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RESEARCH ARTICLE

Twenty years of achievements in China's implementation of the Stockholm Convention

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HIGHLIGHTS

- China's implementation of the SC was systematically studied.
- Implementation process of the SC can be roughly divided into three stages.
- DDT and HCH concentrations in the air have been steadily decreasing.
- China has safely disposed of 6352.1 tons of pesticide POPs.

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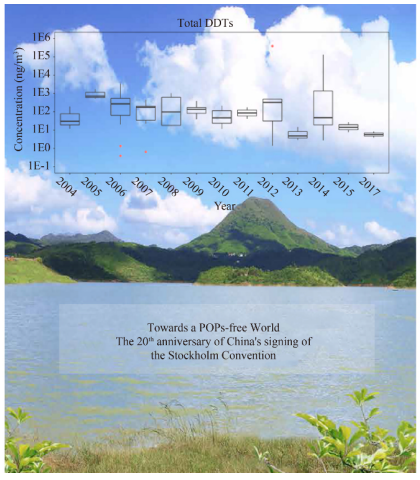
GRAPHIC ABSTRACT



ABSTRACT

Persistent organic pollutants (POPs) are extremely harmful to the environment and human health; the Stockholm Convention on Persistent Organic Pollutants was therefore adopted by the international community in 2001 to eliminate or reduce the production, use, and emissions of POPs. China is the largest developing country that has signed the Stockholm Convention, and thus plays an important role in its implementation. This paper systematically studies the practice and achievements of China since it signed the Stockholm Convention 20 years ago. China has established an implementation guarantee system including institutions, implementation mechanisms, policies, law enforcement, and scientific and technological support. During the 20 years since the implementation of the Stockholm Convention, dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane (HCH) concentrations in the air have been steadily decreasing, and Perfluorooctane sulfonic acid/Perfluorooctane sulfonyl fluoride (PFOS/PFOSF) concentrations in water bodies have decreased. In the past 20 years, China has safely disposed of 6352.1 tons of pesticide persistent organic pollutants and 36998 sets of electrical equipment containing polychlorinated biphenyls (PCBs), with a disposal rate of 100%. In the future, China will further strengthen the construction of persistent organic pollutant monitoring networks, scientific research, publicity, education, and international cooperation to improve environmental quality, providing a reference for other countries to implement the Stockholm Convention.

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1 Introduction

Persistent organic pollutants (POPs) are a class of chemical substances that pose a serious threat to human health and the ecological environment owing to their persistence, toxicity, bioaccumulation, and long-range environmental transport. Therefore, in its decision 18/32 in May 1995 the Governing Council of the United Nations Environment Programme (UNEP) called for an international assessment of a preliminary list of 12 POPs, including nine organochlorine pesticides (OCPs), PCBs, polychlorinated dibenzodioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs). The UNEP Governing Council, in its 19/13C decision in February 1997, requested that the UNEP prepare and convene meetings of the Intergovernmental Negotiating Committee (INC) to develop a legally binding international instrument for action on 12 POPs. The Stockholm Convention on Persistent Organic Pollutants (hereinafter referred to as the Stockholm Convention) was adopted and opened for signature at the Conference of Plenipotentiaries held in Stockholm, Sweden, from May 22 to 23, 2001 (Secretariat of the Stockholm Convention, 2019). To date, approximately 18 additional chemicals have been included in the Stockholm Convention, making the total number of POPs approximately 30.

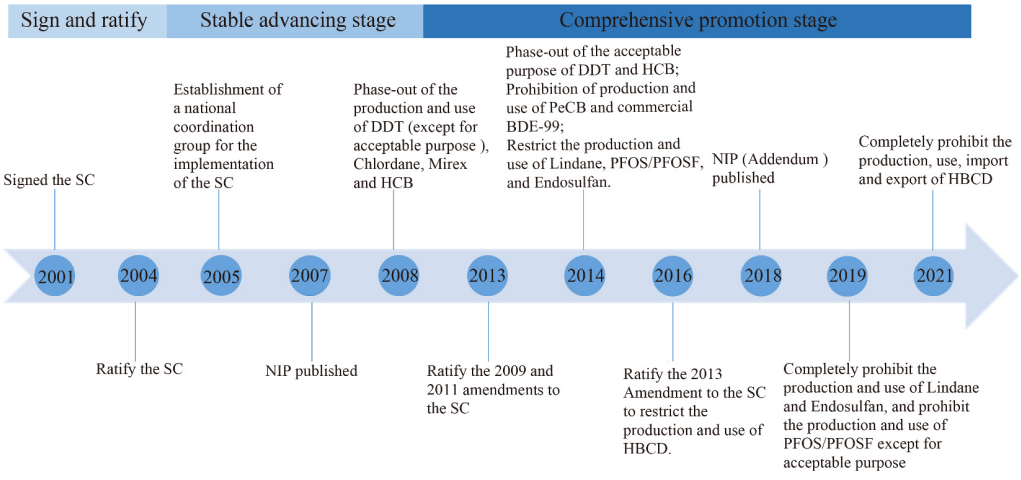
According to the requirements of the Stockholm Convention, parties should first develop a National Implementation Plan (NIP) as a programmatic document for POP reduction, elimination, control, and environmental management. However, owing to the wide scope of NIP preparation, China faces issues such as lack of basic information, insufficient funds, and backward technology in the field of POPs. To solve the above issues, the Chinese government has coordinated with experts, relevant line ministries, industry associations, local governments, and other parties, and successfully completed the preparation of the NIP for the implementation of the Stockholm Convention in China. This was submitted to the Secretariat of the Stockholm Convention in November 2006, thus fulfilling China's commitment to the international community. Concurrently, the Chinese government has gradually strengthened capacity development to meet all the requirements to comprehensively promote the implementation of the Stockholm Convention.

Over the past 20 years, China has attached significant importance to implementing the Stockholm Convention. In the National Tenth Five-year Plan of Environmental Protection issued by State Environmental Protection Administration of China in December 2001, China proposed to gradually ban the production and use of POPs. To date, China's implementation of the Stockholm Convention has made promising progress in numerous fields, making significant contributions to the global elimination and minimization of POPs environmental emissions. Among the 30 substances controlled by the Stockholm Convention, 23 have been approved by the Chinese government, and the remaining substances will take effect after the legal approval process is completed. However, to the best of our knowledge, there has been no comprehensive and systematic research on the history, practice, and effectiveness of China's implementation of the Stockholm Convention. The lessons and experiences from China will shed light on practical applications for the global prevention and control of POPs.

2 Implementation of the Stockholm Convention in China

2.1 Process of China's implementation

China's implementation can be divided into three stages (Fig. 1). The first stage, from 2001 to 2004, was the stage of signing and domestic approval. The Stockholm Convention was signed on May 23, 2001, and the Standing Committee



SC: Stockholm Convention; NIP: National implementation plan; HCB: Hexachlorobenzene; PeCB: Pentachlorobenzene; BDE-99: Pentabromodiphenyl ether; HBCD: Hexabromocyclododecane

Fig. 1 The process of China's implementation of the Stockholm Convention.

of the Tenth National People's Congress ratified the Stockholm Convention on June 25, 2004. The Stockholm Convention came into effect in China on November 11, 2004, and was applicable to the Hong Kong Special Administrative Region (China) and the Macao Special Administrative Region (China) (National Coordination Group, 2008). The second stage, from 2005 to 2012, was stable advancement. At this stage, China established a national coordination group, published an NIP, and controlled dichlorodiphenyltrichloroethane (DDT), chlordane, mirex, hexachlorobenzene (HCB), and other OCPs in accordance with the requirements of the Stockholm Convention. The third stage, from 2013 to the present, is comprehensive promotion. Throughout this stage the implementation process has accelerated significantly, with POPs coming under control, including industrial chemicals (such as PFOS and hexabromocyclododecane). The Chinese government has published an updated version of the NIP with an addendum and has issued relevant standards, guaranteeing the implementation of the Stockholm Convention.

2.2 Implementation guarantee system

After 20 years of development, China has established an implementation guarantee system, which includes the following five systems: mechanisms, institutions, policies, law enforcement, and scientific and technological support (Fig. 2). Mechanisms refers to the establishment of a national coordination group for implementation. Institutions refers to regulations and standards. The policy system refers to national implementation plans, ecological environmental protection plans, and similar directives. Law enforcement refers to the ecological environment law enforcement carried out by the domestic ecological environment departments, and the implementation of joint law enforcement carried out by multiple ministries. Scientific and technological support refers to the basic scientific and technological application research on POPs. These five systems support each other to form a complete implementation guarantee system.

2.2.1 National coordination mechanisms

China has embarked on efforts to control POPs since the signing of the Stockholm Convention. After the Stockholm Convention came into force, the State Council approved the establishment of a national coordination group for implementation in May 2005, consisting of 14 ministries and commissions, including the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, and the National Development and Reform Commission (Fig. 3). As a result, a working mechanism led by the Ministry of Ecology and Environment has been formed, with relevant departments performing their respective duties and cooperating to promote the implementation of POPs. As the national coordination mechanism for the Chinese government to implement the Stockholm Convention, the national coordination group is responsible for reviewing and implementing national guidelines and policies on POPs management and control and coordinating national POPs management and implementation of major issues. To make decision-making more scientific, an expert

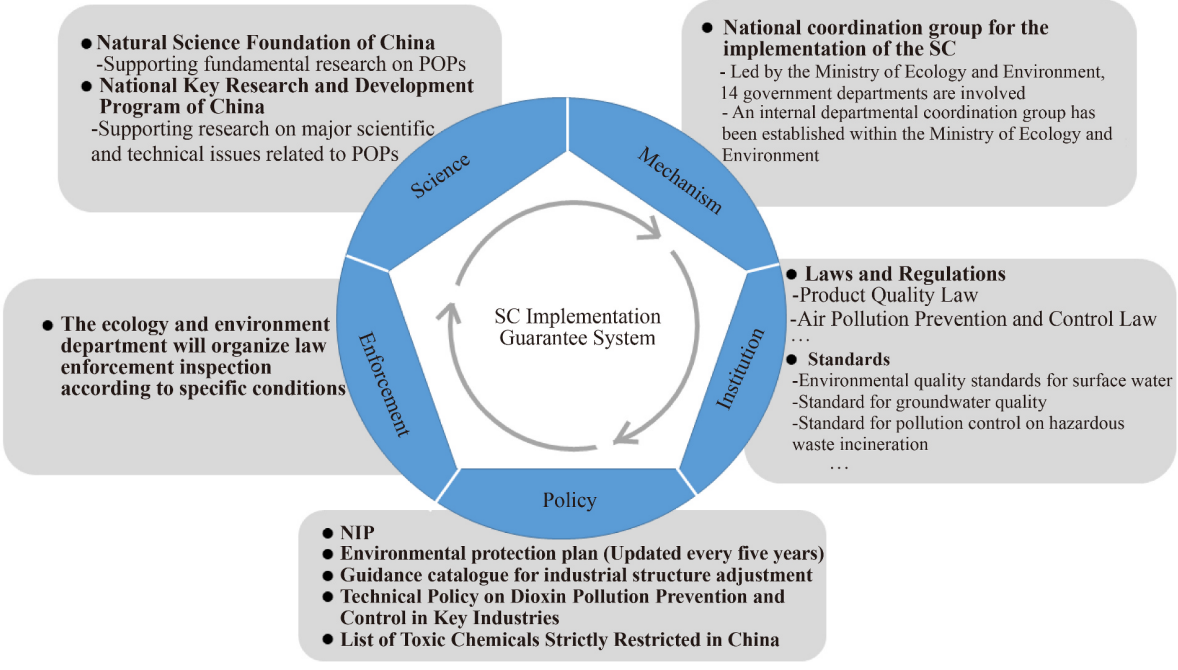


Fig. 2 National implementation guarantee framework.

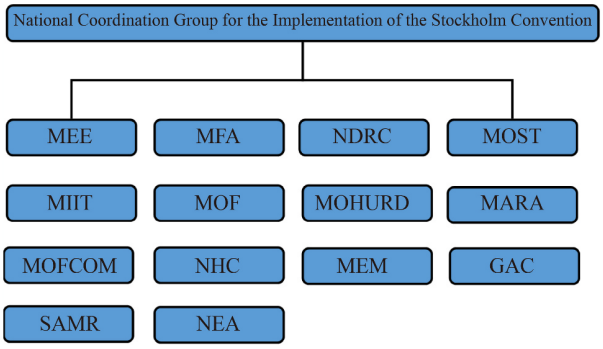


Fig. 3 Composition of the national coordination group for the implementation (MEE: Ministry of Ecology and Environment; MFA: Ministry of Foreign Affairs; NDRC: National Development and Reform Commission; MOST: Ministry of Science and Technology; MIIT: Ministry of Industry and Information Technology; MOF: Ministry of Finance; MOHURD: Ministry of Housing and Urban–Rural Development; MARA: Ministry of Agriculture and Rural Affairs; MOFCOM: Ministry of Commerce; NHC: National Health Commission; GAC: General Administration of Customs; SAMR: State Administration for Market Regulation; MEM: Ministry of Emergency Management; NEA: National Energy Administration).

committee was established under the coordination group mechanism. The national coordination group for implementation holds relevant meetings on a regular basis every year, formulates work plans, and summarizes the work of the previous year.

2.2.2 Institution

1) Laws and Regulations: To effectively reduce and eliminate POPs, the Chinese government has formulated corresponding regulations for each process where POPs may enter the environment. For example, in the production process, the Product Quality Law stipulates that manufacturers are not allowed to produce products explicitly eliminated by the state. The Cleaner Production Auditing Measures stipulate that mandatory cleaner production audits should be implemented if the substances listed in the annex of the Stockholm Convention are used as raw materials. Regarding emissions, the Law on the Prevention and Control of Air Pollution stipulates that enterprises, institutions, and other producers and operators that emit POPs into the atmosphere, and operators of waste incineration facilities shall, in accordance with relevant state regulations, be equipped with effective purification devices and adopt technical methods and processes that are conducive to reducing persistent organic pollutant emissions, in order to achieve the emission standard. The National Hazardous Waste List identifies substances banned by the Stockholm Convention as hazardous wastes. In the hazardous waste identification and standard toxic substance content identification, it was clarified that solid wastes containing PCBs, chlordane, DDT, HCB, mirex, toxaphene, aldrin, dieldrin, endrin, and heptachlor in an amount ⩾ 50 mg/kg are considered hazardous wastes, and solid wastes containing PCDDs and PCDFs with ⩾ 15 μg toxic equivalency quotient (TEQ)/kg are classified as hazardous waste.

In addition to the above regulations, another policy tool for implementing the Stockholm Convention is the joint announcement issued by the member units of the implementation coordination group and the supporting management measures. Since the signing of the Stockholm Convention, the implementation coordination group has issued four announcements on the substances controlled by the Stockholm Convention and has completely phased out 20 intentionally produced POPs, including the initial batch of 12 POP compounds, and has strictly restricted the production, use, import, and export of PFOS and PFOSF. The detailed announcement contents and effective times are listed in Table 1.

2) Standards are an important means of environmental management. Although research on POP-related standards in China was initiated relatively late, it has made great progress since 2000. In particular, after 2012, the construction of an ecological civilization has been highly valued, and POPs have been included in many new environmental standards, with more than a hundred management policies and technical standards related to implementation. The risk control standards for soil contamination of agricultural land (GB15618-2018) and the risk control standard for soil contamination of development land (GB36600-2018) were formulated in 2018. In the risk control standard for soil contamination of agricultural land, HCHs and DDT were listed as the selected targets and marked with clear indicators, and the risk screening value of the two substances was 0.1 mg/kg. The risk control standard for soil contamination of development land includes pentachlorophenol, chlordane, DDT, endosulfan, heptachlor, HCHs, HCB, mirex, and PCBs. Water quality standards, such as the Groundwater Quality Standard, Environmental Quality Standards for Surface Water, Sea Water Quality Standards, and Water Quality Standard for Fisheries, and the limit values of relevant POPs are tabulated in Table 2. China has formulated emission limits for various industries for dioxins that are released unintentionally, as shown in Table 3.

2.2.3 Policy

In September 2003, the State Council approved the establishment of the “Leading Group for the NIP of the Stockholm Convention on POPs” with the participation of 11 ministries and commissions, which is responsible for reviewing the preparatory work of the NIP, and the national macro-management policies and departmental coordination involved in its formulation process. The State Council approved the publication of the NIP for the initial 12 POPs in 2007, which identified the requirements for meeting the Stockholm Convention and environmental

protection and proposed strategies and action plans for implementing the Stockholm Convention. In 2018, an updated version of the NIP was published based on the newly added substances listed in the Stockholm Convention. In addition, since the National Environmental Protection Tenth Five-year Plan has incorporated the relevant requirements for POPs, as detailed in Table 4.

The Ministry of Ecology and Environment published the Technical Policy for the Prevention and Control of Dioxin Pollution in Key Industries in 2015 and proposed technical routes and methods for the prevention and control of dioxin pollution, targeting iron ore sintering, electric arc furnace steelmaking, recycled non-ferrous metal (copper, aluminum, lead, zinc) production, waste incineration, pulping and papermaking, cremation, and other industries. The policy includes source reduction, process control, end-of-pipe treatment, new technology research and development for pollution, providing technical guidance for environmental management, and corporate pollution prevention and control in key industries related to dioxin pollution prevention and control planning, emission standards, and environmental impact assessment.

2.2.4 Law enforcement

An effective way to ensure the implementation of the relevant policies and regulations of the Stockholm Convention is through inspections by law enforcement; this mainly involves the inspection of enterprises' discontinuation and use of POPs, decommissioning, sealing or dismantling of production facilities, and use of substitutes.

Table 1 Announcements on POPs that have entered into force for China in the Stockholm Convention

Release date	Files	Jointly released Sector	Controlled substances	Effective date
Apr. 16, 2009	Announcement on Prohibition of Production, Distribution, Use and Import and Export of DDT, Chlordane, Mirex and HCB	MEP, NDRC MIIT, MOHURD, MOA, MOFCOM, MOH, GAC, GAQSIQ, and GASS	DDT, Chlordane, Mirex and HCB	May 17, 2009
Mar. 25, 2014	Announcement on the Entry into Force of the Stockholm Convention on Persistent Organic Pollutants, and the Amendments to Annex A, Annex B and Annex C on the newly added list of POPs, and the Amendments to Annex A concerning the newly added endosulfan	MEP, MFA, NDRC, MOST, MIIT, MOHURD, MOA, MOFCOM, HFPC, GAC, GAQSIQ, GASS	α-HCH, β-HCH, Chlordecone, Pentachlorobenzene, Hexabromobiphenyl, Tetrabromodiphenyl ether and pentabromodiphenyl ether, Hexabromodiphenyl ether and heptabromodiphenyl ether, Lindane, PFOS and its salts and PFOSF, Endosulfan (except for specific exemptions and acceptable uses)	March 26, 2014
Dec. 26, 2016	Announcement on the entry into force of the Amendment about the Newly Added HBCD to the Stockholm Convention on Persistent Organic Pollutants	MEP, MFA, NDRC, MOST, MIIT, MOF, MOHURD, MOFCOM, GAC, GAQSIQ, and GASS	HBCD (except for specific exempt purposes)	December 26, 2016
Mar. 4, 2019	Announcement on Prohibiting the Production, Circulation, Use and Import and Export of Lindane and Other Persistent Organic Pollutants	MEE, MFA, NDRC, MOST, MIIT, MARA, MOFCOM, NHC, MEM, GAC, SAMR	Lindane, Endosulfan, PFOS and its salts and PFOSF (except for acceptable uses)	March 26, 2019
Dec. 30, 2019	List of Strictly Restricted Toxic Chemicals in China (2020)	MEE, MOFCOM, GAC	HBCD, PFOS and its salts and PFOSF	January 1, 2020
Dec. 30, 2020	Catalogue of Goods Prohibited from Import (Seventh Batch) Catalogue of Goods Prohibited from Export (Sixth Batch)	MOFCOM, GAC, MEE	Chlordane, Mirex, DDT, Pentachlorobenzene, HCB, Hexabromobiphenyl, Chlordecone, α-HCH, β-HCH, Lindane, Tetrabromodiphenyl ether and pentabromodiphenyl ether, Hexabromodiphenyl phenyl ether, Heptabromodiphenyl ether, Endosulfan, Aldrin, Dieldrin, Endrin , Heptachlor, Toxaphene, Polychlorinated biphenyls	January 1, 2021

Notes: MEP: Ministry of Environmental Protection; MOA: Ministry of Agriculture; MOH: Ministry of Health; GAQSIQ: General Administration of Quality Supervision, Inspection and Quarantine; GASS: General Administration of Safety Supervision; HFPC: Health and Family Planning Commission.

Table 2 POPs controlled in China's water environment standards

Water bodies	Standards	Main controlled substances
Groundwater	Standard for groundwater quality (GB/T14848-2017)	PCBs, PCP, HCHs, Lindane, DDT, Heptachlor
Surface water	Environmental quality standards for surface water (GB3838-2002)	Hexachlorobutadiene, PCP, DDT, Lindane, PCBs
Seawater	Sea water quality standard (GB3097-1997)	HCHs, DDT
Fishery water	Water quality standard for fisheries (GB11607-89)	HCHs, DDT, Sodium Pentachlorophenate

Table 3 Dioxin emission limits for different industries in China

Standards	Dioxins limit	Remark
Standard for pollution control on hazardous waste incineration (GB18484-2020)	0.5 ng TEQ/Nm^3	Under standard conditions
Standard for pollution control on medical waste treatment and disposal (GB 39707-2020)	0.5 ng TEQ/Nm^3	Under standard conditions, Determination of the mean
Emission standard of air pollutants for crematory (GB13801-2015)	0.5 ng TEQ/m^3	
Emission standard of pollutants for secondary copper, aluminum, lead and zink industry (GB-31574-2015)	0.5 ng TEQ/m^3	
Emission standard of air pollutants for sintering and pelletizing of iron and steel industry (GB 28662-2012)	0.5 ng TEQ/m^3	
Emission standard of air pollutants for steel smelt industry (GB 28664-2012)	0.5 ng TEQ/m^3	
Emission standard of air pollutants for pharmaceutical industry (GB 37823-2019)	0.1 ng TEQ/m^3	
Emission standard of pollutants for caustic alkali and polyvinyl chloride industry (GB 15581-2016)	0.1 ng TEQ/m^3	
Emission standard of pollutants for petroleum chemistry industry (GB31571-2015)	0.1 ng TEQ/m^3	
Standard for pollution control on the municipal solid waste incineration (GB 18485-2014)	0.1 ng TEQ/m^3	Determination of the mean
Standard for pollution control on co-processing of solid waste in cement kiln (GB 30485-2013)	0.1 ng TEQ/m^3	
Discharge standard of water pollutants for pulp and paper industry (GB 3544-2008)	30 pg TEQ/L	

Table 4 Contents of POPs in the National Ecological Environmental Protection Plan

Plans	The main content on persistent organic pollutants
National Environmental Protection Tenth Five-year Plan (2001)	● Phase out the production and use of POPs in accordance with the process of implementing international conventions ● Develop policy measures to control POPs, etc.
National Environmental Protection 11th Five-year Plan (2007)	● Focus on research and prevention of POPs in water ● Prioritize technologies for POPs control as technological innovation ● Conduct surveys on persistent organic pollutants
National Environmental Protection 12th Five-year Plan (2011)	● Aim to achieve remarkable results in the prevention and control of POPs by 2015 ● Focus on POPs emitting enterprises, comprehensively investigate key environmental risk sources and environmentally sensitive points, and establish an environmental risk source database ● List POPs as a key area of environmental risk prevention projects ● Research and development of POPs control technology
The 13th Five-Year Plan for Ecological Environmental Protection (2016)	● By 2020, phase out chemicals controlled by the Stockholm Convention on Persistent Organic Pollutants, such as lindane, PFOS, PFOSF, and endosulfan. Strengthen the research and development of alternatives to POPs to be restricted or banned, and best available techniques and related monitoring and testing equipment ● Strengthen the monitoring of persistent, bioaccumulative and harmful pollutants in drinking water sources and soils

It also includes inspection of enterprises' storage of POPs and the safe disposal of hazardous waste, the pollution level, and safe disposal at relevant sites, as well as the pollution prevention and control facilities and pollutant discharge compliance. For example, in 2010, the former Ministry of Environmental Protection carried out law enforcement inspections on DDT, chlordane, mirex, and HCB enterprises, which became officially enforceable for China in 2009. Subsequently, corresponding law enforcement inspections are conducted for the newly listed substances to ensure that the relevant requirements in the Stockholm Convention have been implemented.

2.2.5 Scientific research

The framework for scientific research includes basic and applied technology research. The search results of the CNKI and Letpub websites using POPs as keywords show that since 2001, the total number of research projects on POPs has reached 203, of which 175 are basic research projects, with a total research funding of 149 million yuan. The research field mainly focuses on aspects such as the methods of analyzing and detecting POPs, regional characteristics, environmental fate, risk and control principles, and environmental health. For example, since 2008, a number of studies have been carried out on the monitoring of POPs, such as the National Major Basic Research Program - "POPs Regional Pollution Status and Evolution Trend", the Major Project of National Natural Science Foundation of China - "Environmental Process and Toxicological Effects of Typical Persistent Organic Pollutants", the National Environmental Protection Public Welfare Scientific Research Project - "Research on Key Technologies Supporting Decision-making for Environmental Management of New Persistent Organic Pollutants", and the 973 Project - "Environment Behavior, Toxic Effects, and Principles of Control Techniques of Persistent Organic Pollutants".

China's POP monitoring technology has developed rapidly through scientific research investments in related fields. Taking dioxin as an example, at present there are almost 100 dioxin analysis laboratories in China that meet international standards. Among them, the Dioxin Laboratory at the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences was named the "Pilot Laboratory of Global POPs Monitoring Program"

by the UNEP (Liu et al., 2013; Gao et al., 2020). Chinese scientists have also developed dioxin analysis methods for soil, sediment, water, atmospheric, and industrial emission sources based on the actual situation in China and have developed relevant analysis standards, as shown in Table 5. The establishment of these standards lays the foundation for the prevention and control of dioxin pollution in China. In addition, Chinese researchers have developed a dioxin inventory survey methodology. Through an in-depth and systematic investigation of 10 categories and 62 subtypes of dioxin emission sources in China, the dioxin emission factors of various emission sources in China were determined, and a Chinese dioxin emission inventory was proposed. Relevant results have been cited in many places in the "Standard Toolkit for Identifying and Quantifying Dioxin Emissions" compiled by UNEP, which has played an important technical support role in implementing international conventions (UNEP, 2013). Thus, scientific research on POPs has provided China with valuable support in implementing the Stockholm Convention and conducting POP governance and has laid the foundation for the formulation of relevant management policies.

3 Effectiveness

As summarized above, the Chinese central government has actioned a broad array of policies to reduce and eliminate the production, release, and use of POPs. These actions may alter the levels and occurrence of POPs in the environment. In the following section, using OCPs and per- and poly-fluoroalkyl substances (PFASs) as representations of legacy and emerging POPs, we attempt to address their profile in selected environments to ascertain the effectiveness of management.

3.1 Temporal trend of dichlorodiphenyltrichloroethane and hexachlorocyclohexanes in the air

DDTs and HCHs are the predominant components of OCPs, which have been widely used in China since the 1950s (Fang et al., 2017). The Ministry of Agriculture of China officially declared the prohibition of DDT in agricultural production in an announcement in 2002. However, because DDT is a raw material for the production of dicofol and antifouling paints, its production has not been completely banned (Zhang, 2020). In 2009, in order to implement the Stockholm Convention, 10 ministries and commissions, including the Ministry of Environmental Protection and the National Development and Reform Commission, issued a joint announcement, officially banning the production, circulation, use, import, and export of DDT in China.

To evaluate the relevant effects of these actions, we evaluated the exposure level and occurrence of DDTs in the atmosphere by collecting relevant reports published in PubMed, Scopus, CNKI, Web of Science, and others. We obtained a total of 121 articles on DDTs monitoring based on the atmospheric environment. By analyzing the relevant data, we estimated that the median (interquartile range, IQR) concentration of DDTs in China's atmospheric environment is 0.116 (0.367) ng/m^3, far lower than the concentration of 1.65±0.33 ng/m^3 in India in 2019 (Chakraborty et al., 2019). The highest values of DDTs and their isomers in the atmosphere of China appeared during 2004–2005 (Figs. 4(a) and 4(b)), after which the concentrations showed a downward trend, which may be related to the implementation of the Stockholm Convention in China in 2004. As illustrated in Figs. 4(c) and 4(d), it can be concluded that the *o*,*p*'-DDT/*p*,*p*'-DDT ratio in 2000–2006 was higher than 1; this was related to the large-scale production and usage of dicofol. During 2006–2008, the value was lower than 1 in coastal areas, given that DDT-containing antifouling paints were used in fishing boats. In addition, the ratio of *p*,*p*'-DDT/*p*,*p*'-DDE was higher than 1 prior to 2004, indicating that most of the DDTs in the air came from newly used DDT pesticides (Pozo et al., 2006). After 2004, the rate was lower than 1, indicating that DDTs began to age, proving that DDTs in the atmospheric environment were mainly derived from photodegradation. These results are similar

Table 5 Standards for dioxin analysis in China

No.	Standards	Effective date
1	Environmental Dioxins monitoring technical specification (HJ 916-2017)	2018-04-01
2	Soil and sediment Determination of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) Isotope dilution HRGC-LRMS (HJ 650-2013)	2013-09-01
3	Soil and sediment Determination of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) Isotope dilution HRGC-HRMS (HJ 77.4-2008)	2009-04-01
4	Solid waste Determination of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) Isotope dilution HRGC-HRMS (HJ 77.3-2008)	2009-04-01
5	Ambient air and waste gas Determination of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) Isotope dilution HRGC-HRMS (HJ 77.2-2008)	2009-04-01
6	Water Determination of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) Isotope dilution HRGC-HRMS (HJ 77.1-2008)	2009-04-01
7	Technical Guideline of Monitoring on Dioxins Emission from Hazardous Waste (including Medical Waste) Incinerators (HJ/T 365-2007)	2008-01-01

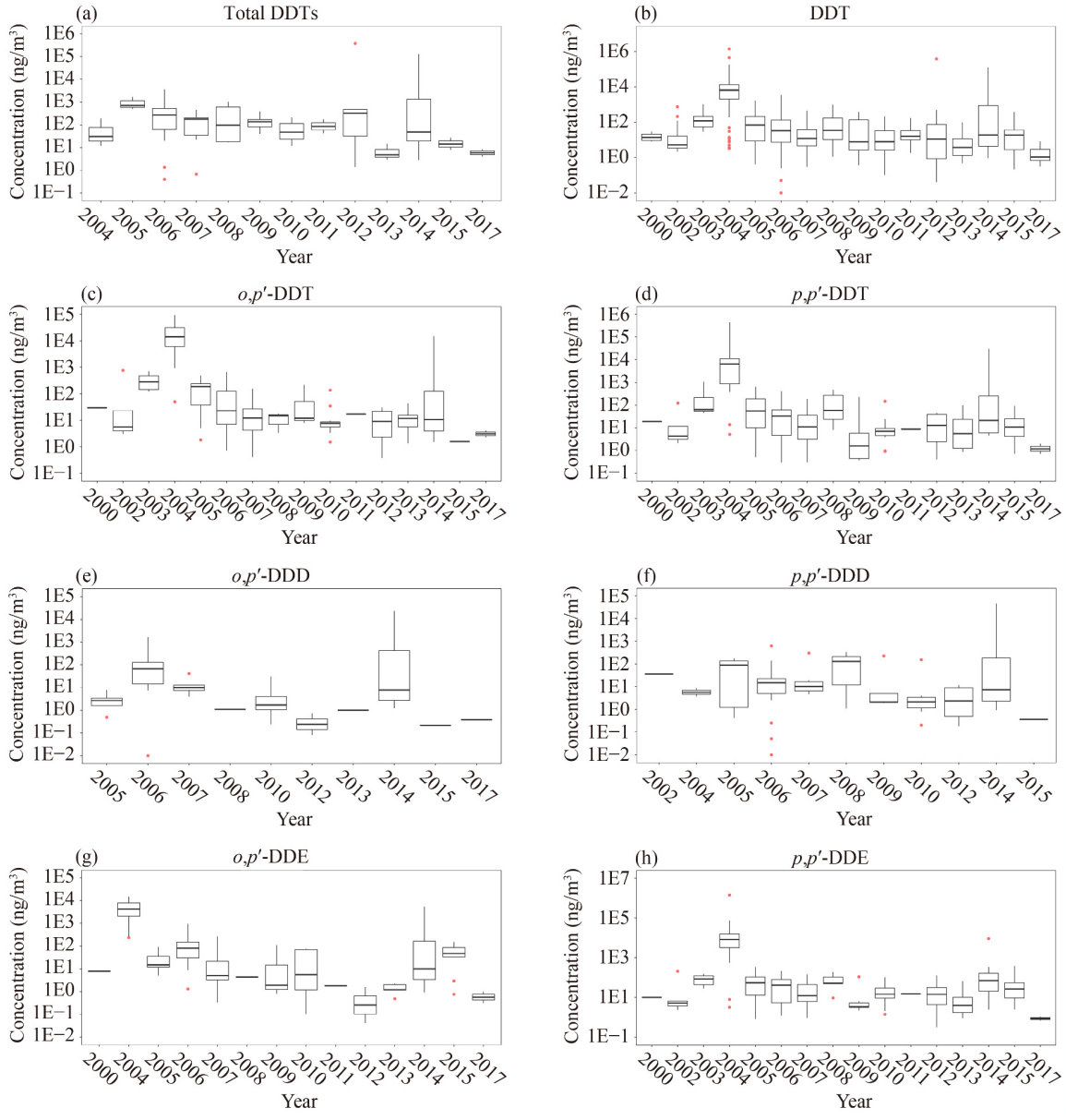


Fig. 4 Trend of DDT concentration in air over the past 20 years: (a) total DDTs, (b) DDT, (c) *o*,*p*'-DDT, (d) *p*,*p*'-DDT, (e) *o*,*p*'-DDD, (f) *p*,*p*'-DDD, (g) *o*,*p*'-DDE, and (h) *p*,*p*'-DDE.

to the temporal trends in DDT concentration and the *o*,*p*'-DDT/*p*,*p*'-DDT ratio in the atmosphere in Canada (Shunthirasingham et al., 2016).

China began to produce HCHs in 1958. The country's ban on HCHs in the agricultural sector was officially published in 2002 in an announcement by the Ministry of Agriculture, but a small amount of production capacity was reserved for exports, sanitation, anti-corrosion, and other needs. In 2014, China officially banned the production, circulation, use, import, and export of HCHs to implement the Stockholm Convention.

There were 59 research articles with 386 data records related to HCH monitoring in atmospheric environments (Fig. 5). The highest values of HCHs and their isomers in the atmosphere appeared around 2006 (Fig. 5(a)), which was closely related to the implementation of the Stockholm Convention in China in 2004. The lowest α-HCH/γ-HCH ratio in 2003 was only 0.65, and the value was still below 1 before 2010, indicating that lindane was the main source of HCHs. In contrast, the α-/γ-HCH ratio increased to greater than 1 after 2010.

3.2 PFOS/PFOSF in water and sediments

PFOS and its salts, as well as PFOSF, were listed as controlled substances in the Stockholm Convention of 2009 (UNEP, 2009). Historically, PFOS/PFOSF has been used extensively in the production of fire extinguishing

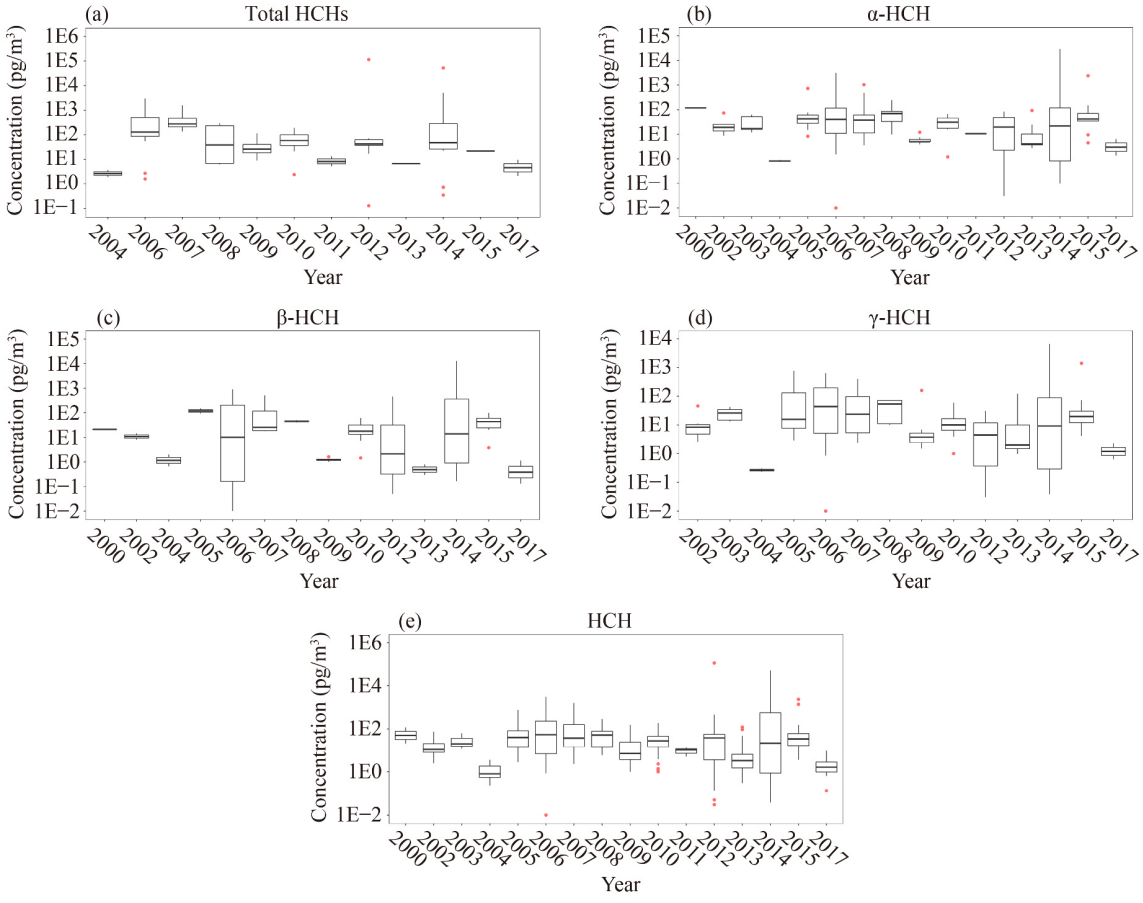


Fig. 5 Trend of HCH concentration in air over the past 20 years: (a) total HCHs, (b) α-HCH, (c) β-HCH, (d) γ-HCH, and (e) HCH.

foam, carpets, leather products or clothing, textiles and lining materials, packaging materials, and additives in paints and pesticides (UNEP, 2006), and as a result, it has been detected in many environmental media. For example, studies in the USA have identified the occurrence of PFOS in the effluent of wastewater treatment plants, surface water, and sediment at concentrations of 41–5290 ng/L and ND–138 ng/L, and ND–53.1 ng/g dw, respectively (UNEP, 2006).

In China, PFOS is used in fire extinguishing foam in the fire protection industry, chemical oil recovery in the petroleum industry, chrome mist inhibitors in the metal plating industry, and sulfluramid hygienic insecticides (Qiu et al., 2010; Leng et al., 2021). To implement the relevant requirements of the Stockholm Convention, China listed a timetable for phasing out PFOS at the national level; that is, by March 26, 2019, the production, use, import, and export of PFOS/PFOSF (except for acceptable uses) was completely banned. Various local governments in China have actively participated in achieving these goals. For example, in Changzhou City, Jiangsu Province, the electroplating industry is intensive, and it stated in its "13th Five-Year Plan" for Ecological Environmental Protection (2016–2020) that it meant to implement clean transformation and elimination of outdated processes for its domestic electroplating enterprises. After the relevant treatment, the level of PFOS/PFOSF emissions in its territory dropped significantly. An et al. (2021) continuously monitored the concentrations of PFASs, including PFOS, in 60 bodies of water and 33 emission sources in the region from 2018 to 2019. The results showed that in 60 surface water bodies, the average concentrations of PFASs in 2018 was 205.6 ng/L, and the concentration of PFASs in 2019 was 171.9 ng/L. At the monitoring sites of the 33 emission sources, the average concentration of PFASs in 2018 was 6650.1 ng/L, and the average concentration in 2019 was 4483 ng/L. These results show that the concentration of PFASs in surface water and sewage treatment plant drainage has decreased significantly, which has been attributed to the adjustment of the local industrial structure, especially in the treatment of industries such as electroplating. Meng et al. (2021) studied the content of PFASs in the sediments of the Bohai Sea and found that the median concentration of PFOS in marine sediments decreased over time, from 0.060 ng/g dw in 2011–2012 to 0.043 ng/g dw in 2018.

3.3 Trends in dietary exposure of POPs

A recent study analyzed 27580 items of data from 753

articles published in the past 30 years and found that the content of DDTs and HCHs in fish and shrimp has shown a significant downward trend. The concentration of DDTs in particular went from 7.68 mg/kg in 2002 to 0.84–8.1 μg/kg recently. In addition to DDTs and HCHs, there was an observable downward trend for dioxins and polybrominated diphenyl ethers (PBDEs) in fish and shrimp (Fan et al., 2021). Similarly, studies from the China National Nutrition and Health Survey conducted in 1992–1993, 2002, 2010–2013 and 2015–2017 also revealed a significant decrease in legacy POPs (Zhou et al., 2012; Chen et al., 2020). These findings support the downward trend in POP concentrations in fish and shrimp over time, which may be attributable to China's management of POPs, indicating that China has achieved remarkable results in implementing the Stockholm Convention (Dong et al., 202Dong et al., 2021).

3.4 POPs waste disposal

Article 6 of the Stockholm Convention requires that measures be taken to reduce or eliminate emissions from stockpiles and waste (UNEP, 2019). Over the past 20 years, China has safely disposed 6352.1 tons of POP pesticides and treated 42000 tons of soil contaminated by POP pesticides. In terms of PCBs, China disposed of 36998 sets of electrical equipment containing PCBs, with a disposal rate of 100% for all identified equipment, and safe disposal of 6463.467 tons of PCB waste. In addition, China has also compiled documents for technical specifications and monitoring standards, such as Technical Specifications for Centralized Incineration Disposal Engineering on PCBs Waste (HJ2037-2013) and Ambient Air—Determination of Polychlorinated Biphenyls—Gas Chromato graphy/Mass Spectrometry Method (HJ 902-2017).

4 Summary

Over the past 20 years, China has made remarkable progress in implementing the Stockholm Convention and has established an implementation guarantee system, which has laid a solid foundation for the control, elimination, and prevention of POPs. Looking to the future, as the public's understanding of POPs continues to deepen and the demand for environmental health continues to increase, it is necessary to further consolidate the foundation for the implementation of the Stockholm Convention, and some priorities are suggested as follows:

1) Strengthen the monitoring network. Environmental monitoring is the basis for POP prevention and evaluating the effects of implementation. The development of the monitoring system includes establishing national and provincial monitoring sites for the atmosphere, water, sediment, and soil to monitor the trend of POPs concentrations; regularly monitoring the concentration of POPs in aquatic organisms; carrying out ecological risk assessment and prediction; regularly conducting surveys on the levels of POPs in breast milk; and promptly formulating monitoring standard methods for newly listed POPs.

2) Strengthening scientific research. A number of research areas require more attention, such as the migration and transformation of POPs in the environment and their impact on the ecological environment and human health; the development of products and technologies to reduce or eliminate POPs emissions, as well as their substitutes; the POPs degradation and removal mechanisms, and technologies for POPs waste disposal; the development of non-incineration technologies, especially in the context of carbon reduction; the development of portable POPs monitoring instruments and equipment; and the implementation of law enforcement monitoring.

3) Further strengthening publicity and education to raise public awareness, establishing a platform and long-term mechanism for publicity and education, and incorporating POP-related content into primary and secondary education, such as establishing a cooperative education mechanism with primary and secondary schools; strengthening the cooperation between the community and women's protection organizations to raise women's protection awareness; carrying out training on safety production and occupational health for key industries and key groups; and disseminating knowledge about POPs, practical daily protection, and emergency self-rescue skills.

4) Strengthen international cooperation to jointly deal with POPs. Given the long-range transport characteristics of POPs, countries around the world must cooperate to deal with the pollution. This would involve promoting the construction of a global POP monitoring network and of data sharing, improvement of monitoring capabilities, and providing strong support for scientific decision-making systems. Implementation experience should be exchanged with developing countries with the help of the "Belt and Road" Green Development International Alliance, China Center for Shanghai Cooperation Organization Environmental Cooperation, China-ASEAN Environmental Cooperation Center, China-Africa Environmental Cooperation Center, and other cooperation platforms. Finally, strengthen cooperation in POP monitoring and waste disposal; jointly improve POP environmental governance capacity; and jointly take the path of green, low-carbon, and sustainable development.

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