



Hydrochemical Evaluation of Pesticide Residues in Surface and Groundwater from High-Input Agricultural Zones of Konaseema region, AP, India

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(Received: 27 October 2025 Revised: 05 November 2025 Accepted: 04 December 2025)

Keywords:

Subsurface water, Pesticide residues, Environmental monitoring, Groundwater contamination.

Abstract

The East Godavari district, along with selected regions of Konaseema in Andhra Pradesh, forms an intensive agricultural belt supported by the distributary channels of the Gouthami Godavari. Owing to sustained agricultural activity and extensive pesticide application, these areas face an elevated risk of contamination in both surface and subsurface water sources. This study examines residues of organochlorine (OCPs) and organophosphate pesticides (OPPs) in surface and subsurface water samples collected from agricultural and river-associated locations within these specific zones. Standard USEPA-based extraction methods and GC-MS analytical techniques were employed for pesticide determination. The findings reveal comparatively higher contamination in surface water than in subsurface water, with OPPs being the predominant group. The study offers essential baseline data to aid ongoing environmental monitoring and to guide public health and water-quality management efforts in the region.

1. Introduction

The konaseema region supports extensive paddy cultivation, horticulture, aquaculture, and coconut-based cropping systems, all of which contribute significantly to local livelihoods and agricultural productivity. However, the persistent use of chemical pesticides in these farming systems raises concerns regarding the potential contamination of surface and subsurface water

resources. Understanding the presence and distribution of pesticide residues in these waters is critical for assessing environmental risks and ensuring the long-term sustainability of the region's agricultural and aquatic ecosystems. Fertile alluvial soils, abundant irrigation water, and tropical climatic conditions encourage high agricultural productivity, resulting in substantial dependence on synthetic pesticides for crop protection [1–3]. The widespread use of pesticides



across multiple cropping cycles has raised growing concerns regarding contamination of surface and groundwater resources.

Pesticides enter aquatic ecosystems through runoff, leaching, atmospheric deposition, spray drift, and canal discharge [4,5]. Once introduced, they undergo various physicochemical transformations influenced by soil properties, hydrology, microbial activity, and climatic parameters. Persistent organic pollutants such as organochlorine pesticides (OCPs) can remain in the environment for decades due to their hydrophobicity, long half-lives, and strong adsorption tendencies [6–8]. In contrast, organophosphate pesticides (OPPs), though less persistent, pose acute toxicity risks to aquatic organisms and humans [9,10]. Global monitoring studies consistently report pesticide residues in river systems, lakes, wetlands, reservoirs, and aquifers across Europe, North America, Africa, and Asia [11–14]. These findings underscore the need for region-specific monitoring programs.

Several studies in Europe, including long-term monitoring in Hungary, Germany, and France, document the presence of triazines, chloroacetanilides, phenoxy acids, neonicotinoids, and residual organochlorines in water bodies subjected to agricultural pressures [15–18]. The Hungarian monitoring program revealed significant spatio-temporal variation in pesticide concentrations governed by cropping intensity, rainfall patterns, and hydrological connectivity [19]. Similar patterns have been observed in the Danube, Rhine, Seine, and Thames river systems [20–22]. The European Water Framework Directive (WFD) and WHO guidelines have classified many pesticides as priority hazardous substances due to their endocrine-disrupting effects, carcinogenic potential, and chronic toxicity [23,24]. In Asia, large river systems such as the Yangtze, Mekong, and Ganga have shown widespread contamination with DDT, HCH, endosulfan, chlorpyrifos, and cypermethrin [25–27].

Indian studies reveal significant pesticide contamination in both surface and groundwater across major river basins. The Yamuna River exhibits residues of OCPs and OPPs beyond permissible limits due to intensive vegetable cultivation and peri-urban pesticide use [28]. The Ganga basin studies report persistent detection of DDT, HCH isomers, aldrin, dieldrin, and chlorpyrifos

[29–31]. Research from the Krishna, Cauvery, and Brahmaputra regions highlights the widespread use of chlorpyrifos, phorate, endosulfan, monocrotophos, and profenofos [32–34]. Studies conducted in rural Haryana, Punjab, Rajasthan, and Telangana have documented contamination of drinking water wells with both historical and contemporary pesticides [35–38]. Despite the agricultural prominence of East Godavari region of Konaseema, published data on pesticide contamination in the Gouthami Godavari–Yanam–Kakinada belt remain limited, creating a significant knowledge gap.

Aquaculture intensification in Konaseema and Yanam adds further pressure on water resources. Pesticides used in crop protection can enter aquaculture ponds, affecting microbial ecology, fish health, and sediment quality [39]. Agro-aquatic interactions in deltaic environments often amplify pesticide mobility due to shared canal networks and frequent water exchange cycles [40]. Additionally, shallow groundwater tables, high irrigation inflow, and intensive cropping in the region increase leaching potential, contributing to groundwater vulnerability [41]. The complexity of these hydrological interactions necessitates systematic monitoring.

Agricultural intensification has led to the extensive use of pesticides, resulting in their accumulation in surrounding water bodies through runoff, leaching, and percolation. Such contamination poses significant risks to aquatic ecosystems and to communities that rely on these waters for domestic, agricultural, and livelihood needs. To address these concerns, the present study investigates organochlorine and organophosphate pesticide residues in both surface and subsurface water sources collected from agricultural regions. The findings generated will provide essential baseline data to support environmental monitoring, water quality assessment, and the development of effective management and policy strategies aimed at safeguarding water resources.

2. Materials and Methods

Study area

The study area for the present investigation is the Konaseema region of East Godavari district, Andhra Pradesh, India, which falls under an agricultural climatic zone. The study area map is presented in Fig.



l(a) respectively.

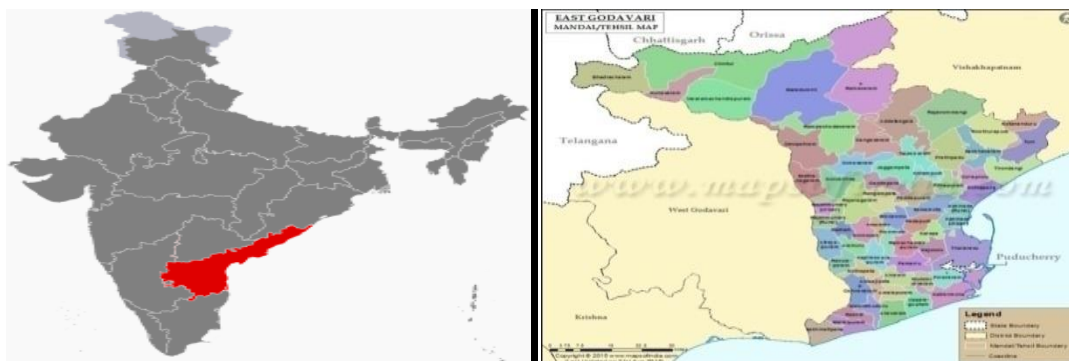


Figure – (a): Location map of the study area, Source: Google maps

Sample collection

The sampling locations within the study area were selected from regions characterized by intensive agricultural activity. Across the three study zones, a total of 20 groundwater samples were collected during both the pre-monsoon (April–May) and post-monsoon (November–December) seasons. From these samples, five representative composite samples were prepared for pesticide residue analysis. All sampling and handling procedures were carried out following standard protocols.

Chromatographic Parameter Conditions

Gas chromatography–mass spectrometry (GC–MS) was employed for the detection and quantification of pesticide residues in groundwater samples. The analysis was performed using a Thermo GC–Trace Ultra Ver. 5.0 gas chromatograph coupled with a Thermo MS DSQ II mass spectrometer under the following conditions:

- Column: DB-35 MS Capillary Column (non-polar)
- Dimensions: 30 m × 0.25 mm ID × 0.25 μm film thickness
- Carrier Gas: Helium (99.999% purity) at a constant flow rate of 1.0 mL/min
- Oven Temperature Program: 80°C (initial), ramp at 10°C/min up to 250°C
- Injection Volume: 0.5 μL
- Injection Mode: Split (10:1)

- Injector Temperature: 250°C
- Ion Source Temperature: 280°C
- Ionization Mode: Electron Impact (EI) at 70 eV
- Mass Scan Range: 40–550 m/z
- Scan Interval: 0.5 s

GC–MS Calibration, Standard Preparation, and Method Validation

GC–MS calibration and method validation were carried out following standard protocols to ensure accuracy, precision, and reproducibility. Calibration standards were prepared by dissolving known concentrations of target pesticides in purified water and processing them identically to the samples.

The analytical separation involved purging the target pesticide residues from the aqueous matrix using high-purity helium. Samples were placed in sealed headspace vials and equilibrated at a constant temperature to establish gas–liquid equilibrium. The volatile analytes in the headspace were withdrawn with a gas-tight syringe and introduced into the GC–MS system.

During purging, analytes were released from the aqueous phase and trapped onto adsorbent materials such as silica gel or suitable GC packing media. The adsorbent traps were subsequently heated in the carrier-gas stream to thermally desorb the analytes. The desorbed components were transferred into the GC column for separation and detection under the specified chromatographic conditions.



A multi-level calibration curve was established for each target pesticide to quantify detection efficiency. Method validation included checks for linearity, precision, recovery, sensitivity, and detection limits following standard guidelines [42].

3. Results & Discussion

Physico-chemical parameters

The pH of the groundwater samples ranged from 6.97 to 7.64, indicating that all samples were within permissible limits. The temperature varied between 31.23°C and 33.43°C. Total dissolved solids (TDS) values ranged from 240.3 to 363.6 mg/L, and all samples were within the recommended guideline value. Total hardness (TH) in the groundwater samples ranged from 251.6 to 351.6 mg/L. In Samples 1, 2, 3, and 4, the TH values exceeded the permissible guideline limit. Chloride concentrations ranged between 23.49 and 47.26 mg/L, while sulphate levels ranged from 8.53 to 50.59 mg/L; both parameters remained within acceptable limits in all samples. Phosphate concentrations in the groundwater ranged from 0.05 to 8.90 mg/L. In Samples 1 and 5, phosphate levels exceeded the guideline value. Nitrate concentrations varied from 3.47 to 5.51 mg/L, and all samples were within permissible limits.

Pesticide residue analysis

The concentration levels of organochlorine (OC) and organophosphorus (OP) pesticides in groundwater samples collected are presented in the table-1 and Figure (a) respectively. A total of 10 compounds were detected, of which 8 were OCPs and 2 were OPPs.

Organochlorine Pesticides

The mean concentrations of terbuthylazine, dimethachlor, and bifenthrin in samples 1, 2, 3, 4 and 5 were 1460 µg/L, 1280 µg/L, 1320 µg/L, 1750 µg/L and 850 µg/L respectively, exceeding their respective guideline limits of 7µg/L, 20 µg/L, 20 µg/L, 20 µg/L & 20 µg/L [13]. The average concentrations of simazine and acetochlor were 158 µg/L and 698 µg/L in sample-1, and 435 µg/L and 565 µg/L in sample-2, also surpassing the guideline value of 20 µg/L [39, 40]. These compounds were below detection limits in sample-3, 4 and 5. Heptachlor epoxide levels were 698 µg/L (sample-1) and 998 µg/L (sample-3), while sample-2, 4 and 5 showed no

detectable amounts. Propachlor concentrations were 10 µg/L in samples 1 and 3 and 10 µg/L in sample-2, 4 and 5 all below guideline values [13]. Iprodione was detected at 318 µg/L and 154 µg/L in samples 1 and 2 and 120 µg/L in sample-5.

Organophosphorus Pesticides

The concentrations of Ethion in samples 1, 2, 3, 4 and 5 were 40 µg/L, 85 µg/L, 55 µg/L, 23 µg/L and 80 µg/L, respectively. Phosmet levels were significantly high at 668 µg/L, 585 µg/L, and 885 µg/L in the three samples.

Conclusion

The findings of this study indicate that groundwater in the investigated agricultural regions is significantly impacted by pesticide contamination, primarily due to the discharge of agricultural runoff. Elevated total hardness (TH) in groundwater near intensive farming zones reflects the encrustative nature of the water, while higher phosphate concentrations further confirm the influence of agricultural inputs on groundwater quality.

Several pesticides—including terbuthylazine, dimethachlor, bifenthrin, Dimethrimol, Ethion, Bifenithrin, simazine, acetochlor, Diazinon, and Butachlor—were detected at comparatively higher concentrations in the sampled locations. The presence of these compounds, some of which exceed recommended guideline limits, demonstrates the vulnerability of the groundwater system to contamination from agrochemical usage.

Overall, the study highlights that groundwater in the study area is contaminated with pesticide residues, posing potential health risks to the local population relying on these sources for drinking and domestic purposes. Continuous monitoring, along with the adoption of sustainable agricultural practices, is essential to safeguard groundwater quality and protect public health.

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Table-1: Physicochemical properties of groundwater samples from regions affected by agricultural practices

Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Guideline Status
pH	6.97	7.12	7.28	7.46	7.64	All within limits
Temperature (°C)	31.23	31.88	32.41	32.97	33.43	Within limits
TDS (mg/L)	240.3	275.8	298.6	335.2	363.6	All within limits
Total Hardness (mg/L)	351.6	338.4	322.1	301.3	251.6	Samples 1–4 exceed limit
Chloride (mg/L)	23.49	28.36	33.12	41.68	47.26	All within limits
Sulphate (mg/L)	8.53	19.44	26.87	37.12	50.59	All within limits
Phosphate (mg/L)	8.90	1.24	0.48	0.31	5.67	Samples 1 & 5 exceed limit
Nitrate (mg/L)	3.47	4.12	4.96	5.22	5.51	All within limits

Table 2: Pesticide residue values of groundwater near investigative domain

Pesticide	Type	Guideline Limit (µg/L)	Sample-1 (µg/L)	Sample-2 (µg/L)	Sample-3 (µg/L)	Sample-4 (µg/L)	Sample-5 (µg/L)
Terbuthylazine	OCP	7	1460	1280	1320	1750	850
Dimethachlor	OCP	20	1460	1280	1320	1750	850
Bifenithrin	OCP	20	1460	1280	1320	1750	850
Simazine	OCP	20	158	435	BDL	BDL	BDL
Acetochlor	OCP	20	698	565	BDL	BDL	BDL
Heptachlor epoxide	OCP	—	698	BDL	998	BDL	BDL



Pesticide	Type	Guideline Limit (µg/L)	Sample-1(µg/L)	Sample-2(µg/L)	Sample-3(µg/L)	Sample-4(µg/L)	Sample-5(µg/L)
Propachlor	OCP	(Guideline available)	10	10	10	10	10
Iprodione	OCP	—	318	154	BDL	BDL	120
Ethion	OPP	—	40	85	55	23	80
Phosmet	OPP	—	668	585	885	—	—

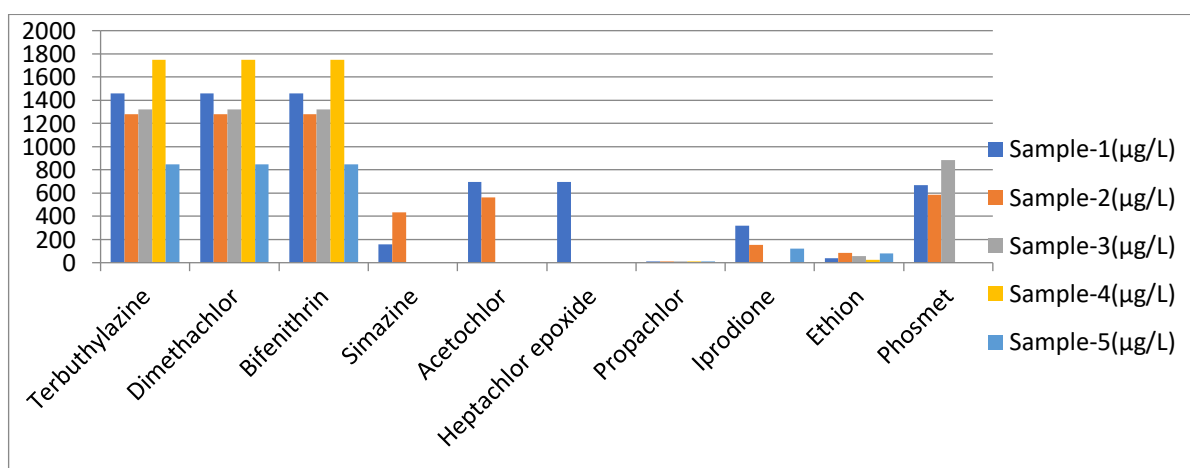


Figure (b) Pesticide residue concentrations of different groundwater samples near agricultural areas