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Meeting report

A scoping review of agrochemical use in Southeast Asia: implications to health, socioeconomic, knowledge, interventions, and policies aspects

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ILRI

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Abstract

This scoping review aims to provide a comprehensive analysis of pesticide usage in Southeast Asia, focusing on its implications for health, socioeconomic status, knowledge gaps, interventions, and policies from 2014 to 2024. Agrochemicals, particularly pesticides, are integral to agricultural practices, yet their use is associated with significant public health risks and environmental concerns. The review synthesizes quantitative data on pesticide application trends across the region, revealing fluctuating usage patterns that vary by country and type of pesticide. Health implications include acute and chronic health risks, particularly among farmers and agricultural workers who are frequently exposed to harmful chemicals. The review highlights significant associations between pesticide exposure and adverse health outcomes, including respiratory issues, neurological damage, and mental health disorders. Furthermore, socioeconomic factors such as the economic dependence on agriculture and limited access to training exacerbate the reliance on hazardous pesticide mixtures.

Knowledge gaps persist regarding safe pesticide use, with many farmers exhibiting a disconnect between awareness of risks and the adoption of protective measures. The review identifies successful interventions that promote good agricultural practices (GAP) and ecological engineering, which can mitigate pesticide dependency and enhance sustainability. Additionally, policy recommendations emphasize the necessity of stricter regulations on pesticide use, improved monitoring systems, and the promotion of biopesticides as safer alternatives.

Overall, this scoping review underscores the urgent need for coordinated efforts among stakeholders to develop and implement effective strategies for managing pesticide use in Southeast Asia. By fostering a comprehensive understanding of the complexities surrounding agrochemical application, the review aims to guide future research, inform policy-making, and contribute to healthier, more sustainable agricultural practices in the region.

Contents

Introduction

Agrochemicals encompass a broad range of substances used in agriculture, including pesticides, fertilizers, growth regulators, and other chemical or biological agents. The Agrochemicals Act (Chapter 35:09) defines agrochemicals as:

"*Any organic, inorganic or live biological material intended or offered for sale for purposes of (a) destruction, control, repulsion, attraction or prevention of any undesirable life forms injurious to plant and animal growth; or (b) promotion or inhibition of plant growth such as fertilisers, growth regulators, hormones, defoliants or legume inoculants*" [1].

Among these agrochemicals, pesticides stand out due to their widespread use and significant impact, particularly in Southeast Asia [2], [3]. The application of pesticides has profound direct and indirect effects on human health, environmental quality, and agricultural sustainability. The use of pesticides involves a complex interplay of factors including efficacy, safety, environmental impact, and socioeconomic considerations, necessitating focused attention to fully understand the challenges and opportunities in the region.

Pesticides are subject to specific regulations and international conventions due to their potential hazards, making it crucial to understand the policy landscape for promoting responsible use. The rapid technological advancements in the chemical industry, including the development of new active ingredients and formulations, further underscore the importance of staying informed for effective decision-making.

The public health implications of pesticide use are significant, with both acute and chronic health risks posed to farmers, agricultural workers, and consumers. These health concerns drive much of the policy and research in the field. Additionally, pesticides can have far-reaching effects on ecosystems, including impacts on non-target organisms, water quality, and biodiversity. These environmental concerns are particularly relevant in the biodiverse landscapes of Southeast Asia [3].

The pesticide market represents a significant economic sector, with implications for trade, agricultural productivity, and farmer livelihoods [4]. While agrochemicals as a whole have contributed significantly to agricultural productivity, pesticides in particular have raised substantial concerns about environmental and health impacts. The intensive use of pesticides in Southeast Asian agriculture has led to issues such as pest resistance, ecological imbalances, and contamination of food and water resources [5].

This review aims to provide a comprehensive analysis of pesticide usage, associated challenges, and relevant policies in Southeast Asian countries, focusing on the period from 2014 to 2024. By concentrating on pesticides, we can delve deeper into specific issues surrounding their use. Understanding agrochemical use aspects is crucial for developing sustainable pest management strategies that balance agricultural productivity with environmental protection and public health in Southeast Asia. This focused approach will allow for a more nuanced and actionable set of insights to inform future research, policy-making, and agricultural practices in the region.

Objectives

The objectives of this scoping review are designed to provide a comprehensive understanding of pesticide use in Southeast Asia and its multifaceted impacts. Our primary aim is to conduct a thorough analysis of pesticide use patterns and trends across Southeast Asian countries from 2014 to 2024, offering insights into the types, quantities, and distribution of pesticides used in the region.

Building on this foundation, we seek to delve deeper into the human aspect of pesticide use by assessing the perceptions and attitudes of key stakeholders, including farmers, policymakers, and the public. This will provide valuable context for understanding the drivers and barriers to sustainable pesticide use practices.

A critical component of our review is the evaluation of the risks associated with pesticide use in Southeast Asia. We will examine the environmental, health, and socioeconomic impacts, considering both immediate and long-term consequences. This holistic approach will help identify the most pressing challenges facing the region in terms of pesticide management.

To address these challenges, we aim to review and evaluate existing interventions and policies aimed at mitigating the negative impacts of pesticide use. This will include an assessment of their effectiveness and potential for wider implementation or improvement.

Finally, our review seeks to identify knowledge gaps in current research and practice. By doing so, we aim to propose future research directions and policy recommendations that can contribute to more sustainable and responsible pesticide use in Southeast Asia. This forward-looking approach will help guide future efforts in balancing agricultural productivity with environmental protection and public health in the region.

Through these interconnected objectives, our scoping review aims to provide a comprehensive, nuanced, and actionable understanding of pesticide use in Southeast Asia, serving as a valuable resource for researchers, policymakers, and practitioners in the field.

Methods

Quantitative data on pesticide use:

The methodological approach for this scoping review is designed to capture a comprehensive and nuanced understanding of pesticide use in Southeast Asia. A mixed-methods strategy was employed that combines quantitative data analysis with an extensive review of both peer-reviewed and grey literature.

The foundation of the quantitative analysis rests on data from the FAOSTAT pesticide use domain [3]. This robust dataset provides annual pesticide use figures by major pesticide groups for all Southeast Asian countries from 2014 to 2024. This ten-year period allows us to identify significant trends and patterns in pesticide use across the region.

Literature review:

To complement this quantitative data, we conducted a thorough literature review. The search strategy utilized Boolean query syntax in major scientific databases such as NCBI and PubMed. The

selected keywords were described in table 1, that encompass various aspects of agrochemical use, including specific types of pesticides (e.g., bactericides, fungicides), their applications (e.g., in livestock, aquaculture, crops), and all Southeast Asian countries. This approach ensures we capture a wide range of relevant studies while maintaining focus on our specific research questions.

Recognizing the importance of non-academic sources in this field, grey literature was also incorporated into this review. This includes reports from national agricultural ministries, international organizations such as FAO, WHO, and UNEP, as well as relevant NGOs.

By integrating these diverse sources of information, the report aims to present a holistic view of pesticide use in Southeast Asia. The methodology allows to triangulate data from multiple sources, enhancing the reliability and comprehensiveness of our findings. This approach enables us to not only describe current pesticide use patterns but also to delve into the underlying factors influencing these patterns, the associated risks and challenges, and the effectiveness of current interventions and policies.

Through this multifaceted methodological approach, the review strives to provide a robust foundation for evidence-based policymaking and to contribute meaningfully to the development of more sustainable agricultural practices in Southeast Asia.

Table 1 Keywords used for search

Subject	Aspect of search	Keywords
Agrochemical use	Perception, risk, and intervention of pesticide in SE	((agrochemical) OR (bactericide) OR (herbicide) OR (fungicide) OR (pesticide)) AND (use) AND ((livestock) OR (aquaculture) OR (crop) OR (plant)) AND ((Brunei) OR (Cambodia) OR (Indonesia) OR (Laos) OR (Malaysia) OR (Myanmar) OR (Philippines) OR (Thailand) OR (Timor-Leste) OR (Vietnam) OR (Southeast Asia))

This review was guided by the questions: what are the attitudes and awareness of farmers and authorities to pesticide use? What are the risks to human health and the economy? Are there any interventions and policies to fix the problems? Questions focused on Southeast Asian (SEA) countries (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam).

The publications were reviewed with two steps. The first level of screening, title and abstract were screened for relevance. Next, all citations deemed relevant went through a review of the full text articles. Studies were eligible for inclusion if they explored the risks of pesticides to human health; environment and economy, awareness, or intervention to reduce pesticide use (Table 2).

Table 2. Inclusion and exclusion eligibility criteria applied during screening of articles to identify articles describing the impact of pesticides to health, socioeconomic, knowledge, interventions, and policies aspects in Southeast Asia.

Category	Inclusion	Exclusion

Geographic area	Southeast Asia (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam)	Any other region
Research topic	Impact of pesticide to agricultural and economic aspect	Describe genomic experiment, efficacy of pesticide, extraction
Publication date	1st January 2014 to 20th December 2024	Studies published before 2014
Study design	Peer-reviewed articles published in English Reports from FAO, WHO, UNEP and relevant NGOs	Review, commentaries, theses

The flow diagram of the literature search is as presented in Figure 1.

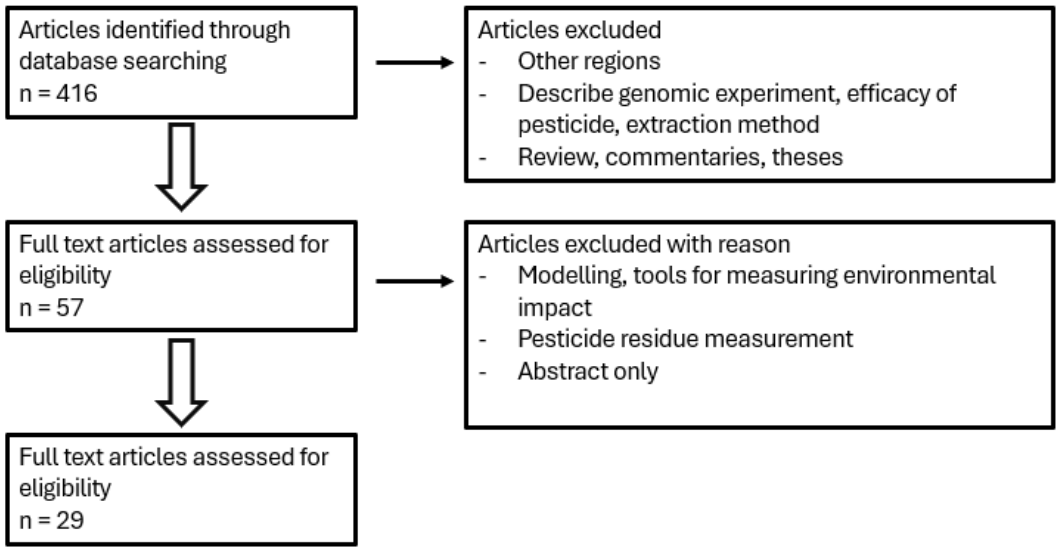

Figure 1. Flow diagram of articles, reports and documents screening and selection. The figure provides an overview of the strategy used to identify articles, reports and documents that met the inclusion criteria. In total, 29 studies met the inclusion criteria for this review.

Results and discussion

Patterns of pesticide use

Figure 2 shows that the total pesticide used in SEA countries fluctuated greatly. In 2014, around 450 thousand tons of pesticide was used, this peaked at nearly 600 thousand tons in 2016 before diving to 420 thousand tons in 2020. This number then increased to over 550 thousand tons in the over recent years (2021-2022).

However, the usage patterns of various pesticide types have shown distinct trends over recent years. Insecticide use has seen a notable increase, rising from 200,000 tons in 2014 to peak at nearly 300,000 tons in 2022, with some gentle fluctuations along the way. Fungicides and bactericides have followed a similar, albeit less dramatic, upward trajectory, climbing from roughly 90,000 tons to just over 100,000 tons by 2022. In contrast, herbicide usage has remained relatively stable, hovering around 140,000 tons in both 2014 and 2022, with one significant exception: a sharp spike to nearly 200,000 tons in 2016.

When examining the proportional use of these pesticides, a clear hierarchy emerges. Insecticides dominate the landscape, accounting for nearly half of all pesticide use. Herbicides follow, representing about 30% of total usage, while fungicides and bactericides combined make up the remaining 20%. This distribution underscores the agricultural sector's heavy reliance on insecticides compared to other pesticide categories, reflecting ongoing challenges in pest management and crop protection strategies.

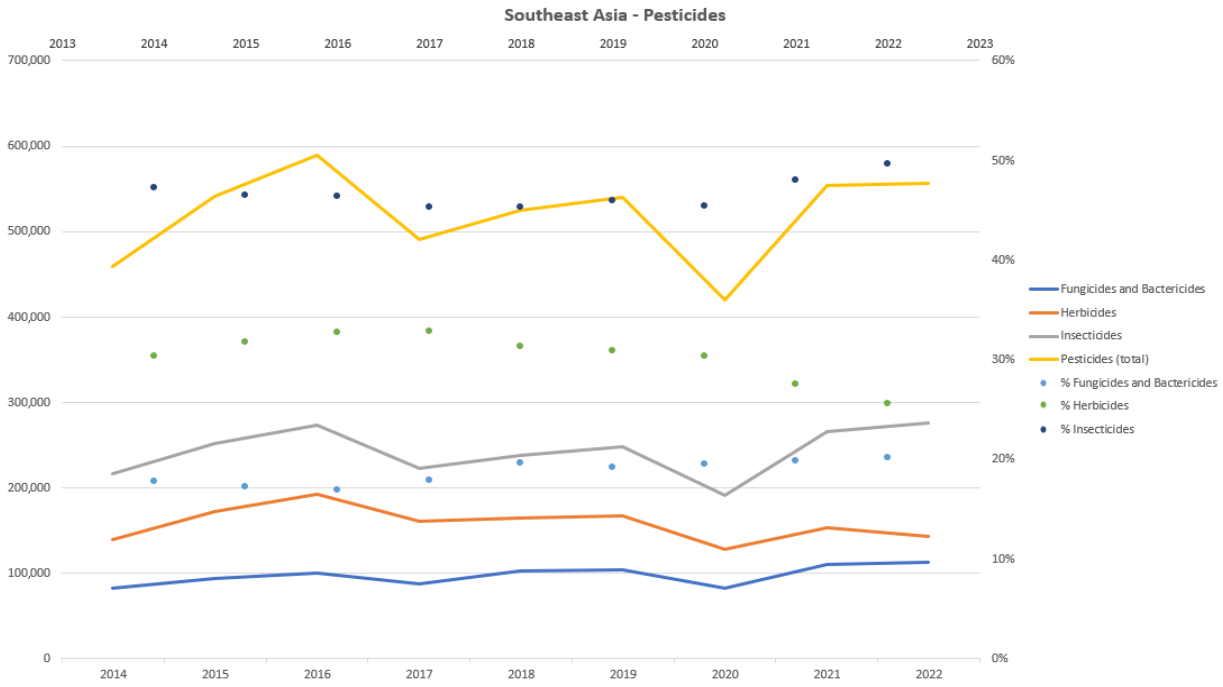

Figure 2. Pesticide use and the proportion of types of pesticides in SE between 2014 to 2022

Figure 3 provides a revealing snapshot of pesticide usage across Southeast Asian countries from 2014 to 2022. Indonesia and Vietnam stand out as the region's heavyweights in chemical consumption. Indonesia's usage reached a staggering peak of 350,000 tons in 2016, maintaining an impressive average of over 280,000 tons annually throughout the decade. Vietnam, not far behind, saw its pesticide use climb steadily, ultimately peaking at more than 160,000 tons in 2022, with an average annual consumption of 118,000 tons.

While not matching the scale of their larger neighbours, Cambodia and the Philippines have shown a consistent upward trend in pesticide use. By 2022, Cambodia's consumption had risen to 18,300 tons, while the Philippines reached 37,600 tons. This growth pattern contrasts sharply with the declining trends observed in Malaysia, Myanmar, and Thailand. Malaysia witnessed a significant

drop from 67,000 tons in 2016 to 25,600 tons in 2022. Similarly, Myanmar's usage fell from 17,300 tons to 11,700 tons over the same period. Thailand experienced the most dramatic decline, with consumption plummeting from over 34,000 tons in 2017-2018 to a mere 6,000 tons in 2022.

At the lower end of the spectrum, Timor-Leste and Brunei maintain minimal pesticide usage, with each country consistently using less than 300 tons annually. This diverse range of consumption patterns across Southeast Asia reflects the varying agricultural practices, environmental policies, and economic factors at play in each nation.

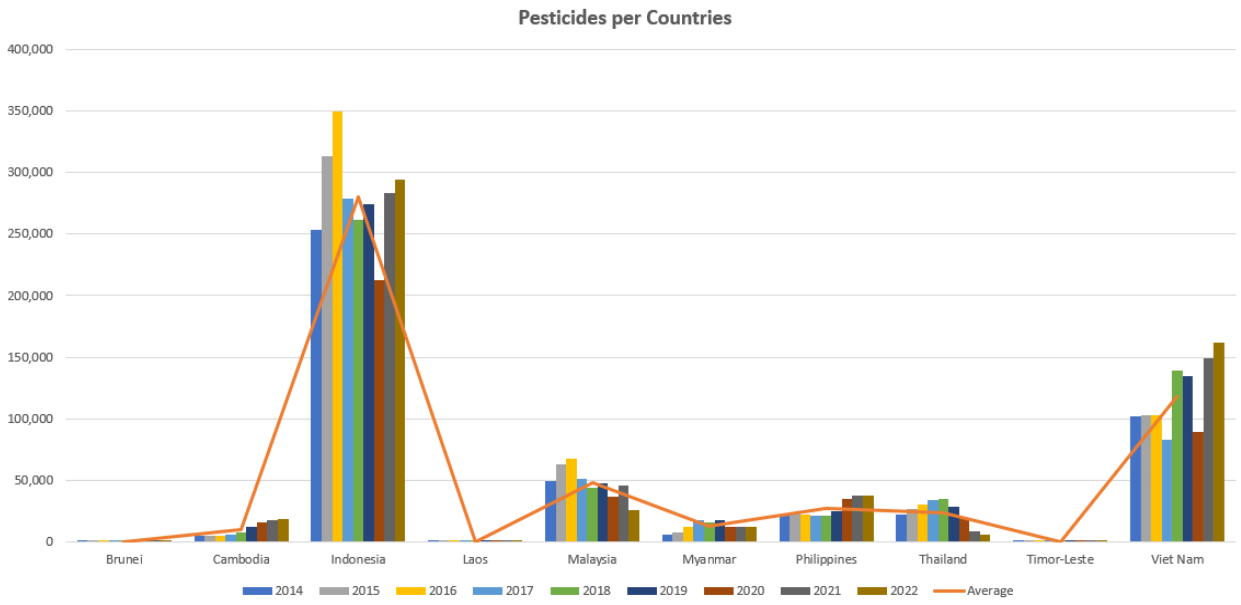

Figure 3. Pesticides usage in SE countries by years

Figure 4 paints a vivid picture of fungicide and bactericide usage across Southeast Asia, revealing a stark contrast between the region's top consumers and the rest. Indonesia and Vietnam stand out as the leaders, with average annual consumption rates of nearly 40,000 tons and 35,000 tons, respectively. These figures dwarf those of their neighbours, where usage rarely exceeds 10,000 tons per year.

The story becomes even more intriguing when we examine the trends over time. Vietnam, in particular, has seen a dramatic surge in usage. Starting from around 30,000 tons in 2014, the country's appetite for these chemicals grew steadily, reaching an impressive peak of nearly 45,000 tons by 2022. This upward trajectory is mirrored, albeit on a smaller scale, in the Philippines, Indonesia, and Cambodia, all of which have seen gradual increases in their fungicide and bactericide consumption.

However, not all countries follow this upward trend. Myanmar and Thailand present a striking counterpoint, with both nations experiencing significant declines in usage. Myanmar's consumption peaked at over 4,000 tons in 2017 but plummeted to just 1,700 tons by 2022. Thailand's drop was even more pronounced, falling from a high of nearly 8,000 tons in 2018 to a mere 2,000 tons in 2022.

These divergent patterns highlight the complex interplay of factors influencing agricultural practices across Southeast Asia. While some nations are ramping up their use of fungicides and bactericides, perhaps in response to changing climate conditions or evolving crop diseases, others are scaling back, possibly due to shifts in agricultural policies or growing environmental concerns. This dynamic landscape underscores the importance of continued monitoring and analysis of pesticide use in the region.

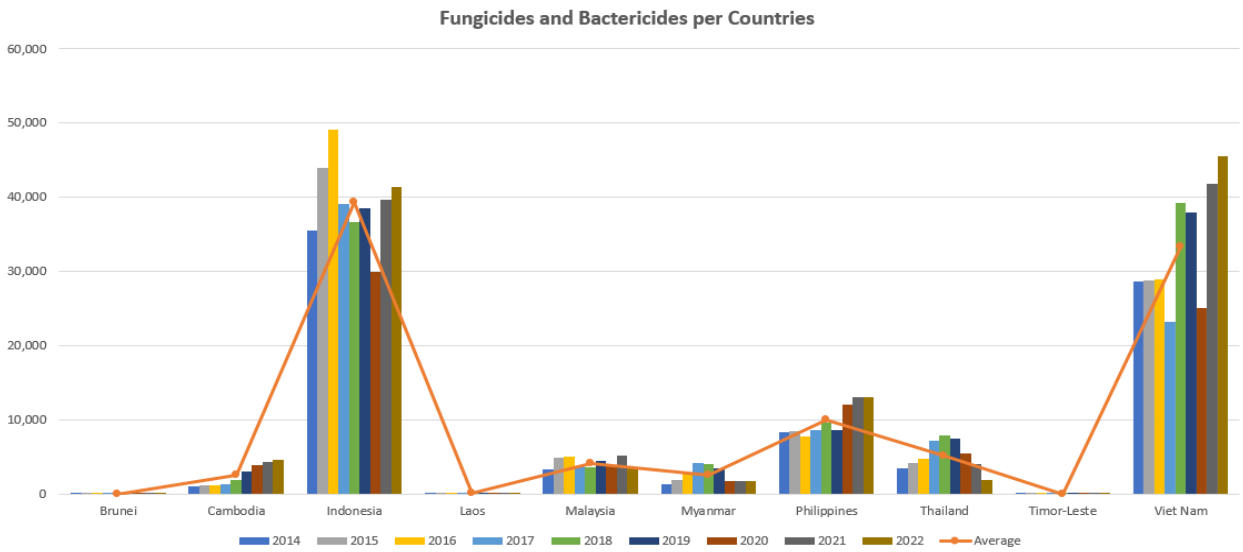

Figure 4. Fungicides and Bactericides used in SE countries by years

Figure 5 unveils a compelling story of herbicide usage across Southeast Asia, revealing a landscape dominated by three major players: Indonesia, Malaysia, and Vietnam. These nations stand far above their regional counterparts, with average annual consumption rates that dwarf those of their neighbours.

Indonesia leads the pack, consistently applying around 60,000 tons of herbicides each year, a testament to its vast agricultural lands and intensive farming practices. Malaysia follows closely behind, with an average annual usage of about 40,000 tons, while Vietnam rounds out the top three, typically consuming around 25,000 tons per year.

The next tier of herbicide users includes Thailand, the Philippines, and Myanmar, with average annual consumption rates of approximately 15,000, 10,000, and 5,000 tons respectively. However, these figures only tell part of the story. When we examine the trends over time, a more nuanced picture emerges.

Vietnam's herbicide use has been on a steady upward trajectory. From a starting point of 20,000 tons in 2014, the country's consumption has climbed consistently, reaching over 32,000 tons by 2022. This trend suggests an intensification of agricultural practices or an expansion of cultivated land areas.

In contrast, Indonesia's usage has remained relatively stable, fluctuating only slightly around its average. This consistency might indicate a well-established and stable agricultural sector with consistent practices.

The most dramatic changes, however, are seen in Thailand and Malaysia. Thailand's herbicide use has plummeted from a peak of around 25,000 tons in 2016-2018 to a mere 1,500 tons in 2022 - a staggering 94% reduction. Malaysia, too, has seen a significant decline, with usage dropping from 57,000 tons in 2016 to 16,000 tons in 2022, a decrease of nearly 72%.

These sharp reductions in Thailand and Malaysia could signal major shifts in agricultural policies, possibly driven by environmental concerns or changes in farming practices. They might also reflect the adoption of alternative weed management strategies or a transition to crops that require less herbicide use.

The diverse patterns observed across Southeast Asia highlight the complex and dynamic nature of agricultural practices in the region. As countries grapple with the challenges of food security, environmental sustainability, and economic development, their approaches to herbicide use continue to evolve, shaped by a myriad of factors from policy decisions to technological advancements.

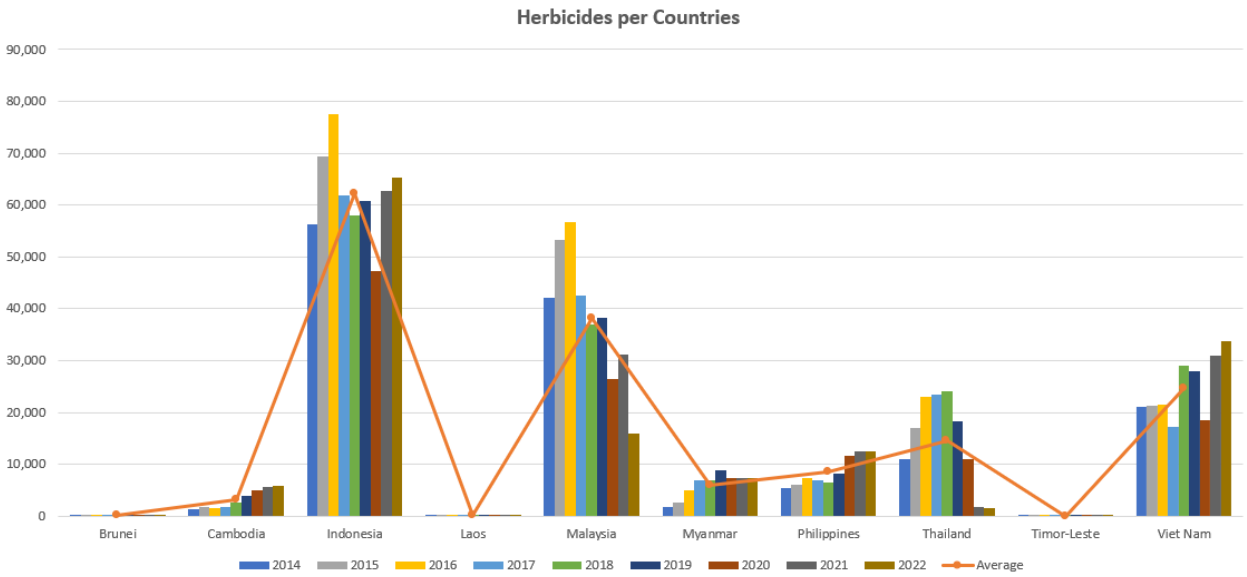

Figure 5. Herbicides used in SE countries by years

The story of insecticide usage in Southeast Asia, as revealed in the data, presents a fascinating and unique pattern. Two giants dominate this landscape: Indonesia and Vietnam, dwarfing their regional neighbours with their massive consumption rates.

Indonesia, the heavyweight champion of insecticide use in the region, consumes an average of 163,000 tons annually. However, this figure barely scratches the surface of the country's complex relationship with these chemicals. Indonesia's insecticide use has been on a rollercoaster ride over the years. In 2016, it reached a dizzying peak of over 203,000 tons, painting a picture of intensive pest management across its vast archipelago. But the story took an unexpected turn as

consumption plummeted to 124,000 tons in 2020. Insecticide use then rebounded to 171,000 tons by 2022.

Vietnam, while not matching Indonesia's scale, tells a story of steady growth. Starting from around 60,000 tons in 2014, the country's insecticide use has climbed gradually but consistently, reaching 82,000 tons by 2022. This upward trend hints at an expanding agricultural sector, possibly grappling with increasing pest pressures or intensifying farming practices.

The rest of Southeast Asia presents a stark contrast to these two giants. Other countries in the region maintain a much lower profile, each using less than 5,000 tons of insecticides annually. More intriguingly, their consumption patterns have remained relatively stable over the years, suggesting well-established agricultural practices or possibly stricter regulations on insecticide use.

This diverse landscape of insecticide use across Southeast Asia tells a tale of contrasting agricultural strategies, varying environmental policies, and differing approaches to pest management. As the region continues to balance the demands of food security with environmental sustainability, the story of insecticide use will undoubtedly continue to evolve, shaped by technological advancements, policy shifts, and changing climate conditions.

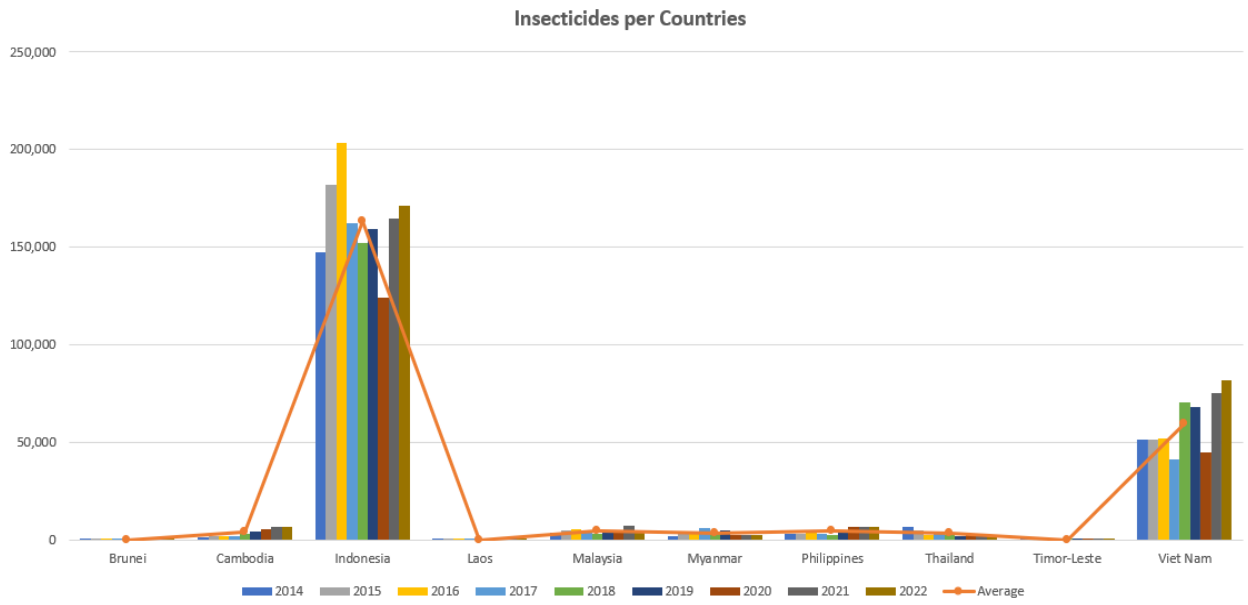

Figure 6. Insecticide use in SE countries by years

Critical pesticides of concerm

A summary of health risks caused by pesticides, farmer's awareness and recommendations found from the reviewed article was shown in table 3.

Table 3. Research Findings Summary: Health risks, Farmer awareness and Recommendation in Southeast Asia

Area	Research topic	Key issues	Recommendation
Cambodia [7] [28]	Factors influencing Poisoning symptoms	Nervous system, gastrointestinal and Respiration Symptoms This study found that mixing an average of four to six types of insecticides (odds ratio [OR] = 4.6; P = .03) and abnormal ChE level (OR = 4.09; P = .004) was associated with central nervous system (CNS) symptoms. Age group >45 years (OR = 2.8; P = .04) and type of vegetable "other" (OR = 2.73; P = .02) were associated with gastrointestinal symptoms. Type of insecticide, organophosphates (OPs) and carbamates (CMs) (OR = 3.2; P = .04), was associated with respiratory symptoms. It is recommended that farmers should reduce insecticide spraying times, increase their use of personal protective equipment (PPE), and undergo training on insecticide use. These combined measures should improve the insecticide-related health status of vegetable farmers in this area.	
	Pesticide residue	Risk analysis showed that bromophos-ethyl, dichlorvos, and iprobenfos presented a very high risk to aquatic organisms in both the dry and rainy seasons, with risk quotient values of 850 for both seasons, of 67 in the dry	The urgent need for monitoring and improving pesticide practices and regulations in the region.

		season and 78 in the rainy season for bromophos-ethyl, 49 in the dry season and 16 in the rainy season for dichlorvos. Overall, this work highlights the occurrence of pesticide residues in surface water and soil along the Mekong River in Cambodia and emphasizes the urgent need for monitoring and improving pesticide practices and regulations in the region.	
Thailand [4], [6], [8], [10], [12], [16], [17], [19], [25]. [29], [30]	Factors affecting safe pesticide use behaviors	This study revealed that the factors affecting safe pesticide-use behaviors among farm plant agriculturists included knowledge about pesticide use, social support, reading pesticide container labels, perceived self-efficacy in the modification of pesticide-use behaviors, gender, rice farmer status, corn farmer status, perceived susceptibility to pesticide use, having received information from the internet, and perceived severity of impact from pesticide use.	Our findings indicate that there is a need to increase the number of promotional activities related to the safe use of pesticides through social support and training, with the aim of increasing the overall level of knowledge, perceived self-efficacy, perceived susceptibility, and modification of the perceived impact severity of pesticide use. Thus, relevant agencies should promote and support the safe use of pesticides by farm plant agriculturists.
	Health risk assessment	Dermal exposure of Chlorpyrifos The results showed that chlorpyrifos concentrations were greater in males (526.34 ± 478.84 mg/kg)	

		than females (500.75 ± 595.15 mg/kg). Average daily dose sampled from seven points on male and female farmers were 31.72 × 10−4, 193.32 × 10−4, 5.38 × 10−4, 190.48 × 10−4, 170.47 × 10−4, 465.91 × 10−4, and 43.04 × 10−4 mg/kg-day. The hazard quotient (HQ) at the mean and 95th percentile level was found to be greater than acceptable (HQ > 1). Rice growing farmers in this area may be at risk for adverse health effects due to continuous dermal exposure to chlorpyrifos from their improper use of personal protective equipment (PPE).	
	Pesticide exposure	These findings suggest that Pyrethroid use in rice farms and households may be significant sources of PYR exposure among children living in agricultural areas.	
	Pesticide exposure	6–8-year-old Thai children have significantly higher exposures to OPs than US children of similar age and a sample of US farm children. Rice farm children have significantly greater exposure to OP pesticides than aquaculture children.	
	Pesticide exposure	Positive significant associations were found between some OP pesticides and total testosterone	
	Pesticide toxicity	When examining the association between health literacy and pesticide use behaviors, we found that functional literacy was significantly associated with pesticide use behaviors. This suggests	It may be necessary to develop approaches to reduce pesticide use and promote health literacy, thereby protecting

		that health literacy, which includes self-management and decision-making skills, should be given greater attention as pesticide use behaviors were unsafe.	farmers, consumers, the environment (soil, water, and air) and ecosystems from pesticide-related hazards.
	Pesticide residue/release/pollution	In aquaculture, near Bangkok, water quality was severely affected by urban pollution in the canals. Aquaculture activity released herbicides/algaecides into canals. Extensive aquaculture attenuated faecal pollution inputs from the canals.	
	Occupational exposure	These results demonstrated that farmers experience multiple exposure to pesticides(?) while farming and that risk communication with education or training programs may mitigate exposure.	
	Pesticide exposure effect mental health	About 86.7% reported having used pesticides on their crops at some point in their lives—mostly glyphosate, paraquat, 2,4-D, methomyl, and carbofuran. All functional groups, as well as pesticide classes like organochlorines, organophosphates, and carbamates, were significantly associated with a higher risk of probable mental disorder based on exposure duration, frequency, personal protective equipment usage, and hygienic behavior. In a model with multiple pesticides, there was an association between mental disorder and	Consequently, an intervention to provide knowledge and training on the potential risks of occupational pesticide exposure as well as prevention of mental disorders among Thai farmers should be considered. Furthermore, the effects of pesticide exposure on mental health conditions should be of concern to governments.

		exposure to endosulfan (AOR = 2.27, 95%CI = 1.26–4.08) and methyl parathion (AOR = 2.26, 95%CI = 1.26–4.06). Having previously reported pesticide poisoning symptoms was related to mental disorder (AOR = 7.97, 95%CI = 5.16–12.31), the findings provided evidence of pesticide exposure posing a risk to farmers' mental health, particularly from long-term and high-intensity exposure.	
	Intervention, policy		We find that Thailand has adopted a biopesticide registration system that facilitates a fast-track registration, but it is still relatively costly considering the small market size. While 65 % of the sampled farmers used biopesticides, most farmers still heavily relied on conventional pesticides as their main method to control pests. Education, farming experience, positive attitudes of biopesticides, adoption of other integrated pest management methods and contacts with government extension agents were positively

			associated with biopesticide use. Coordinated action is needed to stimulate the supply of a wider range of biopesticide products while promoting adoption among farmers.
	Behaviour	Thai farmers had a mean health literacy (HL) score of 34.7 ± 8.7, and the farmers in the northern region of Thailand had the highest frequency of limited HL (75.8%). Socio-demographic factors that were associated with HL included gender, region of living, marital status, education level, co-morbidity, and number of family members. Agricultural factors associated with HL included planting status, working hours on farm, spraying pesticides, harvesting crops, pesticide use of >1 type, access information from government officers, access information from posters/brochures, information from online multimedia, and access information from neighbours. Personal protective factors that were associated with HL included wearing a hat, goggles, a rubber apron, and a long-sleeved shirt.	Our study recommends that strategies and interventions to enhance the HL of farmers should be focused on the target populations, which include men, widows, or divorcees, those with low levels of education, those who have co-morbidities, and those who applied pesticides of more than 1 type, and improper personal protective equipment (PPE) use.
The Philippines[9], [14]	Pesticide exposure	The farmers and farm workers also reported pesticide-related illnesses but none of them sought any medical attention.	

		Intervention to reduce farmers' pesticide exposure can focus on the risk factors identified, primarily the toxicity of pesticides used, the unsafe application practices, and the adverse health effects of pesticide exposure.	
	Pollution and Occupational health of vegetable farmers	The use of insecticides was associated with weakness, easy fatigability, and weight loss.	
Vietnam [11], [13] , [15], [20], [21] ,[23], [31], [33]	Pesticide exposure	Chlorpyrifos used in rice farming inhibit the brain AChE activity in Climbing Perch. The inhibition of the AChE activity is followed by decreased growth and survival rates.	
	Pesticide accumulation	Twelve commonly used pesticides have been detected in a dyked area. Soil under paddy rice contain hydrophobic pesticides. Sediment of irrigation ditches contains frequently the same pesticides as in the soil.	
	Pesticide residue	Residues of pesticides were present in all agricultural land use systems, including shrimp aquaculture. Active ingredients were mostly fungicides with a maximum concentration of 67 µg kg−1 found for isoprothiolane in permanent rice systems, followed by alternating rice-shrimp and permanent shrimp systems. All concentrations were below critical lethal threshold values.	
	Influences of agrochemicals on health and ecology	The findings indicate that the ecology component is undergoing the most negative impact from	Science information needs to be closely linked and fed back to policy

		excessive agrochemical use in mango farming. The article results also show that mango cultivation should consider rejecting the banned active ingredients of glyphosate, paraquat, and carbendazim as well as reducing fungicide and paclobutrazol usage and encouraging cooperative participation to safeguard the environment and human health.	development to boost the management of the awareness of the ecological risks for farmers associated with reducing agrochemical use in mango cultivation.
	Recommendation		Two seasons of field trials were conducted to compare different crop establishment practices for rice production in the Mekong River Delta using environmental and economic sustainability performance indicators. In comparison with direct seeding methods, mechanized transplanting decreased the seed rate by 40%. It also led to a 30–40% reduction in pesticide use during the main crop season (WS).
	Pesticide residue	Among the ten target pesticides, cypermethrin, difenoconazole, and fenobucarb were detected at the highest frequencies (72%, 41%, and 37%, respectively). Pesticide	The paper provides recommendations for mitigation measures (both technological and social) in reducing

		residues varied between seasons at both study provinces. Pesticide contamination in the wet season was significantly higher than in the dry season. This study also discovered a potential health risk associated with fipronil residues in vegetables in Thua Thien Hue province.	potential health risks linked to pesticide use in vegetables in the region.
	Pesticide hazard	Data for 184 eligible participants were analyzed, including 116 farmers in the pesticide spray group and 68 non-farmers in the control group. Pesticide spray contributed to a decrease in the sperm quality index of 6.253 units (95% CI, 4.472–8.749).	Preventive methods for organophosphate pesticide exposure, such as administrative controls, engineering controls, substitution, and personal protective equipment should be applied to control health risks. In the An Giang setting, personal protective equipment is feasible, but most types of equipment are not used. The immediate priority is to determine the cause of personal protective equipment not being used and to find solutions to encourage people to use them.
	Pesticide effects on bees	The four bee species (the Asian honey bee (*Apis cerana*), the European honey bee (*A. mellifera*), the giant honey bee (*A.*	These findings highlight the need to develop a pesticide risk assessment and

		dorsata), and the red dwarf honey bee (*A. florea*)) differ in degree of sensitivity to the insecticides: bifenthrin, imidacloprid, thiacloprid, thiamethoxam, and chlorantraniliprole. The results indicated significant variability in toxicity among the pesticides and honeybee species, with the managed species *A. cerana* showing the highest tolerance across all tested insecticides. In contrast, the wild species *A. dorsata* and *A. florea* were significantly more sensitive.	improve pesticide regulations that consider the impacts on a broader range of honeybee species beyond *A. mellifera*.
Indonesia [18], [22], [26]	Cumulative exposure	Seventy-one subjects (46.7%) were classified as the high exposure group. The use of multiple pesticide mixtures was common among our study population, with 94% of them using 2 or more pesticides. 73% reported direct contact with concentrated pesticides product, and over 80% reported being splashed or spilt during preparation or spraying activity. However, we found that the proportion of proper personal protective equipment (PPE) use in our subjects was low. Higher volumes of mixture applied ($p < 0.001$) and broader acres of land ($p = 0.001$) were associated with higher cumulative exposure level, while using long-sleeved clothes and long pants ($p < 0.05$) during pesticide spraying were associated with lower cumulative exposure after	Recommend comprehensive training on pesticide usage and encourage proper PPE to reduce the exposure level.

		adjusted for age and gender.	
	Farmers' knowledge and practice	A high level of knowledge does not mean that farmers will apply this knowledge in practice: this is particularly relevant to wearing gloves and masks, using tools to remove blockages, never clearing blocked nozzles by blowing into them, and disposing empty containers properly. Cases of pesticide exposure affecting human health by causing symptoms such as dizziness, nausea, and vomiting confirm that GAP for pesticide usage are not being implemented properly by some farmers.	It is therefore recommended that their knowledge should be enhanced through the series of technical training programs using participatory approaches, so that farmers accumulate knowledge which will drive them to adopt GAP for safe pesticide usage.
	Contaminants of emerging concerns (CECs) in a municipal wastewater treatment plant	The concentrations of most CECs were within the range of those reported in Southeast Asia and the rest of Asia. *N*-Diethyl-*meta*-toluamide (DEET) concentration was significantly higher than those recorded in wastewater in Asia.	
The Philippines [5]	Intervention	Smallholder farmers in Southeast Asia produce rice in flooded plots (<2 ha) surrounded by raised levees (bunds). To decrease pesticide use among farmers, researchers have promoted ecological engineering as a series of practices that optimize farm diversification to enhance the activities of pests' natural enemies and reduce pest damage. This study examined the impact of farm diversification and other sustainability practices on pesticide use	Farmers with relatively high awareness of the beneficial insects that occurred on their farms, who raised ducks in their rice fields, or who planted flowers or vegetables on their bunds tended to perform fewer pesticide applications on their rice crops. We recommend that flower and vegetable strips

		by rice farmers in the Philippines.	be combined with a series of other environmentally friendly pest management options to enhance the outcomes of ecological engineering on rice farms.
Laos and Vietnam [2]	Agrochemical use	Poverty, while influencing agrichemical use in different ways, is also a factor for households in both countries. In both Vietnam and Laos, the management of pests and diseases is important to satisfy consumer expectations and meet commercial demands making them key drivers for risk-taking in relation to agrichemical use. In upland areas of Laos, production pressures presented by labour shortages, especially in maize production areas, have intensified reliance on agrichemicals. Across both countries, sustaining a livelihood is a primary driver of household decision-making around agrichemical use. Across the literature, and in current international forums, the majority of training programs designed to strengthen safe use tend to view farmers and users as having the primary responsibility for improving practice. Training in safe practice is considered a primary mechanism to enable practice change. Our case studies showed that formal training	Repositioning the problem of unsafe agrichemical use away from being the primary responsibility of farmers is necessary to improve current practices and outcomes. Future research opportunities could focus on intensive (social science-led) study of agrichemical use in specific agroecological or socio-cultural settings, including alternatives to agrichemical applications including traditional pest and weed management knowledge. For remote qualitative research settings, we recommend considerable time is set aside for selection of novel data collection methods which suit the research question but also

		programs captured some farmers but not others. The information retained in these forums was also mediated by the farmer's own experience, a neighbour's or family member's advice, and a farmer's level of trust in the training provider. Perceptions of poor quality, ineffective and 'fake' products were commonly attributed to products originating from China, and these also influenced farmers' usage decisions more broadly. While personal protective equipment (PPE) is internationally recognised as important for risk reduction, and mostly inexpensive and easily accessible across both countries, our case studies revealed equipment oftentimes was substandard and advice was not consistently followed, nor aligned with farmer comfort, especially in humid environments. This was despite farmer's knowledge of the risks of not wearing full protective equipment during application. Farming families in Laos shared stories of illness and death in their communities, attributed to mixing or spraying highly toxic chemicals without adequate protection.	the needs of participants involved. The ethical and cultural sensitivities of conducting research on the topic of unsafe agrichemical use should not be underestimated. Projects that seek to investigate agrichemical use require strong and trusted relationships between research staff and research participants. Identifying opportunities to build on new research collaborations and partnerships is important to ensure momentum is not lost. Building core organisational capability in social science (esp. qualitative methods) is required if research questions are to move away from quantifying dosage rates and application techniques.
Southeast Asia [32]	FAO	Many countries around the globe have adopted a pesticide risk management framework which incorporates a range of functions and activities	The Food and Agriculture Organization (FAO), World Health Organization

		including pesticide registration, MRL setting, approval of a pesticide product label, farmer education, pesticide control-of-use regulation, food traceability, verification of good agricultural practices, national residue monitoring programmes, facilitation of trade and market access, traceback investigation and pesticide review.	(WHO), Codex Alimentarius, and members recognize the need for a comprehensive framework for pesticide residue management though science-based risk assessment, management, and communication. Member countries recognize that a sound pesticide residue framework does not rely only on residue monitoring, but it importantly includes at the very least pesticide registration, chemical control-of-use, traceback investigation and a chemical review process. In consultation with the ASEAN Health Cluster 4: Ensuring Food Safety, these findings are the results of a meeting that occurred on 25 August 2020 and it elaborates on the responses from a questionnaire designed to assess the situation responses to the comprehensive questionnaire

			issued on 12 September 2020.
Southeast Asia, mainly in Indonesia and Malaysia [24]	Anticoagulant rodenticides exposure hazards to mammalian carnivores	Anticoagulant rodenticides (Ars) are a secondary exposure hazard to rodent-consuming mammalian carnivores, such as leopard cats and civets, and rodent-consuming raptors, such as barn owls. Consumption of dead, poisoned prey puts scavengers, such as water monitors, at high risk for Ars exposure. Domestic livestock and granivorous birds are at high risk for Ars exposure via primary exposure to toxic bait, while omnivores such as macaques and wild pigs are at moderate risk for both primary and secondary exposure to Ars. The effects of ARs on barn owls have been well studied in the field and in laboratory secondary toxicity studies. Thus, the nest-box occupancy and reproductive parameters of local barn owl populations can be monitored as an indicator of the AR exposure level in the area.	

Health implications

Numerous studies highlight the significant health risks associated with pesticide exposure in Southeast Asia. In Thailand, research indicates that rice farmers face elevated health risks due to dermal exposure to chlorpyrifos, with hazard quotients exceeding safe levels [6]. Studies in Vietnam reveal that agricultural workers experience a range of pesticide-related illnesses, including respiratory and neurological symptoms related to the use of organophosphates and carbamates [7, 20].

Long-term exposure to pesticides has been linked to severe health outcomes. A study in Thailand found associations between pesticide exposure and mental health disorders [25]. Another Thai study observed positive associations between certain organophosphate pesticides and total testosterone levels, suggesting potential endocrine disruption effects [12].

Children in agricultural areas are particularly vulnerable to pesticide exposure. Research in Thailand found that children living in rice farming areas had significantly higher exposures to

organophosphates than children in the United States, including those from farming families [8]. Additionally, pyrethroid use in rice farms and households was identified as a significant source of exposure for children in these areas [8].

In Cambodia, a study found that mixing multiple types of insecticides and having abnormal cholinesterase levels were associated with central nervous system symptoms among farmers [7]. Age and specific vegetable types were linked to gastrointestinal symptoms, while the use of organophosphates and carbamates was associated with respiratory symptoms [7].

In the Philippines, farmers reported pesticide-related illnesses, including weakness, easy fatigability, and weight loss associated with insecticide use [14]. However, many did not seek medical attention, highlighting a concerning gap in healthcare access and utilization [9].

Environmental concerns are also significant. In Vietnam, studies have shown that chlorpyrifos used in rice farming inhibits brain acetylcholinesterase activity in fish, leading to decreased growth and survival rates [11]. This underscores the broader ecological impacts of pesticide use in the region.

Socio-economic impacts

The socioeconomic factors influencing pesticide use in Southeast Asia are complex and multifaceted. In both Vietnam and Laos, poverty significantly influences agrochemical use, albeit in different ways [2]. The management of pests and diseases, meeting consumer expectations, and satisfying commercial demands are key drivers of risk-taking behavior related to agrochemical use across both countries [2].

In upland areas of Laos, labor shortages, particularly in maize production, have intensified reliance on agrochemicals [2]. This highlights how economic pressures can lead to increased pesticide use, potentially at the expense of health and environmental considerations.

The economic dependency on agriculture often compels farmers to utilize multiple and often hazardous pesticide mixtures. A study in Indonesia found that 94% of farmers used two or more pesticides, leading to high levels of cumulative exposure [18]. This practice not only increases health risks but also creates a cycle of dependency that undermines the long-term sustainability of farming practices and affects community health and well-being [2].

In Thailand, research has shown that factors such as education level, farming experience, positive attitudes towards biopesticides, adoption of integrated pest management methods, and contact with government extension agents were positively associated with biopesticide use [29]. This suggests that socioeconomic factors and access to information play crucial roles in shaping farmers' choices regarding pesticide alternatives.

Knowledge and training gaps

Despite relatively high awareness of pesticide risks, significant gaps exist in the practical application of this knowledge among farmers across Southeast Asia. In Indonesia, a study found that while farmers had a high level of knowledge about pesticide risks, this did not necessarily translate into safe practices, particularly regarding the use of personal protective equipment (PPE) and proper disposal of empty containers [22].

In Thailand, research revealed that functional health literacy was significantly associated with pesticide use behaviors [16]. This suggests that improving farmers' ability to understand and apply health-related information could lead to safer pesticide practices. Another Thai study found that factors affecting safe pesticide-use behaviors included knowledge about pesticide use, social support, reading pesticide container labels, and perceived self-efficacy in modifying pesticide-use behaviors [4].

A study in Cambodia highlighted the need for training on insecticide use, emphasizing the importance of reducing spraying times and increasing the use of PPE [7]. Similarly, research in the Philippines identified a lack of knowledge about safe pesticide use as a key factor contributing to unsafe practices [9].

In Vietnam and Laos, while formal training programs reached some farmers, their effectiveness was mediated by farmers' own experiences, advice from neighbors or family members, and trust in the training provider [2]. This underscores the complex interplay between formal education and local knowledge systems in shaping pesticide use practices.

Interventions

Various interventions have been implemented across Southeast Asia to address the challenges associated with pesticide use. In Thailand, a pesticide training program for female farmworkers in Nan province demonstrated effectiveness in reducing pesticide exposure and enhancing safety [27]. This highlights the potential of targeted education initiatives in improving pesticide-related health outcomes.

Ecological engineering approaches have shown promise in reducing pesticide dependency. A study in the Philippines found that farmers who raised ducks in their rice fields or planted flowers or vegetables on their bunds tended to perform fewer pesticide applications [5]. This suggests that promoting agricultural diversification can be an effective strategy for reducing pesticide use.

In Vietnam, field trials comparing different crop establishment practices for rice production showed that mechanized transplanting led to a 30-40% reduction in pesticide use during the main crop season [21]. This demonstrates how technological interventions can contribute to more sustainable farming practices.

The promotion of biopesticides has been identified as a potential intervention to reduce reliance on chemical pesticides. In Thailand, while 65% of sampled farmers used biopesticides, most still heavily relied on conventional pesticides as their main method of pest control [29]. This suggests that while there is potential for biopesticide adoption, more comprehensive strategies are needed to facilitate a broader transition.

Policy recommendations

Effective policy frameworks are crucial for managing pesticide risks and promoting safer agricultural practices across Southeast Asia. In Thailand, recommendations include the need for stricter regulations on pesticide use, improved monitoring systems, and the promotion of biopesticides as safer alternatives [29]. The study also emphasized the importance of coordinated action to stimulate the supply of a wider range of biopesticide products while promoting adoption among farmers.

In Cambodia, research has highlighted the urgent need for monitoring and improving pesticide practices and regulations, particularly in light of the occurrence of pesticide residues in surface water and soil along the Mekong River [28].

A regional assessment of pesticide monitoring programs in ASEAN countries underscored the need for a comprehensive framework for pesticide residue management. This framework should incorporate science-based risk assessments, management, and communication, and include elements such as pesticide registration, chemical control-of-use, traceback investigation, and a chemical review process [32].

In Vietnam, policy recommendations include the need for preventive methods for organophosphate pesticide exposure, such as administrative controls, engineering controls, substitution, and improved use of personal protective equipment [33]. The study also emphasized the importance of determining the causes of low PPE usage and finding solutions to encourage their use.

Across the region, there is a recognized need for policies that promote sustainable pest management strategies, balancing agricultural productivity with environmental protection and public health. This includes supporting research into alternative pest control methods, enhancing farmer education programs, and developing more robust regulatory frameworks for pesticide use and monitoring [2, 5, 29, 32].

Discussion

The data on pesticide usage across Southeast Asian countries from 2014 to 2022 shows divergent trends that reflect the diverse agricultural practices, economic priorities, and regulatory environments in the region. While countries like Indonesia and Vietnam have maintained high levels of pesticide use, others such as Thailand and Malaysia have shown dramatic reductions [3]. These contrasting patterns suggest that some countries may be adopting more sustainable agricultural practices or implementing stricter regulations, while others continue to rely heavily on chemical inputs to maintain crop yields.

The dominance of insecticides as part of pesticide across the region [3] aligns with the reported health impacts, particularly neurological and respiratory symptoms associated with organophosphate and carbamate use [7, 20]. This correlation underscores the urgent need for targeted interventions to reduce reliance on these harmful chemicals.

Health and Environmental Impacts The health implications of pesticide use in Southeast Asia are severe and wide-ranging. From acute poisoning symptoms [7] to long-term effects on mental health [25] and potential endocrine disruption [12], the evidence points to a significant public health crisis. The vulnerability of children to pesticide exposure in agricultural areas [8] is particularly concerning, highlighting the need for more comprehensive protection measures that extend beyond occupational safety to community-wide interventions. More to this environmental impacts, such as the effects of chlorpyrifos on fish populations in Vietnam [11], demonstrate the far-reaching consequences of pesticide use on ecosystems. This ecological dimension adds urgency to the need for sustainable pest management strategies that consider both human and environmental health.

Socioeconomic factors and knowledge gaps

The review reveals a complex interplay between socioeconomic factors and pesticide use practices. Poverty, labour shortages, and commercial pressures often drive farmers towards increased pesticide use [2, 18]. However, the finding that factors such as education, positive attitudes towards biopesticides, and contact with extension agents who are associated with more sustainable practices [29] offers potential pathways for intervention.

The persistent gap between knowledge and practice in pesticide use [22] is a critical issue that requires attention. While farmers often demonstrate awareness of risks, this does not consistently translate into safe practices. This disconnect suggests that interventions must go beyond a simple knowledge transfer to address deeper behavioral and structural barriers to change.

Promising interventions and policy directions

Several promising interventions emerge from the review, including targeted training programs [27], ecological engineering approaches [5], and the promotion of biopesticides [29]. These diverse strategies suggest that a multi-faceted approach is necessary to effectively reduce pesticide dependency and its associated risks.

The policy recommendations highlighted across various studies [28, 29, 32, 33] converge on several key points: the need for stricter regulations, improved monitoring systems, and support for alternative pest management strategies. The emphasis on comprehensive frameworks that include pesticide registration, control-of-use, and review processes [32] indicates a growing recognition of the need for systemic approaches to pesticide management.

Conclusion

This scoping review provides valuable insights into the complexities surrounding pesticide use in Southeast Asia, emphasizing the urgent need for ongoing research and policy development. The intricate interplay between agricultural practices, public health, and environmental sustainability shapes the region's approach to pesticide use. The documented health risks associated with pesticide exposure, coupled with the socio-economic pressures that compel farmers to rely on these chemicals, highlights the necessity of effective interventions.

Future efforts must focus on enhancing farmer education and awareness regarding the safe use of agrochemicals and the long-term benefits of adopting sustainable practices. Policies promoting biopesticides and agroecological methods should be prioritized to mitigate health risks while preserving productivity. Collaboration among stakeholders including governmental bodies, NGOs, and local communities—will be essential to create a comprehensive framework for responsible pesticide management and agricultural innovation.

In conclusion, addressing these challenges requires a coordinated effort to leverage local knowledge and scientific research, thereby ensuring that pesticide use in Southeast Asia aligns with the broader goals of health safety, environmental protection, and food security. By identifying knowledge gaps and promoting sustainable practices, this review contributes to the development of actionable strategies for enhancing the agricultural landscape in the region.

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The **ASEAN-CGIAR Innovate for Food and Nutrition Security Regional Program** is a research collaboration among the ASEAN Member States, ASEAN Secretariat, and CGIAR Centers, with funding support from the government of Australia and the United Kingdom. The program's vision for the next 10 years is to scale up and out bold integrated innovations that will enhance the resilience of ASEAN's agri-food systems to climate change. This ambitious endeavor aims to deliver better livelihoods for food producers and other stakeholders along the value chain. It also seeks to ensure more affordable, nutritious, and healthy food for consumers while fostering a healthier natural environment for all.

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