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Research Article

Environmental and Economic Impacts of Pesticide Use in Intensive Agricultural Systems: A Case Study in Parongpong District, West Bandung Regency

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ABSTRACT

The intensive use of pesticides in agriculture has raised concerns regarding environmental quality and economic sustainability, particularly in Parongpong District, West Bandung Regency. This study aimed to analyze the impact of pesticide use on soil and water quality as well as its economic implicates on farmers. A mixed-method approach was applied through soil and surface water sampling, laboratory analysis, and structured questionnaires with 100 farmers. Soil quality tests revealed low pH, reduced organic carbon (1.61%), and high cadmium (5.2 mg/kg), indicating soil degradation. Water samples from the Cibeureum River showed that BOD (93.5 mg/L), COD (302 mg/L), and total phosphorus (0.475 mg/L) exceeded national standards, suggesting nutrient overload and pollution linked to pesticide runoff. Economically, although 98% of farmers perceived pesticides as beneficial, the Benefit-Cost Ratio (BCR) analysis resulted in a value of 0.57, implying financial inefficiency. This indicated that the cost of pesticides and mitigation outweighs the actual benefits received from increased crop yields. The gap between farmers' perception and objective economic and environmental data highlights the need for sustainable solutions. Organic farming practices introduced by local farmer groups, such as *Semai Organik* and *Farm Organic Parongpong*, offer promising alternatives for improving productivity while preserving environmental integrity. Promoting environmentally friendly farming methods is essential to ensure long-term ecological balance and economic resilience in the agricultural sector.

Keywords: economic impact; pesticide use; soil degradation; sustainable agriculture; water pollution

INTRODUCTION

Agriculture is a vital sector in Indonesia's economic development due to its role in food provision, nutrition improvement, and poverty alleviation (Damanik, 2013; Rozaki, 2020). With the increasing demand for food, a shift in the agricultural system has occurred, marked by production intensification through the use of synthetic fertilizers and pesticides, particularly since the Green Revolution era (Sarfraz *et al.*, 2023). Although this approach has succeeded in boosting crop yields, the long-term use of pesticides has led to significant environmental and health issues.

Pesticides serve as protectants for crops against pests and diseases, but their excessive use can result in soil and water contamination, pest resistance, and disruption of the soil ecosystem (Gangola *et al.*, 2022; Palanimanickam & Sepperumal, 2017). In many cases, only a small portion of the applied pesticide reaches the target organisms, while the remainder accumulates in the environment as hazardous residues (Brillas, 2022). These impacts are exacerbated by farmers' habits of overusing pesticides, mixing active ingredients, or improperly disposing pesticide waste (Ma'rufi *et al.*, 2023).

The Parongpong District in West Bandung Regency is an area that is heavily reliant on horticultural agriculture, particularly for vegetable and flower crops. Pesticide use in this region spans nearly the entire planting cycle, from land preparation to post-harvest stages (Andesgur, 2019). Local studies have revealed a decline in soil and water quality due to the accumulation of pesticide residues, including heavy metal contamination such as cadmium (Cd), and increased Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels in water bodies like the Cibeureum River (DLH Kabupaten Bandung Barat, 2022; Irham *et al.*, 2017).

Economically, pesticides contribute to increased crop yield and short-term farmer income. However, when considered over the long term, the costs of purchasing pesticides, declining soil fertility, and health risks impose a significant economic burden (Budhiawan *et al.*, 2022).

Research on pesticide use in Indonesia has largely examined either environmental degradation or farmers' economic dependence separately, while limited studies have integrated both aspects. This gap highlights the need to analyze the simultaneous impacts of pesticides on soil and water quality as well as their economic implications, particularly in horticultural centers such as Parongpong.

Therefore, a sustainable pesticide application strategy is essential to maintain a balance between agricultural productivity and environmental preservation. This study aimed to analyze the impact of pesticide use on environmental quality (soil and water) and assess its economic effect on farmers in Parongpong District. It is expected that the findings of this study will serve as a foundation for more environmentally friendly policy-making and interventions in agricultural practices.

MATERIALS AND METHODS

Research Design

This research employed a mixed-method approach, combining quantitative and qualitative methods to achieve comprehensive insight. The study was conducted in Parongpong District, West Bandung Regency, over a period of six months, from May 2024 to October 2024.

Population and Sample

The target population consisted of horticultural farmers in Parongpong District, West Bandung Regency. In addition, surface water samples were collected from the Cibeureum River, which flows through agricultural areas in Parongpong. A total of 100 farmers were selected using purposive sampling based on their involvement in pesticide application in vegetable and flower cultivation (Tongco, 2007).

Data Collection Techniques and Instruments Development

Environmental samples of soil were collected from multiple plots within a single agricultural field suspected of pesticide contamination. Samples from these plots were composited to obtain a representative sample for analysis of pesticide residues. Samples of surface water were obtained from the Cibeureum River based on data from *Dinas Lingkungan Hidup Kabupaten Bandung*. The laboratory analysis included parameters such as soil pH, organic matter, and heavy metals. Water quality testing covered BOD, COD, and total phosphorus. Data were collected using a structured questionnaire to assess the economic impact of pesticide use. The questionnaire included variables such as the cost of purchasing pesticides, the increase in crop yields after pesticide use, and the cost of mitigating environmental impacts caused by pesticide use.

Data Analysis Techniques

Environmental quality, including soil and surface water was assessed using descriptive analysis of parameters such as pH, organic matter, heavy metals, BOD, COD, and total phosphorus to evaluate the impact of pesticide use. Similar approaches have been applied in recent studies, highlighting the role of physiochemical analysis in detecting heavy metal and pesticide residues in soil (Alengebawy *et al.*, 2021), the use of water quality indies to summarize water conditions (Chidiac *et al.*, 2023), and the effects of pesticide pollution on organic matter and biodegradability in surface water (An *et al.*, 2025).

Economic impact data were analyzed by evaluating three main variables: the cost of purchasing pesticides, the increase in crop yields following pesticide use, and the cost associated with mitigating environmental degradation caused by pesticide application. The data were processed using descriptive statistics to illustrate cost-benefit relationships and economic burdens borne by farmers. In addition, Benefit-Cost Ratio (BCR) analysis was applied to assess the economic efficiency of pesticide use. The BCR was calculated using the following formula:

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$$Benefit\ Cost - Ratio\ (BCR) = \frac{Benefit}{Cost}$$

Where Benefit represents the additional income from crop yield increases, and Cost includes expenditures for pesticide purchases and environmental mitigation. The resulting BCR values were then interpreted by comparing them with findings from previous studies to evaluate whether pesticide use in the study area provides an economically viable return.

RESULTS AND DISCUSSION

Farmers' Characteristics

The characteristics of the farmers involved in this study are presented in Table 1, which describes variations in gender, age, education, and farming experience. As shown in Table 1, most farmers were male (79%) and fell into the productive age group, particularly those aged 30−39 years (27%) and 50−59 years (28%). Regarding education, the majority had a moderate level of formal schooling, with 39% completing senior high school, 36% junior high school, and 25% having completed only primary school. Farming experience was generally long, with 45% of farmers reporting more than 20 years of engagement in agriculture. Overall, these results suggest that farmers in the study area are mainly male, of working age, moderately educated, and possess substantial farming experience.

Table 1. Respondent characteristics

No.	Category	Frequency	Percentage (%)
1	**Gender**		
	Male	79	79
	Female	21	21
2	**Age (Years)**		
	< 20	5	5
	20−29	7	7
	30−39	27	27
	40−49	25	25
	50−59	28	28
	> 60	8	8
3	**Last Education**		
	Primary School	25	25
	Junior High School	36	36
	Senior High School	39	39
4	**Farming Experience (Years)**		
	< 5	14	14
	5−10	16	16
	11−20	25	25
	> 20	45	45

Soil Degradation Due to Pesticide Dependence

The high dependency of farmers on pesticide use, especially organophosphates such as chlorpyrifos, has caused adverse effects on soil quality in agricultural land in Parongpong District. Field observations by the researcher indicated that most farmers continue to apply chlorpyrifos, resulting in visibly drier, denser, and less fertile soils. Some farmers find that their land has become increasingly difficult to manage and yields have declined.

This condition indicated declining soil fertility, which may lead to crop failure. According to Supriatna *et al.* (2021), excessive pesticide use reduces soil pH and limiting the availability of essential nutrients. Accumulated pesticide residues may also harm soil organisms vital for maintaining soil structure and fertility.

Soil Chemical and Physical Characteristics

A soil quality test was conducted on agricultural land located at coordinates 6°50'12.8"S 107°34' 27.4"E, covering 15,543 m^2. The results are summarized in Table 2. The low organic carbon indicated insufficient organic matter, while cadmium levels exceeded safety threshold, suggesting soil contamination. These conditions may inhibit plant growth and reduce microbial diversity in the soil ecosystem.

Previous studies by Sukarjo *et al.* (2022) and Joko *et al.* (2017) reported the presence of organochlorine and organophosphate pesticide residues in agricultural soil across Indonesia. The widespread detection of these compounds, including chlorpyrifos aligns with findings in Parongpong, confirming long-term chemical accumulation and potential ecological risk.

Table 2. Soil quality test in Parongpong District

No.	Parameter	Unit	Result	Quality Standard
1	pH	-	5.2	< 4.5 ; > 8.5[1)]
2	Moisture Content	%	14.56	-
3	Organic Carbon (C)	%	1.61	>2%[2)]
4	Total Nitrogen (N)	%	0.18	-
5	C/N	-	8.9	-
6	Available Phosphorus (P)	mg/kg	142.37	-
7	Potassium (K_2O)	mg/100g	76	10−30[3)]
8	Iron (Fe)	mg/kg	4.47	55,000[4)]
9	Zinc (Zn)	mg/kg	2.89	150[5)]
10	Cadmium (Cd)	mg/kg	5.2	1[5)]
11	Lead (Pb)	mg/kg	24.6	200[5)]
12	Magnesium (Mg)	(cmol[+]kg-1)	2.09	0.15−1.52)
13	Sand	%	27	Clay
	Silt		26	
	Clay		46	

Note: [1)](Source: *Peraturan Pemerintah Republik Indonesia Nomor 150 Tahun 2000*)
[2)](Source: Food and Agriculture Organization of the United Nations, 2006)
[3)](Source: VDLUFA, 2018)
[4)](Source: United States Environmental Protection Agency (USEPA), 2017)
[5)](Source: Environmental Management (Soil Quality Standards) Regulations, 2007)

Farmers in Parongpong District reported crop failures, particularly in tomatoes due to hard, compacted soils and poor nutrient absorption caused by chemical buildup. These conditions of declining soil fertility may lead to crop failure. They also contribute to plant wilting and death before harvest, as illustrated in Figure 1, which shows tomato crops that failed to reach maturity. In addition, the results of questionnaires from 100 farmers in the study area indicated relatively intensive pesticide use. Specifically, 21% of farmers reported spraying pesticides more than three times a week, while the majority (79%) applied pesticides one to three times a week. The types of pesticides most commonly used were insecticides (63%), followed by fungicides (29%), with the remainder using other categories of pesticides. Such frequent and predominant reliance on chemical pesticides further exacerbates soil degradation and increases crop vulnerability.

Figure 1. Tomato crop failure (Source: personal documentation, 2024)

Long-term pesticide use reduces microbial diversity and soil biomass, affecting organic matter decomposition and soil functionality (Devi *et al.*, 2018). Pesticide residues may persist in soil for an extended period, although Zhou *et al.* (2025)

observed that microbial recovery is possible within months after pesticide application is stopped, aided by photolysis and microbial degradation.

Screening detection limit (SDL) tests were conducted on cauliflower samples, a primary crop in the region. Table 3 presents the results of the analysis of eleven active ingredients. The analysis was carried out using Gas Chromatography-Mass Spectrometry (GC-MS). The results show that no pesticide residues were detected, meaning concentrations were below detection limits. While this indicates good pesticide management, "not detected" does not necessarily mean "residue-free". Further testing using more sensitive methods is recommended for food safety assurance.

Water Quality Degradation in the Cibeureum River Due to Agricultural Activities

This study utilized water quality data from the Cibeureum River, one of the main rivers in West Bandung Regency. The river originates in Sukajaya Village, Lembang Sub-district, and Cihideung Village, Parongpong Sub-district. In 2021, the *Dinas Lingkungan Hidup (DLH) Kabupaten Bandung* measured several water quality parameters along the river. Results are shown in Table 4.

The pH values ranged from 7.39 to 7.64 and still remains within the acceptable range. However, BOD levels significantly exceeded standards across all classes. Pesticide-related BOD pollution occurs when organic materials from pesticides are broken down by microorganisms, consuming large amounts of dissolved oxygen. This process reduces oxygen availability in water, posing a serious threat to aquatic life and altering the ecological balance.

Chemical Oxygen Demand (COD) values were also far above acceptable thresholds. COD represents the oxygen required to oxidize organic and inorganic compounds. Many pesticides, especially organophosphates, pyrethroids, and carbamates, contain persistent chemicals that are difficult to break down, thus raising COD levels and impair-

Table 3. Screening detection of pesticide residues in cauliflower samples

No.	Active Ingredients	Screening Detection Limit (mg/kg)	Sample 1	Sample 2
1.	Permethrin	0.05	Not Detected	Not Detected
2.	Profenofos	0.05	Not Detected	Not Detected
3.	Chlorpyrifos	0.05	Not Detected	Not Detected
4.	Diazinon	0.01	Not Detected	Not Detected
5.	Lambda-cyhalothrin	0.05	Not Detected	Not Detected
6.	Tebuconazole	0.05	Not Detected	Not Detected
7.	Buprofezin	0.01	Not Detected	Not Detected
8.	Chlorothalonil	0.05	Not Detected	Not Detected
9.	Cypermethrin	0.05	Not Detected	Not Detected
10.	Deltamethrin	0.05	Not Detected	Not Detected
11.	Difenoconazole	0.05	Not Detected	Not Detected

Table 4. Water quality of the Cibeureum River

Parameter	Unit	Sampling Location[1]			Quality Standard Class[2]			
		Upstream	Midstream	Downstream	1	2	3	4
pH		7.43	7.39	7.64	6-9	6−9	6−9	6−9
BOD	mg/L	93.5	36.4	36.5	2	3	6	12
COD	mg/L	302	114	87.7	10	25	40	80
Total P	mg/L	0.456	0.475	0.457	0.2	0.2	1.0	-

Note: [1](Source: *DLH Kabupaten Bandung Barat*, 2022)
[2](Source: *Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021*)

ing water quality through oxygen depletion. While BOD and COD in aquatic systems may also originate from domestic effluents, livestock manure, or other agricultural residues, pesticide use constitutes a significant contributor in agricultural areas such as Parongpong. Pesticide formulations not only contain active ingredients but also solvents, surfactants, and other organic carriers that are biodegradable, thus elevating BOD. Meanwhile, many pesticide classes including organophosphates, carbamates, and pyrethroids, contain persistent compounds that resist biological degradation and instead increase COD, reflecting high oxygen demand from both organic and inorganic fractions. Previous studies confirm that pesticide runoff and residues can substantially raise both BOD and COD in surface water, thereby depleting oxygen and threatening aquatic ecosystems (An *et al.*, 2025; Rad *et al.*, 2022).

Total phosphorus (Total P) exceeded class I and II thresholds, indicating nutrient pollution from agriculture. Though fertilizers are the main source of phosphorus, certain pesticides particularly those with organophosphate structures, also release phosphorus when decomposed in aquatic environments. The phosphorus measured in this study refers to water-soluble available P (orthophosphate, PO_4^{3-}), which is the most mobile and ecologically relevant form contributing to eutrophication. Improper or excessive application of fertilizers can therefore lead to phosphorus runoff (Damalas & Koutroubas, 2018). Moon *et al.* (2024), explained that agriculture is a primary non-point source of phosphorus and nitrogen pollution. In addition, Zifa *et al.* (2022) reported that pesticide overuse increases both BOD and COD through organic content in runoff. The intensive and frequent pesticide applications observed in the study area may therefore contribute to elevated phosphorus loading and increased oxygen demand in surface water.

The water quality data from the Cibeureum River reflects significant ecological pressure from nearby farming activities. High levels of BOD, COD, and phosphorus are indicators of eutrophication and declining aquatic health. Compared to soil, pesticide pollution in water is more difficult to control due to runoff dynamics. Thus, sustainable pesticide and fertilizer management is essential to protect water bodies and maintain ecological balance in the region.

Economic Impact of Pesticide Use on Farmers

Pesticide use in agriculture presents measurable economic effects, especially in terms of purchase costs, crop yield increases, and expenses for environmental mitigation. Based on Figure 2, about half of farmers reported an annual pesticide purchase cost below Rp. 2,000,000, though a quarter spent more than Rp. 3,000,001, showing diverse financial commitments. For yield gains, most farmers reported an annual increase in crop yield after pesticide use below Rp. 2,000,000, while only 17% achieved

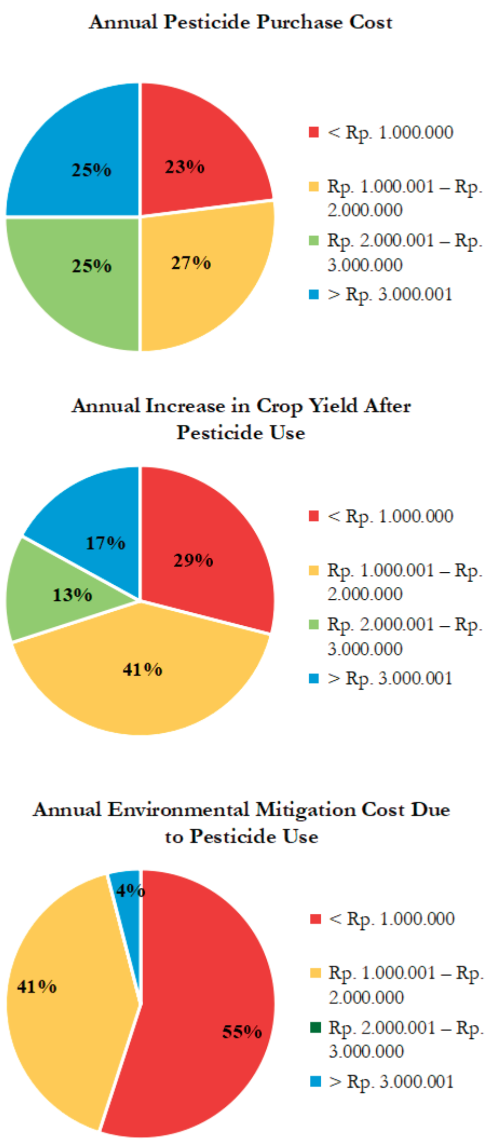

Figure 2. Economic impact variables of pesticide use in Parongpong District

more than Rp. 3,000,001. In contrast, annual environmental mitigation costs due to pesticide use remained low, with most farmers allocating less than Rp. 2,000,000. This pattern reflects an emphasis on short-term yield benefit, alongside limited investment in addressing long-term environmental risks.

Economic analysis of 100 farmers showed total annual expenditures (pesticide purchases and mitigation) of Rp. 295,000,000, while total benefits (yield increase) reached only Rp. 167,000,000. Economic analysis revealed a Benefit-Cost Ratio (BCR) of 0.57, indicating that pesticide use in the study area is financially inefficient, as costs exceed the monetary benefits of yield gains. This indicates that every Rp. 1,000,000 spent returns only Rp. 570,000 in benefit. As the BCR is below 1, the use of pesticides is financially inefficient (Hosseinpour *et al.*, 2022).

It is important to note that yield improvement is not solely attributable to pesticide application. Fertilizers play a central role in enhancing crop productivity, with pesticides mainly preventing losses from pests and diseases. Farmers in the study area reported regular fertilizer use, indicating that pesticide effects are complementary rather than independent. Recent studies show that efficient fertilizer use and integrated nutrient management significantly improve yields while reducing chemical inputs, and reductions in fertilizer and pesticide use are possible without significant yield loss if proper agronomic practices are applied (van Ittersum *et al.*, 2025). Table 5 presents the results of a survey on farmers' perceptions of the economic value of pesticide use.

Table 5. Farmers' perceptions of the economic value of pesticide use

Question	Yes (%)	No (%)
Do you think pesticide use is economically beneficial?	98	2
Do you believe pesticide costs are proportional to yield?	50	50
Have you experienced financial difficuly due to pesticide costs?	92	8

While 98% of farmers view pesticides as economically beneficial, half of them feel the costs are not proportional to yield. Additionally, 92% of farmers admitted experiencing financial difficulty from pesticide expenses. These findings contradict the BCR value of 57, which objectively indicates that pesticide use is not profitable. Farmers may be influenced by short-term yield improvements while overlooking hidden or long-term costs.

When considered alongside earlier findings on environmental impacts, a more integrated understanding of the impact of pesticide use becomes evident. The application of chemical pesticides has been linked to reduced soil fertility due to nutrient depletion, elevated concentrations of heavy metals such as cadmium (Cd) and lead (Pb) in agricultural soils, and a marked decline in surface water quality in the Cibeureum River. This deterioration is demonstrated by high levels of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Phosphorus (Total P), which indicate the presence of organic pollutants and nutrient overload.

While the large majority of farmers consider pesticide use to be economically beneficial, as reflected in survey responses, the calculated Benefit-Cost Ratio (BCR) of 0.57 reveals a different reality. This low ratio shows that the costs incurred from pesticide application, including purchase and mitigation expenses, exceed the financial gains from increased crop yield. Furthermore, the hidden environmental costs such, as soil degradation, water contamination, and ecosystem disruption, are often neglected in farmers' short-term cost-benefit assessments, leading to practices that are ultimately unsustainable and economically burdensome in the long term.

This gap between perceived economic advantage and actual financial inefficiency highlights the urgent need for a transition to more sustainable farming approaches. Encouragingly, some farmers in Parongpong have already begun adopting organic agriculture. This method, which avoids synthetic chemicals and instead focuses on improving soil health through natural inputs, presents a more sustainable and economically viable alternative. In support of this transition, local initiatives such as those led by

Figure 3. Organic farming activites in Parongpong

the *Semai Organik* Farmer Group and *Fam Organic Parongpong* have played a key role. These groups advocate for organic farming practices, deliver training programs for farmers, and utilize green-house systems to maintain productivity throughout the year while reducing environmental impacts. This positive development is visually illustrated in Figure 3, which showcases the organic farming activities undertaken by local farmer groups and producers in Parongpong, including greenhouse-based cultivation and environmentally friendly practices.

Such community-driven efforts represent a positive shift toward environmentally conscious agriculture. By rehabilitating degraded lands, minimizing reliance on chemical pesticides, and aligning agriculture practices with ecological and finansial sustainability, they offer a promising pathway for the future of farming in Parongpong and beyond.

CONCLUSION

Excessive pesticide use in Parongpong has reduced soil fertility, increased heavy metals, and significantly deteriorated water quality in the Cibeureum River, while economically it remains inefficient with a BCR of 0.57 despite farmers' perceptions of its benefit.

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