1 mL. Subsequently, 10 mL of n-hexane was added to the 1 mL concentrated solution in the previous step, and the solution was dehydrated by passing it through the sodium sulphate (Na_2SO_4) as the filter. The solution obtained was again concentrated to a final volume of 1 mL using nitrogen gas stream. Finally, the extract was transferred into a vial and stored at -20 ºC. Prior to GC-MS analysis, 10 µl of internal standard solution was added into each sample, injected samples to GC-MS system for analysis as show in Fig. 2.

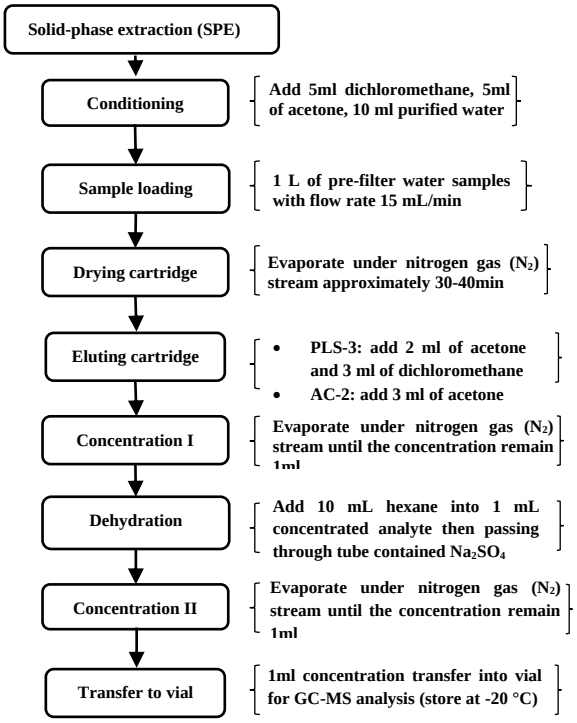

Fig. 2. Experimental flow chart of solid phase extraction

The method was validated with respect to accuracy (expressed as recovery), limit of detection (LOD), and limit of quantification (LOQ). The accuracy of the solid-phase extraction method was validated for the simultaneous analysis of multiple pesticide residues. The accuracy was evaluated by performing the recovery study with two replicates. The recovery study was performed using blank samples and spiked samples, added 1 ml with 1 ppm of external standards into spiked samples. The control samples were prepared by using 90 µl of the extracted blank sample and 10 µl with 10 ppm of external standards. Moreover, extract as described in the extraction section. The recovery yield (%) was calculated following Eq. 1. Limit of detection (LOD) is defined as the lowest amount of compound in the test sample that the analytical instrument can reliably detect. The limit of quantification (LOQ) is the lowest analyte concentration in a sample that can be quantified with surety. Two replicates were conducted for the test of LOD and LOQ. The LOD and LOQ were calculated using Eqs. 2 and 3 [11]. The statistic was conducted using Microsoft Excel software version 2022.

$$\text{Recovery (\%)} = (A_s - A_B) \times 100 / A_c \quad \text{(Eq. 1)}$$

$$\text{LOD} = 3 \times S/N \quad \text{(Eq. 2)}$$

$$\text{LOQ} = 10 \times S/N \quad \text{(Eq. 3)}$$

where:
A_s is peak area of spiking sample
A_B is peak area of blank sample

A_c is peak area of control sample
S/N is signal to noise ratio

2.4 GC-MS analysis

Gas chromatography and mass spectrometry equipment, model TQ8040 series (Shimadzu, Japan), was used to screen pesticides. The MS database contained information on 451 pesticide compounds. With a length of 30 m, a thickness of 0.25 m, and a diameter of 0.25 mm, the DB-5ms was employed as the column. Samples were injected into the GC-MS system using a 1 µl of volume in spitless injection mode. The temperature of the column oven was first set at 4 °C for two minutes before being raised to 310 °C for five minutes at a rate of 8 °C/min. The flow rates for the GC column were 1.23 mL/min and 50 mL/min, respectively, for the ultra-pure helium that served as the carrier gas. The contact was 300 °C and the ion source was 200 °C in temperature. The samples were analyzed in scanned mode in the mass range of 33-600 m/z. The identification of pesticide residue was performed by the data treatment system, which calculates the monoisotopic mass, predicts the structural formula of compounds and compares them using the MS database as show in Table 1.

Table 1. GC-MS Analytical Conditions

Parameter	Condition
Instrument	Shimadzu TQ8040 GC-MS
column	DB-5ms (30 m × 0.25 mm ID × 0.25 m film thickness)
Injection volume	1 µL
Carrier gas	Helium (Ultra-pure)
Flow rate	1.23 mL/min (GC column), 50 mL/min (Purge flow)
Oven temperature program	- Initial: 40°C (hold 2 min) - Ramp: 8°C/min to 310°C (hold 5 min)
MS interface temp	300°C
Ion source temp	200°C
Mass scan range	33–600 m/z (Scan mode)
Database	451 pesticide compounds (Monoisotopic mass, structural formula comparison)

3. RESULTS AND DISCUSSION

3.1. Method validation

The results of the recovery study are presented in Table 2. The obtained recoveries for all 32 target analytes fell within the acceptable range of 70–120 % [18]. Recovery rates exceeding 70% were obtained for 21 of the 32 target pesticide compounds (65.625%), demonstrating satisfactory extraction performance. However, 11 compounds (34.375%) showed recoveries below 70%, suggesting reduced method efficiency for these pesticides. As shown in Table 2, 12 of the 32 target pesticide compounds (37.5%) exhibited LOD and LOQ values below 0.01 and 0.0333 µg.L^{-1}, respectively, indicating high analytical sensitivity. The remaining 18 compounds (62.5%) showed LOD and LOQ values above these thresholds, but some compounds can not be clearly categorized as having both LOD and LOQ values either below or above these values [11]. Following method validation, 21 pesticide compounds met the established validation criteria and were considered suitable for simultaneous multi-residue analysis. These results demonstrate that the proposed method is accurate, sensitive, and reliable for the determination of pesticide residues in groundwater sample.

Table 2. Limit of detection (LOD), limit of quantification (LOQ) and recovery yield of 31 reference pesticide compounds.

Pesticides	LOD (µg. L^{-1})	LOQ (µg. L^{-1})	Recovery (%)
Aldrin	0.027	0.083	11.338
Azoxystrobin	0.0333	0.111	81.390
Biphenyl	0.012	0.035	14.318
Buprofezin	0.0192	0.064	43.680
Carbofuran	0.0333	0.111	104.468
Chlorfenapyr	0.009	0.026	38.744
Chloroneb	0.0050	0.0167	101.745
Chlorothalonil	0.0583	0.1943	72.120
Chlorpyrifos	0.04	0.12	77.399
Cyhalofop Buty l	0.037	0.111	106.543
Dieldrin	0.03	0.092	19.775
Difenoconazole 1	0.0333	0.111	79.989
Dimethametryn	0.02	0.0667	97.211
Fenobucarb	0.005	0.0167	86.829
Fipronil	0.001	0.002	107.663
Hexaconazole	0.01	0.0333	81.522
Isazofos	0.005	0.0167	68.400
Isoxathion	0.025	0.0833	27.091
Malathion	0.022	0.066	99.828
Metalaxyl	0.04	0.122	101.484
Methyl parathion	0.035	0.105	93.037
Metolachlor	0.005	0.014	102.140
Mevinphos 1	0.057	0.173	107.663
o,p'-DDT	0.029	0.088	6.286
Paclobutrazol	0.008	0.024	80.773
Permethrin 1	0.007	0.02	44.350
Phenthoate	0.0025	0.0083	62.436
Pretilachlor	0.004	0.012	88.323
Propanil	0.0250	0.0833	108.042
Propiconazole 1	0.005	0.0167	94.740
Pyroquilon	0.005	0.0167	49.419
Triadimefon	0.007	0.023	101.254

3.2. Physical-chemical parameters of groundwater samples

The groundwater quality results in Table 3 from Koh Thum and Kanghot show variations in electrical conductivity (EC), pH, temperature, depth, and water level, which may reflect differences in groundwater contamination, geology, and agricultural influence. In Koh thum, extremely high EC values were recorded, particularly in shallow wells W01.1 (9,210 µS/cm); W01.2 (6,200 µS/cm), suggesting possible salinity intrusion or contamination from agricultural runoff containing fertilizers and/or pesticides [16,17]. Moderately elevated EC levels in other Koh Thum wells (653–2,320 µS/cm) indicate varying degrees of aquifer pollution, when value of EC is exceeding 1,000 µS/cm [21]. In contrast, Kanghot exhibited lower EC values (722–1,371 µS/cm), reflecting generally better water quality, though the elevated reading in W09 (1371 µS/cm) points to localized contamination. The pH data shows near-neutral to alkaline conditions (Koh thum: 7.15–7.97; Kanghot: 7.5–8.4), with Kanghot's relatively pH may affect pesticide persistence in groundwater, although pesticide degradation is compound-specific and is also influenced by temperature and other environmental conditions. The temperature of all samples remained warm (29–31°C), which may accelerate both pesticide breakdown and leaching processes [22]. Water level profiles reveal that shallow wells in Koh Thum have the highest EC, indicating greater vulnerability to surface contamination, while deeper wells in both regions show better groundwater quality. In Koh Thum, the static groundwater level ranged from 0.16 to 20.0 m below ground surface, and tube well depths ranged from 25 to 60 m. In the Kanghot area, the static groundwater level ranged from 12.6 to 19.35 m below ground surface, while tube well depths ranged from 25 to 67 m. Therefore, the collected samples represent groundwater from shallow to intermediate-depth aquifers in both study areas. However, some total depth of well cannot measure.

3.3. Pesticide qualification and their relationship with groundwater physicochemical parameters

Figure 3 presents identification of pesticides residues in groundwater samples using GC–MS analysis. In Koh Thum, The detection of parathion exclusively in adjacent shallow well W01.1 and atrazine in W01.2, exhibited both high EC, demonstrating significant spatial variability even between proximate sampling points. Parathion binds strongly to soil particles and is less likely to travel far, and rapid degradation [23]. Moreover, it degrades much faster than atrazine, explaining its absence in deep well W01.2, but atrazine is a mobile herbicide that contaminates groundwater through leaching, often traveling meters to tens of meters from application sites [24].The atrazine source may be very close to W01.2, it may not reach W01.1. In addition, pesticides degrade slightly faster at high temperature and pH [22]. Azoxystrobin was found in W02, with 0.16 m of water level, and its shorter half-life under alkaline conditions (pH 7.97), low EC and warm temperature, means azoxystrobin intercepts the uppermost groundwater, directly influenced by recent applications and surface runoff or rapid infiltration that carried both salts and the pesticide into the shallow groundwater table [25]. And in W03, chlorfenapyr and metalaxyl were detected. Low EC typically indicates dilute groundwater with less surface influence. This suggests that chlorfenapyr and metalaxyl likely reached the aquifer through infiltration and subsurface transport processes that carried pesticide residues without increasing dissolved ion in the groundwater. In Koh Thom, azoxystrobin and metalaxyl were widely used to manage fungal diseases, while chlorfenapyr was commonly applied a as an insecticide. Repeated pesticide application, particularly during the rainy season, may enhance pesticide transport through soil profiles into shallow groundwater. However, the detection of parathion in W01.1 in Koh Thum, provides an important comparison with two previous studies conducted at the same mango farm tube well.

Table 3. Chemical and physical parameter of groundwater samples

Location	Sample code	EC (µS /cm)	pH	Temperature (℃)	Total well depth (m)	Static water level (m)
Koh Thum	W01.1	9,210	7.15	31.8	-	1.7
	W01.2	6,200	7.39	29.7	60	20
	W02	1,244	7.97	30.7	-	0.16
	W03	653	7.9	29.6	25	2.5
	W04	2,320	7.93	30.8	-	2.4
Kanghot	W05	797	8.21	30.1	25	17.2
	W06	722	8.4	30	45	14
	W07	779	7.5	30.3	25	12.6
	W08	802	7.9	30.3	40	14.2
	W09	1,371	7.7	29.8	67	19.35

Note: -:no data

In November 2020, only fungicides and plant growth regulators - hexaconazole, paclobutrazol, propiconazole, and azoxystrobin - were detected [15]. Another study in 2022 reported eight pesticide residues in groundwater from the same well: propiconazole (two isomers), difenoconazole (two isomers), hexaconazole, paclobutrazole, azoxystrobin, and biphenyl [14]. These differences suggest a temporal variation in pesticide occurrence, likely reflecting changes in pesticide application practices over time at the same location. suggesting reduced contamination or dilution, and limited transport of applied pesticides to these groundwater points.

In Kanghot, chlorfenapyr found in W05*, W06 and W07 at water depths of 12.6 m, 14.0 m, and 17.2 m, respectively. Chlorfenapyr should not leach to such depths via normal matrix flow. Its presence requires a rapid transport mechanism. In W05*, The detection of chlorfenapyr and spirodiclofen demonstrates that preferential flow pathways that bypassed the sorptive capacity of soil and escaping rapid degradation, allowing immobile compounds to reach depths of meters. Farmers may apply them frequently, there is a higher chance that a recent application coincides with a rainfall or irrigation event that triggers rapid transport via preferential flow [26]. The detection of metalaxyl in W07 further supports rapid recharge with water level (12.6 m), which may increase the vulnerability of the aquifer to contamination from surface agricultural activities [27]. Compared to Koh Thum, where an extremely shallow groundwater level (0.16–20 m) permits direct surface-to-groundwater connectivity that allows even short-lived pesticides (parathion, azoxystrobin) to be detected. This pattern contrasts with Kanghot, the deeper groundwater table ranging from 12.6 m to 19.35 m below ground, filters out short-lived compounds but remains vulnerable to contamination. The low EC (722–797 µS/cm) in these wells indicates dilute, rapidly recharged water – consistent with flushing events that deliver pesticides quickly to depth. The low EC in contaminated wells does not indicate absence of pesticides rather, it reflects a rapidly flushed system that can deliver agrochemicals to deep groundwater when preferential pathways exist [20]. Warm temperatures (30.0–30.3 °C) and mildly alkaline pH (7.5–8.4) would normally accelerate degradation, implying very recent input and travel times of days to weeks. However, wells W04, W08, and W09 showed no detectable pesticide residues.

The pesticide concentrations are presented in Fig. 3, it is also necessary to map the locations of all sample sites with points. Azoxystrobin was detected in W02 at a concentration of 0.1123 µg/L, slightly above the EU guideline value of 0.1 µg/L for individual pesticide compounds, and 0.5 µg/L for maximum concentration of total pesticides [28]. At W03, metalaxyl and chlorfenapyr were detected at concentrations of 0.1702 µg/L and 0.5079 µg/L, respectively. Both compounds exceeded the EU guideline for individual pesticides, and their combined concentration (0.6781 µg/L), highlighting significant contamination risk. In W05*, where chlorfenapyr reached 0.2416 µg/L. Similarly, W06 showed chlorfenapyr contamination with 0.3200 µg/L above the guideline limit. Furthermore, in W07, the detected pesticide concentrations were below the guideline values, with chlorfenapyr measured at 0.0733 µg/L and metalaxyl at 0.04873 µg/L, indicating spatial variability in pesticide occurrence. This contamination was likely related to agricultural practices, as the detected compounds are commonly used in crop protection. Importantly, atrazine, parathion, and spirodiclofen were identified in the samples; however, their concentrations could not be quantified because internal standard solutions for these compounds were not available for further analysis. Comparison between the two study areas indicates that groundwater contamination was more severe in Koh Thom than in Kanghot. Koh Thom exhibited a greater diversity of detected pesticides, higher concentrations, and more frequent exceedances of EU guideline values. In particular, sample W03 from Koh Thom showed the highest contamination level, with chlorfenapyr concentration reaching 0.5079 µg/L and total pesticide concentration exceeding the EU guideline value of 0.5 µg/L. These results suggest that agricultural activities and pesticide application intensity may be greater in Koh Thom, resulting in increased vulnerability of groundwater to pesticide contamination.

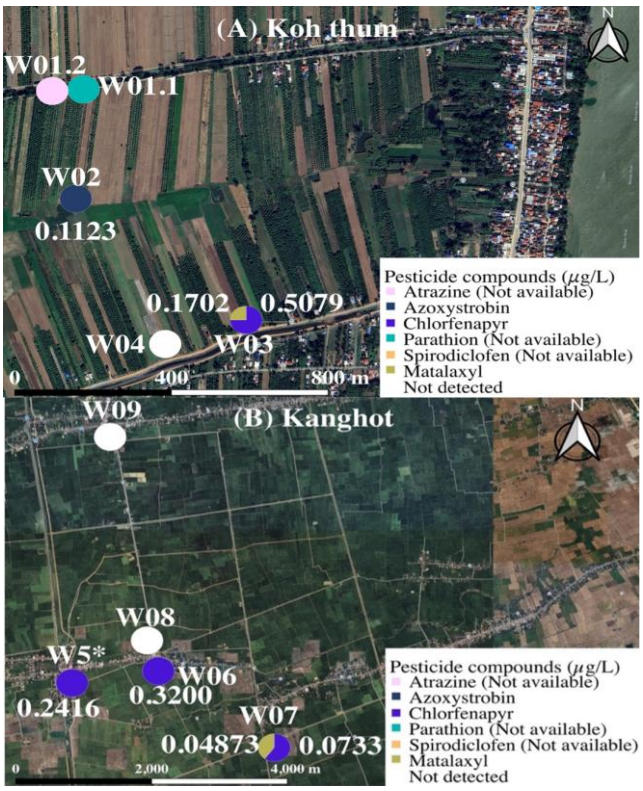

Fig. 3. Groundwater sampling locations indicating detected pesticide compounds and their concentrations (µg/L) in (A) Koh Thum district and (B) Kanghot area.

3.4 Classification and hazard characteristics of detected pesticides in Koh Thum and Kanghot

Groundwater samples collected from the study areas revealed the presence of multiple pesticide residues. In this study area, six pesticides were detected and were classified into different classes based on target organisms and toxicity hazardous according to world health organization [2] in Table 4. Specifically, the following active compounds were detected: atrazine, azoxystrobin, chlorfenapyr, parathion, spirodiclofen and metalaxyl. Pesticides were detected which the main majority determined by fungicides (40%), insecticides (40%), and herbicides (20%). Moreover, pesticides detected were extremely hazardous (20%), moderately hazardous (40%), slightly hazardous (20%), and unlikely to present acute hazard (20%) in Koh Thum. In addition, in kanghot Pesticides were classified as fungicides (20%), insecticides (80%), moderately hazardous (80%), and slightly hazardous (20%).

Table 4. Toxicity and functional role of detected pesticides

N^0	Pesticide	Type	Hazard classes
1	Atrazine	Herbicide	III
2	Azoxystrobin	Fungicide	U
3	Chlorfenapyr	Insecticide	II
4	Parathion	Insecticide	Ia
5	Spirodiclofen	Insecticide	III
6	Metalaxyl	Fungicide	II

4. CONCLUSIONS

In this study, groundwater samples from in Koh Thum district and Kanghot area were analyzed pesticide compounds. Six pesticide compounds—azoxystrobin, chlorfenapyr, metalaxyl, atrazine, parathion, and spirodiclofen—were detected in the groundwater samples. The detection of pesticide residues in groundwater with water levels ranging from 0.16 to 20.0 m below ground surface suggests the potential transport of pesticides from agricultural soils to groundwater systems. In addition, high electrical conductivity, temperature, and pH may influence the occurrence and persistence of pesticide residues in groundwater. In Koh Thum, groundwater samples with relatively high EC values contained detectable pesticide residues, whereas wells with lower EC values showed no detectable pesticides, suggesting that EC may be associated with groundwater contamination in agricultural areas. The presence of pesticides in groundwater samples indicates potential exposure risks for communities relying on wells for groundwater consumption. These findings highlight the need for regular monitoring, the promotion of safe agricultural practices.

For future studies should include groundwater sampling from pesticide-free area and seasonal monitoring to better evaluate pesticide leaching and contamination patterns. The inclusion of soil, rice plants, and surface water samples would also improve understanding of pesticide transport pathways.

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