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Gridded Usage Inventories of Technical Hexachlorocyclohexane and Lindane for China with 1/6° Latitude by 1/4° Longitude Resolution

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Abstract. China banned the use of technical HCH (BHC: 1,2,3,4,5,6-hexachlorocyclohexane) in 1983; lindane has been used in this country since 1991. The total production was around 4 million t for technical HCH from 1952 to 1984, and 11,400 t for lindane between 1991 and 2000. Though the total produced technical HCH was considered to be used in China, only 3,200 t of lindane were used between 1991 and 2000 with the rest for export or on unused stack. Annual usage of these two compounds was located into each province first and then broken for different crops. Inventories of gridded usage of both technical HCH and lindane with 1/6° by 1/4° latitude/longitude resolution have been created by different gridded cropland data sets as surrogate data. The intensive use of technical HCH on croplands was concentrated in the southeastern part of China, but the use of lindane was concentrated in the northern part of China.

1,2,3,4,5,6-Hexachlorocyclohexane (HCH), also called benzene hexachloride (BHC), is an organochlorine insecticide available in two technical formulations: technical HCH (a mixture of different isomers) and lindane (almost pure γ-HCH). Due to its effectiveness and low price, technical HCH was one of the most widely used insecticides in the world. The total usage to date has been estimated to be as high as 10.0 million t (Li 1999a). As a broad-spectrum insecticide, technical HCH has been used for both agricultural and nonagricultural purposes. It has been used in seed and soil treatment on a variety of crops, ornamental trees, lawns, greenhouse soils, wood products, and for vector control. As results, the use of this insecticide has been caused widespread environmental contamination in the global ecosystem (Tanabe and Tatsukawa 1980; Muir *et al.* 1988; Norstrom *et al.* 1988; Barrie *et al.* 1992; Li 1999a). In the 1970s, most developed nations imposed a total ban on or restricted the use of technical HCH and switched to lindane (Voldner and Li 1995). Although the justification for a classification of lindane as being a persistent organic pollutant, is still under debate (Denkler 1996), some countries have been urged to ban the use of this insecticide (World Wildlife Fundation 1999).

During the 1970s and the beginning of the 1980s, China was the largest producer and user of technical HCH in the world (Li *et al.* 1998). During those years, HCH residues accumulated in soil and food and bioaccumulated in living organisms. They became a threat to people's health and the ecosystem in China (Cai *et al.* 1985; Huang 1989; Zhang *et al.* 1996). On April 1,1983, the Chinese government banned the production and use of this insecticide (Chinese Ministry of Agriculture 1989). In 1991, the Chinese government decided to produce lindane for export and for use on certain crops. Since then lindane has been used in a restricted way. Any use of this insecticide must be approved by the authorities.

Production and Usage

The total amount of technical HCH produced in China is 4.5 million t (Li *et al.* 1998). Annual production of technical HCH is depicted in Figure 1 (Li *et al.* 1998). Figure 1 shows that before 1972, the production of technical HCH in China increased almost every year, reaching a peak in 1972. After decreasing for a few years, production increased again and reached a second peak in 1980, decreasing thereafter to zero in 1984. Figure 2 gives annual production and usage of lindane. Lindane has been produced and used in China since 1991. The total production of lindane was estimated to be 11,400 t between 1991 and 2000. Though the total produced technical HCHs was considered to have been used in China, only 3,200 t of lindane were used in China between 1991 and 2000. The rest have been for export or on unused stack. The major uses of lindane are to kill locus, wheat mole cricket, and midges and to kill wood moth. It was reported that lindane was used to eliminate wood moth in forestry of Heilongjiang Province in 1990 (Chinese Ministry of Agriculture 1991).

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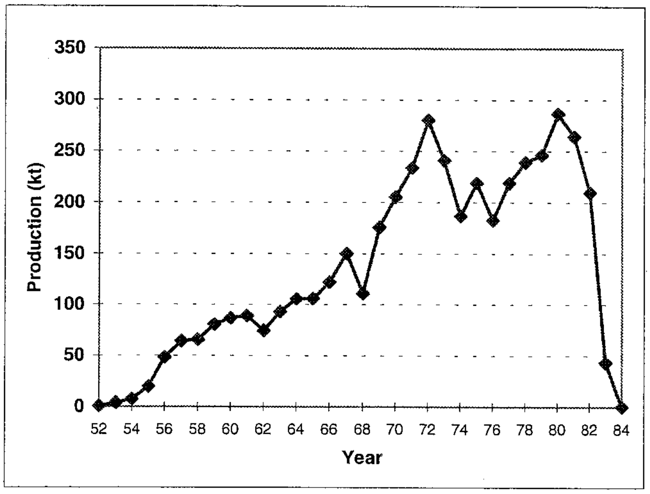

Fig. 1. Annual technical HCH production in China from 1952 to 1984 (Li *et al.* 1998)

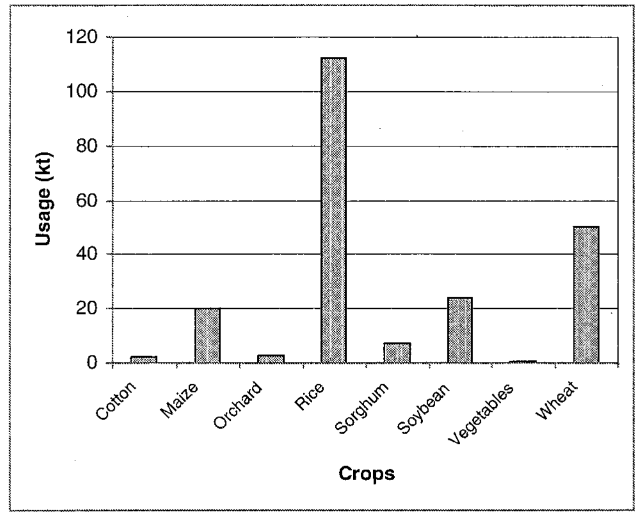

Fig. 3. Technical HCH applied among different crops in 1980 (Li *et al.* 1998)

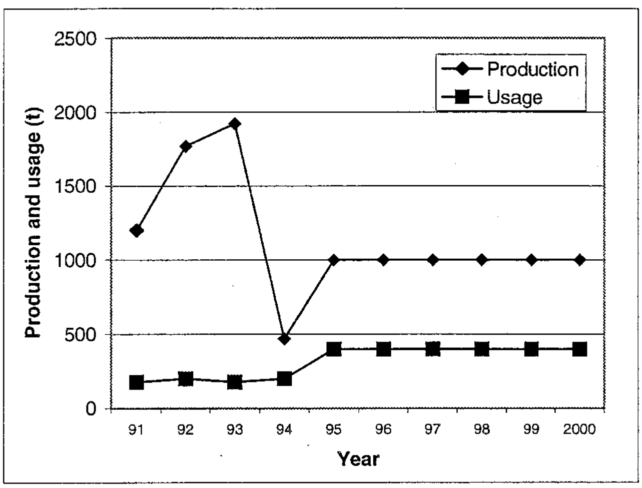

Fig. 2. Annual lindane production and usage in China between 1991 and 2000

Technical HCH Usage Based on Crops and Provinces

In China, technical HCH was mainly used in agriculture, although a small apportion was also used in forestry and public health (Cai *et al.* 1992; Li *et al.* 1998). Crops on which HCH was widely used in China were rice, wheat, soybean, maize, and sorghum. Figure 3 shows the quantities of technical HCH applied among different crops in 1980. Of the total agricultural consumption, about half of this insecticide was used in rice paddies, one quarter on wheat, and 10% on each of soybean and sorghum and maize (Li *et al.* 1998).

To distribute technical HCH usage among different crops in different provinces and autonomous regions in China, the usage of all pesticides (including DDT and technical HCH) based on provinces in 1960 and 1970 (Cai 1996) was used to allocate technical HCH usage between 1952 and 1965 and between 1966 and 1975 among different provinces, respectively, because the information of technical HCH usage based on provinces during this time period is not available. Technical HCH usage based on provinces from 1976 to 1984 was based on the provincial use of technical HCH in 1980 (Li *et al.* 1998). Distributions of application rates among different provinces in China for pesticides in 1960 and 1970 and technical HCH in 1980 are illustrated in Figure 4. The abbreviations and names of provinces in China are given in Table 1.

In each province, use of technical HCH on different crops was estimated according to the main crops growing in that province, keeping the rate of national use among different crops in a ratio similar to those show in Figure 3. The use of technical HCH on vegetables was not taken into account, without losing too much accuracy, as only around 0.2% of technical HCH was used on vegetables (Li *et al.* 1998).

Usage Gridding

It is very important to allocate the use of pesticides on areas where pesticides actually are used, which is the purpose of usage gridding. For example, use of technical HCH was primarily concentrated in the southeastern part of China, and very little or none was used in the west part of China. Even in a province, technical HCH could be used in a large amount in some areas, but little or none in others. Although it is impossible to know exactly where and when technical HCH and lindane were used, it will be very useful if the usage data based on regions or provinces can be distributed among proper usage areas, such as cropland, instead of the entire regions or provinces. In other words, surrogate data are needed to allocate the use of both technical HCH and lindane.

Surrogate Data

A global cropland data set with 1° × 1° longitude and latitude resolution was used for gridding global agricultural usage of

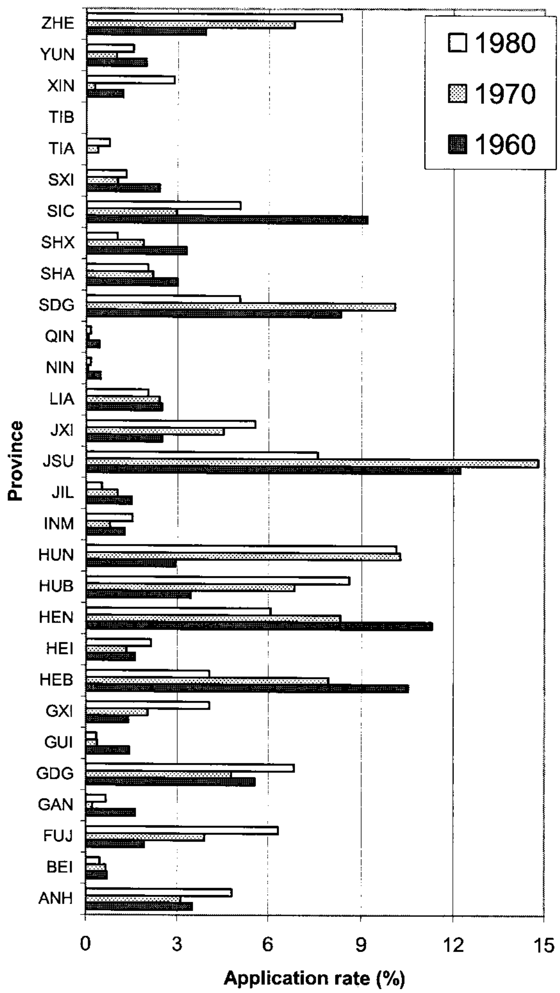

Fig. 4. Distributions of application rates among different provinces and autonomous regions in China for pesticides in 1960 and 1970 and technical HCH in 1980

technical HCH (Li 1999b). To grid agricultural usage of pesticides in China, gridded cropland datasets with 1/6° latitude by 1/4° longitude resolution were created for China (Li *et al.* 1998, 1999). All these cropland datasets were compiled by using an advanced very high-resolution radiometer (AVHRR) global

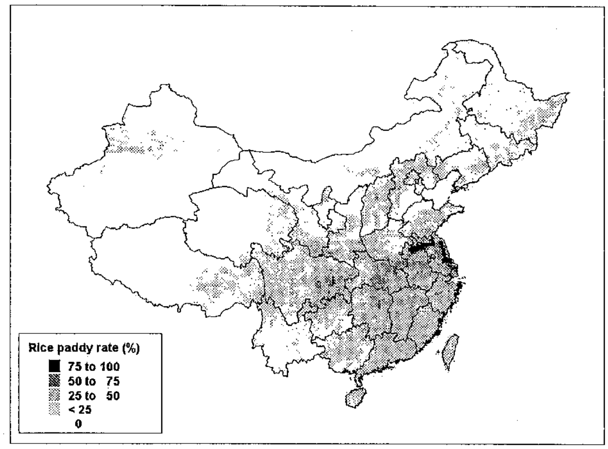

Fig. 5. Distribution of rice paddies in China with 1/4° longitude by 1/6° latitude resolution (the size of each grid cell is around 400 km^2)

land database, which is available from the Web at the EROS Data Center Node, http://edcwww.cr.usgs.gov/landdaac/1KM. To allocate technical HCH usage among different crops, the rice paddies (Figure 5), wheat land (Figure 6), soybean, sorghum, maize, and cotton lands in China have been created in this work.

Gridded Usage for Technical HCH and Lindane

Figure 7 gives gridded technical HCH usage in (a) rice paddies and (b) wheat lands in China with 1/4° longitude by 1/6° latitude resolution (data from Taiwan are not included here). In 1980, the main areas using this insecticide were in southeastern China. Some places in this region have the highest usage densities of technical HCH, reaching more than 400 t per grid cell on rice paddies and 900 t per cell on wheat lands. Distribution of total technical HCH usage in agricultural fields in China with 1/4° longitude by 1/6° latitude resolution is shown in Figure 8 for 1980 and Figure 9 for 33 years from 1952 to 1984. The heavy use of technical HCH in China happened in Jiangsu, Hunan, and Henan Provinces, reaching as high as 950 t per cell in some areas in 1980 and 13,000 t in 33 years.

Because the major uses of lindane are to kill locus, wheat

Table 1. Abbreviations and names of provinces and autonomous regions in China

Abbreviation	Name	Abbreviation	Name	Abbreviation	Name
ANH	Anhui	HUB	Hubei	SHA	Shanghai
BEI	Beijing	HUN	Hunan	SHX	Shaanxi
FUJ	Fujian	INM	Nei Menggu	SIC	Sichuan
GAN	Gansu	JIL	Jilin	SXI	Shanxi
GDG	Guangdong	JSU	Jiangsu	TIA	Tianjin
GUI	Guizhou	JXI	Jiangxi	TIB	Tibet
GXI	Guangxi	LIA	Liaoning	XIN	Xinjiang
HEB	Hebei	NIN	Ningxia	YUN	Yunnan
HEI	Heilongjiang	QIN	Qinghai	ZHE	Zhejiang
HEN	Henan	SDG	Shandong		

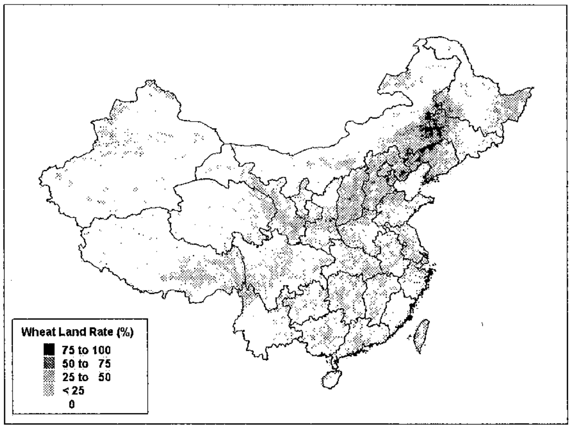

Fig. 6. Distribution of wheat land in China with 1/4° longitude by 1/6° latitude resolution

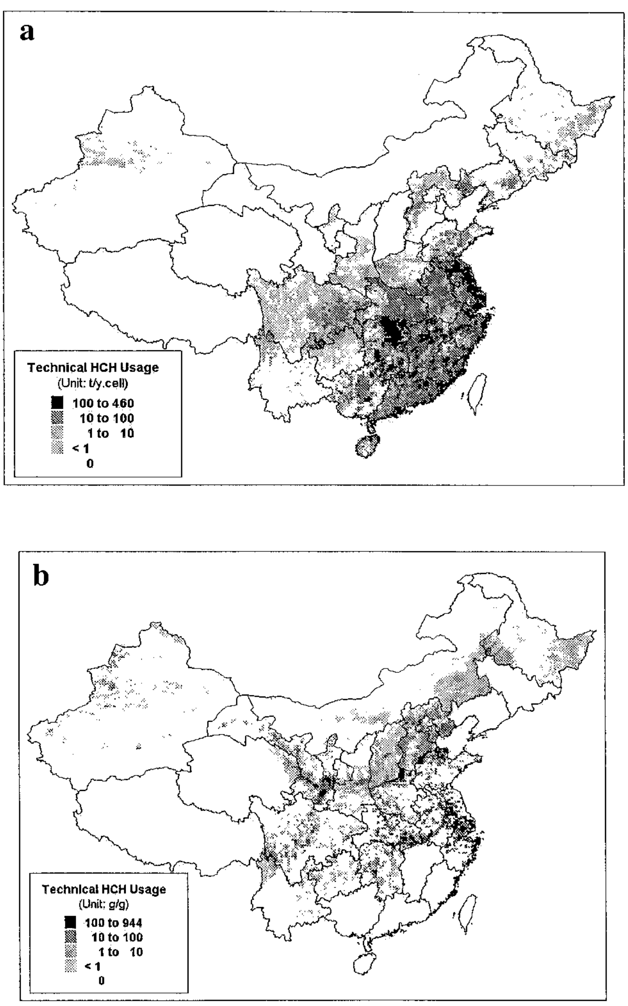

Fig. 7. Distribution of technical HCH usage in (a) rice paddies and (b) wheat lands in China for 1980 (with 1/4° longitude by 1/6° latitude resolution)

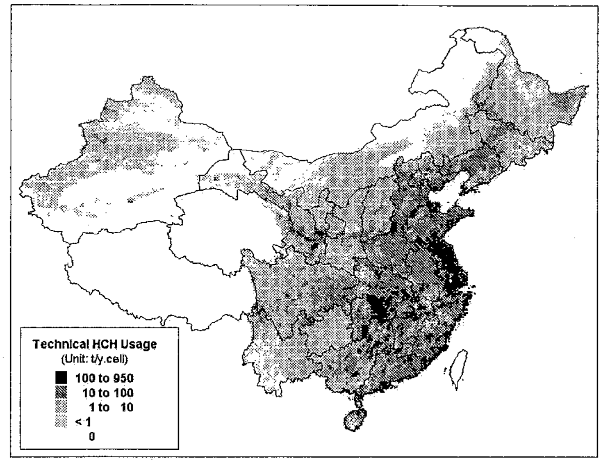

Fig. 8. Distribution of technical HCH usage in agricultural fields in China for 1980 with 1/4° longitude by 1/6° latitude resolution

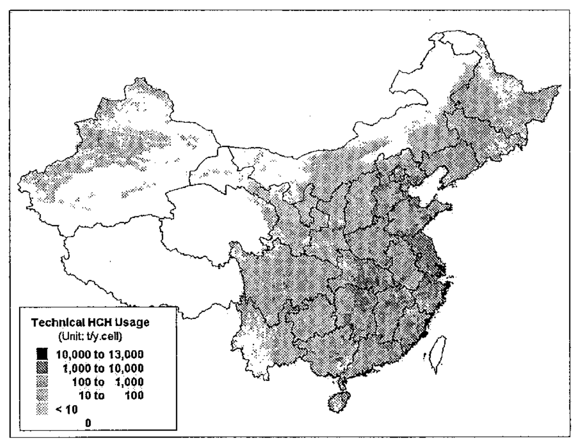

Fig. 9. Distribution of technical HCH usage in agricultural fields in China between 1952 and 1984 with 1/4° longitude by 1/6° latitude resolution

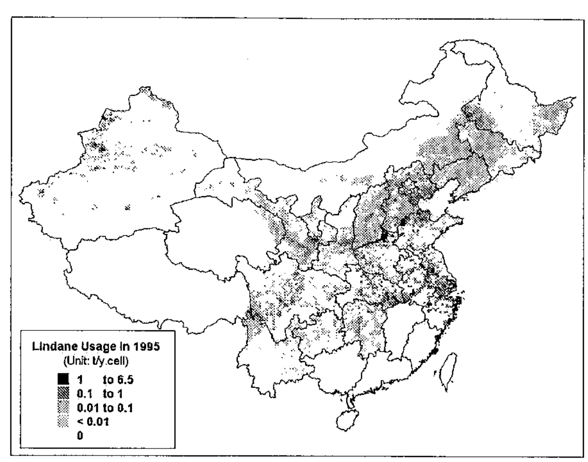

Fig. 10. Distribution of lindane usage in China for 1995 (with 1/4° longitude by 1/6° latitude resolution)

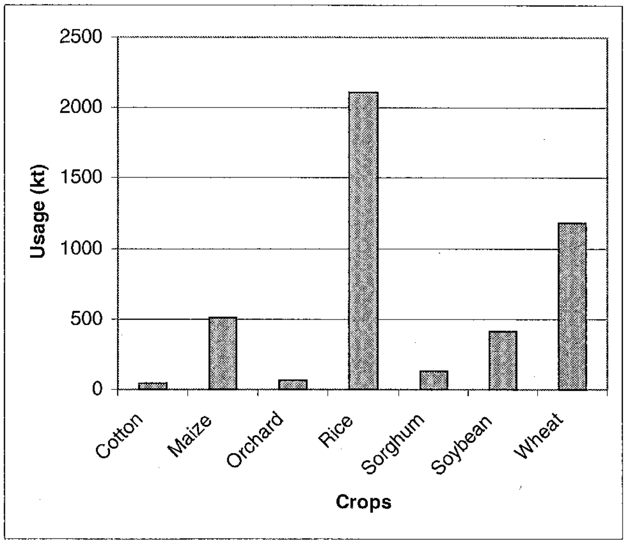

Fig. 11. Technical usage by crops between 1952 and 1984

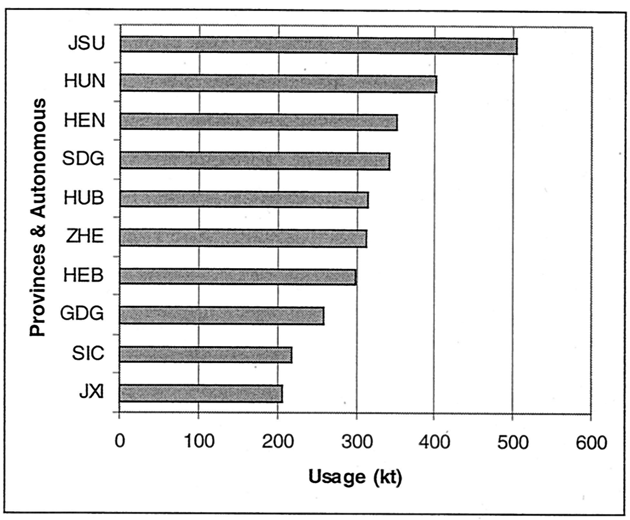

Fig. 12. Top 10 provinces with the highest use of technical HCH between 1952 and 1984

mole cricket, and midges, wheat land dataset was used to distribute application of lindane in China. The result for 1995 is shown in Figure 10. Gridded Chinese usage inventories for both technical HCH and lindane will be used to develop Chinese emission inventories for α- and γ-HCH (Li *et al.* unpublished data).

Results and Discussions

Technical HCH Usage Data Based on Crops

Figure 11 shows the quantities of technical HCH applied on different crops between 1952 and 1984. The total technical HCH applied in agriculture was about 4,400 kt. Of the total agricultural consumption, about half of this insecticide was used on rice paddies, one quarter on wheat, and 10% on each of soybean/sorghum and maize.

Technical HCH Usage Data Based on Provinces

Figure 12 depicts top 10 provinces with the highest usage of technical HCH in China. Use of this pesticide in Jiangsu Province reaches as high as 500 kt between 1952 and 1984, followed by Hunan, 400 kt. The total usage in these 10 provinces is 3,200 kt, 72% of total usage in China.

Case Study: Taihu Lake Basin

Taihu Lake Basin is one of the most developed regions in China, which includes the city of Shanghai, parts of Jiangsu province and Zhejiang province. As shown in Figure 9 and Figure 13 in more detail, this basin was also one of the areas with the highest usage of technical HCH since this insecticide started to apply in China. According to Cai *et al.* (1985), a survey gave an accumulated usage of technical HCH as 375 kg/ha for the whole 33-year period (1952–1984). Consider a grid cell that was covered entirely by cropland, and technical

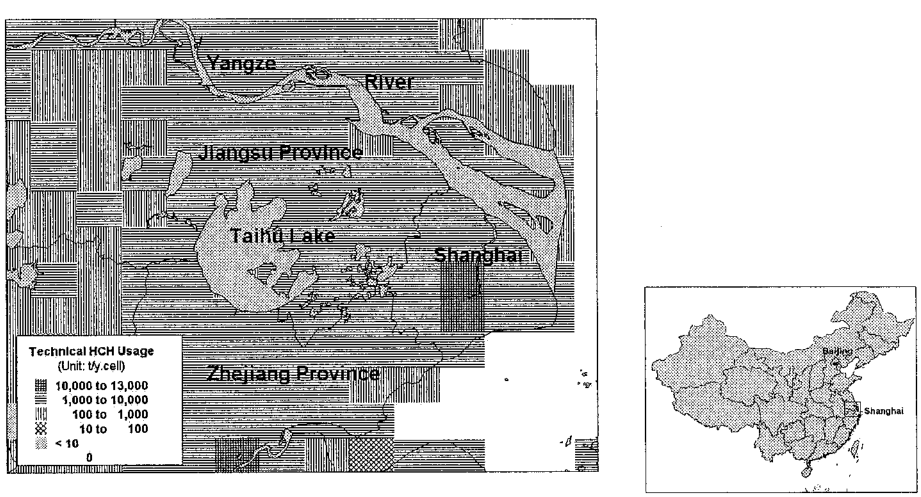

Fig. 13. Distribution of accumulated technical HCH usage between 1952 and 1984 on croplands in Taihu Lake Basin with 1/4° longitude by 1/6° latitude resolution. The small map of China at the right side shows the location of the Taihu Lake Basin

HCH was applied on this total area. If the size of each grid cell is around 400 km^2, then the total accumulated usage of technical HCH in this cell will be 15 kt in 33 years since 1952.

Figure 13 gives accumulated technical HCH usage between 1952 and 1984 on croplands in Taihu Lake Basin from our calculation. The range of the usage is between 1 kt and 13 kt. Two grid cells with around 13 kt usage of technical HCH are located in the rural area of the city of Shanghai. The rates of cropland for these two grid cells are around 90%. If 15 kt usage is applied in grid cells that cropland covers the entire area calculated from the survey, then the usage of technical HCH in these two cells should be 13.5 kt. This shows that the accumulated usage (13 kt) of technical HCH in these two grid cells calculated from our gridding method is highly in agreement with the results (13.5 kt) calculated from accumulated usage rate of 375 kg/ha (Cai *et al.* 1985).

Uncertainty

Uncertainty estimates for usage data are an important part of any inventory. Many factors could create uncertainties for these gridded usage inventories. For example, annual production of technical HCH was used as annual usage, allocation of usage of this insecticide in each province, and the accuracy of surrogate data that is used, are the sources of uncertainties. Although it is very difficult, if not impossible, to provide statistical estimates of uncertainty for each province, or grid cell, the technical HCH and lindane usage inventories for China presented in this work are one of the best usage inventories of chlorinated pesticides we have produced so far. This is mainly due to the good quality of the information for HCH production/usage in China, and the high accuracy of the surrogate data used for the allocation of HCH use, as indicated in the case study carried in the Taihu Lake Basin.

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