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# The Leaching Potential of Pesticides in Song Phi Nong District, Suphan Buri Province, Thailand

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## Abstract

Due to an increase in the import and use of pesticides, agricultural areas in Thailand need to be evaluated in term of the leaching risk of pesticides in order to prevent groundwater from being contaminated with pesticides. In this study, the attenuation factor/ retardation factor model (AF/RF), integrated with GIS software, was used to assess the leaching potential of the applied pesticides, consisting of atrazine, glyphosate, hexazinone, picloram, ethylene dibromide, and metalaxyl in Song Phi Nong District, Suphan Buri Province, Thailand. The results indicated that picloram had the highest risk of leaching due to the sorption coefficient ($K_{oc}$) and half-life ($t_{1/2}$) of the pesticide. The remaining pesticides had a lower risk because of their higher sorption by soils. Additionally, soil with a lower organic matter and higher average water flow rate through soil had a higher pesticide leaching risk than other soils. The results also showed that the groundwater in the study area was safe under the existing conditions, including and the current application rate of pesticides. However, long-term monitoring of pesticide contamination in subsurface soils in the area is necessary.

***Keywords***: AF/RF model; Leaching; Pesticide; Sorption; Suphan Buri

## 1. Introduction

Thailand, considered as an agricultural country, has mostly imported agrochemicals to protect crops and agricultural yield (Thapinta and Hudak, 2000; Chotpantarat and Chanyotha, 2003; Waiyasusri *et al.*, 2016; Chotpantarat and Boonkaewwan, 2018). In 2010, thirty-three percent of the imported pesticides fall under the WHO hazard categories, including insecticide, herbicide, and fungicide (Panuwet *et al.*, 2012). It was reported that concentrations of some of the pesticides have been detected in groundwater and soil located in the central plain of Thailand (DGR, 2009). Hence, government monitoring programs have been implemented for addressing the increase of the use of pesticides in Thailand. The Pollution Control Department (PCD) and Department of Agriculture (DOA) are the main monitoring programs in Thailand. The objective of PCD is to identify the health effects, occurrence in soil, water and agricultural products associated with each pesticide. Typically, the DOA's objective is to engage in local agricultural research projects. Moreover, their purpose is to provide the optimal pesticide application rate mainly for protecting the environment (Thapinta and Hudak, 2000).

Generally, models can be separated in several ways, such as by data requirement and uncertainty (Šimůnek, 2006). There are three principal models: the simple screening model (Tier 1), intermediate model (Tier 2) and complex model (Tier 3). Due to an increase in data requirement, the precision of models may be simulated more precisely (Alavi *et al*., 2007; Chotpantarat *et al*., 2011; Chotpantarat *et al*., 2012; Boonkaewwan and Chotpantarat, 2014; Klongvessa and Chotpantarat, 2014; Wikiniyadhanee *et al*., 2015; Masipan *et al*., 2016; Chotpantarat and Boonkaewwan, 2018; Chotpantarat and Kiatvarangkul, 2018; Waleeittikul *et al*., 2019). In addition, the complex models require more input parameters than those in the Tier 1 model, such as evapotranspiration and root zone water balance for describing a leaching mechanism in the specific area. The output of the models is generally expressed in spatial and temporal concentration variations. However, some site-specific information is not available over large areas (Vanclooster *et al*., 2000; Stenemo *et al*., 2007). For this reason, the Tier 1 model, which provides a simulation of the relative risk based on a few properties (Alavi *et al*., 2007; Stenemo *et al*., 2007; Dusek *et al*., 2011), is still used for a regional or national scale and an area with less specific data as well. One of the widely used Tier 1 models is the attenuation factor/ retardation factor (AF/RF) (Rao *et al*., 1985). This model has been applied to assess the leaching potential of pesticides on a regional scale by many authors (de Paz and Rubio, 2006; Hall *et al*., 2015).

The objectives of this study are to assess the leaching potential of the applied pesticides in the study area using the AF/RF model and to establish a ranking of the pesticides, including atrazine, glyphosate, hexazinone, picloram, ethylene dibromide, and metalaxyl.

## 2. Materials and methods

*2.1 The study area*

This study was conducted in Song Phi Nong district, Suphan Buri province, Thailand (Figure 1). The area is approximately 750 km$^2$, which is mostly used for planting sugarcane and rice. An average annual rainfall over 30 years in this study area is in the range of 3.7 mm to 223.4 mm, with an average of 81.28 mm/yr, and an average annual temperature is in the range of 25.4°C to 31.3°C with an average of 28.8°C. There are several types of soil in the area, which often has a high clay content, with low permeability in the area. However, pesticide pollutants have been reported to be in the groundwater, indicating the pesticide contamination in the soil and groundwater around the area, although the concentrations in the soil and groundwater did not exceed the soil and groundwater quality standards (Thailand) (DGR, 2009).

The most imported pesticides are for application in agricultural areas located in Thailand, and the pesticides commonly used in sugarcane and rice fields are atrazine, glyphosate, hexazinone, picloram, ethylene dibromide, and metalaxyl (Tawatsin, 2015).

*2.2 Model description*

The attenuation/retardation factor model (AF/RF) is a simple screening model or Tier 1 model, applied for estimating the leaching potential of pesticides through the soil profile (Rao *et al*., 1985). The AF values range from 0 to 1. If the AF value is 1, this indicates that the pesticide is non-absorbed and has a high groundwater pollution risk. In contrast, if the AF value is 0, this means that the pesticide is strongly absorbed and has low a pollution risk (de Paz and Rubio, 2006). The AF value is defined as

$$AF = \exp\left(\frac{-\ln 2 \cdot d \cdot RF \cdot \theta_{FC}}{q \cdot t_{\frac{1}{2}}}\right)$$

where d is the depth of groundwater (m), $\theta_{FC}$ is the field capacity water content, q is the net annual groundwater recharge rate or average water flow rate through the soil (m/d), $t_{1/2}$ is the half-life of the pesticide (d), and RF is the retardation factor, defined as

$$RF = 1 + \frac{\rho_b \cdot f_{oc} \cdot K_{oc}}{\theta_{FC}}$$

where $K_{oc}$ is the pesticide sorption coefficient ($m^3$/kg), $\rho_b$ is the soil bulk density (kg/$m^3$), and $f_{oc}$ is the fraction of soil organic carbon (Hall *et al.*, 2015). Moreover, the net annual groundwater recharge rate can be defined by the following equation

$$q = P \cdot I$$

where P is the spatial average rainfall (m/d) and I is infiltration rate (%) (Koontanakulvong & Siripubttichaikul, 2002).

To assess the leaching potential of the different pesticides, the AF valued was classified into five categories, as shown in Figure 2 (Khan and Liang, 1989). This index can be used as a general tool for ranking the leaching potential of different pesticides. Moreover, it can be used to evaluate a large-scale problem due to its few data requirements, although it has several limitations. For the purpose of protecting the groundwater quality and establishing a groundwater monitoring well, this index is useful. However, if the distribution of pesticide

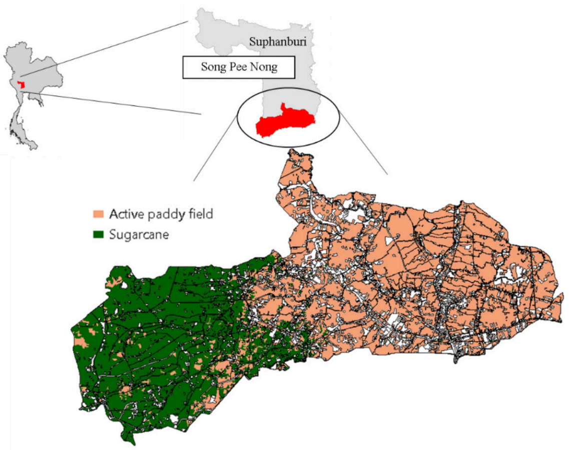


**Figure 1.** The study area, Song Phi Nong district, Suphan Buri province.

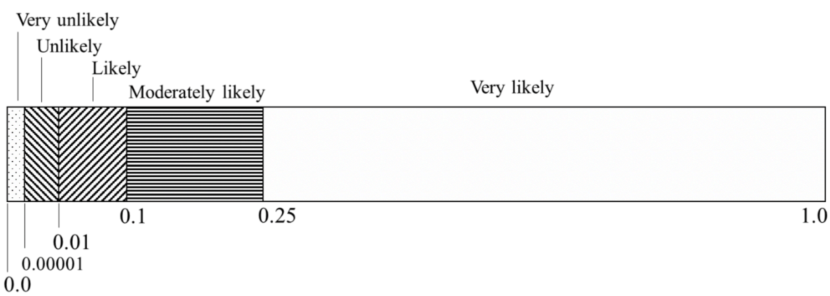


**Figure 2.** Classification of the AF value (Khan & Liang, 1989)

**Table 1**. Physico-chemical properties of three soils.

| Soil types | %Sand | %Silt | %Clay | Soil texture | $^*\rho_b$ (kg/m$^3$) | %OM | pH |
|---|---|---|---|---|---|---|---|
| 1 | 25.8 | 59.2 | 15.0 | Siltloam | 942.3312 | 5.54 | 6.5 |
| 2 | 6.5 | 41.0 | 52.5 | Siltyclay | 1050.067 | 1.48 | 6.5 |
| 3 | 3.0 | 30.0 | 67.0 | Clay | 998.1774 | 2.79 | 6.0 |

*derived from $\rho_b = 100/[(OM/\rho_{bOM}] + [(100\text{-}OM)/\rho_{b\,min})]$,
$\rho_{b\,min} = 0.935 + 0.049(\log(depth)) + 0.0055(sand) + 0.000065\,(sand - 38.96)^2$
and $\rho b\ OM = 0.224$ g cm$^{-3}$

**Table 2**. Pesticide properties

| Pesticides | $t_{1/2}$ (day) | $K_{oc}$ (m$^3$/kg) | GUS | References |
|---|---|---|---|---|
| **Atrazine** | 215 (200-250) | 0.098 (0.087-0.112) | 4.69 | (Accinelli *et al.*, 2001; Blume *et al.*, 2004; Feria-Reyes *et al.*, 2011; Holtschlag & Luukkonen, 1997; Janaki *et al.*, 2012; Satpute *et al.*, 2015; Tagun, 2014; Vlaardingerboek *et al.*, 2009) |
| **Glyphosate** | 47 | 24.00 | -0.64 | (University of Hertfordshire, 2015) |
| **Hexazinone** | 122 | 0.054 | 4.73 | (Spadotto *et al.*, 2002) |
| **Picloram** | 138 | 0.026 | 5.53 | (Khan & Liang, 1989) |
| **Ethylene dibromide** | 126 | 0.061 | 4.65 | (Khan & Liang, 1989) |
| **Metalaxyl** | 36 | 0.016 | 4.34 | (University of Hertfordshire, 2015) |

concentration needs to be evaluated, a more complex model is required (de Paz and Rubio, 2006).

*2.3 Data requirement*

The AF/RF model requires several input parameters, including physico-chemical soil properties, climate and pesticide properties in order to evaluate the leaching potential. The Geographic Information System (GIS) is used to store the database. The field capacity water content ($\theta_{FC}$), $f_{oc}$, and $\rho_b$ are the required soil data for this model. Field capacity water content was given by LDD (2010). The bulk density was estimated by the pedotransfer function of Souza *et al.* (2016) using sand fractions and the organic matter (OM). In this study, three soil types, which cover most of the area, were considered to assess the leaching potential of the pesticides, as shown in Table 1. The information was given by LDD (2010), implying that different leaching potentials were caused by different soil physico-chemical properties.

Moreover, the net annual recharge rate data were provided by DGR (2009).The 30-year annual average rainfall data from four stations were employed. According to the formula of the attenuation/retardation model (AF/RF), the net annual groundwater recharge rate or average water flow rate through the soil (q) are included as important input parameters. This parameter generally estimates the water balance in the subsurface, which concerns the rainfall amount, evapotranspiration rate and water holding capacity of the soil (Konkul *et al.*, 2014; Tiankao and Chotpantarat, 2018). Lastly, the required pesticide properties including Koc and $t_{1/2}$, were input into the GIS.

*2.4 AF/RF-GIS combination*

Integrating the simulation models and GIS software is useful for the evaluating leaching potential of pesticides. The time for model simulation is short, and the AF/RF model algorithm is suitable and easy to run through the GIS software. The ArcMap ver.10.3 GIS was applied as the data storage to link the model and, finally, to show the result maps, indicating the leaching potential of each pesticide. In this study, a compliance depth or groundwater depth of 0.5 m is assumed to represent a scenario of high vulnerability (Ki and Ray, 2015), which has a high potential of being contaminated by pesticides. In addition, the properties of the pesticides are listed in Table 2. The GUS index, expressing the pesticide leaching potentials, is also shown in the Table 2 and can be defined by the following equation

$$GUS = \log t_{(1/2)} (4-\log K_{oc})$$

where $K_{oc}$ is shown in the unit of ml/g (Gustafson, 1989).

## 3. Results and discussion

*3.1 Leaching potential*

The leaching potential of the pesticides in the study site was evaluated by the AF/RF model. For a large-scale simulation, the results can be presented as leaching potential maps. The maps provided a relative risk of the applied pesticides over the study area. In each map, there are differences in the AF value due to the various soil and climate properties. By comparing these maps, it is possible to identify a ranking of the leaching potentials of different pesticides (Figures 3-5).

According to the results, the leaching risk of glyphosate is very low due to its high soil sorption potential ($K_{oc}$) (Table 2). Additionally, the low average water flow rate through soil was another reason, resulting in a low leaching risk of the pesticide. In contrast, picloram is more mobile and persistent due to its chemical properties (Table 2). This result is similar to that of the study reported by Spadotto (2002). The ranking indicated that picloram had a higher leaching potential than atrazine, hexaxinone, and glyphosate.

*3.2 Ranking of the leaching potential of each pesticide*

The AF average values in the study area

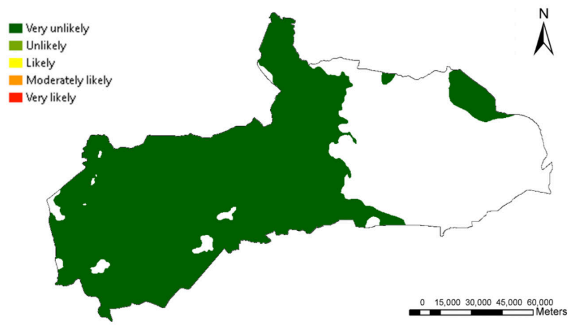


**Figure 3.** Leaching potential map of glyphosate

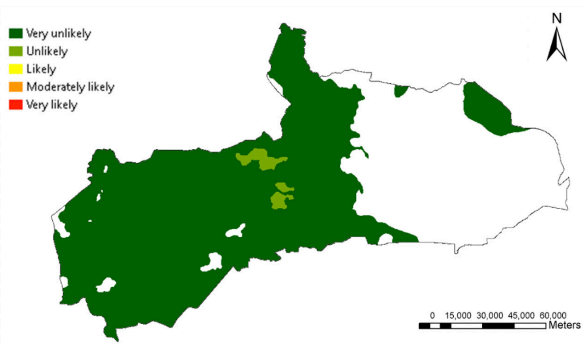


**Figure 4.** Leaching potential map of atrazine, hexaxinone, ethylene dibromide, and metalaxyl

were compared for different pesticides. The results, in descending order, are as follows: picloram (0.00364) > atrazine (0.00043) > hexaxinone (0.00022) > ethylene dibromide (0.00015) > metalaxyl (0.000002) > glyphosate (<0.000001) (Figure 6). The ranking is similar to the ranking established by the GUS index (Table1), showing the pesticide leaching potential risk.

Moreover, the ranking provided in this study was almost the same as that provided by Spadotto (2002). Generally, the average water flow rate through soil (q) can be one of the soil parameters corresponding to the AF value. Furthermore, Figure 7 presented a strong relationship of q and AF. The application of picloram in soil with a q of $3x10^{-4}$ showed an AF value of > 0.01, representing a high leaching possibility in the area.

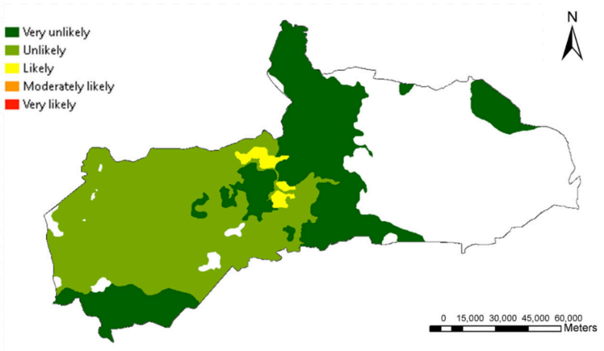


**Figure 5.** Leaching potential map of picloram

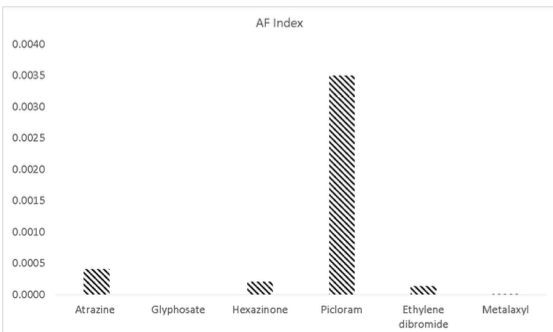


**Figure 6.** Average AF value of each pesticide

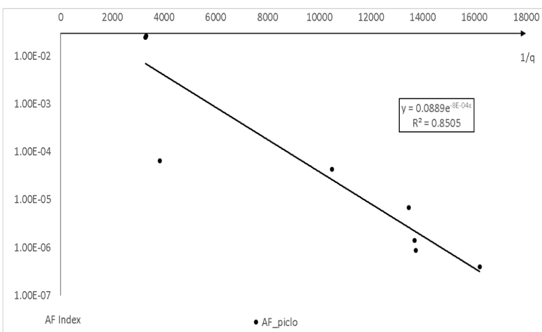


**Figure 7.** Relationship between the AF value and average water flow rate for picloram

## 4. Conclusions

The leaching potential of pesticides applied in the agricultural area of the central plain of Thailand was simulated using the AF/RF model, with GIS software. Additionally, the leaching risk of the pesticides was established, ranking from the highest risk (picloram) to the lowest risk (glyphosate). The result also indicated that soils with a high q through soil have the highest pesticide leaching risk.

The AF/RF model, applied in this study provides suitable information for environmental management and groundwater protection from pesticide contamination. According to the results, the pesticides are safe to be used in the study area under the environmental condition and application rate of pesticides. However, some applied pesticides are found in the soil and groundwater in the area. Thus, it is necessary to establish a soil and groundwater monitoring program for such agricultural chemicals.

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