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Pesticide use in Thailand: Current situation, health risks, and gaps in research and policy

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Abstract

Agriculture in Thailand, which employs over 30 percent of the workforce and contributes significantly to the country's gross domestic product, is a key sector of its economy. Import and use of pesticides has increased over the past decade due to Thailand's major role as a leading exporter of food and agricultural products. The widespread and poorly regulated use of pesticides presents a potential risk to the health of farmers, farm families, the general population including children and the environment. This article is a result of the Southeast Asia GEOHealth Network Meeting of February 2019. It summarizes the current situation on pesticide use and regulation in Thailand and reports research findings on the potential health and environmental impacts of pesticide use, as well as highlighting gaps in research that could play an important and influential role in future policy initiatives on pesticides. Although Thailand has made remarkable progress in improving agricultural health and safety and similarly strong research and policy programs are being developed in other countries in the region, there are still significant gaps in research and policy that need to be filled.

Keywords

Pesticide use; exposure; poisoning; agricultural health and safety; policy initiative; Thailand; Southeast Asia

Background

Thailand has made outstanding progress in social and economic development and became an upper-middle income country in the early 2010s (Asian Development Bank 2019). Although the country has been recognized as an industrialized nation in Southeast Asia, the agricultural sector is still considered to be the foundation of its economy (World Bank 2020). Although the contribution of agriculture to the Gross Domestic Product (GDP) has declined over time, 30% of the country's population is employed in the agriculture sector and Thailand is one of the world's top exporters of commodity crops. Over the past several decades, Thailand has been a major exporter of industrially processed food and agricultural products such as rice, rubber, sugar, tropical fruit, and cassava (Food and Agriculture Organization of the United Nations 2018). The total value of agricultural products exported from Thailand in 2018 reached 8 billion Baht (approx. $0.25 billion USD), which has remained consistent over time (Ministry of Agriculture and Cooperatives 2019; Ministry of Agriculture and Cooperatives 2017).

Rural areas are home to more than 70% of the Thai population and these people are heavily dependent on agriculture as their main source of income. At the end of 2019,37.5 million (56.7% of total population of Thailand) were in the workforce and 11.7 million (~31% of the workforce) were employed in the agricultural sector (National Statistical Office 2020). Data on the occupational accident and injury rates of agricultural workers in Thailand is scant, and likely underreported, since the majority of them work in the informal economy. As such, the diverse set of working activities conducted by farmers are not covered or are insufficiently covered by the Thai labor laws and the social security system. In general, agricultural work is physically demanding, with tasks varying according to the seasonal needs of planting, nurturing and harvesting. During these work processes, agricultural workers are exposed to a variety of hazardous work conditions that put their health and safety at risk, particularly from accidents, musculoskeletal disorders, heat stress and the use of pesticides (International Labour Organization 2011). The indiscriminant and overuse of pesticides should also be considered a risk factor for the health of rural farming families and the local ecosystem.

In this article, we review the findings of our NIH-funded Southeast Asia Global Occupational and Environmental Health (GEOHealth) Hub, as well as those of other researchers who participated in our GEOHealth Hub Network Meeting of 2019. Most of the key researchers in this area in Thailand, as well as specialists from relevant organizations were at this meeting, and many of them serve as authors of this article.

We describe the current situation of pesticide use and regulation in Thailand and research studies conducted by network meeting participants on the health and environmental impacts of pesticide use. Further, we report the network's assessment of existing gaps in research and policy. Our intent is to highlight areas where improvements can be made to better regulate and manage the use of pesticides in Thailand, in order to protect the environment and citizen's health.

Southeast Asia GEOHealth hub for improving agricultural health

Since 2014, the U.S. National Institutes of Health (NIH) through the Fogarty International Center has funded grants to the GEOHealth Hub Project on Improving Agricultural Health in Thailand and Southeast Asia. Mahidol University in Bangkok and the University of Massachusetts Lowell formed the Joint Center for Work, Environment, Nutrition and Development (CWEND). CWEND along with other US and Southeast Asian universities, government ministries and organizations has worked to build the capacity for research, in order to address agricultural health issues in Southeast Asia.

The initial research focus for the core CWEND GEOHealth Hub partners has been on whether some widely used pesticides in Southeast Asian agriculture act as endocrine disrupters, altering endocrine hormone homeostasis. We postulate that this results in an increased risk of metabolic syndrome, obesity and metabolic-related disorders, such as heart disease, diabetes, and stroke. Meanwhile, the matched training program focuses on a broader set of agricultural health topics and on mentored research training for junior faculty and medical staff to build institutional research capacity in the region. Our training partner institutions include the Thai Ministry of Public Health, YARSI University (Indonesia), Mahasarakam University (Thailand), Chiang Mai University (Thailand), University of Indonesia, Thammasat University (Thailand), Sirindhorn College of Public Health (Thailand), Chiang Mai Rajabhat University (Thailand), Laos Food & Drug Administration, and the National Institute of Environmental Health Science (Vietnam). The program is designed to establish an international, interdisciplinary collaborative research group that will continue to work together in the future and to expand the GEOHealth Hub research capacity.

Over time, the CWEND GEOHealth Hub has developed a broad network of researchers and institutions working in the area of agricultural health, and particularly in the occupational, community and environmental impacts of pesticide use. We convened a meeting of this network in February 2019 to update each other on our research progress and to discuss the gaps in research that would provide needed data to policy makers in the pesticide arena. Participants were key researchers or specialists in this area from a variety of institutions and organizations across in Thailand. Hence, the information reported here includes findings from studies within and outside of the GEOHealth Hub program and summarizes much of the recent research into the occupational and environmental impacts of pesticide use inThailand.

Current situation of pesticide use in Thailand

Over the past few decades, agricultural activities have rapidly grown and diversified in Thailand. More mechanical equipment, heavy machinery, hybrid seeds, and synthetic chemicals have been introduced into agricultural work. Such changes in the agricultural process and work pattern have presented Thailand with new challenges in a wide variety of fields, especially the health and safety of agricultural workers and their families, as well as consumers. To meet the global demand, the country relies heavily on pesticides to control pests (insects, weeds and fungi), in order to maintain high crop yields (Panuwet et al. 2012).

Thailand continues to increase its annual import of pesticides. Commonly imported insecticide classes included organophosphate (OP; e.g., chlorpyrifos), carbamate (e.g., fenobucarb, methomyl), and pyrethroid (e.g., cypermethrin, deltamethrin). The most commonly imported herbicides were paraquat, glyphosate, 2,4-D, ametryn, and atrazine. The most commonly imported fungicides were dithiocarbamate, mancozeb, carbendazim, and captan (Ministry of Agriculture and Cooperatives, 2020). The import trends of these 3 major types of pesticides from 2008–2019, as well as the total value of these imports are shown in Figure 1.

It is unfortunate that statistics on the distribution of pesticides within Thailand are not officially reported. However, based on agricultural activities and land areas, it might be assumed that the majority of these pesticides were used in the north, northeastern, and central parts of the country. Overall, the use of pesticides in Thailand has increased significantly over time. About one third of them are either WHO classification in class I or II pesticides. Herbicides make up the largest proportion of imported pesticides, followed by insecticides and fungicides. Interestingly, the total cost of pesticides imported into the country has increased dramatically in the past few years, although the quantity imported during that time did not increase significantly for insecticides and fungicides.

Pesticide exposures among various populations of Thailand

Most recent studies in Thailand have reported exposure to a single type of pesticide in a single crop type despite the fact that most Thai farmers use multiple pesticides in multi-crop cultivation. In a study focused on evaluating biomarkers of pesticide exposure among people living in northern Thailand, it was found that people living in agricultural areas were exposed to organophosphate, synthetic pyrethroid, and glyphosate through multiple pathways. Pesticide metabolite monitoring found dialkylphosphate metabolites of OP and carbamate pesticides in almost all samples, 3-phenoyxbenzoic acid, the metabolite of pyrethroids, in 12–45% of farmer and non-farmer group samples and glyphosate herbicide in 11–30% of farmer group samples, but not in non-farmers. These findings suggest that pesticides are used in the home, as well as agriculturally and that food residues may contribute to population exposures (Wongta et al. 2018).

In Thailand, there are indigenous ethnic minority groups living along the mountainous areas in the North and the West. These hill people comprise several local tribes including the Hmong (Meo), Mien (Yao), Lahu (Mu Ser), Akha (Egor), etc. Highland Hmong farmers have abandoned cultivation of subsistence crops and turned to chemical-intensive cultivation of non-narcotic permanent field cash crops. Like other Thai farmers, they apply pesticides by backpack and machine sprayers and by hand. Most Hmong reported knowing of the health hazards of pesticides, but many failed to use adequate protective clothing to prevent exposure. Screening showed large number of Hmong adults with risky or unsafe levels of cholinesterase inhibition, an indicator of exposure to organophosphate and carbamate pesticides. Exposure rates are as high among those who do not actually apply pesticides as among those who do, suggesting exposure by other routes, such as ingestion of contaminated crops, use of pesticide containers for other purposes or poor storage practices and not simply due to direct contact during application (Kunstadter et al. 2001).

Agricultural workers are unique in that they often live where they work and their family members also participate in farming activities resulting in direct or inadvertent exposure to the potential health hazards of farming.

Hence, pesticide poisonings remain common work-related illnesses in Thailand with poisoning occurring across all ages (Figure 2) (Ministry of Public Health 2019) The most common pesticide poisoning agents reported were insecticides (carbamates, organophosphates, and pyrethroids) followed by herbicides (glyphosates and paraquat).

The rates of pesticide poisoning cases appear to be exceptionally high among children and elderly, as shown in Figure 2. This suggests that Thai children and the elderly could be unintentionally exposed to pesticides at home from poor storage practices for pesticides as well as re-use of pesticide containers in the home area. Farmers may perform some activities such as pesticide mixing and preparation at home, potentially contaminating the soil. In terms of physiological and behavioral differences that impact exposures, children and the elderly are considered susceptible populations. Some previous studies have shown that Thai children (aged 4–15) have higher pesticide exposures, assessed through biomonitoring of urinary pesticide metabolites, than those in other countries (Panuwet et al. 2009a; 2009b).

Pesticides and farmers health research

Since most farming activities are carried out in open air, farmers are exposed to the intense conditions of the equatorial climate of Thailand, which also brings exposure to insect-borne diseases, parasites, animal bites, and allergic reactions to plants other than those being cultivated. Additional risks include exposure to grain and animal allergens, smoke from the controlled burning of agricultural fields, and from the widespread use of hazardous chemical substances that are potential skin or respiratory irritants and systemic toxicants. However, information on the population prevalence of these hazards or their health impacts among Thai agricultural workers is not available (Kaewboonchoo et al. 2015). In addition, self-employed agricultural workers, are not covered by the Thai labor laws. Although some legal measures have been developed to expand the scope of protection to these informal workers, they are generally ineffective in implementation due to the lack of practical enforcement mechanisms. The current Thai social security system does not typically provide agricultural workers with treatment of work-related accidents, diseases, and injuries; unemployment and retirement insurance; or workers compensation (Kongtip et al. 2015). As a result, the national Universal Health Coverage System (UHCS) carries the financial burden of covering occupational illnesses and injuries among informal sector workers, like farmers. Therefore, data on agricultural illnesses and injuries are only available through the UHCS medical treatment payment system.

According to a systematic review of scientific articles on agricultural pesticide exposures in Thailand from 2009–2016, there were 36 studies, mainly on organophosphates, showing that agricultural workers suffer from a range of adverse health effects (Rivera et al., 2016).

The Bureau of Occupational and Environmental Diseases – Ministry of Public Health has evaluated the health risk of agricultural workers by providing occupational health services via the primary care units, and community hospitals throughout the country. These workers were interviewed and had their fingertip blood samples taken to test for plasma acetyl cholinesterase, which is inhibited when workers are exposed to excessive levels of organophosphate and carbamate pesticides. Cases of pesticide poisoning from the UHCS health care system have also been reported by the Ministry (Ministry of Public Health 2020; Ministry of Public Health 2018). From 2008–2019, the trend of pesticide poisoning cases as well as the rates (per 100,000 agricultural workers) are shown in Figure 3.

Despite Thai governmental legislation to control pesticide use, many farmers continue to use banned pesticides, apply higher concentrations than recommended, and do not use adequate personal protective equipment (PPE) (Rivera et al. 2016). Their decisions regarding pesticide use are often based on information given by retailers, other farmers, agricultural extension service agents and even the pesticide companies themselves (Tawatsin et al. 2015). Due to lack of knowledge, availability and affordability or discomfort in the equatorial climate, studies have shown that few farmers use proper PPE when applying pesticides (Kongtip et al. 2018; 2019). PPE use does vary among farmers across crop types, with flower/vegetable farmers reporting the highest frequency of good exposure prevention practices during pesticide use. They were the most likely to report using cotton or rubber gloves or a disposable paper masks during insecticide spraying. Those farmers who only grew vegetables had the lowest frequency of good exposure prevention practices, including use of PPE (Kongtip et al. 2018). Research has shown that even the use of regular clothing to cover the body can reduce pesticide exposures during spraying and should be more widely encouraged (Mahaboonpeeti et al. 2018).

Most of the human health research to date on pesticides in Thailand has focused on the acute effects of exposure (Kaewboonchoo et al. 2015). Little work has been done to look at the chronic health effects of pesticides or the impact of being exposed to a mixture of pesticides, as is the case for virtually all Thai farmers. However, laboratory studies in Thailand have shown that common pesticides like glyphosate and chlorpyrifos may be endocrine disrupters that may also increase the risk of cancer in humans (Thongprakaisang et al. 2013; Suriyo et al. 2015; Sritana et al. 2018). To fill this gap in understanding the chronic health impacts of pesticides, the GEOHealth Hub has focused on examining whether some of the high-volume pesticides used in Thailand may act as endocrine disrupters, altering endocrine hormone homeostasis, resulting in an increased risk of metabolic syndrome and associated diseases such as diabetes and cardiovascular disorders. Researchers under the GEOHealth Hub have found that conventional pesticide using farmers are more likely to have many metabolic and cardiovascular risk factors and biomarkers compared to organic farmers, increasing their risk of developing metabolic disease (Kongtip et al. 2018). In addition, research has shown that thyroid hormone (i.e., TSH, FT3, T3, T4) levels in conventional farmers were significantly higher than those of organic farmers after adjusting for covariates (Kongtip et al. 2019). Other GEOHealth network partners have evaluated organochlorine exposures and Parkinsonism (Kukreja et al. 2015).

Gaps and future needs for research to policy initiatives in the area of farmers health and pesticides

For some time now, there have been concerns about the accuracy and precision of the reactive paper test widely used in Southeast Asia to measure blood cholinesterase. A validated portable, inexpensive and simple-to-use immunoassay-based test kit, which could be in the field by local primary care nurses, or public health and agricultural officers, is needed to more accurately investigate the extent to which acute poisoning by OP and carbamate insecticides is occurring. Ideally, similar screening tests should be developed for other widely used pesticides. However, this process may not be as straightforward, as the mechanism of acute human toxicity is not well understood for many pesticides. Regardless, tests measuring more acute toxic effects may not adequately evaluate low-level, chronic exposures, whose health outcomes may present through differing mechanisms. This research need aligns with the more general gap in university or government labs that are currently able to measure biomarkers of human exposure (metabolites or parent compounds measured in urine, blood or other body fluids) to the wide number of pesticides used by farmers. Without better surveillance of human exposures, linking acute and chronic health risks will be difficult.

Currently, there are many potential gaps in the protections afforded agricultural workers in Thailand. Since the majority of these workers are in the informal sector, they generally fall outside the scope of coverage by labor protection laws and other standard social support systems developed by the government. Currently there is only limited data on medical treatment costs for some outcomes, without any measures of short term and disability losses in worktime, income and production. Development of data collection methods to document the national prevalence and severity of agricultural hazards, illnesses and injuries, and the cost to society and the economy are needed to inform legislation for the protection of safety and health for agricultural workers (Thepaksorn and Pongpanich 2014; Yogyorn 2020).

For the administration of health, the Primary Care Unit (PCU)/Health Promoting Hospital is considered the foundation of the health-care system in Thailand. Each PCU is a local clinic staffed by public health nurses, and public health officers, with assistance from village health volunteers. They provide preventive care, health education, and treatment of common health problems including issues on occupational health and safety, and are generally well-trusted and respected by their community members. However, in general, PCU staff have limited knowledge on occupational disease diagnosis, agricultural health and safety, and the prevention of pesticide poisoning, likely because they have to cover a broad range of health services/information which can hinder deeper understanding of pesticide-related health issues. Currently 58% of PCU's are considered to have "beginner" level knowledge of occupational safety and health (OSH) issues (Siriruttanapruk 2019). Funding and prioritization (from the Ministry of Public Health) is critically needed for development of a robust surveillance system for agricultural health impacts, starting from health screening, disease diagnosis, and the reporting system. Health risk assessments for dermal exposures to pesticides could be used by the PCU's for education to produce a significant impact on farmer pesticide exposures, if combined with provision of low-cost PPE. In addition, intervention studies are needed to document the how PCU OSH training impacts agricultural occupational injuries and illnesses and ultimately medical treatment costs.

Apart from pesticide problems, studies that focus on other issues relating to farmers' health such as climate change and heat related diseases, musculoskeletal disorders, and injuries are also recommended.

Environmental impacts and food contamination from pesticides

Extensive use of pesticides also results in widespread environmental contamination including effects on wildlife and food safety. At the network meeting, several research reports illustrated the water, soil, and biota contamination of pesticides in many regions of Thailand. Residual pesticides have been found in the community water supply, edible plants, and the human food chain. The level of detected pesticides in the environment depend on many factors including the type of pesticide, the sources of that pesticide in the sub-river basins, the characteristics of the stream (such as water flow), and the physical and chemical properties of the pesticide (such as water solubility) (Ananpattarachai and Kajitvichyanukul 2020). For soil contamination, the soil, climate, and the pesticide properties are the major factors affecting the residual concentrations in each area. In all cases, surface runoff is the major mechanism of pesticide mobility from the top soil to surface water bodies, including rivers, lakes, and streams. Among detected herbicides, atrazine was commonly present in surface water and groundwater samples in levels higher than other chemicals. As a result, groundwater contamination of pollution in wells by herbicides like atrazine and 2,4-D and carbamate insecticides like carbofuran has been observed (Thapinta and Hudak 2003).

On the other hand, the herbicides paraquat and glyphosate rapidly and tightly bind to soil particles, making them more immobile and less likely to leach to the water, but producing higher soil levels. Nevertheless, paraquat and glyphosate were still detected in fresh surface water samples in many provinces (Nan, Phitsanulok, Chiang Mai, Nongbua Lamphu, and Nakhon Si Thammarat) in Thailand (Noicharoen et al. 2012; Anlauf et al. 2018). The CWEND GEOHealth Hub partners at the Department of Agriculture measured pesticides in soil, surface water and drinking water during the rainy and dry seasons over two years in 3 provinces. Drinking water samples in the rainy season were found to contain herbicides such as glyphosate and atrazine and organophosphates such as fenitrothion, fenthion and diazinon. In most cases, more pesticides were measurable in the rainy season than the dry season for both surface water and soil samples (Klaimala 2019).

The bioaccumulation of pesticides poses a potential risk to the human food chain, as these herbicides have been found in the edible plants and aquatic organisms. With regard to aquatic organisms, sentinel species such as the rice field crab were found to have high levels of paraquat in their meat. When made into crab paste that is used in food preparation, the residue levels of paraquat and glyphosate exceeded the maximum residue limits (MRLs) in food set forth in the Codex Alimentarius. The rice frog, another sentinel species, was found to have significantly higher levels of atrazine and paraquat, when captured in fields with intensive herbicide use compared to fields without herbicide use. Rice frogs from heavy herbicide-use fields showed evidence of immune/endocrine system effects from exposure (Jantawongsri et al. 2015).

The Thailand Pesticide Alert Network (Thai-PAN) has been testing fresh vegetables and fruits for pesticide residues since 2010. Food samples from markets all over Thailand were tested for carbamates, OPs, organochlorines, pyrethroids, glyphosate, atrazine and paraquat. Recently, 56 pesticides (mainly insecticides and fungicides) were detected as the residual contaminants in fresh oranges collected from the markets in Thailand (Thailand Pesticide Alert Network (Thai-PAN), 2020).

Gaps and future needs for research to policy initiatives in the area of environmental impacts and food contamination

Few studies have examined biodiversity in Thai agricultural lands that use pesticides compared to those which do not and how this may impact productivity in the face of climate change. Organisms that contribute to soil biodiversity by cycling nutrients and participating in the nitrogen cycle can improve soil fertility. In addition, maintaining a diverse crop rotation improves soil fertility. Research in this area could be used to train farmers in agricultural practices that would increase productivity and aid in climate change resilience.

Development of natural methods of remediation of pesticide contamination in farm and home soils would benefit not only the quality of food produced by conventional farms, but hasten the time for conversion to organic farming. Several studies have shown high efficiency in pesticide removal such as dichlorvos and pymetrozine from the water (Binh et al. 2020). Additional research in this area and policy initiatives to encourage the education of farmers in these remediation technologies is needed.

There are currently no drinking water standards for pesticides in Thailand. Research is needed to understand the extent of the problem by evaluating the contamination levels of a wide range of pesticides in the drinking water across various parts of Thailand. This data will aid in recommending contaminant removal methods to improve the water quality. Understanding the sources and pathways of contamination will aid in protecting the water supply (Kruawal et al. 2005). With sufficient evidence based research, the country is more likely to issue a new policy on pesticide standards for drinking water.

More widespread and routine testing of agricultural food products is also needed. Ideally, this would be conducted by government bodies, but currently that function falls between the Ministry of Public Health and Ministry of Agriculture and Cooperatives, neither of which has a robust system in place for testing. Testing would benefit from the development of simple and quick test kits for measuring pesticides that could be used by purchasing agents to ensure food quality. This would also benefit the high value organic markets which have, in some cases, been undermined by the introduction of “false” organic products. Maintaining customer confidence in the organic label is imperative to ensure expansion of that sector and the willingness of consumers to pay a premium for organic products.

Pesticide impacts on children

Although work on the neurodevelopmental effects of pesticides has been reported in the US and Europe, until recently little work had been done to look at the health consequences of pesticide exposures in children. The CWEND GEOHealth Hub has investigated the neurobehavioral impact of in-utero exposure to pesticides. Exposures to pesticides were measured in pregnant women and in the newborn meconium (Kongtip et al. 2013; 2017; Konthonbut et al. 2018; Onchoi et al. 2020). Higher maternal exposure to OP pesticides during pregnancy was associated with significantly increased Neonatal Behavioral Assessment Scale (NBAS) scores (Range of State and Habituation) and a borderline significant increase in the number of abnormal reflexes. These findings mirror those in the US (abnormal reflexes) and the Habituation score could represent a higher risk of behavioral issues associated with attention deficit hyperactivity disorder (ADHD) and autism (Kongtip et al. 2013; Woskie et al. 2017). At 5 months of age, these babies were tested using the Bayley Scales of Infant Development and a significant decrease in infant cognitive and motor scores was found with increasing maternal OP pesticide levels during pregnancy (_S1_Reference40Kongtip et al. 2017). Other researchers in the network have reported that in Thai women with low paraoxonase (PON) enzyme activity, birth weight and length decreased as maternal OP metabolite levels increased. Also, maternal OP metabolite levels in the first trimester were associated with increased abnormal reflexes in newborns tested by NBAS, and second trimester OP pesticide levels were associated with decreases in motor and attention scores on NBAS (Naksen et al. 2015). Other Asian countries have conducted similar studies. For example, Bangladeshi women whose prenatal urinary 4-nitrophenol (metabolite of parathion and methyl parathion) levels were in the upper quartile were over 3 times more likely to deliver a preterm and small-for-gestational-age child. Similarly, women with measurable urinary levels of a diazinon metabolite were also at increased risk of having a child born with low birth weight (Jaacks et al. 2019).

The Thai Educational Foundation used the reactive paper test to look at cholinesterase levels in elementary students in Lao, Philippines, Thailand and Vietnam. They reported that 41%, 92%, 32% and 57%, respectively, had risky or unsafe levels of cholinesterase, reflecting OP exposures. Among primary school students in Chiang Mai in 2018, 100% had measurable OP metabolite levels in their urine. These findings suggest that the fruits and vegetables used in school feeding programs may have considerable pesticide residues. Other possible sources of exposure include unsafe disposal of empty pesticide containers and spray drift from farmlands adjacent to schools (Jatiket 2019).

Gaps and future needs for research to policy initiatives in the area of children and pesticides

From the GEOHealth Hub Network meeting, research about childhood exposures and health effects was also highlighted as a priority by participants. Additional studies to investigate the sources of childhood exposure to pesticides are needed so that interventions can be developed. If safe levels of exposure could be determined, screening of pregnant women for pesticide exposures could be initiated if and when a simple, inexpensive test kit could be developed to target the most commonly used pesticides. In addition, studies of the long-term consequences of childhood exposures on neurodevelopment, endocrine and reproductive disruption, metabolic disorders and cancer are needed. The GEOHealth Hub is now preparing to conduct a longitudinal study to investigate the risk in children of metabolic-related disorders, and disruption of endocrine and pubertal development from pesticide exposures.

National administration & policy initiatives around pesticides

Currently, the primary legal instrument used to regulate all hazardous chemicals in Thailand, including pesticides, is the Hazardous Substances Act B.E. 2535 (1992), *amended B.E. 2544 (*2001*), B.E. 2551 (*2008*), and B.E. 2562 (2019)* (Government of Thailand 1992; Government of Thailand 2001; Government of Thailand 2008; Government of Thailand 2019). This Act covers the issues on importation, production, marketing, and possession of all hazardous chemicals used in the country. Under this Act, the Hazardous Substance Committee (HSC) was set up as the governing body that assigned various aspects of governance to three ministries; the Ministry of Industry, the Ministry of Public Health, and the Ministry of Agriculture and Cooperatives, based upon chemical usage.

The regulatory process for registration, production, distribution, and sale of pesticides used in crop production is controlled by the Ministry of Agriculture and Cooperatives, under these two main regulations:

1. Notification of Ministry of Agriculture and Cooperatives on Registration, License Issuance and Renewal of Hazardous Substances under the Responsibility of Department of Agriculture B.E. 2552 (2009)

2. Notification of Ministry of Agriculture and Cooperatives on Production, Importation, Exportation and Being in Possession of Hazardous Substances under the Responsibility of Department of Agriculture B.E. 2547 (2004)

For the control of pesticides, the divided regulatory functions between various ministries renders Thai pesticide regulation fractured and inefficient. Problems regarding pesticide regulations often involve the management of existing or registered pesticides. Because the current Hazardous Substance Act was broadly defined to include the control of all hazardous chemicals without intentionally considering end-use, areas of particular importance to the effective regulation of pesticides are not covered. For example, the Act relies heavily on the industry itself for chemical management, from importation until the point of sale. Much of the misuse and mishandling of pesticides occurs after the point of sale, thus leaving pesticide use largely uncontrolled. Figure 4 shows the shared responsibility of government agencies (at the department level) for pesticide control regulation.

Another challenge in controlling the point of sale is the numerous trade names for the same or similar products. Trade names are loosely controlled by current legal instruments; one chemical can have multiple trade names making control of the active ingredient difficult. This also creates a major barrier to collecting self-reported pesticide use data from farmers. Currently, over 20,000 pesticide formulations are sold in Thailand. Some single-ingredient pesticides may have as many as 300 different trade names, making the control of use and the maintenance of a chemical inventory difficult. In addition, testing of fresh fruit and vegetables in local markets by Thai-PAN found measurable residue levels of 24 pesticides that are not registered for importation into Thailand (Ousap 2019).

For the past several years, there has been active movement to strengthen the control of pesticides led by Thai-PAN and collaborative partners. This includes the push for the government to release new regulations covering pesticides exclusively (Khaosod Online 2020). Since the current Hazardous Substances Act 1992 does not have direct regulations specific to the chemicals used in agriculture, updated legislation could better control pesticide importation, sale and use in Thailand. The essence of this new act is to focus more on the Precautionary Principle, as well as set minimum criteria for pesticide use in accordance with international standards. As for safety measures, more stringent requirements regarding labels on pesticide containers would be implemented to ensure that all necessary information is included. The licensing of distributors or sellers, as well as the sales promotion or advertisement of pesticides, would be controlled more strictly and any propaganda prohibited to minimize direct influence of industry on pesticide use among farmers. New regulations would also have an enhanced compliance mechanism on the registration of pesticides from imports to distribution throughout the process with traceability from cradle to grave. New provisions on the determination of MRLs and health surveillance criteria would also be included (IsraNews Agency 2020). Although, the proposed regulations have been drafted and discussed at several public hearing events, the process at the government level to release such regulations involves many steps that typically take several years to approve and are subject to intensive political and industry lobbying.

Another approach to controlling pesticides is to prohibit the use of highly hazardous pesticides (instituting a ban). One of the most rewarding aspects of our GEOHealth work has been the impact on the debate in Thailand over banning harmful pesticides. Based on the research findings available about pesticide exposures and their effects to human health, NGOs and many other civil society groups launched a campaign to support the Ministry of Public Health's recommendation to ban the use of Paraquat, Chlorpyrifos, and Glyphosate. Over 57,000 medical staff, researchers, and members of the public have signed a petition pushing for a ban on these three pesticides. In October 2019, Thailand's HSC voted in favor of banning all three of pesticides, and demanded abandonment of their use by December of 2019 (AFP News 2020). This decision was made based on their toxicity and potential human health effects as established by scientific evidence (Pesticide Action Network Asia and the Pacific (PANAP), 2020; Bangkok Post 2020). The U.S. Agricultural Department encouraged Thailand to delay the ban of glyphosate, as it would disrupt Thailand's import of US agricultural products grown with the use of glyphosate. These include crops worth over 1.5 billion USD annually (soybean, wheat, coffee, apples and grapes) (The Nation Thailand 2020). Extensive pressure from farmers, lobbyists for chemicals companies, as well as the U.S. government, forced the HSC to lift the scheduled ban on glyphosate, and delay the ban on chlorpyrifos and paraquat by six months (Bangkok Post 2020a; 2020b). Currently, both chlorpyrifos and paraquat have been officially banned in Thailand, effective June 1st, 2020 (Government of Thailand 2020; Thai PBS World 2020). However, a glyphosate ban is not planned for the near future, although its use will be restricted within the MRL requirements (Bloomberg 2020; Reuters 2020; Thai Examiner 2020).

Regulating pesticide residues in food and water

In 2016, the National Bureau of Agricultural Commodity and Food Standards (ACFS) in the Ministry of Agriculture and Cooperatives issued a revised notification entitled the Thai Agricultural Standards on Pesticide Residues: Maximum Residue Limits (TAS 9002–2016) covering 53 pesticides commonly used in Thailand including paraquat and chlopyrifos (no MRL for glyphosate listed under this standard) (Government of Thailand 2016). Typically, these MRLs are revised every 5–10 years based on supervised residue trials by the Department of Agriculture, and the recommendations by the Joint FAO/WHO Food Standard Program, as well as the database of harmonized MRLs used among the Association of Southeast Asian Nations (ASEAN). The standard states that the method used for the sampling and analysis of pesticide residues for compliance with MRLs shall comply with the latest Recommended Methods of Sampling established by Codex Alimentarius Commission, Joint FAO/WHO Food Standard Program. Where appropriate, alternative methods may be used if issued by a national competent authority or international standards organization, as well as other validated methods in accordance with internationally accepted guidelines.

An alternative regulation by the Thai Food and Drug Administration (FDA), which is under the Ministry of Public Health, proposed a revision on the Ministry of Public Health

Notification regarding Food Containing Pesticide Residues (Foreign Agricultural Service 2020). This notification revised MRLs and standards for pesticide residues in food, and prescribed the analytical methods to be used to detect such pesticides residues. It came into force as the Notification of the Ministry of Public Health No. 387 re: Pesticide Residues in Food, B.E. 2560 (2017) (Government of Thailand 2017). Furthermore, the Notification of the Ministry of Public Health No.393 issued MRLs for carbosulfan, dithiocarbamates, imidacloprid and dinotefuran in mangosteen, longan and mango which entered into force in 2018 (Government of Thailand 2018).

Gaps and future needs for research to policy initiatives in the area of regulating pesticides

The MRLs issued by the Thai FDA were mainly for consumer protection. Meanwhile, the use of MRLs under the Thai Agricultural Standards are aimed at the production, trade control and inspection of agricultural commodities on sale, or for import and export. Residues of legally registered pesticides found in food or feed commodities are not allowed to exceed the MRLs established by both authorities. However, mechanisms for monitoring compliance with these MRLs are still generally ineffective. As reported by Thai-PAN and presented at the GEOHealth Hub Network Meeting in 2019, pesticide residues found in many vegetables and fruits still exceed the MRLs (Biodiversity -Sustainable Agriculture - Food Sovereignty Action Thailand (BioThai), 2020). This is a current issue that needs to be solved in the near future.

In addition, the MRLs for pesticides should be updated regularly based on research findings. The methods used to establish Thai MRLs should be revised to be more comprehensive and not focus only on acute effects, but use the most sensitive indicators of health effects among sensitive sub-populations. For example, levels associated with neurodevelopmental delays in children. Studies examining MRLs and subsequent Acceptable Daily Intake (ADI) levels should be compared using different health outcomes. In addition, MRL's should be in place for all government approved pesticides. In addition, since different residue testing protocols generate different results, research and development of a gold standard for testing is needed. This would also aid in the development of simple quick test kits recommended above under *Gaps and Future Needs for Research to Policy Initiatives in the area of Environmental Impacts and Food Contamination*.

Intervention studies to evaluate the impact of stricter regulations on the sale of pesticides, as well as training and licensure of sellers and users, are needed to ensure efficacy of the policy. Provision of safe pesticide disposal sites in all agricultural districts are needed. Other research priorities include review of policy, infrastructure, and regulations for pesticide management comparing countries in Southeast Asia and study of the health and economic costs and benefits from banning chlorpyrifos and paraquat.

Recent status, challenges and policy initiatives in Southeast Asia

The use of agricultural pesticides has rapidly increased in Southeast Asia, particularly in the neighboring countries of Thailand such as Cambodia, Laos, and Vietnam. Such trends are driven by land use intensification related to the expansion of higher value crop production and integration of farmers into wider markets. Several main challenges to pesticide risk reduction have been identified by the Food and Agriculture Organization (FAO) of the United Nations: (a) the rapid expansion of pesticide trade—in terms of total volume, number of products and number of selling points, combined with a weak regulatory and enforcement capacity; (b) a high level of satisfaction among farmers with pesticides combined with low levels of risk awareness, lack of technical know-how about integrated pest management (IPM), and general unavailability of bio-control agents; and (c) no regular monitoring of pesticide risk, which makes it difficult for legislators, regulators, farmers and consumers to make rational decisions (Schreinemachers et al. 2015).

In the past decade, the FAO has supported the implementation of a project under its technical cooperation program to assist seven participating countries in Southeast Asia toward achieving greater pesticide regulatory harmonization. The purpose of the project was to review regulatory processes, prepare guidelines for harmonization, strengthen information exchange, train pesticide regulatory officers and plan sustainable future activities. Guidelines on the harmonization of pesticide registration, labeling, and monitoring of pesticide residues in agriculture products were issues and distributed to all Southeast Asian member states. Each country has been reviewing their regulatory processes and developing detailed action plans for improving its pesticide management in line with the harmonized standards (Food and Agriculture Organization of the United Nations (FAO), 2013). The FAO has supported the development of legislation on pesticides and other chemicals and the program by providing advice on technical as well as legal issues. As a key player in this regional collaboration on chemicals management, Thailand has developed the Fifth National Strategic Plan on Chemical Management outlining priorities for 2022–2026. In Myanmar, following promulgation of a new pesticide law in 2016, the FAO supported capacity building for an improved pesticide registration process. In Cambodia, the development of an environmental code, including a specific chapter on chemicals was being developed in 2017. In Lao, a decree by the Prime Minister on Pesticide Management was developed and promulgated in 2017, with aims to better protect the environment and human health and calls for inter-ministerial collaboration to strengthen pesticide management (Food and Agriculture Organization of the United Nations (FAO), 2017).

Directions for sustainable development

Thailand's long-term economic aspirations are laid out in its recent 20-year strategic plan (2018–2037), which contains reforms dealing with economic stability, human capital, equal economic opportunities, environmental sustainability, competitiveness and effective governance. To achieve inclusive and sustainable economic growth, the Government also launched the so-called strategy "Thailand 4.0" to create a value-based economy founded on creativity, innovation and intellect. It consists of various strategic plans for national development, and includes the promotion of sustainable agriculture as an important mechanism that will enable the country to be in accordance with the United Nation Sustainable Development Goals (SDGs) (Government of Thailand 2020; United Nations 2020).

Hence, Thailand is shifting to organic and higher-value production, which aligns with the Government's objectives under the National Organic Agriculture Development Strategy 2017–2021 (Ministry of Agriculture and Cooperatives, 2020). The Government is also introducing reforms to help transform the sector's cultivation, processing and marketing techniques. The reforms include a greater focus on agricultural cooperatives and support for growers to raise product quality as well as the improvement of agricultural health and safety by the elimination or reduction of pesticide use. Agricultural workers are encouraged to shift from chemical-dependent agriculture to organic agriculture under King Rama IX's "Sufficiency Economy" philosophy for sustainable development (Hangsoongnern et al. 2014; Ministry of Agriculture and Cooperatives, 2020). The aims of the Sufficiency Economy are to conserve watershed forests, increase crop diversity and reduce use of chemical fertilizers and pesticides. Organic agriculture is a survival track for small farmers as there is increasing demand from consumers in Thailand and abroad. A large number of farmers practice organic agriculture across the country, but they have not been collaborating in groups or clusters to manage their organic agriculture businesses, so the value chain remains fragmented. To deal with this challenge, a social enterprise initiative for organic agriculture was launched under the collaboration of involved local government, business agencies, and the community. Overall, improved agricultural safety and productivity could have a direct effect on Thailand's agribusiness and food-processing sectors further increasing agriculture's contribution to GDP and global food security (FFTC Agricultural Policy Platform 2020).

Conclusion

In this article, produced from the proceedings of the CWEND GEOHealth Hub network meeting in 2019, we develop a set of research needs. We believe that by providing strong, independent research results to governing bodies that we can promote the development of new policies to protect workers, the environment and children from the impacts of poorly regulated pesticide exposures.

Further research is needed to evaluate the long-term health effects of pesticide exposure particularly among vulnerable groups such as children, and to develop appropriate preventive measures based on the specific context of each type of agricultural work. Important areas for research, as proposed by GEOHealth Hub Network, that could influence future pesticide policies in Thailand include:

1. Identification and characterization of pesticide exposures and hazards, particularly for chronic effects such as endocrine disruption, neurological conditions, metabolic disorders and cancer. A special focus is needed to protect vulnerable sub-populations of children and the elderly from harmful effects of pesticide exposure.

2. Development of a transparent surveillance system to monitor pesticide residues in food, water and the environment.

3. Development of a transparent surveillance system for agricultural workers that includes information on economic impacts of injuries and illnesses.

4. Development of quick, simple and accurate test methods to aid in the measurement of pesticide exposures in humans for use in the OSH surveillance system (3) as well as for children and consumers and quick and simple residue test methods for use as part of the environmental surveillance system (2).

5. Development of methods of health risk assessment that incorporate the most sensitive human health outcomes in the development of MRLs in food and water.

6. Determination of the ecologic consequences of pesticide use

7. Development of methods of remediation of pesticide contaminated land and water and evaluation of the effects on ecosystem restoration.

Lastly, the impact of policies that promote or restrict the use of pesticides should be measured and evaluated systematically. Outreach and education of the public and younger generations in the precautionary principle will be key to the sustainable development of agriculture in Thailand.

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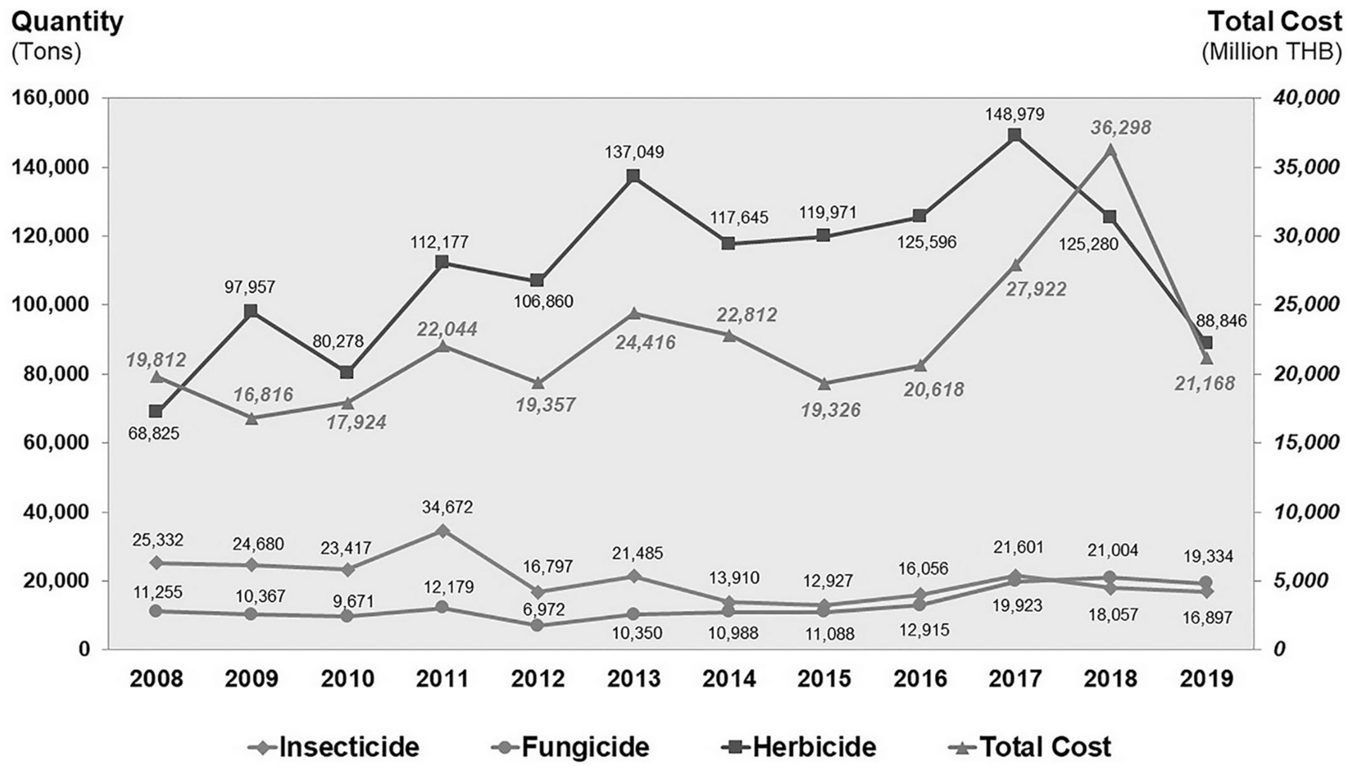

Figure 1.

Summary of Imported Pesticides into Thailand, 2008–2019.

(**Source:** Office of Agricultural Economics, Ministry of Agriculture and Cooperatives.)

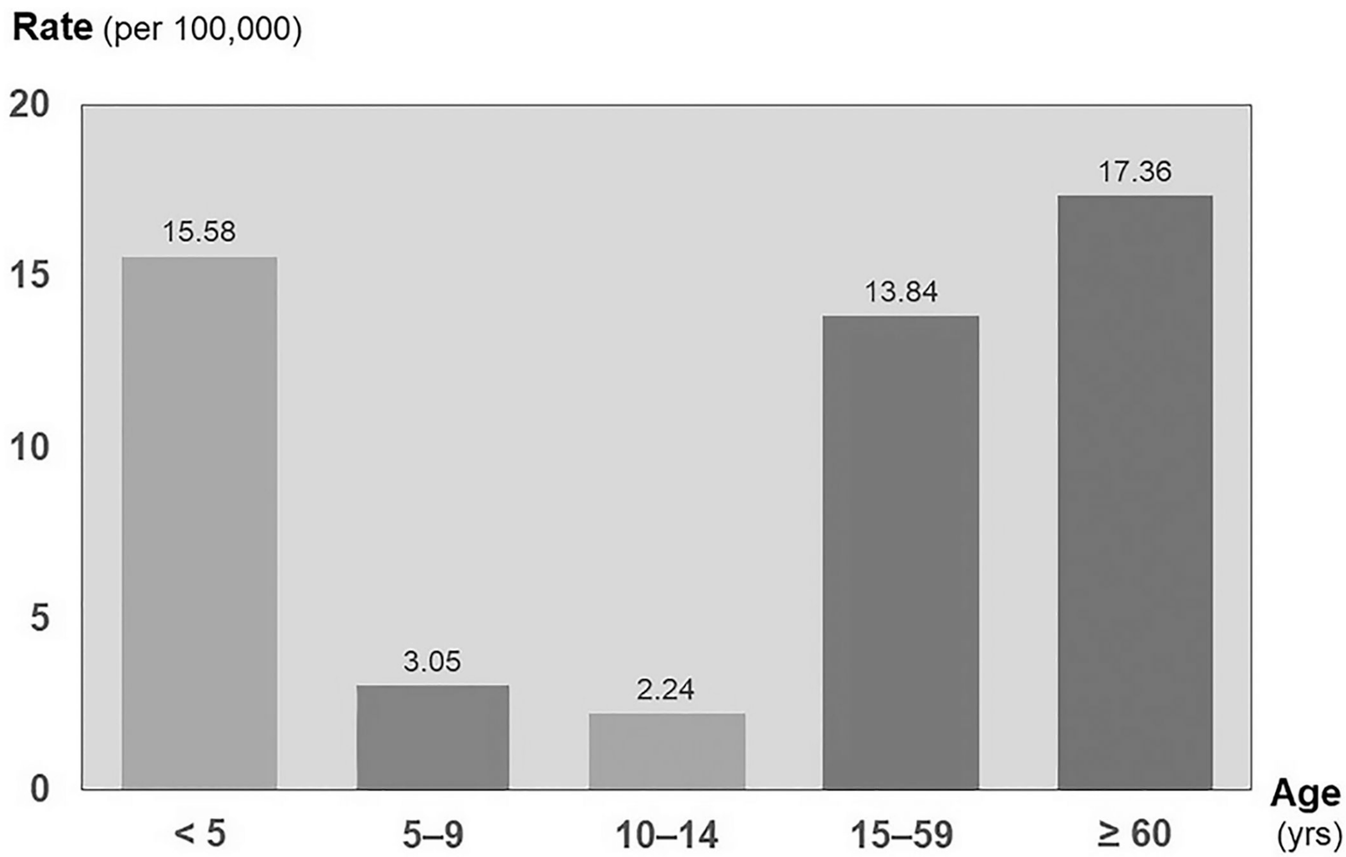

Figure 2.

Rate of Pesticide Poisoning Cases in Thailand, by Age group, 2019.

(**Source:** Health Data Center (HDC), Ministry of Public Health.)

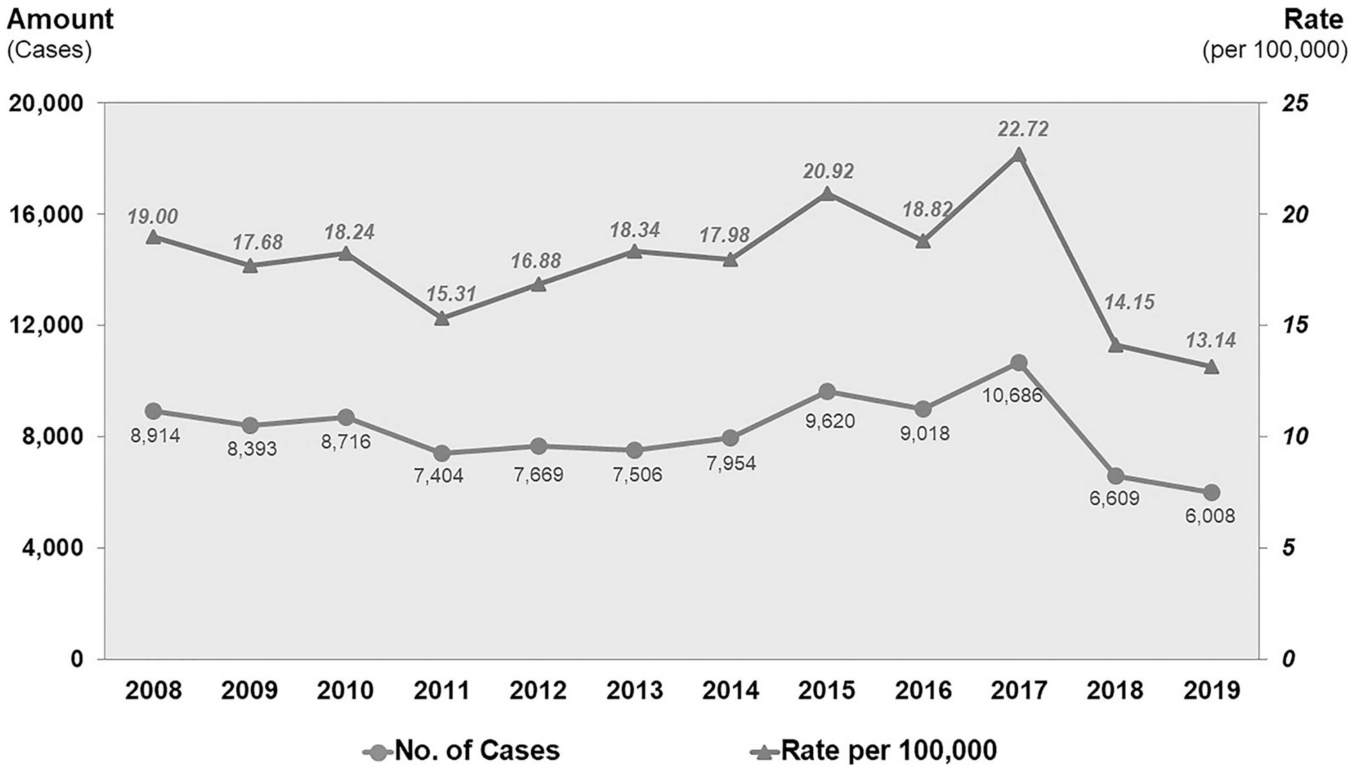

Figure 3.

Summary of Pesticide Poisoning Cases and Rates in Thailand, 2008–2019.

(**Source:** Health Data Center (HDC), Ministry of Public Health.)

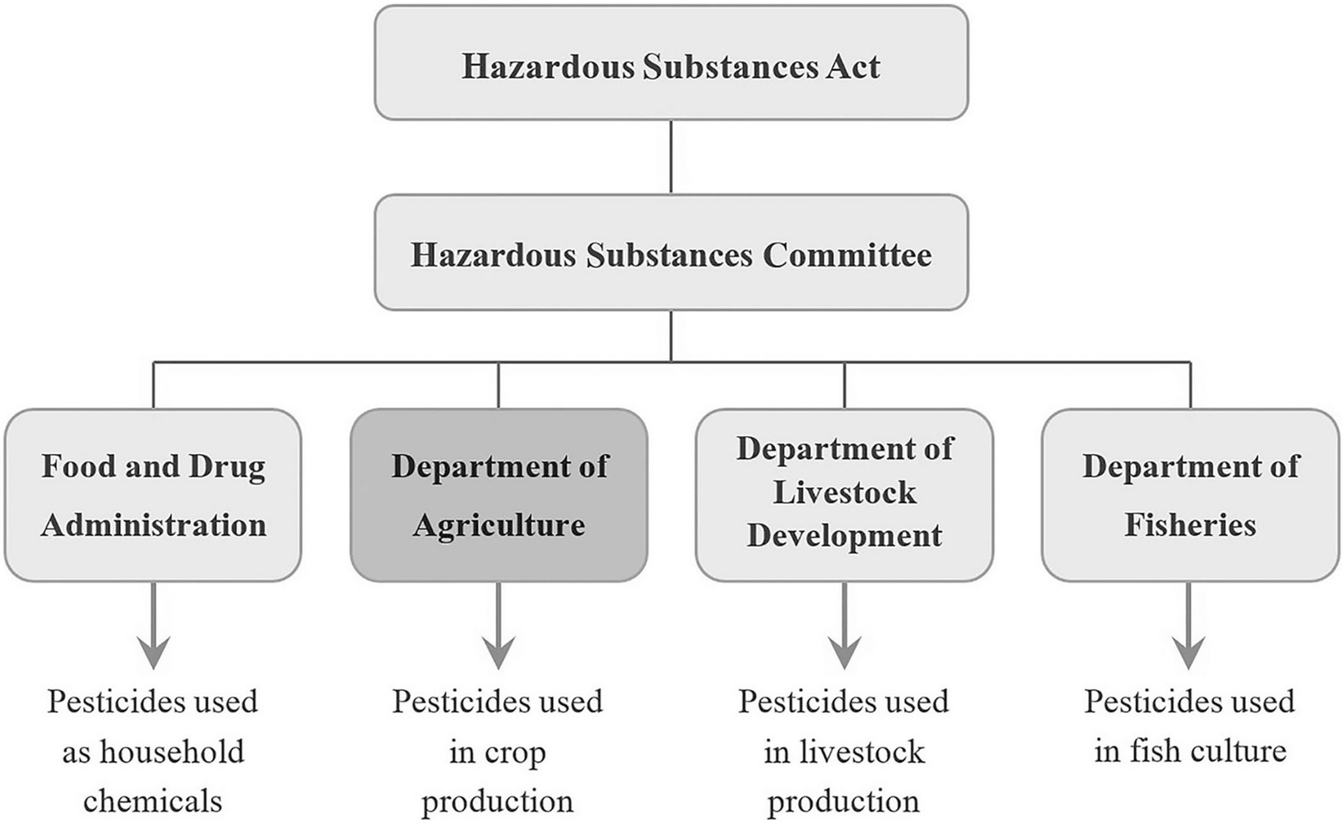

Figure 4.
Regulatory Body for the Administration of Hazardous Substance Act.