# Title: Environmental incidents in China: lessons from 2006 to 2015

**Authors:** Guozhi Cao[a, b], Lei Yang[a], Lingxuan Liu[c], Zongwei Ma[a,*], Jinnan Wang[a, b,*], Jun Bi[a]

## Affiliations:

a State Key Laboratory of Pollution Control & Resource Reuse, School of the Environment, Nanjing University, Nanjing, China

b State Environmental Protection Key Laboratory of Environmental Planning and Policy Simulation, Chinese Academy for Environmental Planning, Beijing, China

C Lancaster University Management School, Lancaster, United Kingdom

## * Corresponding Authors:

Zongwei Ma

Tel.: 86-25-89681526, Fax: 86-25-89680586.

Address: Nanjing University Xianlin Campus, 163 Xianlin Avenue, Nanjing 210023, China

E-mail: njumazw@163.com

Jinnan Wang

Tel.: 86-10-84910681, Fax: 86-10-84918581

Address: Chinese Academy for Environmental Planning, 8 Dayangfang, Beiyuan Road, Chaoyang District, Beijing 100012, China

E-mail: wangjn@caep.org.cn

# ABSTRACT

Environmental incidents are among the most significant environmental challenges in China. Hundreds of environmental incidents occur every year, endangering human health and ecosystems. In this paper, we conducted an analytical study of environmental incidents from 2006 to 2015 in China. We first examined the spatiotemporal characteristics of the total 5,213 incidents based on the statistical data collected from the *China Statistical Yearbook on Environment*. We then examined the characteristics of the sources of risk, causes of harm and resulting damage of environmental incidents based on first-hand data from 1,369 cases collected by the Ministry of Environmental Protection (MEP) of China, which obtains detailed incident information. The results show that (1) there is a significant downward trend in the overall number of environmental incidents between 2006 and 2015, and developed eastern regions were high incidence areas; (2) hazardous chemicals were the main risk stressors; (3) production safety accidents and traffic accidents were the two major causes, and (4) most of these incidents resulted in polluted water and air. This paper is the first to provide a longitudinal analysis of the full scope of environmental incidents across the different regions of China, which has useful implications for policy-making and environmental management.



**Keywords:** Environmental incidents; Spatiotemporal characteristics; Types of risk sources; Causes of incidents; Damage of incidents

# 1. Introduction

With an increase in the social productivity, industrialization has been accelerating in China since the Reform and Opening Up Policy in 1978. Accompanying the rapid economic growth are environmental issues, and continuous occurring environmental incidents have gradually become one of the most serious environmental problems in China in recent decades. Tens of hundreds of environmental incidents have occurred in China each year, which have increasingly raised the concerns of both the Chinese Government and the public (Wan, 2006).

Environmental incidents are incidents during which toxic and harmful substances enter into the air, water, soil, and other environmental media as a result of pollutant discharges, natural disasters, production safety accidents and other problems, causing a sudden decline in environmental quality. These incidents endanger human health and property security, or damage the ecological systems, or seriously disrupt social stability, therefore emergency actions are always required (General Office of the State Council, 2014). An environmental incident is always accidental, it occurs very quickly and is of great uncontrollability, posing great risks to the environment, production and social life (Wiens and Parker, 1995). Generally, air, water, soil, radiation and other types of environmental pollution are involved in these incidents (General Office of the State Council, 2014; United Nations Environment Programme(UNEP), 2012).

Since China's 11th Five-year Plan period (covering the years 2006-2010), a series of legal, planning, and policy measures regarding the coordination of risk prevention and emergency response for environmental incidents were undertaken (Zhang et al., 2017). The goal that "environmental risk shall be effectively controlled by 2020" was proposed in China's 13th Five-year Plan for Ecological and Environmental Protection (Ministry of Environmental Protection(MEP), 2016). However, the problem is still in sharp focus due to its high occurrence

66 rate and serious negative effect. To prevent and control these environmental incidents more
67 effectively, a comprehensive assessment, supervision and management system in China is
68 urgently called for. In order to achieve that goal, the underlying premise is to accurately
69 understand the situation regarding China's environmental emergencies. In this context, this paper
70 aims to explore the current situation of China's environmental incidents.
71 Analyses of the characteristics of environmental incidents is of great significance to
72 environmental risk management. Such studies can help both authorities and the public to
73 understand and handle these incidents more comprehensively. They lay the basis for further
74 decision-making and the construction of incident prevention and control systems. In recent years,
75 a number of studies which focused on this issue have been conducted. All these studies have
76 enhanced our understanding of the nature of the problems related to environmental incidents. In
77 particular, statistical methods have been widely employed in these studies (Glickman and
78 Golding, 1992; Shin, 2013; Uth, 1999).With regard to China's environmental incidents, these
79 studies have mainly concentrated on the analysis of characteristics (Ding et al., 2015; Hou and
80 Zhang, 2009; Lu et al., 2012; Yao et al., 2016), the evaluation of damage loss (Li et al., 2008;
81 Xue and Zeng, 2011) as well as the evaluation of influencing factors (Li et al., 2008; Yang et al.,
82 2013) based on the public statistics. Some studies have focused on a specific type of material or
83 sector, such as industrial incidents (Chan et al., 2015; Wei and Lu, 2015), hazardous chemical
84 incidents (Duan et al., 2011; He et al., 2011; Zhang and Zheng, 2012), and traffic incidents
85 (Yang et al., 2010). Other scholars have examined the overall characteristics and trends (Ding et
86 al., 2015; Lu et al., 2012). Some studies focused on a typical or widely concerned case (Tang and
87 Jiang, 2013; the State Council, 2016).A part of these studies concerned environmental incidents
88 but only featured small proportions of the cases in China due to the small amount of available

89 case data (Hou and Zhang, 2009). Moreover, data regarding environmental incidents in existing
90 studies were mostly collected from journals, reports, news and other public sources of
91 information because additional information was confidential or missing, which might lead to a
92 problem of uncertainty and inaccuracy of these results.

93 Another shortage is that all the existing analyses were conducted beyond the basic theory of
94 environmental risk system and the theory of the whole process of environmental risk. According
95 to the theory of environmental risk system, environmental risk is typically described as an event
96 in which damage to human health and the environment is caused by natural disasters or human
97 activities; the term "risk" is generally defined as the product of frequency and its consequence
98 (Bi et al., 2006). From this point of view, environmental incidents are indeed a form of
99 environmental risk, so they can be analyzed and studied by using the theory of environmental
100 risk system and the whole process of environmental risk. In general, a single environmental risk
101 system includes 3 interrelated elements: risk source(s), risk control mechanism and risk
102 receptor(s). The specific process of an environmental risk event (or incident) mainly follows four
103 stages: (a) generation of the source(s) of risk, (b) release of risk factor(s) from the risk source(s),
104 (c) translocation of risk factor(s) and finally, (d) exposure and impacts on risk receptor(s). It is
105 crucial to identify the weak links among the whole process in the field of further risk prevention,
106 so the theory of environmental risk system should be considered and applied during the entire
107 management process. Detailed information about the theory environmental risk system can be
108 found elsewhere (Bi et al., 2015).

109 As mentioned above, for the existing studies, it is difficult to truly and fully reflect the
110 characteristics of environmental emergencies in China. The general characteristics of these
111 incidents cannot be well recognized without the perspective of risk system and whole process of

environmental risk. What is the current situation of environmental incidents in China actually like? By the use of more detailed case data from the MEP, we conduct an analytical examination of the environmental incidents that occurred from 2006 to 2015 based on the theory of risk system and whole process of environmental risk to accurately and comprehensively answer the following research questions (RQ):

RQ1: What are the spatiotemporal characteristics of China's environmental incidents?

RQ2: What are the characteristics of the sources of risk, the causes of harm, and the resulting damages of these incidents based on the theory of environmental risk system?

## 2. Data and Methods

### *2.1. Data collection*

Environmental incident data were collected from two sources. First, we collected the general statistical data regarding environmental incidents that occurred from 2006 to 2015 from the *China Statistical Yearbook on Environment* (National Bureau of Statistics(NBS) and Ministry of Environmental Protection(MEP), 2007-2016). Second, we collected first-hand data regarding the environmental incidents handled by the MEP of China from the Chinese Academy for Environmental Planning, in which contains detailed incident information (e.g., time, location, source, cause, main pollutants, and means of disposal). These data were summarized from information collected during the MEP's handling of an incident from its occurrence to the emergency response. It should be noted that Hong Kong, Macao, and Taiwan were not included in analysis due to the lack of data.

After collection, two sets of data with different levels of accuracy regarding the environmental incidents are finally used to analyze the general characteristics of these incidents in China. The first dataset contains general statistical information about 5,213 environmental

incidents that occurred during the 2006-2015 period. These incidents are total the environmental incidents that recorded by MEP in the study period. Of the 5,213 incidents, there is detailed information for the 1,369 incidents that the MEP was involved in handling; information with regard to this group of incidents formed our second dataset.

### *2.2. Data analysis*

To understand the general circumstances of the environmental incidents, the 2 datasets were used to analyze the spatiotemporal characteristics of these incidents at different scales. As environmental incidents are actually outbreaks of sudden environmental risk events (Lu et al., 2012), we conducted a descriptive analysis regarding the sources of risk, causes of harm and resulting damages in each event based on the theory of environmental risk system based on information from the MEP-handled incidents. Descriptive analysis includes the description of the absolute value of the number of incidents and the percentage of each category of incidents. In this method, the probability of the occurrence of an environmental incident is defined as the number of ways an incident occurs divided by the total number of all observed results (Yang et al., 2010). In addition, the spatial characteristics of environmental incidents are demonstrated by the use of software ArcMap 10.3.

## 3. Results and Discussion

### *3.1. Spatiotemporal characteristics of incidents*

A total number of 5,213 environmental incidents occurred in China between 2006 and 2015, with an annual average over 500. Overall, the quantity of environmental incidents presented a downward trend (Fig.1): In2015, there were 330 incidents in total, the incidence number has decreased by 512 when compared with the 812 incidents occurred in 2006. During the 12th Five-year Plan period (2011-2015), the annual number of incidents also decreased year by year,

except for the abnormal increase in number to 712 in 2013. However, despite a significant drop in the annual number of environmental incidents during the study decade, the incidence remained relatively high in 2015 in terms of absolute numbers. From 2006 to 2015, on average, an incident occurred each day, and more than 10 incidents occurred in each province each year.

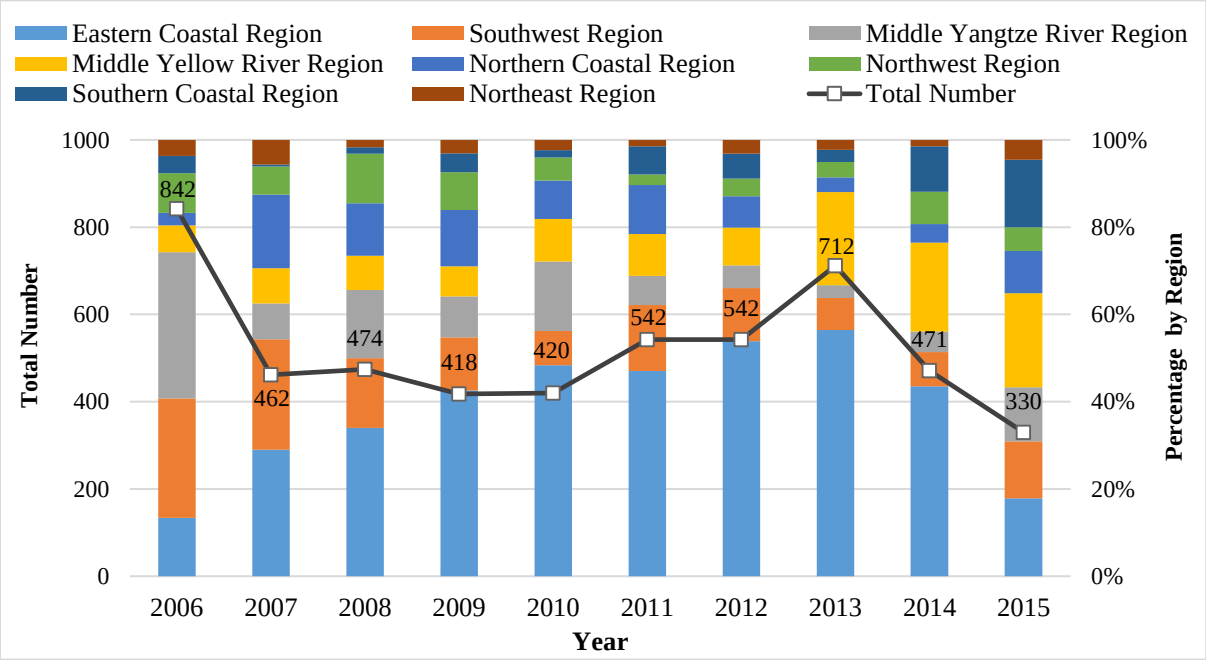



**Fig.1 Quantity and regional distribution of annual environmental incidents from 2005-2016.**

To examine the spatiotemporal distribution of 5,213 environmental incidents, all provinces and municipalities were divided into 8 regions according to their geographical locations and socioeconomic conditions (details in Appendix Fig.S1). With regard to the regional distribution of incidents, in terms of quantity, Eastern Coastal Region, Southwest Region and Middle Yangtze River Region are the top 3 regions with largest incidences, there were 2002, 787 and 648 environmental incidents in these regions respectively.

In 2006, 282 environmental incidents happened in Middle Yangtze River Region, accounted for 33.5% and ranked 1st among all 8 regions, while the incidence decreased gradually and only

contributed 12.4% in 2015. Conversely, the percentage of incidents occurred in the Middle Yellow River Region of China continued to increase and accounted for nearly a quarter (21.5%) of all incidents in 2015. Among all 8 regions, Eastern Coastal Region shared a large portion of the total number of incidents (with a yearly average 38.4%) during 2006-2015; a total number of 2,002 incidents occurred in this region during the 10-year period. Based on detailed provincial information (Fig.2), it is seen that Shanghai, Zhejiang, and Jiangsu also rank the top three of all 31 provinces and municipalities, which is consistent with the regional distribution. During 2006-2015, 1209 incidents occurred in Shanghai, which is nearly 3 times the number in Zhejiang. When considering the 1,369 MEP-handled cases only, Zhejiang, Guangdong and Jiangsu provinces ranked as the top three with more than 100 environmental incidents in each province.

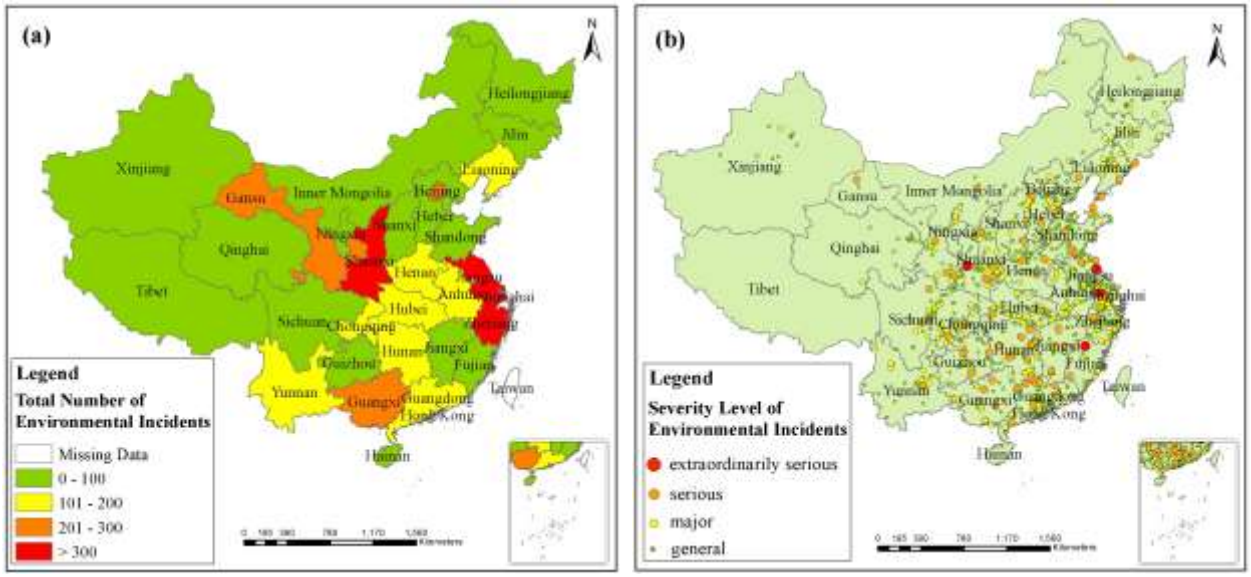



**Fig.2 Spatial distribution of environmental incidents from 2006-2015. (a) Provincial distribution of the total environmental incidents; (b) Spatial distribution of the 1,369 cases handled by the MEP**

Generally, environmental incidents occurred more often in southern regions than northern China, especially in more developed coastal regions or provinces with traditional heavy industries. It is worthwhile to notice that developed eastern regions were high incidence areas.

Enormous social and economic disparity in different regions of China is a long-standing

problem, despite the high rate of economic growth. The number and distribution of local industries and the business management level are two important factors of environmental incidents' frequency. Some regions prone to environmental incidents are places with a larger number of and a greater scale operating industries and enterprises. For example, the Eastern Coastal Region (also called Yangtze River Delta, including Shanghai, Zhejiang, and Jiangsu) is one of the most economically developed regions of China; the total GDP of this region accounted for more than one-fifth of the national's total. The region has a large number of industrial enterprises of various sectors which account for 26% of the nation's total (National Bureau of Statistics(NBS), 2016). All industries are of good development including chemical relating manufacturing industries. In addition, because of the dense river networks and high population density, it carries a relatively higher risk of environmental incidents with well-developed transportation system. Environmental incidents occurred more frequently there than in other regions, as shown in Fig.2. Nonetheless, although the largest number of incidents were found in Shanghai, the overall impacts were relatively small: of the 1,209 incidents, 1,205 incidents were classified as level IV (see Appendix Table S1) from 2006-2015; the remained 4 incidents are classified Level III, this can be explained by greater environmental awareness and relatively high level of emergency response management in Shanghai. Environmental incidents there were reported and handled at the first time and all the cases, even those in small severity, were well recorded. Shaanxi ranked in the middle position in terms of economic development and the number of industrial enterprises. However, it ranked 4th nationwide in consideration of the number of environmental incidents. Metallurgy, chemical, and utility power industries are among its core sectors, coupled with a relatively low risk management level. In addition, in industrially underdeveloped regions, such as Tibet, Hainan, and Ningxia, industries need to be

214 further developed so the fewest environmental incidents were recorded.

215 It is worthwhile to note that the most serious incidents occurred mainly in the central and
216 western regions rather than in developed southeastern China. Guizhou ranked 1st with 9 level I
217 and level II cases, followed by Hunan with 8 cases (Appendix Fig.S2). In these regions, heavy
218 and traditional industries, such as mining, metal smelting and processing, with distinct
219 competitive advantages, have occupied an important position because of rich natural resources,
220 and local management mechanisms are usually insufficient, which potentially leads to higher
221 environmental risks. Additionally, considering the way of data collecting: these statistical data
222 regarding China's environmental incidents were obtained from information reported in a bottom-
223 up way by the local governments, the large number of environmental incidents in Shanghai and
224 other places may be due to greater environmental awareness among the public and the
225 government as well as a relatively more accurate environmental statistical system in these places,
226 a relatively small incidents can be well recorded and handled at the first time.

227 *3.2. Types and sectors of risk sources*

228 In China, environmental incidents have caused complex and extensive pollution. Pollutants
229 come in different types and are associate with a variety of industries. When considering the
230 different risk stressors (pollutants) in the 1,369 environmental incidents, 7 types of pollutants
231 with different chemical properties were mainly involved: (a) oils, (b) heavy metals, (c) hazardous
232 chemicals, (d) hazardous wastes, (e) POPs, (f) no specific pollutants, and (g) others. These
233 stressors are classified based on their properties and specific damage to human beings and the
234 environment. Hazardous chemicals (benzene, ethylene, etc.) were the main risk stressors of 614
235 of the 1,369 incidents, which accounted for 44.9% in total. The proportions of incidents
236 associated with oils, hazardous wastes, heavy metals, and POPs are 14.0% (192 incidents), 8.5%

(116 incidents), 7.6% (104 incidents), and 1.5% (20 incidents) the total incidents, respectively. For 12 incidents, a lack of specific pollutants meant the incidents were mainly classified as mass turbulences. Due to the presence of other or uncertain pollutants, 311 incidents were classified as others (Fig.3(a)).

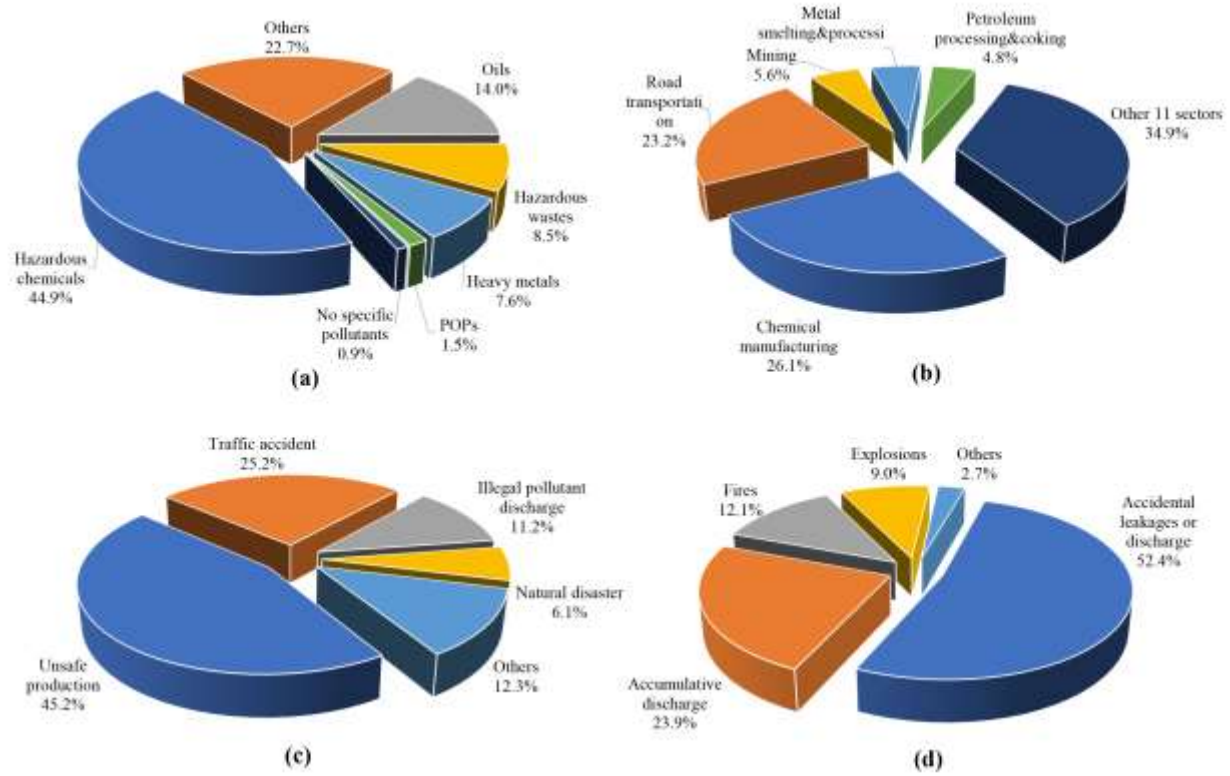



**Fig.3 Types of risk sources (a), types of sectors (b), causes of incidents (c), and methods of releasing risk stressors (d)**

Different types of industrial sectors involved in environmental incidents were screened out due to the *Classification and Code Standard of National Economy Sectors in China (GB/T 4754-2011)*. Fig.3(b) shows that chemicals manufacturing, road transportation, mining, metal smelting and processing, petroleum processing and coking (and nuclear fuel processing) ranked top the 5 among the 16 sectors, which account for 65.1% of all the incidents. Both chemicals manufacturing and road transportation were identified as high-risk industries with more than 300

related incidents respectively, which was consistent with the current research focus (Wu et al., 2011; Yang et al., 2010).

Closer analysis shows that hazardous chemicals are most risk stressors of incidents in chemical manufacturing and road transportation sectors. In mining, metal smelting&prcessing and petroleum processing&coking industries, hazardous wastes, heavy metals and oils are respectively main stressors, which accords with their individual industry characteristics (Appendix Table S2). The occurrences of incidents in the industries relevant to chemicals, such as chemical raw materials and products manufacturing and road transportation of chemicals, is far greater than in other sectors. In addition, the chemicals, especially hazardous chemicals, are the most common types of risk stressors or pollutants in China's environmental incidents. This is possibly attributable to two reasons. First, China, next only to the United States, has already become the world's second largest producer and consumer of hazardous chemicals, using and producing large amounts of a wide variety of chemical substances. Currently, 2,828 types of hazardous chemicals are being produced and consumed in China (State Administration of Work Safety, 2015). These chemicals are industrial necessities but are also high-risk threats to the environment. During the whole industrial process (i.e., production, storage, transportation, waste disposal, and other links) relevant to such hazardous chemicals, the potential fires, explosions, leakages, and even a low-level pollutant discharge tend to trigger an environmental incident if there exists any insufficiency in the field of management. Second, the growing number of industries and enterprises also causes problems to the risk management of chemicals in industrial areas. The current level of management is incompatible with production level. Current measures to prevent environmental incidents from all risk sources are not systematic and effective enough, and the government generally pays more attention on post-event contingency emergency.

Therefore, a more comprehensive system of environmental incidents is undoubtedly urgent, especially in the chemical related industries.

### *3.3. Causes of incidents*

In China, there is a 4-type classification for environmental incidents based on the different causes, these are (a) production safety accidents (e.g., sudden fires, explosions, and leakages during various production activities), (b) traffic accidents, (c) accidents caused by illegal pollutant discharge (sudden or cumulative illegal discharge of pollutants by enterprises), and (d) natural disasters and other factors (such as floods, typhoons, and earthquakes, as well as rumors about incidents). As shown in Fig.3(c), 45.2% of the 1,369 events were connected with production safety accidents and 25.2% were due to traffic accidents. These two kinds of incidents occurred most in the chemical and road transportation sectors (Appendix Table S2). In addition, 6.1%, 12.3% and 11.2% of all these events were caused by pollutant discharge, natural disasters and other factors respectively. It is noted that accidents caused by illegal pollutant discharge were always due to the undue acts of chemical and metal manufacturing sectors(Appendix Table S2). Of these 1,369 environmental incidents, 1,120 incidents occurred due to mismanagement, improper operation, ineffective prevention and careless inspection, especially in chemical manufacturing and road transportation sectors(Appendix Table S2), implying the systems of management, training and safety operation of these industries are not sound enough. 177 incidents were linked to undue irregularities and illegalities, which always occurred in chemical and metal manufacturing sectors. It reveals some defectiveness in China's current regulations and actions and which also means further improvements and progress can be made. Only 72 incidents were classified as being caused by external causes, such as natural factors and weather conditions, for example, typhoons. In a word, environmental incidents in

296 China were generally caused by human factors.

297 When examining the method of release of stressors (pollutants) during these incidents, 4
298 main pathways are considered: (a) fires, (b) explosions, (c) accidental leakages or discharges,
299 and (d) cumulative discharge. As shown in Fig.3(d), accidental leakages or discharges were the
300 main release pathway for 717 incidents, accounting for 52.4% of the total number of incidents. It
301 is also the main releasing way of pollutants in almost all sectors(Appendix Table S2), the number
302 of incidents of pollutants released by cumulative discharge, fires, and explosions were 327
303 (23.9%), 165 (12.1%), and 123 (9.0%), respectively.

304 The results show that two types of incidents stand out, namely, unsafe production accidents
305 and traffic accidents. When the reasons are considered, we can conclude that the majority of
306 environmental incidents occurred because of mismanagement and undue irregularities and
307 illegalities, which can always lead to accidental pollutant discharges and leakages, or other
308 releasing ways of pollutant in environmental incidents. China has a large number of industrial
309 enterprises engaged in high-risk sectors including petrochemical engineering, chemical
310 engineering, as well as mining. During the entire process of production, by their nature, small
311 faults in these industries can result in large consequences. Factors such as violations of operating
312 specifications and equipment failures may lead to production safety accidents (Wu et al., 2011),
313 which further lead to environmental incidents (Duan et al., 2011). Therefore, well-trained
314 workers and machine operators are necessarily required, however, in China, these occupational
315 groups are usually less well educated. In addition, in China, a large volume of chemicals,
316 matching the large number of industrial sectors, is transported by road. Each year, more than 300
317 million tons of hazardous chemicals are transported by road, accounting for over 30% of the
318 annual freight tonnages and presenting an increasing trend (Federation of Logistics &

Purchasing, 2015). Traffic accidents occur frequently due to weary drivers, speeding and other human errors. Possible traffic accidents may damage the containers and therefore lead to the leakage of gases or liquids during material transport. In addition, the supervision of high-risk industrial enterprises is relatively weak, and enterprises also have a poor awareness of production safety and environment protection standards; there are always cases of deliberate pollutant discharge being discovered.

### *3.4. Damage caused by incidents*

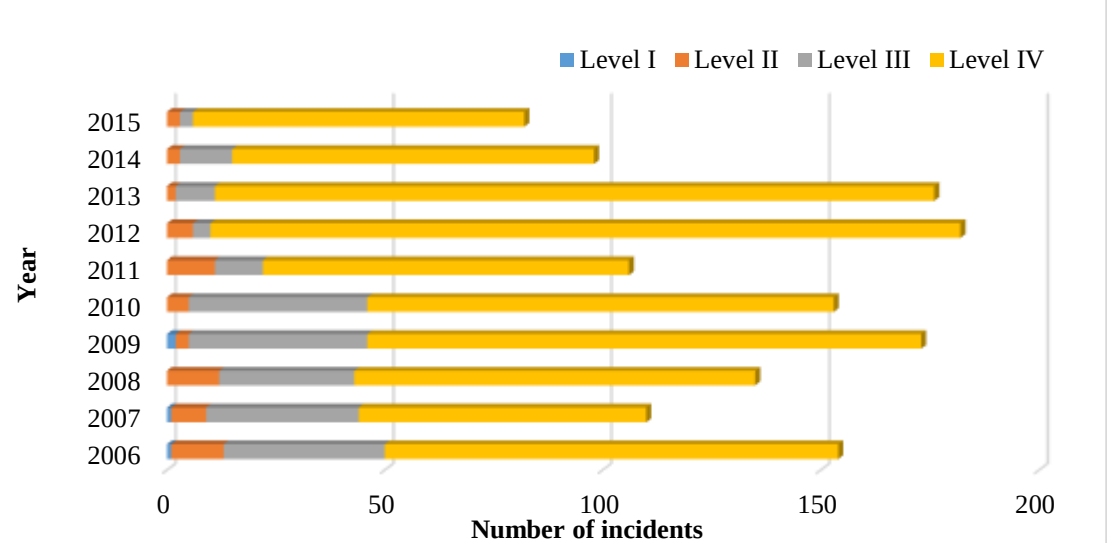
The pollutants released during environmental incidents are transmitted into the environment through different media such as water, air and soil, which directly causes water pollution, air pollution, soil pollution, and others. Four types of damage were considered: (a) water pollution, (b) air pollution, (c) soil pollution and (d) others (e.g. noise, etc.). Besides, there were several incidents unrelated to specific media, such as the environmental mass disturbances that occurred in 2012 in Shifang County (in Sichuan Province) and Qidong City (in Jiangsu Province) (Zhu and Lin, 2013). Results can be seen in Table 1.

**Table 1 Contaminated media due to environmental incidents**

| Contaminated media | | Numbers of incidents | Percentage of total incidents (%) | Accumulated Percentage of total incidents (%) |
|---|---|---|---|---|
| No contaminated media | | 3 | 0.22% | 0.22% |
| Single media | Water | 604 | 44.12% | 44.34% |
| | Air | 519 | 37.91% | 82.25% |
| | Soil | 19 | 1.39% | 83.64% |
| | Others(Noise, etc) | 4 | 0.29% | 83.93% |
| Multiple medium | Water&Air | 114 | 8.33% | 92.26% |
| | Water&Soil | 52 | 3.80% | 96.06% |
| | Air&Soil | 16 | 1.17% | 97.22% |
| | Air&Noise | 1 | 0.07% | 97.30% |
| | Water&Air&Soil | 37 | 2.70% | 100.00% |

83.93% of these incidents polluted only a single environmental media. Water and air

pollution due to environmental incidents happened at most, and there were multi-media pollutions due to the contamination of multiple media such as the 37 incidents associated with water, air and soil pollution (Table 1). As to different sectors, air pollution happened most in chemical manufacturing, metal smelting&processing and petroleum processing&coking industries. Incidents of road transportation and mining sectors usually lead to water contamination (Appendix Table S2).




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| Level I | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Level II | 12 | 8 | 12 | 3 | 5 | 11 | 6 | 2 | 3 | 3 |
| Level III | 37 | 35 | 31 | 41 | 41 | 11 | 4 | 9 | 12 | 3 |
| Level IV | 104 | 66 | 92 | 127 | 107 | 84 | 172 | 165 | 83 | 76 |

**Fig.4 Yearly distribution of 1,369 environmental incidents based on level of severity.**

According to *the National Contingency Plan of Environmental Incidents (Document No.119)* published by the State Council of China in 2014 (General Office of the State Council, 2014), environmental incidents are generally divided into four levels based on different criteria (deaths, injuries, and direct economic losses) of severity (Appendix Table S1). During the 2006-2015 period, 69 environmental incidents were classified as level I and level II (Fig.4), which

included a total of 4 extraordinarily serious incidents (level I) that occurred primarily during the former 11th Five-year Plan period (2006-2010): 1 in 2006, 1 in 2007, and 2 in 2009. Level II incidents occurred 6.5 times each year on average, causing tens of millions of dollars in economic loss and serious harmful social impacts, although this presented a declining trend in the number of incidents over these 10 years. The majority of incidents were classified as level III and level IV. Despite relatively small impacts, the high incidence rate of small incidents also led to non-negligible environmental risks. Generally, the number of level I - level III incidents decreased gradually; level IV incidence presented a fluctuating trend, implying the severity of environmental incidents have reduced in China recently (Fig.4).

### *3.5. Discussion*

Since the significant water pollution accident on the Songhua River in northeastern China in 2005, China has gradually increased its support for efforts in environmental risk prevention and response to environmental incidents (Chan et al., 2015). Much progress has been made: *The Emergency Response Law of China* was enacted, and amendments related to risk prevention and emergency management were already added to the *Environmental Protection Law of China* and the *Law of Atmospheric Pollution Prevention and Control of China*. Additionally, environmental risk prevention was established as one of the environmental priorities for China's 12th and 13th Five-year Plans. Detailed regulations and guidelines about environmental emergency management have gradually been published.

Our study period exactly corresponds to the period of China's 11th and 12th Five-year Plans. Due to the development and implementation of all these policies and measures, the total number of environmental incidents in China has decreased notably over the studied decade, 2006-2015, when compared with previous studies: There were 35,737 environmental incidents in

372 total from 1990-2007 (Xue and Zeng, 2011) and 13,060 from 2000-2009 (Lu et al., 2012).
373 Additionally, the number of incidents of great severity (levels I and II) has declined. The decline
374 in the number of incidents is mostly attributed to the increasing awareness of prevention
375 measures against environmental risks, yet these incidents are still considerable in number: a total
376 number of 2,616 incidents occurred from 2006-2010 and 2,597 incidents in 2011-2015.
377 Despite China's intensive efforts in environmental protection and regulation, enterprises'
378 awareness of the need to fulfill their environmental responsibilities and the government's
379 oversight capacity fail to match the current environmental risk level. The attitudes, available
380 resources, and organizational capacities vary among environmental agencies (He et al., 2013). As
381 a consequence, frequent environmental incidents occurred in the wake of production safety
382 incidents such as sudden fires, explosions, and leakages. Some environmental incidents were
383 even caused by enterprises' illegal pollutant or hazardous waste discharges. The outbreak of
384 "historical legacies" is another reason. Longstanding, extensive, unregulated industrial activities
385 were pervasive in previous decades (e.g., large-scale mining, beneficiation and the smelting of
386 nonferrous metal deposits) and have resulted in serious heavy metals contamination in many
387 areas, which when coupled with natural disasters such as floods, cumulative water pollution and
388 soil pollution, will lead to the sudden occurrence of environmental incidents that affect a wide
389 area.
390 It should be noted that despite the decreasing trend in environmental incidents in the recent
391 decade, the public demand for improved environmental safety continues to increase (Wen et al.,
392 2017). The conflict between the public demand and the actual level of environmental risk is
393 increasing. Moreover, detailed information regarding environmental incidents is still of a low
394 public availability in China. Inaccurate perceptions and understandings may lead to sharp

conflicts between the rising public awareness of the need for environmental protection and the conditions leading to environmental incidents in recent years. Limited information disclosure by the government has sparked the Not In My Backyard (NIMB) effect (Guo et al., 2015), engendering environmental mass disturbances. These incidents always cause large losses and negative effects and do harm to the development of environmental management (Zhu and Lin, 2013). More efforts in the control of environmental incidents are needed to meet the rising public demand.

In one of our previous reports, we have preliminarily analyzed the characteristics of the environmental incidents in China using data mainly collected from the news report and the Internet(Bi et al., 2015). Compared to this report, the present study has two major contributions in the field of environmental risk study in China. Firstly, we conducted analysis based on internal data instead of the general statistics or information collected from the Internet used in previous studies. By the use of first-hand data, more accurate information is provided for further analysis. Secondly, we analyzed the features of risk sources, causes and damage of these environmental incidents based on the theory of environmental risk system, which haven't been seen in existing studies. It can help us identify the weak links of the whole environmental risk system in China.

## 4. Conclusions

Based on the analysis of the spatiotemporal characteristics of 5,213 environmental incidents, a significant downward trend in overall quantity is shown from 2006 to 2015. On average, more than 500 incidents occurred each year during the study period. These incidents were mostly concentrated in the relatively industrially developed eastern regions of China, particularly the Yangtze River Delta. The results of the analysis of the sources of risks, causes of harm and resulting damages of 1,369 incidents show that hazardous chemicals were the main

risk stressors, corresponding to highest incidence of incidents in the chemical-related sectors. Production safety accidents and traffic accidents are two leading causes in greatest number of environmental incidents. The primary cause of these incidents is rooted in human factors such as mismanagement, irregularities and illegalities. Generally, accidental leakages or discharges were the main release pathway for pollutants. Most of these incidents polluted the water and air as a consequence.

Overall, the severity of the environmental incident situation has been reduced during the study decade. Despite intensive efforts in environmental protection and regulation, enterprises' awareness of environment protection and the current mechanisms for risk prevention and control need to be improved to keep up with China's wide public concern regarding environmental incidents and the rising public demand for better environmental safety levels.

**Acknowledgment:**

This work was supported by the National Natural Science Foundation of China (71433007) and the National Science and Technology Support Program (2015BAK12B02). Helpful comments from the anonymous reviewers are greatly appreciated.

## References


Bi J, Greene G, Qu J, Wang K, Wang J, Andrews S, et al. Special Policy Study Report: Eco-environmental Risk Management. China Council for International Cooperation on Environment and Development (CCICED), 2015. (in Chinese)

Bi J, Yang J, Li QL. Regional environmental risk analysis and management. Beijing: China Environmental Science Press, 2006. (in Chinese)

Chan EY, Wang Z, Mark CK, Da LS. Industrial accidents in China: risk reduction and response. Lancet 2015; 386: 1421.

Ding L, Chen KL, Liu T, Cheng SG, Wang X. Spatial-Temporal Hotspot Pattern Analysis of Provincial Environmental Pollution Incidents and Related Regional Sustainable Management in China in the Period 1995–2012. Sustainability 2015; 7: 14385-14407. (in Chinese)

Duan W, Chen G, Ye Q, Chen Q. The situation of hazardous chemical accidents in China between 2000 and 2006. Journal of Hazardous Materials 2011; 186: 1489-1494.

Federation of Logistics & Purchasing. Five major problems need to be solved in the logistics industry of hazardous chemicals, 2015. (in Chinese)

General Office of the State Council. The national contingency plan for environmental emergency, 2014. (in Chinese)

Glickman TS, Golding D. Recent trends in major natural disasters and industrial accidents. Resources(United States) 1992; 108.

Guo Y, Ru P, Su J, Anadon LD. Not in my backyard, but not far away from me: Local acceptance of wind power in China. Energy 2015; 82: 722-733.

He G, Zhang L, Lu Y, Mol AP. Managing major chemical accidents in China: towards effective risk information. Journal of Hazardous Materials 2011; 187: 171-181.

He GZ, Zhang L, Mol APJ, Lu YL. Profiling the environmental risk management of Chinese local environmental agencies. Journal of Risk Research 2013; 16: 1259-1275.

Hou Y, Zhang TZ. Evaluation of major polluting accidents in China—Results and perspectives. Journal of Hazardous Materials 2009; 168: 670-673.

Li J, Lv YL, He GZ, Wang TY, Luo W, Shi YJ. Spatial and Temporal Changes of Emerging Environmental Pollution Accidents and Impacts Factors in China. Environmental Science 2008; 29: 2684-2688. (in Chinese)

Lu J, Sun N, Xia JX, Hou GG. Analysis on Present Status and Development Trend of China's Environment Risks. Environmental Science and Management 2012; 37: 10-16. (in Chinese)

Ministry of Environmental Protection(MEP). 13th Five-year Plan for Ecological and Environmental Protection, 2016. (in Chinese)

National Bureau of Statistics(NBS). China Industry Statistical Yearbook 2016. Beijing, 2016. (in Chinese)

National Bureau of Statistics(NBS), Ministry of Environmental Protection(MEP). China Statistical Yearbook on Environment. Beijing: China Statistics Press, 2007-2016. (in Chinese)

Shin IJ. Major Industrial Accidents in Korea: The Characteristics and Implication of Statistics 1996–2011. Process Safety Progress 2013; 32: 90–95.

State Administration of Work Safety. China's Inventory of Hazardous Chemicals(2015), 2015. (in Chinese)

Tang JC, Jiang HY. Research on the Environmental Pollution Liability Compulsory Insurance in North Bay Area —Thinking based on cadmium pollution in Longjiang River. Journal of Regional Financial Research 2013: 44-49.

the State Council. The investigation report of "8.12" extraordinary serious fire and explosion accident of dangerous goods warehouse of Ruihai Company in Tianjin port, 2016. (in Chinese)

United Nations Environment Programme(UNEP). Further improvement of environmental emergency prevention, preparedness, assessment, response and mitigation, 2012.

Uth HJ. Trends in major industrial accidents in Germany. Journal of Loss Prevention in the Process Industries 1999; 12: 69-73.

Wan BT. Emergency monitoring and disposal technology of sudden environmental pollution accidents. Beijing: China Environmental Science Press, 2006. (in Chinese)

Wei J, Lu S. Investigation and penalty on major industrial accidents in China: The influence of environmental pressures. Safety Science 2015; 76: 32-41. (in Chinese)

Wen T, Wang J, Ma Z, Bi J. Driving forces behind the Chinese public's demand for improved environmental safety. Science of The Total Environment 2017; 603: 237-243.

Wiens JA, Parker KR. Analyzing the Effects of Accidental Environmental Impacts: Approaches and Assumptions. Ecological Applications 1995; 5: 1069-1083.

Wu ZZ, Zhang SZ, Zhang Y, Shi C, Liu N, Yang GL. Statistical analysis of hazardous chemicals accidents occurring in China during 2006-2010. Journal of Safety Science & Technology 2011: 5-9. (in Chinese)

Xue P, Zeng W. Trends of environmental accidents and impact factors in China. Frontiers of Environmental Science & Engineering in China 2011; 5: 266-276.

Yang J, Huang L, Li FY, Zou L, P., Fei H, X., Bi J. Decomposition analysis on the variation of China's annual environmental pollution accidents, 1991-2010. China Environmental Science 2013; 33: 931-937. (in Chinese)

Yang J, Li F, Zhou J, Zhang L, Huang L, Bi J. A survey on hazardous materials accidents during road transport in China from 2000 to 2008. Journal of Hazardous Materials 2010; 184: 647-653.

Yao H, Zhang T, Liu B, Lu F, Fang S, You Z. Analysis of Surface Water Pollution Accidents in China: Characteristics and Lessons for Risk Management. Environmental Management 2016; 57: 868-878.

Zhang HD, Zheng XP. Characteristics of hazardous chemical accidents in China: A statistical investigation. Journal of Loss Prevention in the Process Industries 2012; 25: 686-693. (in Chinese)

Zhang K, Zheng BG, Jia XF, Zhang ZJ. Research on Domestic and Foreign Environmental Risk Prevention and Emergency Management System and Development Strategies. Environmental Science and Management 2017; 42. (in Chinese)

Zhu Q, Lin Z. Analysis on the Group Incidents of Environmental Pollution Conflict. environment and sustainable development 2013; 3. (in Chinese)