Organochlorine pesticides in soils around Guanting Reservoir, China

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Abstract Fifty-six representative samples of topsoil were collected around Guanting Reservoir, which is an important water source for Beijing. Concentrations of the insecticides HCH, DDT, and their metabolites were quantified by use of gas chromatography (GC) with electron capture detection (ECD). Organochlorine pesticides (OCPs) are still present in surface soils in the Guanting area. DDT accounts for about 93% of the total OCP content. Concentrations of α/γ , β/γ , and DDT/DDE are the result not only of historical use, but

also of more recent depositions. Statistical analyses, including principal component analysis (PCA) and cluster analysis (CA), revealed associations between concentrations of OCPs and major soil characteristics. Geographical information system (GIS) technology was used to develop maps of the distributions of OCP concentrations. The areas of greatest contamination were primarily in the central part of the study area and were correlated with greater population density, heavier traffic, and more industrial activity.

Keywords HCH · DDT · Multivariate statistics · GIS · Asia · Insecticides

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Introduction

HCH and DDT have been the most used organochlorine pesticides (OCPs) in agriculture for the control of pests all over the world since 1945. From 1981 to 1983, about 1.8×10^5 tons of HCH and 3.1×10^5 tons of DDT were consumed in 103 countries annually (Jones and Voogt 1999; Wang et al. 2006). Over the past 30 years, the presence of OCPs in the environment has been of concern due to their persistence long-range transport nature as well as toxic effects (Wania and Mackay 1996; Fillmann et al. 2002; Rodan 2002). Technical HCH and DDT were the most widely used pesticides in China from the 1950s to 1983, but they are officially banned now. Total production of HCH and DDT in China

was approximately 4.9×10^6 and 4.0×10^5 tons, respectively, accounting for 33% and 20% of the total world production, respectively (Wang et al. 2005). Although concentrations of OCPs in the environment have decreased considerably during the past 20 years, they can still be detected in various environmental matrices (Allen-Gil et al. 1997; Wu et al. 1999; Wong and Poon 2003; Zhang et al. 2006) and can pose potential risks for humans and other organisms (Woodwell et al. 1971; Iwata et al. 1994; Lee et al. 2001). OCPs can affect the normal function of the endocrine system of humans and wildlife (Colborn and Smolen 1996). Thus, OCPs in different environmental media have attracted extensive interest from both environmental scientists and the public.

Guanting Reservoir is Beijing's second largest source of water for agricultural and industrial purposes, and historically was also used for drinking water. Recently, due to runoff from non-point sources, direct dumping of wastes, mineral exploitation, and pollutants carried by rivers, Guanting Reservoir has suffered from extensive pollution (Hao et al. 2002; Liang et al. 2003). Due to its degraded water quality, which currently does not meet national health standard its use as a source of potable water was discontinued in 1997. The tributaries of Guanting Reservoir flow through agricultural areas containing large amounts of agrochemicals, which were used intensively to improve crop yields in these areas from the late 1940s through 1983 (Xue et al. 2006). Although regional surveys continue to monitor DDT and HCH residues in water and sediments (Ma and Wang 2001; Wang et al. 2003; Zhang et al. 2004), few studies have documented the soil concentrations and spatial patterns that have developed.

The objectives of the present study were to: (1) measure concentrations of DDT, HCH, and their metabolites in soils of Guanting Reservoir area; (2) determine their relationships with the way land is used and other environmental factors by using multivariate statistical methods; and (3) evaluate the risk of OCPs and their possible sources by using GIS spatial analysis. This analysis facilitated better understanding of the sources of OCP contamination in the area, and thus is considered crucial for management and remediation of Guanting watershed for the future of the municipal water supply.

Materials and methods

Study area

The 920 km² Guanting Reservoir study area, located to the northwest of Beijing (E115.43°, N40.19°–E115.97°, N40.50°), includes 100 km² of water and 820 km² of land. The area has a cool continental monsoon climate, with an average annual temperature between 3 and 9°C. Mean annual precipitation is between 370 and 480 mm. The annual accumulated temperature greater than 10°C ranges from 2,100 to 3,600°C. Land in the area is used for farms and orchards, and there is also fallow land. Much of the area is dedicated to agricultural cultivation, with a focus primarily on corn and cash crops.

Soil sampling

Fifty-six soil samples were collected in the spring of 2003 (Fig. 1). Each sample was taken from the upper 20 cm of soil and consisted of soil from at least five sub-sites, covering a radius of about 7 m to 10 m in a cross pattern. Sites were described relative to land use and major environmental features. Soils were air-dried at room temperature and sieved to pass a 2-mm nylon mesh milled using a ball mill.

Soil extraction and cleanup

Soils were extracted according to the procedures described by Kim and Smith (2001). Ten-gram samples were extracted twice and placed in 100 ml of hexane:dichloromethane at a ratio of 7:3 (v:v) for 30 min in an ultrasonic bath. To eliminate impurities extracts were centrifuged and decanted to a separating funnel, and 10 ml of concentrated sulfuric acid were added two or three times. Samples were then washed with 50 ml of 10% sodium chloride solution twice or more, until the pH value of the solution was near to 7.0. The resulting extract volume was concentrated to about 3 ml by a rotary evaporator and reduced to 0.5 ml under a gentle stream of ultra-pure nitrogen (99.99%). Reagent blanks were also analyzed simultaneously with the experimental samples.

Fig. 1 Study area and sample locations in Guanting Reservoir

Chromatographic analysis

Samples were analyzed using an Agilent Gas Chromatograph 6890 equipped with a Nickel 63 electron capture detector (uECD). Separation of OCP compounds was accomplished using an HP-1 50m $\times$ 0.32 mm id fused silica capillary column with a liquid phase thickness of 0.17 μ m. The temperature regimen was as follows: 150°C for 2 min, 5°C/min to 200°C, 200°C for 2 min, 8°C/min to 270°C, and 270°C for 5 min. The carrier gas was helium, with a flow rate of 1 ml/min. Nitrogen (0.6 ml/min) was used as the make-up gas for the electron capture detector, and injections were made in splitless mode. Peak areas were quantified using mirex as the internal standard and calculated by Chemstation software (from Agilent).

Quality control

All solvents used were distilled in glass (PR grade) and were checked for interference prior to use. The substance amounts in the extracts were quantified using the internal standard (2,4,5,6-tetrachloro-m-xylene, ab. TCMX) supplied by Supelco. The OCP standard admixture including α -, β -, γ -, δ -HCH and *pp'*-DDE, *pp'*-DDD, *o,p'*-DDT, *pp'*-DDT was obtained from the National Research Center for Certified Reference Materials of China. Method blank, duplicate samples and spiked (standard spiked into solvent) were analyzed. The average recoveries of α -, β -, γ -, and δ -HCH were $69.1 \pm 7.0\%$, $65.2 \pm 9.2\%$,

$66.0 \pm 5.3\%$, and $69.6 \pm 5.7\%$, respectively; those for *pp'*-DDE, *pp'*-DDD, *o,p'*-DDT, and *pp'*-DDT were $68.1 \pm 4.9\%$, $78.7 \pm 9.2\%$, $66.1 \pm 1.3\%$, and $57.4 \pm 2.8\%$, respectively. The limits of detection of OCPs were described with a signal-to-noise ratio (S/N) of three. The detection limits for the substances were 6.0×10^{-2} to 1.5×10^{-1} ng/g dw for HCHs, and 7.0×10^{-2} to 1.9×10^1 ng/g dw for DDTs. The relative standard deviation (RSD) varied from 4 to 9%.

Soil characteristics

Soil organic C (TOC) and total N (TN) were analyzed using a Universal CHNOS Elemental Analyzer (Elementar Vario EL III, Germany). Total phosphorus (TP) concentrations were determined following HNO_3 – HClO_4 digestion (Olsen and Sommers 1982). Soil texture was measured by analyzing the proportion of clay, silt, and sand particles present using the pipette method, and the soil type was classified by consulting the soil texture triangle (Smith 1996). Soil pH was measured using a soil:water ratio of 1:2.5 by a potentiometric glass electrode. Cation exchange capacity (CEC) of mineral soils is the sum of $\text{Ca} + \text{Mg} + \text{K} + \text{Na} + \text{Fe} + \text{Al} + \text{Mn}$ extractable with 1M NH_4 -acetate (Liu 1996).

Statistical analysis

Concentrations of OCPs in soil were summarized using arithmetic means, and the values were less than

the LOD (limits of detection) were set to zero for statistical purposes. All statistical analyses, including principal component analysis (PCA) and cluster analysis (CA), were performed using SPSS for Windows, version 11.0, from LEAD Technologies Inc. The software used for the mapping and spatial analysis was ArcGis (ESRI, US). An interpolation method called Ordinary Kriging was adopted for the interpolation of geographical data. Three-dimensional views of the map of the soil pollutants were also formed using Surfer 8.0 (Golden Software) to provide better visualizations.

Results and discussion

Absolute and relative concentrations of OCPs

Concentrations of HCH, DDT, and their isomers measured for the soil samples are summarized in Table 1. The mean concentration of total HCH was 6.6×10^{-1} ng/g dw, ranging from 0.0 to 7.3 ng/g dw with a standard deviation of 1.3. For each isomer of HCH, the minimum value was less than the limit of detection and thus set to 0.0 ng/g dw, while the maximum concentration was 7.8×10^{-1} ng/g for α -HCH, 2.7 ng/g for β -HCH, 1.4 ng/g for γ -HCH, and 3.6 ng/g for δ -HCH. HCH isomers could not be detected in samples from most of the study sites (due to their small detection ratios) and were only found in two

locations (Beixinpu Town and Huailai County). These two locations are predominantly used for orchards. According to our recent survey, relatively large amounts of pesticides, including lindane and dicofol, are still used in this area. The α/γ -HCH ratio can serve as an indicator of previous HCH use (Kim et al. 2002). Lesser ratios indicate that HCH was applied at a relatively distant location and transported to the detection region by air, while a greater value indicates that HCH or an HCH surrogate, such as lindane, has been applied locally. The α/γ -HCH ratio (max value) for this research is 3.4, with a mean ratio of 9.8×10^{-1} . A ratio of this magnitude suggests that the current HCH pollution in the area resulted from other HCH-like pesticides or lindane applications in the vicinity. The ratio of β -HCH to γ -HCH was also used in this study to indicate historical application and trace pollution sources. The β/γ ratios of all samples ranged from 0.0 to 2.0×10^1 , with a mean of 6.3, because γ -HCH has a greater leaching ability than β -HCH (Wang 2004).

The minimum values of the four DDT isomers in the soils were all less than the limit of detection and thus set to a proxy value of 0.0 ng/g dw. As with HCH, and the maximum values were 5.2×10^1 ng/g dw for p,p' -DDE, 3.4 ng/g dw for p,p' -DDD, 1.2×10^1 ng/g dw for o,p' -DDT, and 3.3×10^1 ng/g dw for p,p' -DDT. Total concentrations of DDT in soils ranged from less than the LOD to 7.6×10^1 ng/g dw with a mean of 9.5 ng/g dw and a rather large

Table 1 Concentrations (ng/g dw) of OCPs in soils

Variables		Mean $\pm$ SD	Median	Minimum*	Maximum
HCHs group	α -HCH	$6.0 \times 10^{-2} \pm 1.4 \times 10^{-1}$	0.0	0.0	7.8×10^{-1}
	β -HCH	$3.6 \times 10^{-1} \pm 6.8 \times 10^{-1}$	0.0	0.0	2.7
	γ -HCH	$6.0 \times 10^{-2} \pm 2.0 \times 10^{-1}$	0.0	0.0	1.4
	δ -HCH	$1.9 \times 10^{-1} \pm 6.0 \times 10^{-1}$	0.0	0.0	3.6
	Σ HCH	$6.6 \times 10^{-1} \pm 1.3$	0.0	0.0	7.3
DDTs group	p,p' -DDE	4.7 ± 9.4	1.4	0.0	5.2×10^1
	p,p' -DDD	$2.4 \times 10^{-1} \pm 6.1 \times 10^{-1}$	0.0	0.0	3.4
	o,p' -DDT	$8.4 \times 10^{-1} \pm 2.3$	0.0	0.0	1.2×10^1
	p,p' -DDT	3.7 ± 7.8	0.0	0.0	3.3×10^1
	Σ DDT	$9.5 \pm 1.8 \times 10^1$	0.0	0.0	7.6×10^1
Index	a/r	$9.8 \times 10^{-1} \pm 1.1$	0.0	0.0	3.4
	b/r	6.3 ± 6.3	4.8	0.0	2.0×10^1
	DDT/DDE	$8.1 \times 10^{-1} \pm 1.1$	8.0×10^{-1}	0.0	4.2

* The values less than LOD (limits of detection) were set to zero for statistical purpose

standard deviation of 1.8×10^1 . The major OCP in the soil samples was DDT, accounting for about 93% of the total pesticide concentration. DDT is very resistant to biodegradation and is strongly absorbed by soil particles (Keith 1997). This work indicates that it was persistent in the top layers of the study area. DDT isomers and transformation products persist in the environment and gradually degrade to DDE and DDD. The relative concentration of different DDT isomers in the Guanting area was found to be: p,p' -DDE > p,p' -DDT > o,p' -DDT > p,p' -DDD. p,p' -DDE (82.1%) and p,p' -DDT (73.2%) were detected in many study sites. The ratio of parent compound to metabolites was used to infer sources and to qualitatively determine the age of contaminant residues in soil. The DDT/DDE ratios were quite variable, ranging from 0.0 to 4.2, with a mean of 8.1×10^{-1} . The predominance of the DDE isomer in the soils indicates that extensive contamination by DDT occurred in the past. However, the relatively great concentration of p,p' -DDT indicates that recent inputs of DDT compounds must have occurred in this region. Current concentrations of DDT are still less than the concentrations (3.6×10^2 ng/g ww) found at the beginning of the 1990s (Yue et al. 1990).

Relationship between OCPs and land use

The major agricultural activities in the Guanting area include row crops and intensive planting of fruits and vegetables. The intensive agriculture relies heavily on

the use of pesticides for the control of weeds, pests, and diseases. Although the use of HCH and DDT ceased in China in 1983, the aforementioned results indicate that residues still persist in the topsoil even after a period of nearly 20 years. How pesticides were applied in this region in the past is not clearly known, but it is reasonable to assume that pesticides containing HCH and DDT were used in considerable quantities. Concentrations of OCPs for areas with different agricultural functions are given in Table 2. The eight categories of land use were further subdivided into three general groups: farming (including cabbage, maize, and wheat), orchards (including apple, peach and grape), and fallow land (including meadow and shrub-land). Statistically significant differences in the total concentrations of HCH and DDT were found among these three general groups, which can be ranked in decreasing order of concentration as orchard > farm > fallow. Because of the susceptible orchards to pests and diseases, these fields have continually received a large number of pesticide applications. Some of the pesticides contained considerable amounts of POP-like substances, especially in the case of peach fields (4.0 ng/g dw for HCH and 4.6×10^1 ng/g dw for DDT). A campaign to combat insect pests resulted in a blanket input of insecticidal DDT and HCH in this region in the 1980s (Hua and Shan 1996).

Total concentrations of DDT found in soils used for growing vegetables (e.g., cabbage, 1.9×10^1 ng/

Table 2 Concentrations (ng/g dw) of OCPs in soils from different land use types

OCPs	Land-use categories							
	Apple <i>n</i> = 9	Peach <i>n</i> = 3	Grapevine <i>n</i> = 5	Cabbage <i>n</i> = 2	Maize <i>n</i> = 21	Wheat <i>n</i> = 2	Fallow <i>n</i> = 8	Shrubwood <i>n</i> = 6
α -HCH	1.2×10^{-1}	3.8×10^{-1}	9.0×10^{-2}	1.3×10^{-1}	3.0×10^{-2}	0.0	0.0	0.0
β -HCH	6.2×10^{-1}	1.4	6.8×10^{-1}	3.8×10^{-1}	2.7×10^{-1}	0.0	0.0	2.0×10^{-1}
γ -HCH	4.0×10^{-2}	6.1×10^{-1}	3.0×10^{-2}	4.0×10^{-2}	3.0×10^{-2}	7.0×10^{-2}	0.0	1.0×10^{-2}
δ -HCH	1.0×10^{-1}	1.6	0.0*	0.0	2.0×10^{-1}	4.7×10^{-1}	0.0	0.0
Σ HCH	7.9×10^{-1}	4.0	8.0×10^{-1}	5.5×10^{-1}	5.4×10^{-1}	5.4×10^{-1}	0.0	1.8×10^{-1}
p,p' -DDE	4.7	2.7×10^1	9.5	7.8	2.9	5.9×10^{-1}	4.7×10^{-1}	2.2
p,p' -DDD	1.1×10^{-1}	1.6	5.3×10^{-1}	7.5×10^{-1}	1.2×10^{-1}	0.0	2.0×10^{-2}	1.7×10^{-1}
o,p' -DDT	1.9	5.4	1.4	7.6×10^{-1}	2.3×10^{-1}	3.0×10^{-1}	0.0	0.0
p,p' -DDT	5.5	1.2×10^1	5.8	9.5	2.9	8.3×10^{-1}	3.2×10^{-1}	1.5
Σ DDT	1.1×10^1	4.6×10^1	1.7×10^1	1.9×10^1	6.1	1.7	8.0×10^{-1}	3.2

* The values below LOD (limits of detection) were set to zero for statistical purpose

g dw) were greater than those found in soils used for growing wheat (1.7 ng/g dw) and maize (6.1 ng/g dw). A greater portion of the parent compound *p,p'*-DDT in soils used for planting cabbage indicates that considerable amounts of pesticide were still being applied, and some DDT compounds or DDT surrogates were apparently contained in these pesticides. The similarly great fractions of *p,p'*-DDE observed in the orchard soil might be due to the intensive use of pesticides in the past. The data from the present soil monitoring study clearly indicate an anthropogenic pollutant input in the past that remains today even after a period of nearly 20 year, although the degree to which the pollutants might pose a long-term ecotoxicological risk is uncertain.

Results of multivariate statistics

Principal component analysis (PCA)

PCA is one of the simplest and oldest eigenvalue analysis-based ordination methods for quantitative community data. In PCA, the principal components are calculated based on the correlation matrix. Varimax with the Kaiser normalization was used as the rotation method in the analysis. When the first two axes of the ordination function are plotted, data from an experimental system with similar characteristics lie close together, while those with dissimilar characteristics are far apart (van Wijngaarden et al. 1995).

PCA was applied in this work to determine the degradation behavior of DDT and HCH. OCP concentrations and major soil characteristics (Table 3) analyzed by PCA are illustrated (Fig. 2). Three principal components (factors) were considered in the PCA analysis, accounting for over 80% of the total variance. The first principal component was associated mainly with compounds such as α -HCH, β -

HCH, γ -HCH, δ -HCH, *p,p'*-DDE, *o,p'*-DDT, *p,p'*-DDT, *p,p'*-DDD, total DDT, and total HCH, which explained over 45% of the total variance, and accounted for the greatest loading for factor 1. However, the results reported in the same area by Zhang (2005) showed that HCH, DDT, and their isomers were associated in different principal components. TOC was found to be associated with TN, TP, CEC, and Clay in factor 2, which explains about 20% of the total variance and accounts for the greatest loading for factor 2. This might result from anthropogenic activities, such as pesticide input, fertilization, and cultivation.

Cluster analysis (CA)

Cluster analysis has proven useful in solving classification problems. R-cluster multivariate analysis was conducted to examine the distribution of geochemical indicators in soils in the Guanting area and to find any relationships that might exist among them. The distance measure used in CA was the Pearson correlation. The results of the analysis yielded a dendrogram, which is illustrated in Fig. 3. The distance cluster represents the degree of association between the variables. The less the value on the distance cluster, the more significant the association is. A criterion for the distance cluster between 15 and 20 was used in the analysis.

Three distinct clusters that can be identified in the soils are shown as follows: cluster I: contained α -HCH, β -HCH, γ -HCH, δ -HCH, *p,p'*-DDE, *o,p'*-DDT, *p,p'*-DDT, *p,p'*-DDD, and also total DDT, and total HCH. This cluster was further subdivided into two groups—a DDT group and a HCH group. Cluster II: contained TN, TP, TOC and CEC. They are connected with soil organic fertility. The association might reflect the input from some anthropogenic

Table 3 Descriptive statistics of major soil properties

Variables	Mean $\pm$ SD	Median	Minimum	Maximum
TOC (g/kg)	$1.5 \times 10^1 \pm 6.6$	1.5×10^1	3.1	3.2×10^1
TN (g/kg)	$1.0 \pm 3.1 \times 10^{-1}$	1.0	4.2×10^{-1}	1.8
TP (g/kg)	$5.7 \times 10^{-1} \pm 2.0 \times 10^{-1}$	5.2×10^{-1}	2.9×10^{-1}	1.1
PH	$7.5 \pm 2.0 \times 10^{-1}$	7.5	7.0	7.8
CEC (emol/kg)	$1.3 \times 10^1 \pm 7.6$	1.1×10^1	3.3	3.4×10^1
Clay (%)	$1.3 \times 10^1 \pm 5.0$	1.4×10^1	3.8×10^{-2}	2.4×10^1

Fig. 2 Principal component analysis for soil chemical variables **Fig. 3** Dendrogram of hierarchical cluster analysis for variables (R-cluster)

activities and/or the natural geochemical system. Cluster III: contained Clay, which mainly came from natural materials and was controlled by soil formation and its development processes.

It has been reported that the intensity of OCP degradation depends on several environmental factors, such as temperature, soil type, moisture, organic carbon, and pH (Hitch and Day 1992; Cousin et al. 1999). However, the clustering of pH was formed at a greater distance criterion (about 25) in this study than in the previous study by Zhang (2005). This shows that there is no significant association between pH and other elements. Little deviation of pH values

(mean = 7.48, SD = 0.20) in all soil samples is a possible explanation for this. In general, the results from PCA agreed well with those from CA. The relatively great influence of anthropogenic activities on soil pollutants and major physiochemical properties were well illustrated in both analyses.

Spatial distribution of OCPs

Soil pollution maps of HCH and DDT were generated by using GIS. A clear spatial pattern around Guanting Reservoir was observed for both HCH and DDT, with significantly greater concentrations in the central area

than in other regions (Figs. 4 and 5). A relatively great amount of HCH and DDT was used in this region during the 1970s to protect the forests (Wang et al. 2005). Because most of the area was converted to orchards, abundant pesticides (including dicofol) are still being used to control pests and diseases. The areas with greatest risk are located around the town of Beixinpu (Fig. 4). In areas upstream of Guanting Reservoir (the northeast corner of the map), the HCH concentration was relatively small, and was unlikely to pose an ecological risk. The general trend of DDT is presented (Fig. 5). The greatest value occurred in the center of the plot (the area surrounding Beixinpu), but relatively great DDT content was also noticeable at the eastern and western margins of the research area. The occurrence and the formation of OCPs might originate from similar sources, and they are dependent both on historical application and contemporary anthropogenic activities.

Furthermore, three-dimensional maps of concentrations of OCPs and major indicators were plotted to investigate the effects (Figs. 4 and 5). Some of the areas where the greatest concentrations were measured were rather similar. That is, greater concentrations of OCPs were observed at the more central sites for both pesticides. This is consistent with the known

historical usage in the region. Moreover, a pesticide factory was once located near Beixinpu, which might also have been a source of OCPs. The northeast and the northwest parts were found to be more polluted for DDT than the other parts of the study area, except for the central area. This result shows that the soils in these areas contain elevated concentrations of DDT that exceed the Dutch new target values (1.0×10^1 ng/g dw), but are less than the Dutch intervention value (4.0×10^3 ng/g dw) (NMH 2000).

Traffic emissions and other human activities may be a common source governing the distribution of HCH and DDT in soils. Three zones with greater population density, heavier traffic, or more industrial activities were identified: Yanqing County, Huailai County, and the agricultural town of Beixinpu. Vehicular transport emissions from intensive traffic activities likely contribute to the enrichment of OCPs in these areas, in addition to the historical agricultural application. The effect of wind may have led to the further dispersion of the pollutants from these heavy traffic areas to the surrounding areas through atmospheric deposition. The three-dimensional maps of the indicators (a/r-HCH, b/r-HCH, and DDT/DDE) give a clear illustration that HCH and DDT may originate from both historical

Fig. 4 Map of the distribution of HCH and its degradation products in soils from Guanting area

Fig. 5 Map of the distribution of DDT and its degradation products in soils from Guanting area

usage and new input in the central area and two counties mentioned above, while most other places are mainly affected by historical application.

HCH and DDT were used heavily in agricultural fields for the control of pests and diseases in China from the 1960s until 1983, when their application was banned in China by government mandate. Lindane and dicofol have since been used as substitutes. Although the usage of OCPs was phased out for decades, the large inputs of OCPs in the past, coupled with great soil adsorption, have allowed these chemicals to remain detectable in the soil in their original form (e.g., lindane, and *p,p'*-DDT). In most instances, absolute concentrations in soils are less than 50 ng/g dw, which has been set for use of agricultural lands in China (Environmental standard committee of China, 1995). Only rarely are their concentrations in this region great enough to pose any immediate ecological concern.

Conclusions

HCH and DDT in soils from the Guanting area were detected for assessment in this study. DDT was the

primary pollutant as compared to HCH. Their concentrations were less than the national standard for China and target values set by the Netherlands. For different land uses, both concentrations of HCH and DDT were found to have the same rank of orchard > farm > fallow. In addition, multivariate statistical methods were used to provide an overview of OCP-degradation behavior and spatial pattern in the area. The results from PCA and CA showed distinctly different associations and clustering patterns between the organic pollutants and physicochemical properties. The soil pollution maps of OCPs were generated by using a GIS technique to indicate the degree of contamination in the soils. The three-dimensional maps were plotted to identify the hot-spot areas in different sites. In some typical sites, relatively great concentrations of DDTs were observed. They may result from a combination of heavy historical use, retarded degradation, and possible new input (e.g., dicofol).

This research demonstrates the value of GIS and multivariate statistical methods by studying OCP contamination on a regional scale. It suggests that more environmental risk assessments should be carried out on such chemicals, more progress should be made to understand issues related to OCPs, and further exploration is

needed to better understand the environmental behavior of OCPs.

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