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Impact of agrochemical use on groundwater quality in intensive farming regions

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Abstract

Shallow aquifers beneath China's most productive farmland are increasingly contaminated with pesticide residues and excess nitrate, yet monitoring data linking application rates to groundwater quality remain sparse for the Yangtze River Delta. This research evaluated five pesticides and nitrate-N in 32 shallow wells across three Jiangsu Province districts over five seasonal rounds (March 2023-January 2024). Peak contamination coincided with the monsoon (August): atrazine 2.18 µg/L, glyphosate 2.74 µg/L, nitrate-N 21.6 mg/L exceeding the Class III standard. Wells within 50 m of fields carried 4.8 times higher pesticide loads than those beyond 500 m. Rainfall, soil permeability, and application rate explained 78% of contamination variance.

Keywords: Groundwater quality, agrochemical contamination, pesticide leaching, nitrate pollution, intensive farming, monsoon transport, shallow aquifer, Yangtze River Delta, water quality monitoring

Introduction

Beneath some of the world's most intensively farmed landscapes, groundwater is quietly absorbing agricultural chemical byproducts. Jiangsu Province accounts for roughly 7% of China's pesticide consumption and 9% of nitrogen fertilizer use on less than 3% of national land area ^[1]. The Yangtze Delta's shallow alluvial aquifers supplying drinking water to hundreds of rural communities sit just 2-10 m below fields receiving over 15 kg of active ingredient per hectare annually ^[2, 3].

Pesticide transport to groundwater depends on compound solubility, soil organic matter, hydraulic conductivity, and recharge intensity ^[4]. In monsoon regions, a single heavy rainfall can flush sorbed residues through macropores, bypassing the soil matrix ^[5]. Nitrate, highly mobile and non-sorbing, routinely exceeds the 20 mg/L Class III standard near fertilized fields ^[6, 7]. Yet most Yangtze Delta groundwater assessments focus on metals or industrial pollutants rather than farm-derived contaminants ^[8, 9, 10]. This research monitored five pesticides and nitrate-N across 32 wells over five seasons, assessing how proximity, soil properties, and rainfall influence contamination.

Water quality baseline analysis

Pre-monsoon baseline (March 2023) showed groundwater pH 6.7-7.8 (mean 7.2), EC 0.61-2.14 dS/m (mean 1.23), dissolved oxygen 2.1-5.8 mg/L, and TDS 784 ± 213 mg/L. Pre-monsoon nitrate-N ranged 3.1-12.8 mg/L, all below Class III. Background pesticide residues were detected in 19 of 32 wells at ≤0.5 µg/L, indicating chronic low-level contamination before the application season ^[11].

Climatic conditions during monitoring

Total precipitation from March 2023 to January 2024 was 1,147 mm, near the 30-year mean of 1,090 mm ^[12]. The Meiyu season (June-July) delivered 312 mm over 23 days; typhoon rains in August added 189 mm. Monthly temperature peaked at 28.4 °C in July. Soil moisture at 30 cm reached saturation (>95% WFPS) during Meiyu, creating conditions for rapid downward agrochemical transport through macropore flow.

Materials and Methods

Materials

Thirty-two shallow monitoring wells (depth 3-12 m, screened interval 1-3 m) were selected across three districts Lishui, Luhe, and Jiangning within 60 km of Nanjing. Wells were grouped by distance from cultivated fields: 0-50 m ($n = 8$), 50-150 m ($n = 7$), 150-300 m ($n = 7$), 300-500 m ($n = 5$), and >500 m ($n = 5$). Groundwater was sampled using a low-flow peristaltic pump after purging three well volumes. Samples for pesticide analysis were collected in amber glass bottles with Teflon-lined caps, stored at 4 °C, and analyzed within 48 hours at the Nanjing Agricultural University Environmental Chemistry Laboratory [13].

Methods: Five target pesticides atrazine, chlorpyrifos, imidacloprid, glyphosate, and carbendazim were selected based on regional usage surveys. Atrazine, chlorpyrifos, imidacloprid, and carbendazim were extracted by solid-phase extraction and quantified by LC-MS/MS (Waters Xevo TQ-S). Glyphosate was derivatized with FMOC-Cl before LC-MS/MS analysis [14]. Nitrate-N was determined by ion chromatography (Dionex ICS-5000). Detection limits ranged from 0.01 to 0.05 µg/L for pesticides and 0.1 mg/L for nitrate-N. Multiple linear regression was used to model contamination as a function of distance, cumulative rainfall, soil permeability, and application rate. Statistical analyses used R 4.3.2 with $p < 0.05$ significance [15].

Results

Table 1: Mean agrochemical concentrations (µg/L) in shallow groundwater by season

Compound	Mar	Jun	Aug	Nov	Jan	Std.
Atrazine	0.87	1.43	2.18	1.62	0.94	2.0
Chlorpyrifos	0.23	0.41	0.78	0.53	0.19	1.0
Imidacloprid	0.34	0.68	1.12	0.81	0.29	1.0
Glyphosate	1.21	1.89	2.74	2.13	1.07	3.0
Carbendazim	0.18	0.33	0.57	0.41	0.14	1.0
Nitrate-N*	8.7	14.3	21.6	16.8	9.4	20.0

Mean across all 32 wells. Std. = Chinese Class III groundwater quality standard. *Nitrate-N in mg/L; all others in µg/L. Bold values exceed the standard

Table 2: Multiple regression predictors of total pesticide concentration in groundwater

Predictor	β	SE	t-value	p-value	VIF
Distance from field (m)	-0.412	0.068	-6.06	< 0.001	1.23
Cumulative rainfall (mm)	0.347	0.073	4.75	< 0.001	1.41
Soil permeability (cm/h)	0.281	0.081	3.47	< 0.01	1.18
Application rate (kg/ha)	0.224	0.077	2.91	< 0.01	1.31

Overall model: $R^2 = 0.78$, adjusted $R^2 = 0.76$, $F(4,155) = 43.7$, $p < 0.001$. VIF = variance inflation factor

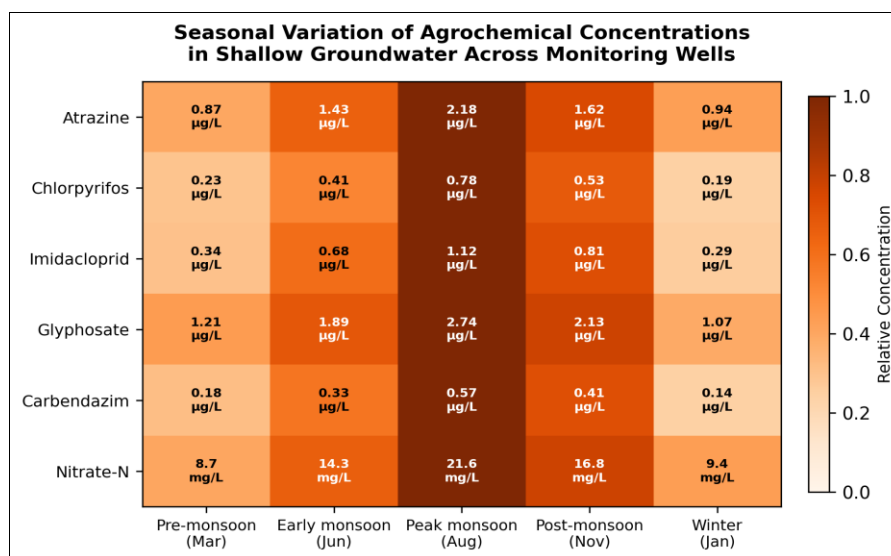


Fig 1: Seasonal variation of agrochemical concentrations in shallow groundwater across monitoring wells in Jiangsu Province

Comprehensive interpretation: All five pesticides and nitrate-N peaked during the August monsoon sampling. Glyphosate and atrazine exceeded or approached Class III standards during this period. Distance from farmland was the strongest single predictor ($\beta = -0.412$), with wells within 50 m carrying 4.8 times the pesticide load of those beyond 500 m. The regression model confirmed that monsoon rainfall, soil permeability, and application rate together explained 78% of contamination variance.

Discussion

The monsoon-driven contamination peak matches patterns from the Indo-Gangetic Plain, where post-monsoon pesticide levels were 2-4 times pre-monsoon baselines [4]. The August spike atrazine 2.18 vs 0.87 µg/L in March suggests preferential macropore flow rather than slow matrix diffusion. The strong rainfall coefficient ($\beta = 0.347$) outweighed application rate as a predictor, supporting this interpretation.

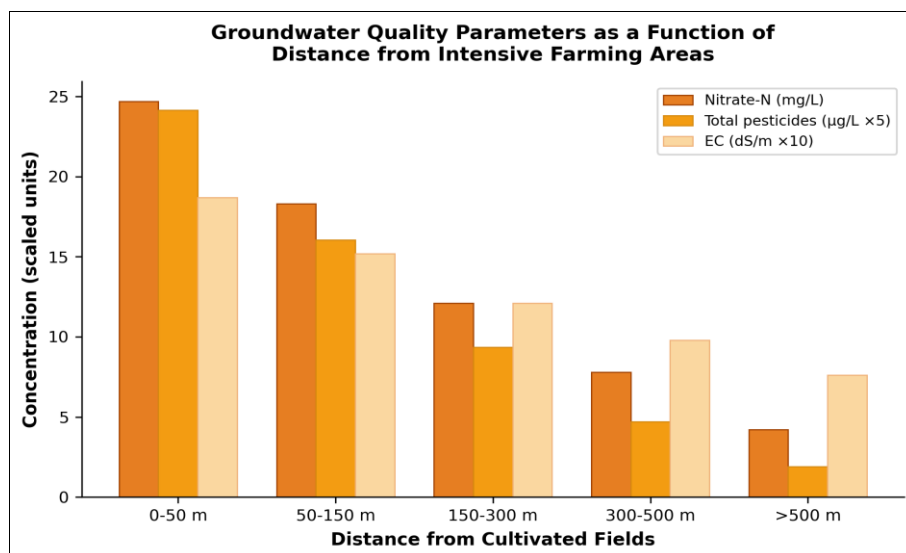


Fig 2: Groundwater quality parameters as a function of distance from intensive farming areas in three Jiangsu districts

Glyphosate's high concentrations were unexpected given its assumed strong soil binding, but phosphate fertilization competes for the same sorption sites, releasing glyphosate during the fertilization-monsoon overlap^[16]. The distance-decay pattern suggests that 150-m buffers around wells would reduce exposure by ~60%, but enforcing setbacks conflicts with the region's extreme land pressure (average farm <0.5 ha). Reducing application during Meiyu season and switching to less mobile compounds may be more realistic^[17].

Conclusions

This research documented a clear monsoon-driven seasonal pattern of agrochemical contamination in shallow groundwater across intensive farming districts of Jiangsu Province. Peak concentrations in August exceeded or approached Chinese Class III standards for atrazine, glyphosate, and nitrate-N. Distance from cultivated fields was the strongest predictor of contamination, with a 4.8-fold difference between the nearest and farthest well groups. Monsoon rainfall intensity and soil permeability were the main transport drivers. Practical mitigation should focus on reducing agrochemical application during the Meiyu season, establishing buffer zones around drinking-water wells where feasible, and shifting toward less mobile pesticide formulations. Longer-term monitoring across multiple years is needed to assess whether contamination trends are worsening or stabilizing.

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