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Agricultural Pesticides in Groundwater of Kanchana Buri, Ratcha Buri, and Suphan Buri Provinces, Thailand

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Groundwater contributes significantly to Thailand's water demands. Pesticides threaten groundwater quality beneath agricultural regions of the country. Applications of herbicides, insecticides, and fungicides more than doubled from the mid 1980s to mid 1990s (DOA 1996).

Identifying polluted locations and areas vulnerable to groundwater pollution enables selective deployment of limited monitoring resources. This study's objectives were to map and evaluate factors influencing concentrations of six pesticides in groundwater beneath an agricultural region of central Thailand.

MATERIALS AND METHODS

The study area occupies three provinces in west-central Thailand (Figure 1). Most of the population, approximately 2.5 million people, live in the eastern third of the study area (DLA 2002).

Mountainous terrain in the western half of the study area transitions to alluvial lowlands in the east. Predominant land cover includes tropical evergreen and deciduous forest in the mountainous west, with local agriculture in alpine valleys, and widespread agriculture in the eastern lowlands (Thapinta 2002). Rice and sugarcane occupy about half of the agricultural land (OAE 1999). Other field crops grown in the study area include cassava, corn, cotton, soybean, mung bean, and pineapple.

The study area averages approximately 1180 mm of annual rainfall, ranging from 570 mm in the southeast to 2540 mm in the north. Unconsolidated aquifers underlie most of the eastern lowlands (Piancharoen 1982; Ramnarong 1993). These aquifers comprise sediments of deltaic plains, recent alluvial plains, and rolling terraces. Consolidated aquifers in the western part of the study area consist of various igneous, sedimentary, and metamorphic rocks, locally enhanced by solution and fracturing. Yields of all aquifers in the study area range from approximately 1 to 50 m^3/h.

Soils of the study area range from very fine to coarse textured. Generally, finer-

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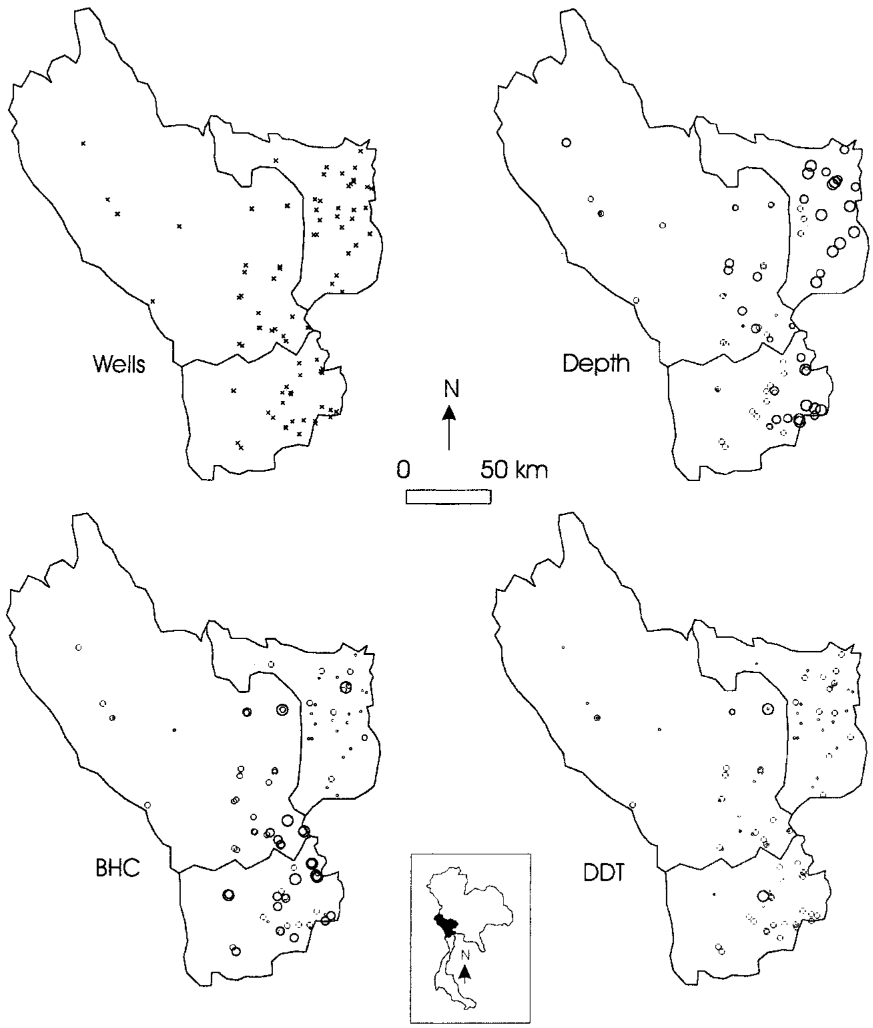

Figure 1. From upper left to lower right, sampled wells (x), depths of wells (12-20, 21-50, 51-100, 101-180 m), BHC (ND, 0.001-0.100, 0.101-0.200, 0.201-0.300, 0.301-0.575 ug/L), and DDT (ND, 0.001-1.000, 1.001-2.000, 2.001-9.681 ug/L); interior lines bound provinces (Kanchana Buri in west, Ratcha Buri in south, Suphan Buri in northeast); ND - not detected; circle size increases with category; inset shows study area (black) in Thailand.

textured soils occupy the lowlands in the east and southeast, and coarser-textured soils occupy the west and northwest highlands.

Four variables potentially influencing pesticide occurrence in groundwater — soil texture, land use, well depths, and average annual rainfall — were compiled at 90 domestic water wells. Concentrations of six pesticides — BHC, DDT, dicofol, dieldrin+aldrin, endosulfan, and heptachlor+heptachlor epoxide — were measured in each well (PCD 1995). All but dicofol and endosulfan were banned in the 1980s.

ArcView and ArcInfo geographic information systems (Environmental Systems Research Institute, Redlands, CA) mapped pesticide concentration categories. Logistic regression models predicted presence or absence of pesticides as a function of the two continuous (well depth and rainfall) and two categorical (soil texture and land use) independent variables. Soil texture and land use were divided into three and six integer categories, respectively. Higher categories were assigned to coarser soils and heavier inferred pesticide usage, based upon crop type. A limited number of categories ensured non separation of data points in the regression models. Rank correlation statistics quantified associations between pesticide concentrations and well depth.

RESULTS AND DISCUSSION

Depths of wells ranged from 12.2 to 180 m, with a median depth of 48 m. Most wells were located in the more populated eastern part of the study area (Figure 1). Generally, the deepest wells occupied the northeast and southeast corners of the study area (Figure 1).

Several locations had relatively high concentrations of one or more pesticides (Figures 1 and 2). Pesticide concentrations were generally lower in the northeast and extreme southeast corners of the study area. In contrast, maps revealed relatively high concentrations of most pesticides in the east-central part of the study area, characterized by relatively shallow wells.

Similar patterns of mapped pesticide concentration categories, for example BHC compared to dieldrin+aldrin, and dicofol compared to endosulfan, are consistent with multiple pesticides applied and reaching groundwater at particular locations (Figures 1 and 2).

Each pesticide was detected in at least one-third of the wells sampled (Table 1). BHC, dieldrin+aldrin, and DDT were most frequently detected, with BHC detected in more than two-thirds of the wells. Frequent presence of these banned pesticides suggest lingering residues from past applications, or continued usage since the 1980s. Observed concentrations of each pesticide exceeded respective standards, or zero in the case of no listed standard (Table 1). The maximum dieldrin+aldrin concentration was more than 100 times its standard. Highest heptachlor+heptachlor epoxide and DDT concentrations were more than two and five times the respective standards.

Logistic regression models were significant, at a 95% significance level, only for endosulfan and dicofol. Depth and texture were significant independent variables

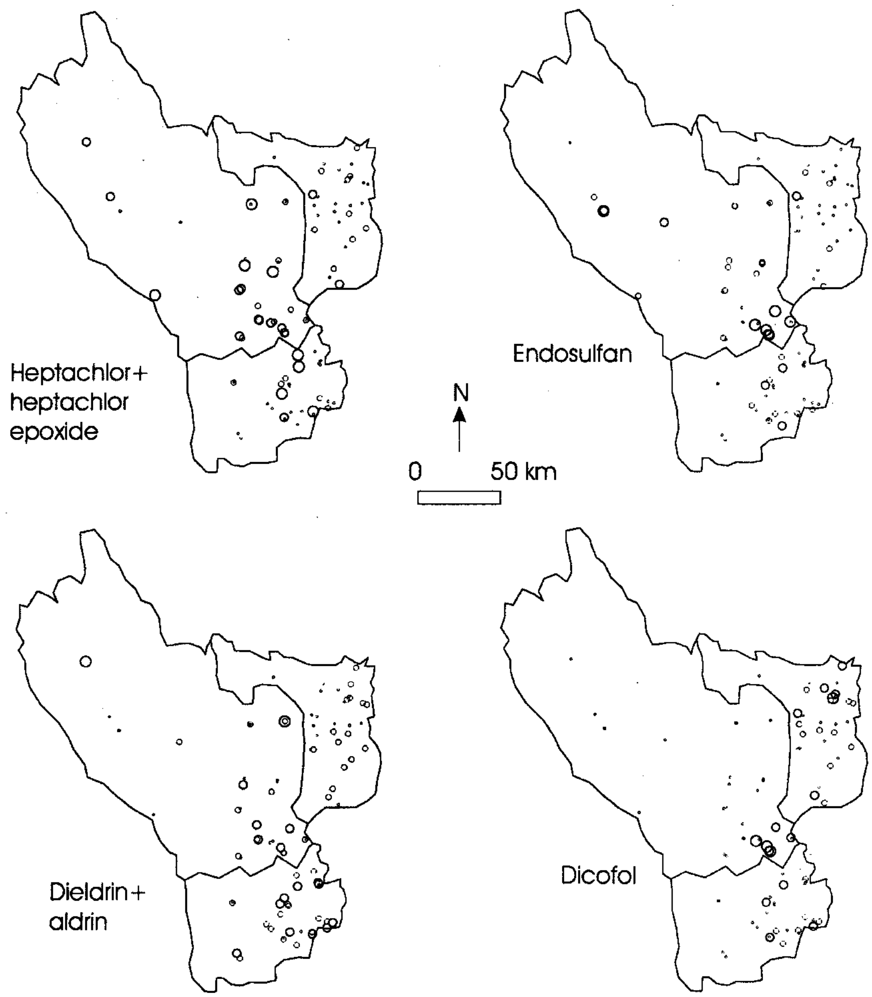

Figure 2. From upper left to lower right, heptachlor+heptachlor epoxide (ND, 0.001-0.200, 0.201-0.500, 0.501-1.369 ug/L), endosulfan (ND, 0.001-0.050, 0.051-0.100, 0.101-0.298 ug/L), dieldrin+aldrin (ND, 0.001-0.030, 0.031-0.100, 0.101-3.440 ug/L), and dicofol (ND, 0.001-0.050, 0.051-0.100, 0.101-0.270 ug/L); ND - not detected; circle size increases with category.

for the endosulfan and dicofol models, respectively. Probability of detecting endosulfan increased for shallower wells. Despite this expected result, overall the models were poor predictors of detectable pesticide levels in groundwater. Other factors not considered in the models, or inadequacy of included factors may account for poor model fit.

Table 1. Minimum, maximum, and median pesticide concentrations in 90 wells.

Pesticide	Min	Max	Med	Detects	Thai Std[1]	U.S. Std[2]
Dicofol	ND	0.270	ND	33	-	-
Dieldrin[3]+aldrin[3]	ND	3.440	0.006	57	0.03	-
Endosulfan	ND	0.298	ND	36	-	-
Heptachlor[3]+ heptachlor epoxide[3]	ND	1.369	ND	43	0.6	0.6
BHC[3]	ND	0.575	0.035	65	-	-
DDT[3]	ND	9.681	0.008	55	2	-

Notes: All concentrations ug/L; Min - minimum; Max - Maximum; Med - Median; Std - Standard; 1 - PCD (2000); 2 - USEPA (2004); 3 - Banned effective 1980-1988 (PCD, 1994); ND - not detected.

For example, rainfall may be a poor predictor of pesticide occurrence in groundwater because irrigation compensates for sparse rainfall in drier parts of the study area. Thus, pesticides may leach to groundwater in relatively wet as well as dry parts of the study area. Soil texture is a proxy for infiltration rate, but does not account for percolation through deeper formations in the vadose zone, which also govern the movement of pesticides to groundwater. Though not available, actual pesticide application rates rather than inferred application categories based upon crop type would likely improve model fit.

Rank correlation statistics revealed predominantly inverse relationships between pesticide concentrations and well depth, but were significant only for endosulfan (Table 2). An overall lack of significance between pesticide concentrations and well depth reflects residues in deeper intervals of the saturated zone.

Table 2. Rank correlation matrix.

	BHC	DDT	HHE	ENDO	DA	DICO
DDT	0.360*					
HHE	0.146	0.063				
ENDO	0.206	0.339*	0.338*			
DA	0.272*	0.202	0.186	0.047		
DICO	0.040	0.083	0.134	0.338*	0.110	
DEPTH	-0.206	-0.068	-0.153	-0.341*	0.038	0.111

Notes: HHE - heptachlor+heptachlor epoxide; ENDO - endosulfan; DA - dieldrin+aldrin; DICO - dicofol; * - Statistically significant (95% level).

There were positive correlations between every pair of pesticides, statistically significant in five cases (Table 2). These results reinforce visual similarities of mapped concentration categories.

Clusters of relatively high pesticide concentrations warrant localized investigations of groundwater pollution and vulnerability. Such investigations may involve sampling soil and rock above aquifers in addition to groundwater in existing and new wells. Devising effective groundwater monitoring protocols, including sampling locations and frequency, and implementing pesticide management practices would reduce the threat of contaminating drinking water. With sufficient field data governing occurrence, fate, and transport of particular chemicals, simulation models could further assess local-scale soil and groundwater vulnerability to pesticide contamination in the study area.

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