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RESEARCH ARTICLE

Trends of environmental accidents and impact factors in China

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Abstract An overview of the spatial and temporal variations of the environmental accidents in China in recent years was presented in this paper using available data. The results showed that the frequency of pollution accidents was significantly decreased, from 3462 in 1990 to 462 in 2007. The water and air pollution accidents were found to be the dominant types, accounting for more than 80% of the total accidents. Considering the classification of environmental accidents at 4 scales, the general environmental accident, i.e., the least serious type, was the most frequent event, taking up 58.98% of the total pollution accidents. In addition, the distribution of environmental accidents was generally in accordance with the industrial layout in the country during the past decade. It is very important to note that the extraordinarily severe environmental accidents showed an increasing trend in underdeveloped regions, which was caused by the transfer and the development of heavy polluted industry in these areas. As to the losses of environmental accidents, the casualties presented an obvious reduction tendency, while the direct economic loss per accident tended to climb up. Furthermore, some key factors that affect the spatial and temporal tendencies of environmental accidents in China were discussed and some suggestions were put forward, hoping to shed light on environmental risk management and emergency plans making associated with environmental accidents in China.

Keywords environmental accidents, spatial and temporal trends, environmental risk

1 Introduction

Since the Open Door Policy was initiated in 1978, China's economy has been undergoing an incredible high-speed development. However, along with the rapid economic growth, many environmental problems that haunted the developed countries in different phases of their 100-year-long industrialization have occurred in China nearly all at the same time, one of which that has been bothering China is the environmental accidents. Taking the Songhua River accident as an example, over 100 tons of nitrobenzene and related compounds were released into the Songhua River and formed an 80 km pollution slick belt flowing downstream because of the explosion of Jilin Petrochemical Corporation on 13 November, 2005 [1]. The water pollution accident forced Harbin City with four million inhabitants, located 200 km downstream from the nitrobenzene discharging site, to stop water supply for four days, and even resulted in a widespread panic for purchasing drinking water [2]. But the worst was that the pollution slick belt in the Songhua River would finally flow into the Heilong River on the Sino-Russian border, known in Russia as the Amur River, which threatening the water safety of the Russian border city Khabarovsk with more than 600000 residents [3]. The Songhua River accident had taught China a bitter lesson. In addition, a cadmium pollution incident in Beijiang River (December, 2005), the water crisis with odorous tap water in Wuxi City (May, 2007), and the lead poisoning accident in Shaanxi (August, 2009) also seriously affected the life safety in China and also posed a sudden threat to the environment. The frequent occurrence of the environmental accident has sounded alarms and deserves much attention paid to it from several viewpoints.

The existing analysis of the environmental accidents in China has mainly focused on particular aspects, such as toxicological effects [4–7], methodologies for risk evaluation [8–13], treatment technologies [14–19] as well as environmental emergency response [20,21]. These research projects have improved and enhanced our understanding of the nature of the problem caused by the environmental accidents. Additionally, lessons learnt from accidents are essential sources for updating state-of-the-art

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requirements in accident prevention [22]. To improve this art in China, Hou and Zhang [23] presented a summary evaluation on 80 major polluting events from 2002 to 2006 in China and drew some basic lessons focusing on the root causes of the environmental accidents.

Given the importance of pollution accidents to the environmental safety, it is necessary to give an overall picture and a well-grounded prospect of environmental accidents in China. However, this article does not intend to provide a complete in-depth assessment of environmental accidents in China, but to present a better understanding of the observed variations, current situation and future challenges through the historical data and analysis of key factors affecting the trends of environmental accidents.

2 Data source

It is well known that the work of environmental protection in China lags far behind the West industrial countries. The formal environmental management and administration in China was begun in 1973. But only by 1990, did environmental protection really start to exert its full presence on the political agenda in China. Since then the environmental data including the information of pollution accidents have been collected and published in the form of the *China Environmental Statistical Yearbook*. The environmental accident data presented in this paper are mainly collected from the *China Environmental Statistical Yearbook.*

Compared with the numerous databases of environmental emergencies providing the available clean-up technologies in Western countries, the pollution accident data in China are only limited to descriptive information. In the early 1990s, the accident data were very simple, mainly associated with total occurrence frequency. Only in 1993, the government began to compile and report the provincial yearly data, and added the pollution types, accident scales, casualties and direct economic loss. Since 2005, an improvement in the quality of environmental accident data has been observed. The comprehensive information of the process and effects of pollution incidents can be found in the environmental accident statistical data.

The environmental pollution accident in China is required to report to the governments at or above the county level within one or two hours at most. However, almost all accidents were reported within six hours to ten days after its occurrence due to the local interference [23]. As a result, the pollution accident data in the Environmental Statistical Yearbook were not complete or were of low quality. However, they are still an irreplaceable starting point for analyzing the environmental accidents in China and do reflect a tendency to some extent. Since the government has started to pay attention to the pollution accidents in China, it is expected that the future data will be greatly improved.

3 Overview of China's environmental accidents

3.1 General trends

Our analysis is initiated by briefly reviewing the overall trend of total accidents based on the statistical data. There were total about 35737 environmental accidents occurring from 1990 to 2007 in China[24], and the accident number revealed a substantially decreased trend throughout the years of study, from 3462 in 1990 to 462 in 2007, of which three different phases can be identified, see Fig. 1. The first phase was characterized by general decline from 1990 to 1996. During the second period, the value showed a certain fluctuation until the year of 2000, and had resumed another fast decrease in recent years, i.e., from 2001 onwards (the third phase). It is regarded that the noticeable decline of environmental accidents in China is greatly attributed to the raising awareness of environmental risks. Further reduction could be expected if the current prevailing trend continues.

It is important to note that, among the 35737 environmental accidents, more than 80% were water and air pollution incidents, accounting for 55.32% and 36.46% respectively, while 4.07% were related to the solid waste pollution, and 4.15% were unclassified events referring to marine pollution accident, pesticides pollution accidents, or a radioactive pollution accident. As to the proportional difference of different type accidents, Figure 2 shows that water pollution accidents ranged from 46.05% to 63.03%, air pollution accidents from 29.86% to 43.66%, solid waste accidents from 1.03% to 14.57%, and the others varied from 1.81% to 11.22%.Water and air pollution accidents had been the dominant types of the environmental accidents in China since 1993. It is worthwhile to note that the proportion of water environmental accidents were decreasing, which from 53.30% in 1993 to 40.64% in 2007. Whereas, the solid waste accidents displayed an obvious increasing trend during the past decade. The proportion variation of different accidents illustrated the regulation emphasis on pollution events in China.

The environmental accidents in China are classified into four scales according to accident damage: extraordinarily severe, severe, major and general (see appendix for criteria).

Figure 3 shows the proportions assigned to the different scales environmental pollution accidents. In 1993, the proportion of extraordinarily severe accidents accounted for 2.33%, severe accidents 2.89%, major accidents 13.29% and general accidents 81.49%, while the structure changed to extraordinarily severe 0.2%, severe 2.0%, major 2.4% and general 94.7% in 2007. It is easy to note that the general environmental accident was the most frequent pollution event in China, taking up 80.53% of the total accidents during the past decade. In fact, the absolute amount of the general accidents declined from 2250 in 1993 to 434 in 2007, indicating a relatively effective

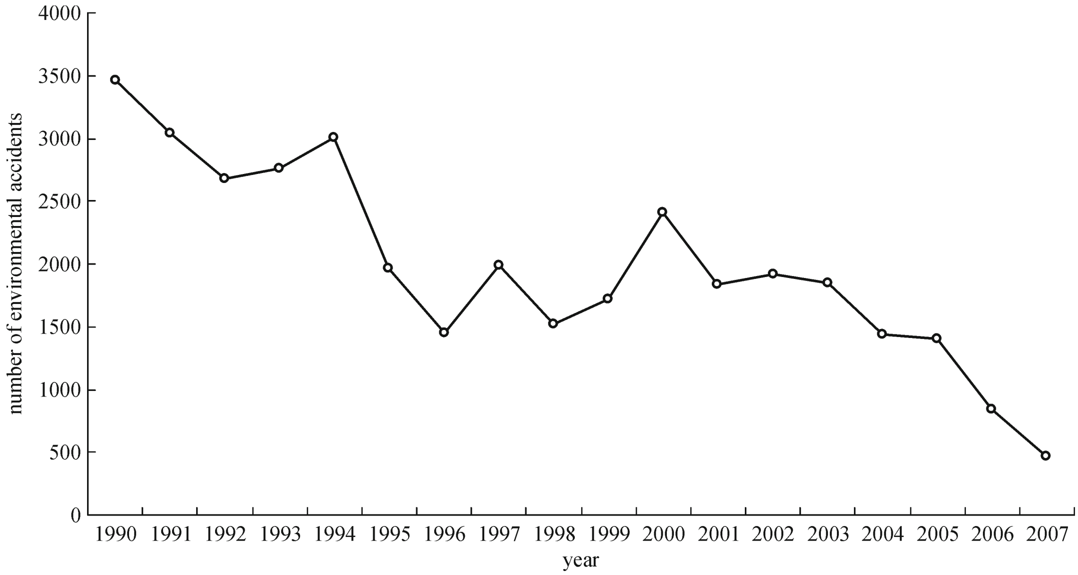

Fig. 1 Variance number of environmental accidents from 1990 to 2007 in China

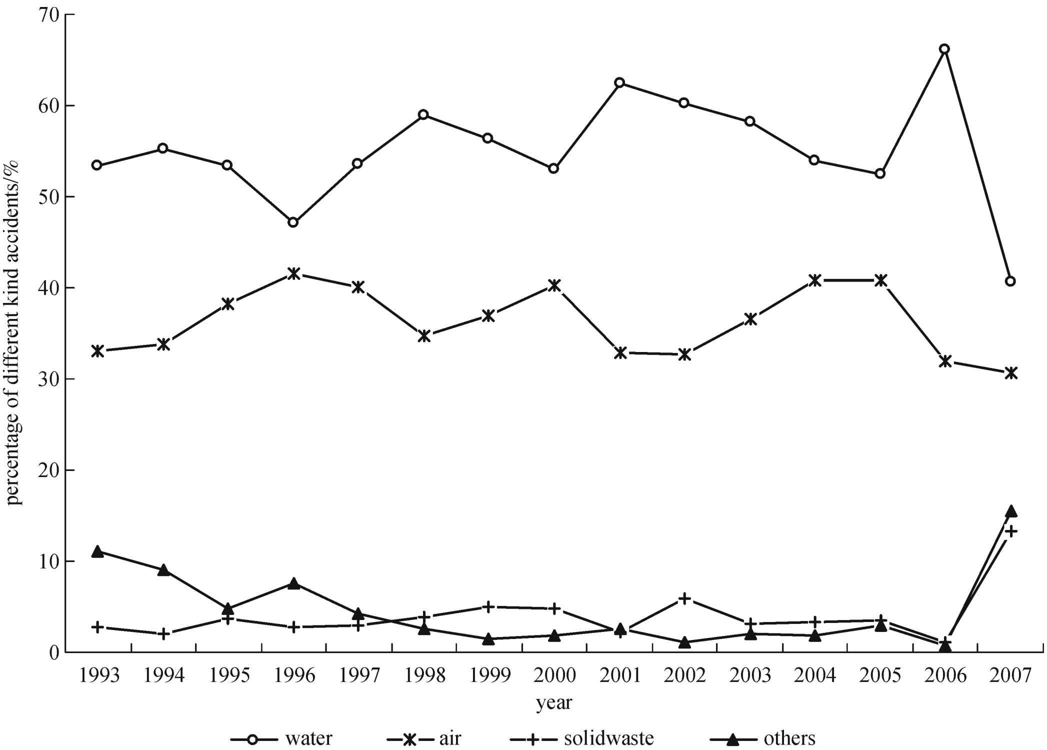

Fig. 2 Proportion of different kinds of environmental accident from 1993 to 2007 in China

prevention of the general environmental accidents in China. The least proportion of the general environmental accident was 73.52% in 1995. At the same time, the extraordinarily severe accidents showed a minor increasing trend. As a whole, the proportion of different scale environmental accidents in China had no significant change from 1993 to 2007.

3.2 The spatial characteristics of China's environmental accidents 1993–2007

Moreover, in the total pollution accidents, there exists a great difference among regions in China. In 2007, for example, the number of environmental accidents varied from 0 to 80 in different provinces. Figure 4 presents that

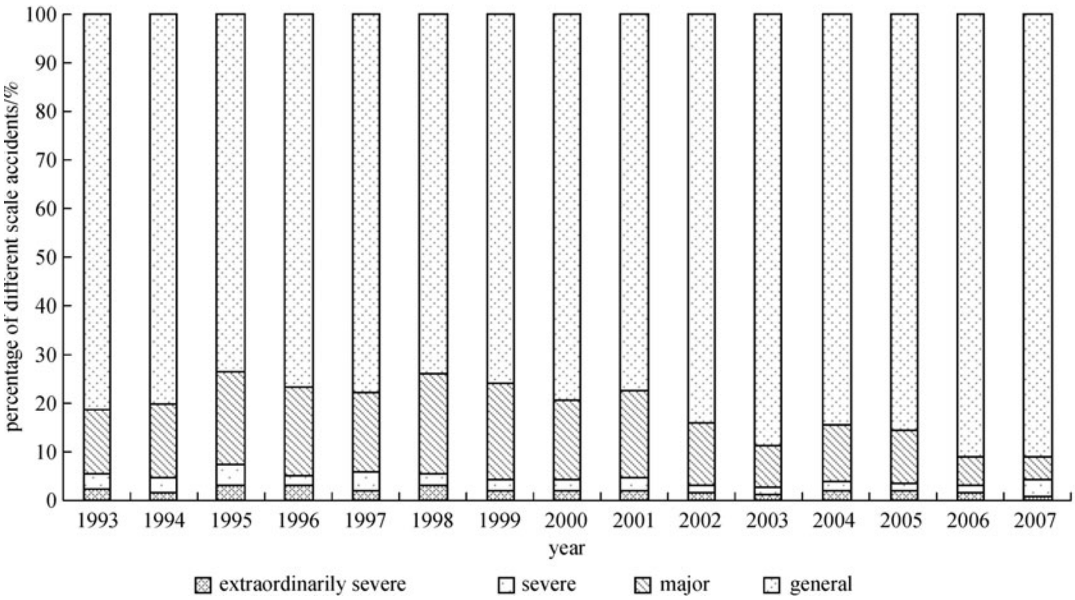

Fig. 3 Proportion of different scale environmental accidents in China from 1993 to 2007

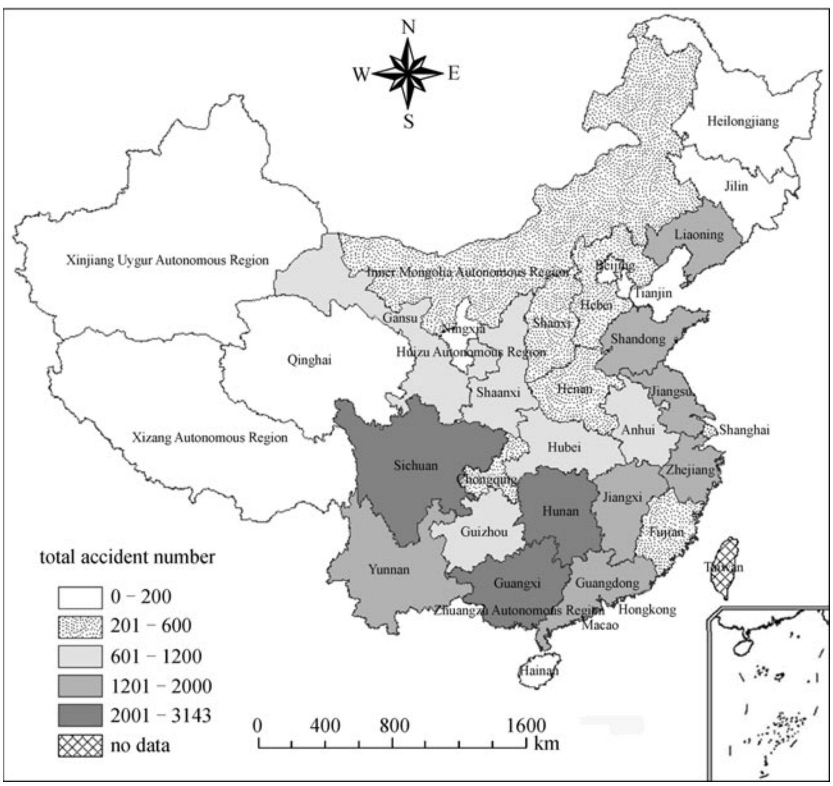

Fig. 4 Provincial distribution of total environmental accidents in China from 1993 to 2007

the frequency of environmental accidents in Guangxi, Hunan and Sichuan provinces ranked in top three. In addition, the coastal areas, including Liaodong Peninsula, Yangtze River Delta, and Pearl River Delta, also had the high frequency of environmental accidents during the past decades. This is not surprising since the vast majority of industrial development in China, especially in the chemical industry, has occurred along rivers and coastal areas, and more than 45% of chemical enterprises are the significant environmental risk sources [25].

Relatively few environmental accidents were found in Xizang Autonomous Region, Xinjiang Uygur Autonomous

Region and Qinghai Province. At a macroscopic level, the frequency of environmental accident was significantly higher in the south than in the north and in the east than in the west.

Regarding the regional characteristics of the pollution accidents, the obtainable information from Fig. 5 indicates that the number of pollution accidents of all regions except Shanghai exhibits a general decreasing trend, though they may experience some fluctuations. The increase of environmental accidents in Shanghai was primarily due to the growth of air pollution accidents from 6 in 1993 to 34 in 2007. According to local official reports, it is believed that the significant increase of high environmental risk sources and the inefficient supervision of air emissions in Shanghai led to this rising tendency.

As the dominant types of environmental accidents in China, the frequency composition of water and air pollution accidents was generally in accordance with the total accident distribution. However, considering the distributions of different scale pollution accidents, extraordinarily severe accident was used in consideration of the disparities of administrative area. The result showed that it was not Guangxi, Hunan and Sichuan areas had the most, but rather Jiangsu, Zhejiang and Liaoning Provinces, as shown in Fig. 6. The main reason was that the developed regions had higher population densities and experienced more rapid economic progresses than other provinces, which aggravated the losses of pollution accidents.

Moreover, Fig. 7 indicates that the extraordinarily severe environmental accident exhibited a rising trend in nine western provinces after the Western Great Development Strategy was put into effect in China in 2000 (including Xinjiang Uygur Autonomous Region, Xizang Autonomous Region, Inner Mongolia Autonomous Region, Qinghai, Gansu, Shaanxi, Sichuan, Hunan, Yunnan Provinces). Taking Shaanxi Province as an example, in the early 1990s, there was scarcely any extraordinarily severe environmental accidents. While since 2000, the leakage accident of crude oil and heavy metal pollution accident had been occurring frequently. There were total about 12 extraordinarily severe pollution accidents from 1993 to 2007 in Shaanxi area, but more than half of them occurred after 2000.

4 The loss of China’s environmental accidents 1993—2007

4.1 Casualties differences

The environmental accidents caused 109 deaths and 53996 casualties from 1993 to 2007 [24]. The death tolls had not declined, as shown in Fig. 8, and the trend of mortality rate among every 10000 people slightly increased across time.

However, the number of casualty showed a noticeable

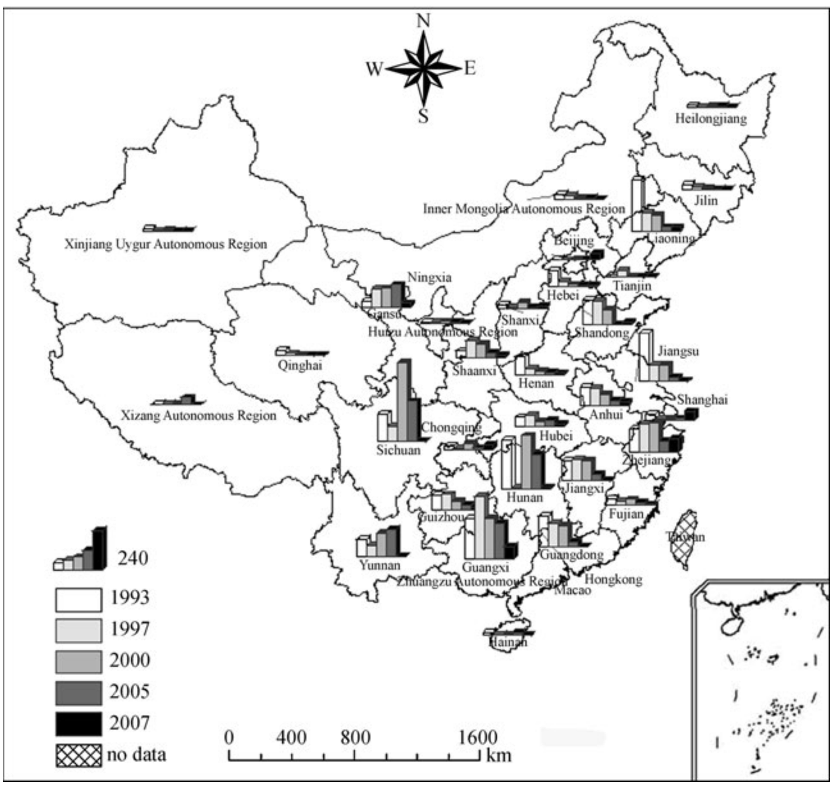

Fig. 5 Provincial distribution of environmental accidents in China in 1993, 1997, 2000, 2005 and 2007

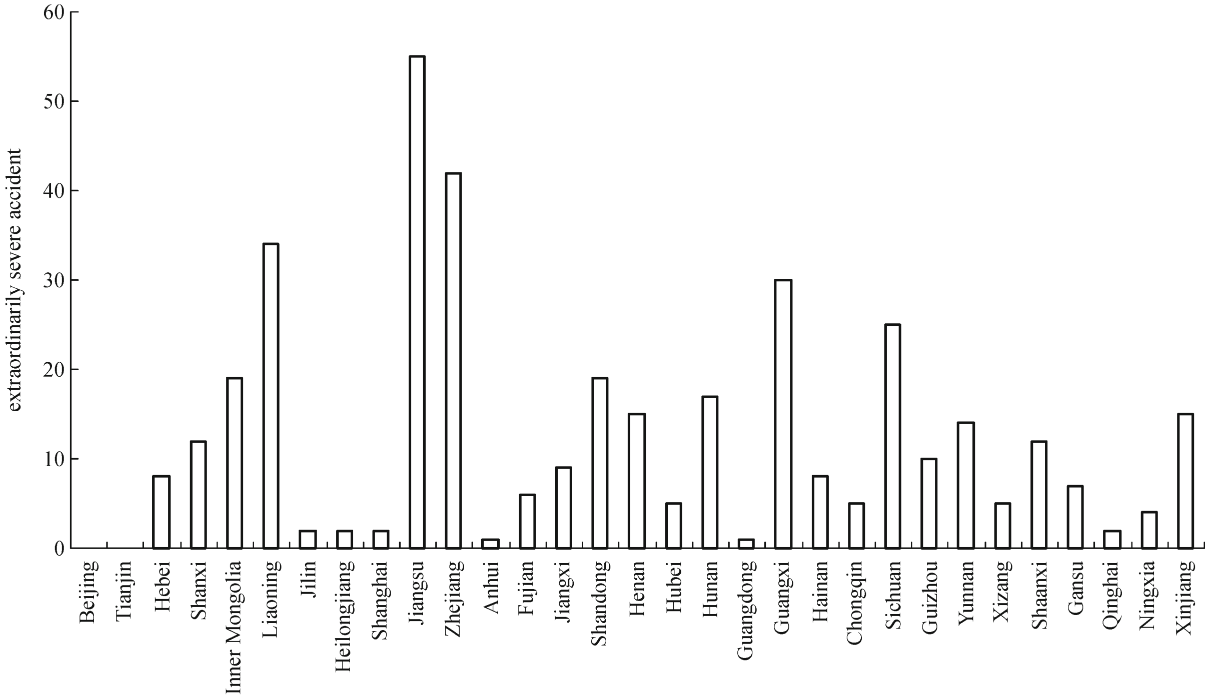

Fig. 6 Provincial distribution of extraordinarily severe accidents in China from 1993 to 2007

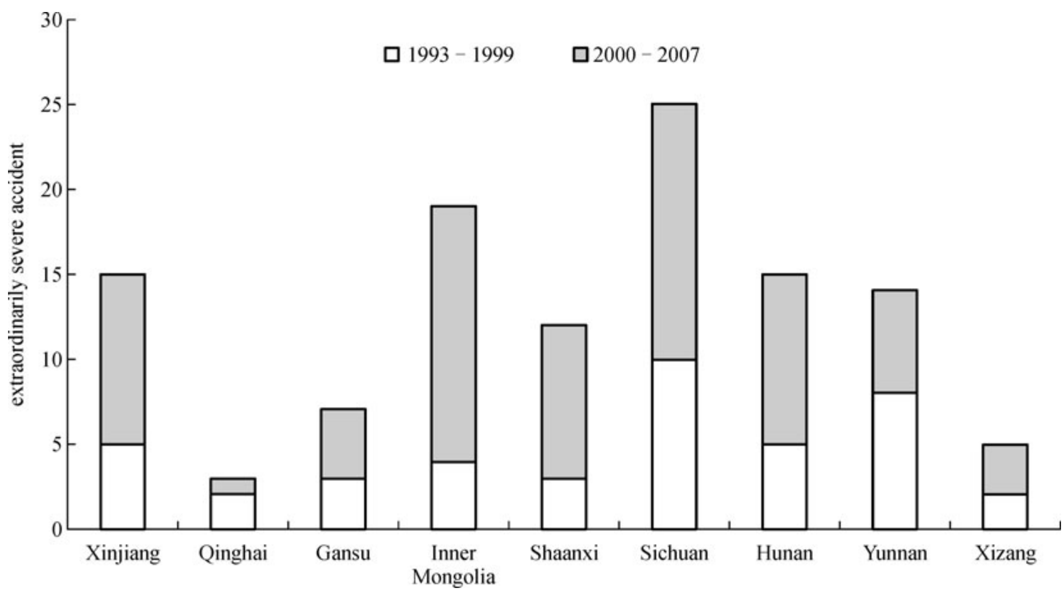

Fig. 7 The trends of extraordinarily severe accidents in western China

reducing trend, from 1436 in 1993 to 358 in 2007. The decreasing tendency was chiefly associated with the implementation of relevant emergency regulations in China, such as *Interim Measures for Environmental Pollution and Destruction Accident* in 1992, *Emergency Monitoring and Treatment Techniques for Environmental Pollution Accident* in 1995 and the *National Emergency Preplan for the Emerging Environmental Events* in 2006. In addition, by March 2009, more than 14 provinces in China had established a provincial environmental emergency preplan to control the losses and impacts of the pollution accidents as low as possible [26]. Moreover, after the Songhuajiang River accident, the emergency exercise was frequently conducted, aimed at enhancing the preparation and coordination in case of an environmental accident in China.

4.2 Direct economic loss variance

As to the direct economic loss of the environmental accidents in China, 71.24% came from water pollution accidents, 19.83% were caused by air pollution accidents, while solid waste and other environmental accidents took up less than 10% altogether. The significant increase of direct economic loss in 2004 (as shown in Fig. 9) is strongly driven by Tuojiang River accident in Sichuan, taking more than 60% of the total direct economic loss in that year [27].

Additionally, Fig. 9 presents the variance proportion of direct economic loss in different scale accidents, from which we can find that the percentage experienced a large fluctuation from 1993 to 2007. The proportion of direct economic loss caused by the extraordinarily severe accidents ranged from 91.63% to 12.61%, the severe accidents 4.24% to 20.41%, major accidents 1.67% to 27.15% and general accidents from 3.86% to 63.71%. It is believed that more than 75% of the total direct economic loss was caused by the extraordinarily severe pollution

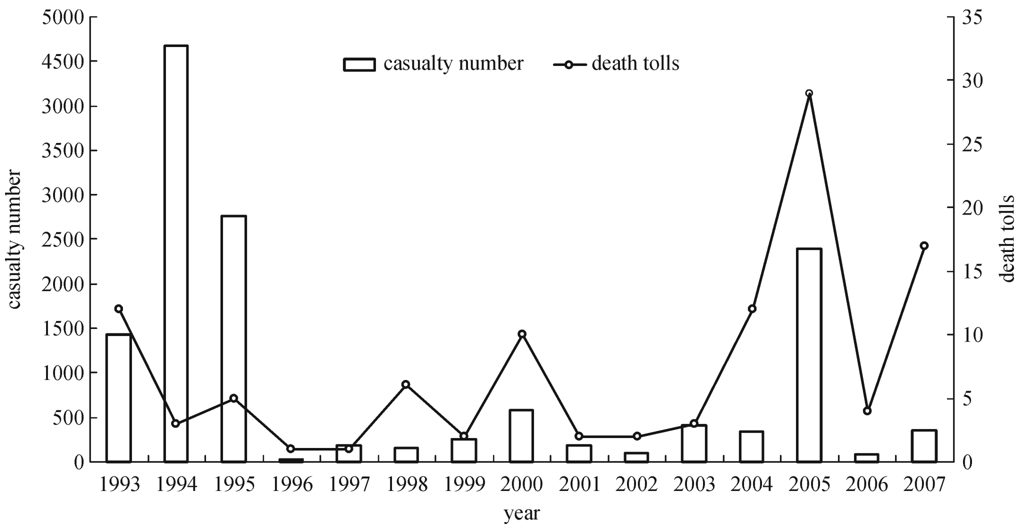

Fig. 8 The casualties and deaths caused by environmental accident from 1993 to 2007

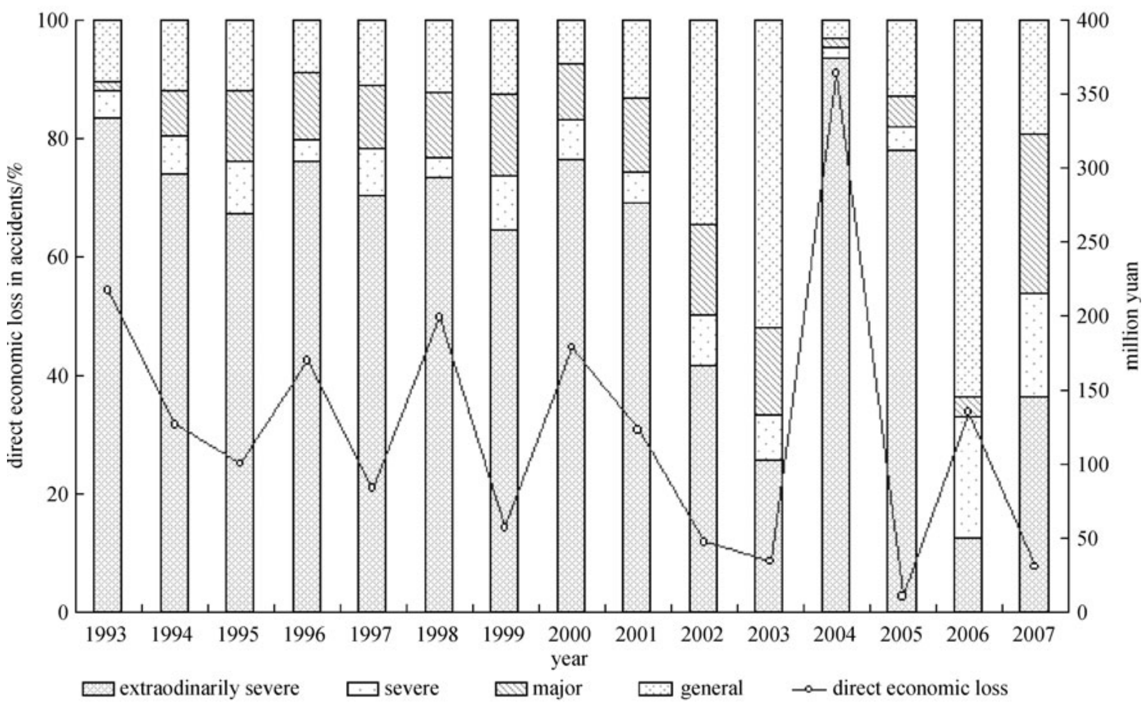

Fig. 9 Total direct economic loss and its proportions in different scale environmental accidents in China from 1993 to 2007

accidents, though its number only accounted for 2% of the total from 1993 to 2007.

By further comparing of the environmental accident number and the direct economic loss during the study period, an obvious upward tendency in direct economic loss per accident can be observed. Taking the extraordinarily severe accidents for example, there were 42 accidents occurred in 2000, a decrease of 14 compared with that in 1995. Nevertheless, the direct economic loss increased by 69.49 million yuan, or 1.92 times. Similarly, comparing 2005 with 2000, the direct economic loss per accident increased 1.72 times as well, and the tendency was particularly evident in 2007, with the economic loss of a single accident in 2007 is 1.96 times that of 2005. Data from 1993 to 2007 suggests that a similar trend could be found in other scale pollution accidents, as confirmed in Table 1.

5 The impact factors of environmental accident trends in China

The overall trend of environmental pollution accidents for the past ten years in China was characterized by the steady decrease in accident frequency. In addition, the spatial change was the trend of transferring from east to west regions of extraordinarily severe pollution accidents in recent years. As to the losses of environmental accident, a ceaseless tendency of increase in direct economic loss of per accident can be easily found from 1993 to 2007.

5.1 The regulations on the environmental accidents control

The observed decline of environmental accidences in China can be largely attributed to implementation of relevant policies and the strengthening of environmental supervision capacity in enterprise pollution in China.

First and foremost, the regulations centering on dangerous chemicals played a critical role in diminishing the risks of pollution accidents in China. Since the first national seminar on risk management of hazardous and toxic chemicals in 1990, the government has been active in controlling the management of hazardous chemicals. For example, in December 1995, China issued the *Regulation on Administration of Chemicals Subjected to Supervision and Control*, and, in accordance with the regulation, issued the *List of Chemicals Subjects to Supervision and Control* and the *Bylaws for the Implementation of the Regulations* in June 1996. Afterwards, *Safety Administration of Hazardous Chemicals* was approved on January 9, 2002 by State Council. The administration makes clear provisions for manufacture, storage, and use of dangerous chemicals, stipulating that the State carries out the unified planning, rational arrangement, and strict control over the manufacture and storage of dangerous chemicals. Additionally, the regulation requires the professional level recognizing system for transportation of dangerous chemicals in China and the qualifications that must be fulfilled by enterprises which transport such chemicals shall be formulated by State Council. Consolidated management in safety usage and transport of dangerous chemical good effectively reduces the chemical incidents in China, and moreover, decreases the risks of pollution accidents to a great extent.

Besides the hazardous and toxic chemicals regulation, the Production Safety Law which was enacted in 2002 for the purpose of supervision and administration of production safety also promotes the accident decline effectively. The regulation lays down a rigid system for guarantees of safety by production and business operation entities, such as eliminating the techniques and equipment that seriously endanger the safety of production. The system also requires regularly servicing, maintaining and checking the safety facilities so as to ensure the normal operation and giving special education and training programs to the employees involved in production safety.

In addition, after the Songhuajiang River accident, the environmental protection departments at all levels issued requests for 3794 enterprises for rectification and improvement and also demanded the 49 enterprises having high environmental risks to carry out technological transformation [28].

As a result, the production accidents which are usually triggered by technical failures, human failures and

Table 1 Pollution accident number and its direct economic loss in 1995, 2000, 2005 and 2007

accident scales	1995		2000		2005		2007	
	the number of accidents	direct economic loss /(million yuan)	the number of accidents	direct economic loss /(million yuan)	the number of accidents	direct economic loss /(million yuan)	the number of accidents	direct economic loss /(million yuan)
extraordinarily severe	56	66.57	42	136.06	15	83.25	1	10.88
severe	84	9.13	65	11.89	22	2.53	9	5.32
major	380	11.70	388	16.59	153	5.39	11	8.19
general	1444	11.82	1917	13.54	1216	13.98	434	5.77

equipment failures are reduced noticeably, and the sudden pollution affairs related to production safety have consistently decreased to a certain extent in recent years.

Environmental Impact Assessment (EIA) is another important legal measure to curb ecological destruction and environmental pollution at the source, and add certainty to preventing the occurrence of environment accidents. In 1998, SEPA promulgated the *Regulations on Environmental Management of Construction Projects*, which required construction projects to design, construct and put into use relevant environmental protection facilities along with the progress of the project itself. *The Law of the People's Republic of China on Environmental Impact Assessment* extends the EIA practice from construction projects to all development plans. The possible pollution accidents and environmental impact resulting from the planning's layout, scale and ways could be controlled by making changes to the site, route or technology in the EIA. Moreover, *Technical Guidelines of Environmental Risk Assessment on Projects* which was announced in 2004 effectively promoted the whole-process project risk management and greatly reduced the environmental risks of polluting accidents of construction projects, especially the projects involving major environmentally sensitive issues.

Moreover, there was no doubt that the reduction of environmental accidents benefited immensely from the strengthening of environmental supervision capacity in industrial pollution. Up to 2006, there were 3854 environmental supervision and environmental law enforcement organizations with more than 50000 staff workers nationwide, responsible for the supervision of nearly 300000 industrial polluting enterprises, some 700000 other industrial enterprises and about 10000 construction sites [29]. Due to the strict supervision, 84000 small enterprises were closed down for having discharged pollutants in violation of the law during the period of China's Ninth Five-Year Plan (1996–2000), and a further 2600 in 2005 [30].

Moreover, five regional supervision centers of environmental protection that lie in the east, south, north-west, south-west and north-east are set up in 2006 as the way forward in effectively curbing those involved in illegal environmental activities. It is important to note that one of the main duties of these centers is to supervise the response of environmental accidents.

Due to the strengthen of environmental supervisory forces and the upgrade of environmental law enforcement in China, the illegal pollutant release, reflected by excessive discharge, are gradually suppressed, further, the environmental accidents relating with the abnormal pollutant release also declined.

5.2 The cause of spatial trend in environmental accidents

As to spatial character of polluting accidents in China, the extraordinarily severe pollution accidents show an increasing tendency in west regions in recent years. To get rid of poverty, a large number of heavy chemical industries are promoted by local government, especially in resource-rich provinces. Until 2006, the oil refining industry in Gansu and Shaanxi, the paper-making industry in Ningxia and the coal chemical industry in Inner Mongolia have become the typical environmental risk sources in west [31]. Moreover, along with the decreasing of environmental capacity and the upgrading of industrial structure in the east, massive power stations, huge chemical plants, textile and dyeing industry continuously transferred from east China to west China because of the lower environmental standard in western areas. These heavy polluting industries seriously destroy the environment, and brought the pollution accidents to these economically backward provinces. Taking lead pollution events as an example, the accidents occurred frequently in eastern coastal areas such as Zhejiang and Guangdong in the 1990s, but now it often happens in Shaanxi and Gansu regions mainly because of the migrating westward of heavy metal smelting industry. The lead poisoning accident of Fengxiang which occurred in Shaanxi in August 2009 is a typical case verified this tendency.

Sufficient attention should be paid to the environmental education to raise the awareness of environmental risk in western areas. Moreover, the environmental threshold of heavy pollution industries needs be lifted in these underdeveloped regions. The industries with high environmental risks and no technological transformation in eastern provinces should be prohibited transferring to the western provinces.

5.3 The analysis of the increasing tendency of accident loss

Concerning the losses of environmental accidents in China, the direct economic loss of per environmental accident shows a continuously upward tendency during the study period. The improper layout of high environmental risk enterprises and the acceleration of industrialization and urbanization probably caused this increase trend.

After the Songhua River accident, SEPA launched an environmental risk investigation of 7555 chemical and petrochemical construction projects in China. The results show that 24.9% of inspected projects are located along big rivers, lakes, coast or even in the important fishing areas; 32.4% are scattered in densely populated regions or around a metropolis; 3.7% are distributed in the upper reaches of drinking water source protection areas, 1.3% are along the South-to-North water diversion projects, and 1.1% are in Three-Gorges Reservoir area [32]. It is no doubt that the irrational chemical and petrochemical industry distribution in China is a huge hidden danger to damage the ecology and social-economic conditions. One ordinary pollution event in chemical and petrochemical industry could threaten a whole city or the entire basin, and even cause ecological disaster and trans-provincial pollution. More importantly, China is now at a stage of rapid economic and urbanization development, so the noticeable increases in population and economic density exacerbate the rising of economic loss per environmental accident.

Focusing on the improper industrial layout in China, it is necessary to carry out the environmental risk assessment prior to the approval and construction of industrial sites, especially in environmentally sensitive areas. Moreover, the inspection frequency of environmental risk sources located at coastal areas, nature reserves and densely-populated regions ought to be increased, and the coordinated emergency response of the whole region and entire basin also needs to be promoted. In addition, the advanced environmental monitoring and early-warning system of pollution accidents in the ecological sensitive areas should be reinforced.

6 Conclusions

The tendency of environmental accidents in China was explored using the available statistical data from 1990 to 2007. As shown by the results, the temporal trend of the environmental accidents exhibited a continued reduction with respect to its quantity, which can largely be attributed to enhanced environmental risk management strategy, strict control of dangerous chemicals and effective staff training. Moreover, the strengthening of environmental supervision capacity in industrial pollution also greatly reduced the environmental accidents in China. As to the spatial distribution of environmental accidents in China, the extraordinarily severe accidents tended to increase in the western regions. The development of high environmental risk enterprises in these provinces after 2000 certainly influenced this transfer tendency. Contrary to the noticeable decrease in environmental accident amount, the direct economic loss per pollution accident experienced an overall increasing tendency. The irrational industrial distribution, particularly the irrational layout of chemical and petrochemical enterprises, was responsible for the rising trend.

Nevertheless, facing the challenges of pollution accidents, China consistently seeks to enhance the support capability of science and technology for preventing environmental emergencies. A few environmental research programs have been implemented in last few years to monitor and control sudden pollution accidents. The project of identification and monitoring technology for the environmental risk sources is one of the State High-Tech Research and Development Plans (863) funded by the Ministry of Science and Technology in 2007, which provides the technical support to forbid the significant environmental pollution accidents. Besides, during the twelfth five-year plan (2010–2015), in-depth research of environmental risk management systems including the environmental risk prevention, environmental emergency monitoring and emergency response will also be conducted by the Ministry of Environmental Protection. All these research projects may have profound influence on preventing the environmental accidents in China.

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Appendix

An accident with any of the consequences as described in Level I is defined as the extraordinarily severe accident.

- Extraordinarily severe environmental accident (Level I)

1) Injury to persons and damage to economy
—causality of 30 persons deaths or serious injury to more than 100 persons,
—the evacuation of persons of at least 50 thousand,
—direct loss to economy of at least 10 million Yuan (an Approximate exchange rate is 1USD = 8CNY).
2) Immediate damage to the environment
—significant pollution to an aquifer or underground water in important cities,
—serious damage to ecological function or serious pollution to the habitat of endangered species.
3) Radiation pollution
—large scale radiation pollution caused by radioactive sources of category 1 and category 2,

An accident with any of the consequences as described in levelIIis defined as the severe accident.

- Severe accident (Level II)

1) Injury to persons and damage to economy
—causality of more than ten but below 29 persons deaths or serious injury to more than 50 but less than 100 persons,
—the evacuation of persons more than ten thousand but below 50 thousand.
2) Immediate damage to the environment
—significant pollution to the major water body or the interruption of drinking water at and above the county level,
—damage to ecological function or pollution to the habitat of endangered species.

An accident with any of the consequences as described in level III is defined as the major accident.

- Major accident (Level III)

1) Injury to persons and damage to economy
—causality of three to nine deaths or serious injury to less than 50 persons,
—any pollution accident with serious social and economic effects beyond administrative region.
2) Radiation pollution
—radioactive sources of category 3 lost/stolen

An accident with any of the consequences as described in level IV is defined as the general accident.

- General accident (Level IV)

1) Injury to persons and damage to economy
—causality of less than two deaths
2) Radiation pollution
—radioactive sources of category 4 and category 5 lost/stolen