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Unexpected malformations in
Xenopus tropicalis



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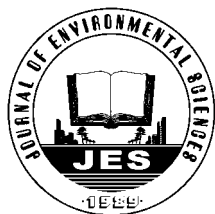
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Upper Yellow River air concentrations of organochlorine pesticides estimated from tree bark, and their relationship with socioeconomic indices

Chang He, Jun Jin*, Bailin Xiang, Ying Wang, Zhaohui Ma

College of Life and Environmental Sciences, Minzu University of China, Beijing 100081, China. E-mail: hechang010101@163.com

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ABSTRACT

Organochlorine pesticide (OCP) concentrations in tree bark from the upper Yellow River region were determined. Total OCP concentrations ranged from 2.7 to 82 ng/g dw, with a mean of 20 ng/g dw. Concentrations of total (Σ) DDTs (0.49–37 ng/g dw), HCHs (0.55–4.5 ng/g dw), and HCB (0.1–1.0 ng/g dw) were much higher than the other OCPs and accounted for 89% of the Σ OCP concentrations. *p,p'*-DDT was the dominant member of the DDT pesticide group and β -HCH was the dominant HCH isomer. The *p,p'*-DDT/*p,p'*-DDE and α -HCH/ γ -HCH ratios suggested that there were recent DDT and γ -HCH releases. OCP concentrations in the air were estimated from the tree bark, and the estimated median Σ DDTs, Σ HCHs, and HCB concentrations in the air were 0.09, 0.14, and 0.024 pg/m³, respectively. The relationship between total OCP concentrations and socioeconomic and natural environment indices were assessed using multiple linear regression analysis, and a regression equation including all these factors was obtained. Population density and tertiary industry were the two dominant factors that appeared to affect OCP concentrations in the upper Yellow River region.

Introduction

Organochlorine pesticides (OCPs) are persistent organic pollutants (POPs) that have been put under controls around the world because of their low biodegradability, high toxicity, and ability to bio-concentrate and undergo long-range atmospheric transport (Norstrom et al., 1988). The semi-volatility of OCPs allows them to migrate around the world through global distillation and the “grasshopper effect”, and they can be found in areas where they have not been used (Ribes et al., 2002). In May 2001, the Stockholm Convention on Persistent Organic Pollutants, in which an agreement was reached that actions would be taken to reduce and eventually eliminate the production and emission of 12 POPs, was signed by a number of countries. Nine of the 12 POPs first put on the controlled list were OCPs, including aldrin, chlordane, DDT, dieldrin,

endrin, heptachlor, toxaphene, hexachlorobenzene (HCB), and mirex (Mohammed et al., 2011). Hexachlorocyclohexane (HCH) has recently been included as a new POP (Vijgen et al., 2011). Between the 1950s and 1980s OCPs were widely used in China because of their high efficiency, low price, and low acute toxicity to humans. Although China has gradually banned the use of OCPs since 1983, OCP residues in the environment are still considerable because of their persistence (Feng et al., 2011a).

Concentrations of POPs in the atmosphere are important indicators for air quality assessment, and there are two methods for monitoring their concentrations in air, active sampling and passive sampling. Active sampling is more direct and simple to interpret, but has disadvantages, including being labor intensive, incurring high costs, and posing practical difficulties in remote areas. Passive sampling (such as measuring concentrations in tree bark) does not suffer from these disadvantages. Tree bark is a good natural passive sampler because it contains more lipids than many other types of vegetation and is exposed to

* Corresponding author. E-mail: junjin3799@126.com

the air throughout the year (Simonich and Hites, 1997). Bark is also cheap and convenient to sample and has been considered as a passive bio-sampler for the determination of polybrominated diphenyl ethers (PBDEs) (Zhu and Hites, 2006), OCPs (Àngels et al., 2012), polychlorinated biphenyls (PCBs) (Hermanson and Hites, 1990; Meredith and Hites, 1987), polychlorinated dibenzodioxins and furans (PCDD/Fs) (Di Lella et al., 2006), and dechlorane plus (DP) (Qiu and Hites, 2007).

The upper Yellow River region, including the Ningxia Hui Autonomous Region, the Inner Mongolia Autonomous Region, Gansu Province, and Qinghai Province, has the highest population density in North-West China, and has a number of minority nationalities. However, until now, only Liu et al. (2012) have reported OCP concentrations in soil in this area, and there have been no studies of OCP concentrations in air.

The main aims of this study were to use OCP concentrations in bark to estimate OCP concentrations in the atmosphere in the upper Yellow River region, and to study the relationship between OCP concentrations and socioeconomic and natural environment indices.

1 Materials and methods

1.1 Chemicals

The chemicals used were acetone, *n*-hexane, and dichloromethane (all pesticide grade; J.T. Baker, Phillipsburg, USA), ultra-pure water (Millipore, Billerica, USA), high purity nitrogen gas, anhydrous sodium sulfate (analytical grade, baked for 5 hr at 450°C), silica gel (100–200 mesh Merck, Germany), and neutral alumina (60 mesh Alfa Aesar, USA). Silica gel and alumina were extracted with dichloromethane, activated at 105°C and 130°C for

12 hr, respectively, then cooled and deactivated with 3% deionized water.

OCP standards (aldrin, *cis*-chlordane, *trans*-chlordane, *p,p'*-DDD, *o,p'*-DDD, *p,p'*-DDE, *o,p'*-DDE, *p,p'*-DDT, *o,p'*-DDT, dieldrin, endosulfan I, endosulfan II, endrin, heptachlor, heptachlor epoxide A, heptachlor epoxide B, hexachlorobenzene, α -HCH, β -HCH, γ -HCH, δ -HCH, isodrin, methoxychlor, mirex, and oxychlordane) were purchased from AccuStandard (New Haven, CT, USA). Internal standards ($^{13}\text{C}_{12}$ -*p,p'*-DDE, $^{13}\text{C}_{10}$ -dieldrin, $^{13}\text{C}_6$ -HCB, $^{13}\text{C}_6$ - β -HCH, $^{13}\text{C}_6$ - γ -HCH, $^{13}\text{C}_{10}$ -mirex, and $^{13}\text{C}_{10}$ -*t*-nonachlor) were purchased from Cambridge Isotope Laboratories (Andover, MA, USA).

1.2 Sample information

Fifteen willow tree bark samples were collected in August 2011. The sampling site distribution is shown in **Fig. 1** and the sampling site information is shown in **Table 1**. There were 10 rural sampling sites (#1, #2, #3, #5, #6, #7, #9, #10, #12, #13), where willows grew on the Yellow River bank, and five urban sampling sites (#4, #8, #11, #14, #15) taken from cities near the Yellow River. All bark samples were chiseled from around 1.5 m height from three willows less than 50 m apart with similar trunk diameters (around 35 cm), to ensure the tree bark had fully absorbed pollutants from the air. The samples were wrapped in aluminum foil, sealed in plastic bags, and stored at 5°C for transport to the laboratory, where they were frozen and stored at –20°C until analysis.

1.3 Sample preparation

Each raw bark sample (10.0 g) was cut into small pieces (< 1 cm) and covered with 20.0 g anhydrous sodium sulfate in a Soxhlet apparatus, spiked with 2 ng OCP internal standards, and extracted with 200 mL of a hexane:acetone mixture (1:1, V/V) for 24 hr. Each extract was concentrated

Table 1 Tree bark sample information

No.	Sampling site	Province	Latitude (°N)	Longitude (°E)	Type
1	Sanhu Estuary	Inner Mongolia	40.61	108.77	Rural
2	Dengkou		40.28	107.02	Rural
3	Dusitu River	Ningxia	39.08	106.89	Rural
4	Yinchuan		38.48	106.26	Urban
5	Yingu Highway Bridge		38.29	106.23	Rural
6	Qingtongxia		37.95	105.99	Rural
7	Jinsha Bay		37.83	105.94	Rural
8	Zhongning		37.49	105.67	Urban
9	Shapotou		37.45	104.98	Rural
10	Wufo Temple		37.46	104.99	Rural
11	Baiyin	Gansu	36.55	104.14	Urban
12	Qingcheng Bridge		36.36	104.22	Rural
13	Shichuan Bridge		36.15	103.99	Rural
14	Lanzhou		36.05	103.86	Urban
15	Xining	Qinghai	36.62	101.77	Urban

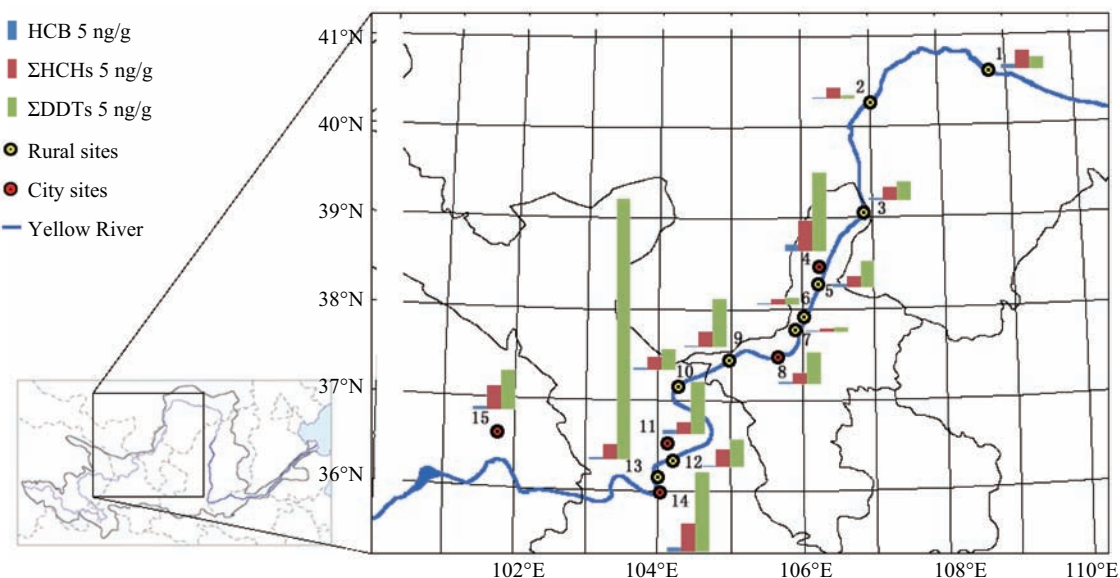


Fig. 1 OCP distributions in tree bark from the upper Yellow River region

to about 2 mL by rotary evaporation and purified with a silica/alumina column (packed, from bottom to top, with 2 g anhydrous sodium sulfate, 8 g deactivated silica gel (3% water), 8 g neutral alumina, and 2 g anhydrous sodium sulfate), which was pre-cleaned with 30 mL of *n*-hexane, eluted with 18 mL *n*-hexane after the sample was

added (discarding the eluent), then eluted with 100 mL hexane:dichloromethane (97:3, V/V). The purified extract was concentrated to 100 μ L by rotary evaporation and under a gentle nitrogen flow before analysis.

Table 2 OCP concentrations in tree bark from the upper Yellow River region

	LOD (ng/g)	Minimum (ng/g)	25th percentile (ng/g)	Median (ng/g)	75th percentile (ng/g)	Maximum (ng/g)	Mean (ng/g)	Detected rate (%)
HCB	0.004	0.10	0.20	0.33	0.60	1.0	0.41	100
α -HCH	0.04	0.12	0.21	0.31	0.52	1.2	0.40	100
β -HCH	0.1	0.21	0.55	0.94	1.72	3.8	1.2	100
γ -HCH	0.04	0.13	0.33	0.42	0.52	1.2	0.46	100
δ -HCH	0.04	0.07	0.14	0.16	0.20	0.47	0.19	100
Σ HCHs	–	0.55	1.7	2.0	2.7	4.5	2.3	–
Heptachlor	0.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
Aldrin	0.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
Isodrin	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
Oxychlordane	0.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
Heptachlor epoxide	0.04	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
<i>t</i> -Chlordane	0.004	0.01	0.01	0.01	0.01	0.02	0.01	100
<i>c</i> -Chlordane + Endosulfan II	0.004	0.04	0.10	0.14	0.32	2.13	0.43	100
Dieldrin	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
Endrin	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
<i>o,p'</i> -DDE	0.02	n.d.	0.05	0.10	0.17	2.1	0.26	87
<i>p,p'</i> -DDE	0.02	0.03	0.10	0.16	0.34	1.6	0.35	100
<i>o,p'</i> -DDD	0.02	n.d.	0.03	0.06	0.18	1.2	0.17	93
<i>o,p'</i> -DDT + <i>p,p'</i> -DDD	0.02	0.11	0.45	1.0	2.2	20	2.7	100
<i>p,p'</i> -DDT	0.02	0.31	1.2	2.0	5.1	12	3.4	100
Σ DDTs	–	0.49	2.4	4.0	6.6	37	6.7	–
Mirex	0.01	n.d.	n.d.	0.01	0.02	0.05	0.01	53
Σ OCPs	–	2.7	10	14	19	81	19	–

n.d.: not detected.

1.4 Instrumental analysis

The extracts were analyzed by gas chromatography-mass spectrometry (GC-MS) (6890-5975N, Agilent Technologies, CA). A DB-5MS column (30 m × 0.25 mm i.d., 0.1 μm film thickness; J&W Scientific, USA) was used to separate the analytes. The GC oven temperature program began with 3 min at 80°C, and then increased to 260°C at a rate of 6°C/min. The temperatures of the injector, MS source, and MS quadrupole were 250°C, 150°C, and 150°C, respectively. Samples were injected using splitless mode, with a carrier gas flow rate of 1.0 mL/min. The MS used a negative chemical ionization source and selected ion monitoring mode. The chemical ionization reagent gas was methane. The m/z ratios for each analyte were chosen as described in a previous study (Wang et al., 2011).

1.5 Quality control

Method blank samples were analyzed. The target compounds, except for the HCHs, were not detected in the blank samples, so blank correction was only necessary for the HCHs. The sample recoveries were in the range 80%–101% and the relative standard deviations (RSD) were between 4.1% and 16.1%. The limits of detection (LOD) are shown in Table 2.

2 Results and discussion

2.1 OCP concentrations in tree bark

The total OCP concentrations (Σ OCPs) in the 15 tree bark samples were 2.7–82 ng/g dry weight (dw), with a mean concentration of 20 ng/g dw. As can be seen from Table 2, DDTs, HCHs, and HCB were detected in all samples at relatively high concentrations, and together made up 89% of the OCPs. Chlordane, endosulfan, and mirex were present at lower concentrations, and aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, isodrin, and oxychlordane were not detected. DDTs were the dominant OCP contaminants, making up the largest proportion (64%) of the Σ OCPs, followed by HCHs and HCB (21% and 4%, respectively). OCP at site 13 (Shichuan Bridge) was 81 ng/g dw, which was higher than at the other sampling points, and the lowest concentration (2.7 ng/g dw) was at site 7 (Jinsha Bay).

The total production of DDT in China from the 1950s to 2004 was 464 thousand tonnes, and, particularly after 1983, DDT was mainly used as an active pharmaceutical ingredient in dicofol and for disease vector control (Xin et al., 2011). The total DDT concentrations (Σ DDTs = p,p' -DDD + o,p' -DDD + p,p' -DDE + o,p' -DDE + p,p' -DDT + o,p' -DDT) in tree bark samples from the banks of the Yellow River bank are shown in Fig. 2, and were 0.49–37 ng/g dw, with a mean of 6.7 ng/g dw. These concentrations

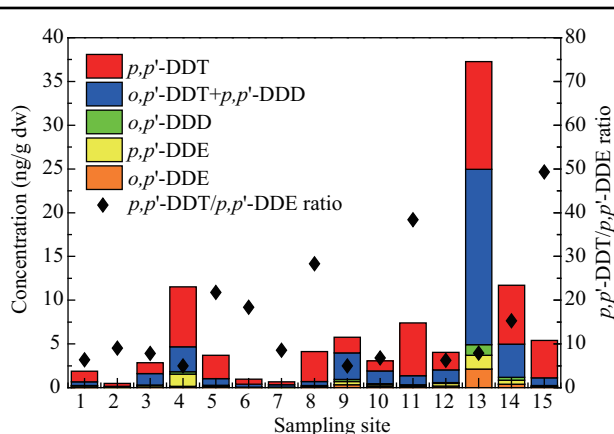


Fig. 2 Profile of the DDTs in tree bark samples from the upper Yellow River region.

are much lower than the DDT concentrations found in tree bark samples collected in Romania in 2005 (Dragan et al., 2006), but are higher than those found in Spain and Portugal in 2008 (Àngels et al., 2012). The p,p' -DDT concentration was far higher than the concentrations of the other DDT chemicals and degradation products analyzed.

HCHs were produced and used in China in greater quantities than the other OCPs (Xu et al., 2007). Figure 3 shows that the HCH concentrations in the tree bark samples ranged from 0.55 to 4.5 ng/g dw, which is far lower than was found in Romania samples in 2005 (Dragan et al., 2006), but much higher than in Spanish and Portuguese samples in 2008 (Àngels et al., 2012).

2.2 Composition of OCPs

2.2.1 DDTs

Technical DDT typically contains 77.1% p,p' -DDT, 14.9% o,p' -DDT, and 4% p,p' -DDE. DDT can be transformed into DDD by biodegradation under anaerobic conditions or into DDE under aerobic conditions (Heberer and Dnnbier, 1999). The p,p' -DDT to p,p' -DDE ratio has been used as an indicator of the DDT source because p,p' -

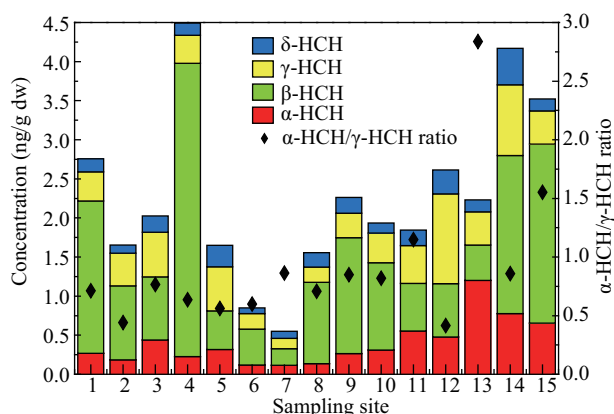


Fig. 3 HCH distributions in tree bark samples from the upper Yellow River region.

DDT is considered to be the only source of *p,p'*-DDE in environmental media (Qiu et al., 2005). If the *p,p'*-DDT/*p,p'*-DDE ratio is less than 1 the principal source of DDT was early industrial use or production, whereas a higher ratio indicates relatively fresh inputs of *p,p'*-DDT. All of the ratios found in our samples were higher than 1 (Fig. 2), suggesting that there were relatively fresh inputs in the upper Yellow River region.

2.2.2 HCHs

β -HCH was the dominant HCH isomer, accounting for 53% of the total HCH concentration, γ -HCH contributed 20% of the total, α -HCH contributed 18%, and δ -HCH 8%. The HCH isomer profile was different from the technical HCH profile, which typically contain 60%–70% α -HCH, 5%–12% β -HCH, 10%–12% γ -HCH, 6%–10% δ -HCH and minor proportions of other isomers (Kutz et al., 1991). This might have been caused by long-term degradation of the HCH, which increases the proportion of β -HCH, the most stable isomer. HCH sources can be investigated using the α - to γ -HCH ratio. This ratio is between 3 and 7 in technical HCH mixtures. However, new inputs of lindane (γ -HCH) will decrease the ratio to below 1 (Willett et al., 1998). Most of the ratios found in this study were between 0.4 and 1 (Fig. 2), showing that new inputs of γ -HCH occurred in these areas.

2.3 Estimated OCP concentrations in the air

The equilibrium of OCPs between bark and air can be presented as Eq. (1):

$$K_{BA} = \frac{C_B}{C_A} \quad (1)$$

where, K_{BA} is the bark-air equilibrium partition coefficient, and C_B (pg/m^3 bark) and C_A (pg/m^3) are the volume-based OCP concentrations in bark and air, respectively.

The bark-air distribution was established by Zhao et al. (2008), and can be presented as Eq. (2). The model accuracy was tested by comparing with the measured levels with model-estimated levels, suggesting the feasibility of estimation of the atmospheric OCPs concentrations from the bark measurements.

$$K_{BA} = \frac{2 \times 10^{-6} \times L^{1.67} \times K_{OA}^{0.542} \times e^{\frac{10^3}{R} \times (-0.964\Delta H_{\text{vap}} + 3.130) \left(\frac{1}{T} - \frac{1}{302.05}\right)}}{1 + B \times C_{\text{TSP}} \times K_{OA}} + \frac{210B \times S^{0.706} \times \left(\frac{P}{154}\right)^{-0.766} \times C_{\text{TSP}} \times K_{OA}}{1 + B \times C_{\text{TSP}} \times K_{OA}} \quad (2)$$

where, L (g/m^3) is the lipid content of the bark, K_{OA} is the octanol-air partition coefficient, R (8.314 ($\text{Pa}\cdot\text{m}^3$)/($\text{mol}\cdot\text{K}$)) is the gas constant, ΔH_{vap} ($(\text{Pa}\cdot\text{m}^3)/\text{mol}$) is the enthalpy of vaporization of the subcooled liquid, T (K) is the ambient

temperature, B ($\text{m}^3/\mu\text{g}$) is a constant dependent on the physical and chemical properties of the contaminant, S (m^2/m^3 bark) is the specific surface area of the bark, P (mm) is the amount of precipitation, and C_{TSP} ($\mu\text{g}/\text{m}^3$) is the total suspended particles in the air.

Zhao et al. (2008) measured willow bark parameters and found that the lipid content, density, and specific surface area were 3.94×10^4 g/m^3 , 4.99×10^5 g/m^3 , and 8.88×10^6 m^2/m^3 , respectively. B has been reported for OCPs as being 1.50×10^{12} $\text{m}^3/\mu\text{g}$ (Douce et al., 1997). K_{OA} for the DDTs, HCHs, and HCB at 285.15 K have been reported as being 6.4×10^9 , 2.5×10^7 , and 2.4×10^7 , respectively (Shen and Wania, 2005; Xiao et al., 2004), and ΔH_{vap} for the DDTs, HCHs, and HCB have been reported as being 88.1, 65.7, and 67.6 ($\text{kPa}\cdot\text{m}^3$)/mol, respectively (Zhao et al., 2009; Shen and Wania, 2005; Xiao et al., 2004). The K_{OA} and ΔH_{vap} values for *p,p'*-DDT and β -HCH were used because those chemicals dominated the DDT and HCH chemical concentrations in this study. Ambient temperatures and amounts of precipitation were found in the Statistical Yearbook for the relevant cities. TSP concentrations in China between 1981 and 2007 were reported by Zhang et al. (2010), who found an average C_{TSP} of 402 $\mu\text{g}/\text{m}^3$ in 93 cities. Putting these parameters into Eqs. (1) and (2) gave the air concentrations shown in Table 3.

The estimated Σ_3 OCPs ($\Sigma\text{DDTs} + \Sigma\text{HCHs} + \text{HCB}$) concentrations in the air ranged from 0.058 to 0.48 ng/m^3 , with median ΣDDTs , ΣHCHs , and HCB concentrations of 0.009, 0.14, and 0.024 ng/m^3 , respectively. Feng et al. (2011b) found OCP concentrations of 0.0378–5.500 ng/m^3 in air in China, and HCHs, DDTs and HCB were the dominant contaminants. The air concentrations we estimated from the bark concentrations were within, but

Table 3 Estimated OCP concentrations in air in the upper Yellow River region (unit: ng/m^3)

No.	Sampling site	ΣDDTs	ΣHCHs	HCB	$\Sigma_3\text{OCP}$
1	Sanhu Estuary	0.005	0.27	0.058	0.34
2	Dengkou	0.001	0.12	0.013	0.13
3	Dusitu River	0.004	0.12	0.016	0.14
4	Yinchuan	0.027	0.37	0.082	0.48
5	Yingu Highway Bridge	0.009	0.14	0.048	0.20
6	Qingtongxia	0.002	0.070	0.013	0.085
7	Jinsha Bay	0.002	0.048	0.008	0.058
8	Zhongning	0.012	0.14	0.024	0.17
9	Shapotou	0.016	0.18	0.013	0.21
10	Wufo Temple	0.006	0.13	0.021	0.16
11	Baiyin	0.016	0.14	0.045	0.20
12	Qingcheng Bridge	0.008	0.20	0.016	0.22
13	Shichuan Bridge	0.097	0.19	0.037	0.33
14	Lanzhou	0.030	0.36	0.053	0.44
15	Xining	0.009	0.21	0.031	0.25

at the lower end of, the range found by Feng et al. (2011b) suggesting that OCP concentrations in the upper Yellow River region are at the lower end of concentrations in China. We found that HCH was the dominant OCP air contaminant in the upper Yellow River region. The estimated HCH concentrations were comparable to concentrations found in air at the Chinese coast in 2006 (0.120 ± 0.084 ng/m³) (Lin et al., 2012), but lower than concentrations in the atmosphere in Guangzhou (0.396 ± 0.564 ng/m³) (Li et al., 2007). There have been 4.9 million tons of HCH were used in China before production was banned in 1983, and after that time, as a substitute, the purified γ -HCH isomer (lindane) was produced in many factories (Qiu et al., 2008). DDT was also used widely in China (Qiu et al., 2005), but DDT has a higher K_{OA} than does HCH, thus DDT volatilizes less readily and is found at lower concentrations in the air relative to soil and other organic environmental media (Shen and Wania, 2005).

2.4 Multivariate regression analysis of OCP concentrations in tree bark with socioeconomic and natural environment indices

2.4.1 Independent variable selection for the regression model

OCP sources are complex, and various factors affect environmental concentrations. We aimed to use quantifiable variables including gross population, population density, GDP, per capita GDP, the proportion of primary industry, the proportion of secondary industry, the proportion of tertiary industry, altitude, temperature and air pressure, to find the relationship with OCP concentration. However, only population density, GDP, the proportion of tertiary industry, altitude and temperature showed correlation with OCP concentration, while gross population, per capita GDP, the proportion of primary industry, the proportion of secondary industry, and air pressure were not correlated. The former indices were chosen as independent variables of the multivariate regression analysis. We only analyzed data from rural sampling sites to eliminate specific local

urban effects.

2.4.2 Multivariate linear regression analysis

Relevant data for the counties in which the sampling sites were located are summarized in **Table 4**.

OCP concentrations in tree bark were set as the dependent variable Y , and population density (X_1), GDP (X_2), tertiary industry proportion (X_3), altitude (X_4), and average temperature (X_5) were set as independent variables. Multivariate regression analysis generated 31 multiple regression equations.

Before the regression analysis, the multicollinearities of selected variables were tested, and the Variance Inflation Factor (VIF) between variables was less than 10, suggesting no significant multicollinearities exist between the various variables.

2.4.3 Regression equation

Multiple step regression analysis was used to select the optimal equation using SPSS software (SPSS17.0 SPSS Inc., USA). The partial regression coefficients for altitude, temperature, and GDP were not significant, so these independent variables were eliminated step by step. Y correlated significantly or very significantly with X_1 and X_3 , so the optimal equation included population density and tertiary industry proportion. The final equation was $Y = 9.655X_1 + 379.065X_3 - 2685.737$. The regression relationship was extremely significant ($P < 0.001$, $R^2 = 0.975$) and each partial regression coefficient showed a strongly significant or significant correlation with OCP concentration.

From the above analysis, it appears that the population density and tertiary industry proportion were the dominant factors affecting OCP concentrations in the upper Yellow River region, with standardized coefficients of 0.744 and 0.272, respectively. Population density had the greatest influence on OCP concentrations in the upper Yellow River region.

Table 4 Regression analysis data for the OCPs

Sampling site	Σ OCPs (ng/g)	Population density (people/km ²)	GDP (billion CNY)	Tertiary industry proportion (%)	Altitude (m)	Average temperature (°C)
Sanhu Estuary	9.9	45.70	96.52	26	1020	9.0
Dengkou	4.6	29.81	37.95	18	1056	9.0
Dusitu River	10	24.33	7.00	44	1094	6.9
Yingu Highway Bridge	3.9	74.51	60.80	25	1117	10.5
Qingtongxia	0.96	51.30	84.83	24	1141	10.3
Jinsha Bay	0.66	24.38	67.29	31	1193	10.9
Shapotou	7.2	27.57	84.21	45	1246	10.0
Wufo Temple	3.1	41.17	33.40	34	1316	8.3
Qingcheng Bridge	4.0	214.58	148.12	36	1448	9.3
Shichuan Bridge	38	5760.11	377.53	77	1523	11.0

3 Conclusions

Total OCP concentrations in tree bark in the upper Yellow River region ranged from 2.7 to 82 ng/g dw, and DDTs, HCHs, and HCB were the major OCPs found, providing 64%, 21%, and 4%, respectively, of the total OCP concentration. β -HCH was the dominant HCH isomer, and the DDTs were dominated by *p,p'*-DDT. The upper Yellow River region appeared to have had relatively recent environmental inputs of lindane (γ -HCH) and DDTs. OCP concentrations in the air in the upper Yellow River region, estimated from the bark concentrations, ranged from 0.058 to 0.48 ng/m³. Regression analysis between total OCP concentrations in bark and major socioeconomic indicators and environmental indices showed that the population density and the proportion of tertiary industry had the greatest influences on OCP concentrations.

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