Journal of Hazardous Materials 187 (2011) 171–181

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Managing major chemical accidents in China: Towards effective risk information

Guizhen He[a,*], Lei Zhang[b,c], Yonglong Lu[a], Arthur P.J. Mol[b,c]

[a] State Key Laboratory of Urban and Regional Ecology, Research Centre for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[b] School of Environment and Natural Resources, Renmin University of China, Beijing, China
[c] Environmental Policy Group, Wageningen University, Hollandseweg 1, 6706 KN, Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 16 September 2010
Received in revised form
30 December 2010
Accepted 4 January 2011
Available online 12 January 2011

Keywords:
Chemical accidents
Database
Historical analysis
China

ABSTRACT

Chemical industries, from their very inception, have been controversial due to the high risks they impose on safety of human beings and the environment. Recent decades have witnessed increasing impacts of the accelerating expansion of chemical industries and chemical accidents have become a major contributor to environmental and health risks in China. This calls for the establishment of an effective chemical risk management system, which requires reliable, accurate and comprehensive data in the first place. However, the current chemical accident-related data system is highly fragmented and incomplete, as different responsible authorities adopt different data collection standards and procedures for different purposes. In building a more comprehensive, integrated and effective information system, this article: (i) reviews and assesses the existing data sources and data management, (ii) analyzes data on 976 recorded major hazardous chemical accidents in China over the last 40 years, and (iii) identifies the improvements required for developing integrated risk management in China.

1. Introduction

Chemical industries, from their very inception, have been controversial due to the high risks they impose on the safety of human beings and the environment. In recent decades, accidents with harmful substances and hazardous chemicals have become major problems worldwide [1] and have been addressed through international agreements—such as the Rotterdam Convention (1998), the Stockholm Convention (2001), the UNEP Strategic Approach to International Chemicals Management (2006), and the EU directive on Registration, Evaluation, Authorization and Restriction of Chemicals (REACH, 2007)— national legislation and policies, and industrial management systems.

China is a major country producing and using chemicals. Over the past two decades the petrochemical industry has become one of the pillar industries of China's national economy, accounting for about 12% of the gross national industrial product in 2009 [2]. As illustrated in Fig. 1, since 2003 the gross industrial product of the petroleum and chemical industry in China has been growing at an annual average rate of 25%, much higher than the annual growth rate of the overall Chinese gross domestic product (GDP) [2,3].

Dangerous chemical accidents are broadly defined as the uncontrolled release of a significant amount of toxic, explosive or flammable materials during production, operation, storage, transportation, use and disposal of chemicals, where people, properties and/or the nearby environment are seriously affected (poisoning accidents of toxic gases and explosive accidents in mine exploitation were excluded). With the accelerating expansion of chemical industries in China, chemical accidents have become a major contributor to health and environmental risks in China [4]. In the wake of a major chemical pollution of the Songhua River, caused by a chemical explosion in November, 2005, an environmental risk review of 7555 major chemical and petrochemical plants by the Ministry of Environmental Protection (MEP) concluded that 81% of these plants are located along rivers and lakes or in densely populated areas [5]. By December 2009 the total number of medium and large scale petrochemical plants (excluding small scale ones) in China reached 34,600 [3]. Along with catastrophic natural disasters ranging from persistent draught in south-western China, an earthquake in Yushu, floods in the south, and the landslides and recent debris flow in Zhouqu, the year 2010 has been experiencing quite a number of chemical accidents. For instance, in July alone the following major chemical accidents were reported: on July 3, the acid poison of Ting River in the southern province of Fujian due to the leakage of wastewater, killing nearly two million kilograms of fish and putting local populations at severe risk; on July 16, the explosion of an oil pipeline in Dalian; on July 28, the explosion of a abandoned plastic factory in the center of Nanjing; and on July 28, 7000 barrels of two chemical plants flooded into Songhua River. The last accident reminded people of the major benzene pollution over Songhua River in 2005, although this time the barrels contained 3-methyl chloride silane and hexamethyl disilazane.

* Corresponding author.
E-mail addresses: heguizh@yahoo.com.cn (G. He), yllu@rcees.ac.cn (Y. Lu).

0304-3894/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2011.01.017

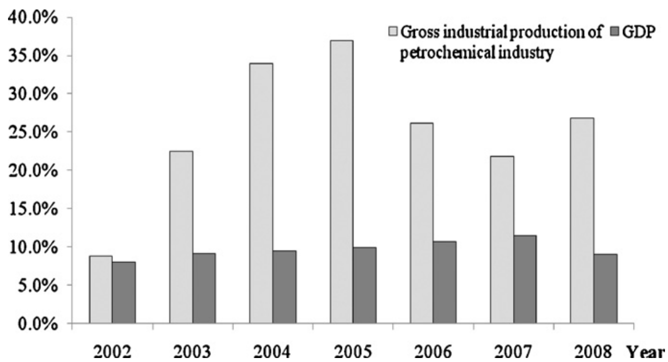

Fig. 1. Annual growth rates of gross industrial product of petrochemical industry and gross domestic product (GDP) of China from 2002 to 2008.
Data from [2,3].

Work safety management is a daily practice for chemical industries, aiming to prevent accidents from happening. In case of an accident, the response to emergencies largely determines the consequences and effects of the accidents. It is commonly observed that many serious chemical pollution accidents have been caused by inappropriate responses or delayed actions following emergencies. Although by now most petro-chemical industries have made emergency response plans, many of these plans are not put into practice. When poorly managed, work safety accidents may also have an effect beyond the industrial site and turn into secondary pollution accidents.

Increasing numbers of chemical accidents in recent years have put the issue of chemical risk management high on China's public and policy agendas [6]. A series of laws, regulations, and standards on chemical accidents has been promulgated and implemented, including the Work Safety Law of the People's Republic of China (2002), the Regulations on the Control over Safety of Dangerous Chemicals (2002), and the National Catalogue of Dangerous Substances (GB12268). However, the rising trend of chemical accidents seems hardly affected by that. In the opinion on strengthening Environmental Emergency Response Management (No. 130 of 2009), the MEP recognized the big gap between the demand for effective risk management and the actual capacity within government and industry to meet that demand. MEP has set targets for 2015 to, among others, establish a database of sources of environmental risk of major economic sectors and to realize an information-based professional environmental risk management system.

To bring chemical risks under effective control, comprehensive, standardized and geo-referenced information on chemical risks and accidents is crucial for decision-making, supervision, assessment, insurances, and management [7]. This calls for shared reliable, accurate and comprehensive data on which an effective public and private chemical risk management system can be constructed. How far is China with developing and installing such a comprehensive data system for chemical risk? This article aims to review and assess the existing data sources and data management on chemical risks in China and some other countries, to analyze data on 976 recorded major hazardous chemical accidents in China over the last 40 years, and to identify the improvements required for developing integrated chemical risk management in China.

2. International overview of chemical accident data management and reporting systems

The importance of an integrated chemical accident database has long been recognized worldwide. Chemical accident databases can serve as foundations for policy and decision making by national and international regulators, financial and insurance companies, industries and the public. It can also serve as reference and knowledge pool in responding to similar emergencies [9,10].

Internationally, industries are increasingly required to make more information available to the public and face more stringent enforcement by the authorities with respect to emergency response. The increased awareness and impetus to prevent and control major accidents involving chemicals has resulted in greater transparency and an increase in available information on chemical accidents, especially in developed countries.

Reviews of international experiences show that such databases exist in many regions and countries. Table 1 compares several major chemical accidents databases in terms of coverage and features. For example, the Major Accident Reporting System (MARS) of Major Accidents Hazard Bureau (MAHB) of the European Union is a distributed information network, consisting of 15 local databases on a MS-Windows platform in each member state of the European Union, combined with a central UNIX-based analysis system at the European Commission's Joint Research Center in Ispra, which allows complex text retrieval and pattern analysis. MARS is used by both EU and OECD member countries to report industrial accidents in the MARS standard format and to exchange accident information on this basis. As a result of an iterative process, two reporting forms have been established. Numerous guidance documents are available, as well as access to chemicals database. Currently, MARS holds data on more than 450 major accident events.

The US Accident Reporting Information System (IRIS), developed by the National Response Center (NRC) under the United States Coast Guard, includes every accident reported by formal governmental sources as well as accidents reported by others. These accidents range from an oil sheen to a major disaster that resulted in casualties. In total, companies, governmental employees and concerned citizens reported more than 605,400 accidents to the NRC over the period 1990–2009. The NRC is the only federal clearinghouse in the United States for receiving information about chemical accidents. It provides the best overall picture of security at chemical and oil facilities in the United States. Moreover, it is a user friendly interactive system, including possibilities for statistical queries, accident summary views, and on-line reporting.

The Relational Information System for Chemical Accidents Database (RISCAD) of Japan includes data on accidents caused by explosives, high pressure gas, chemical substances and chemical plants, and is maintained by the National Institute of Advanced Industrial Science and Technology (AIST). It holds chemical accident records from 1949 onward and has been updated from time to time. A main feature of RISCAD is that accident data are organized chronologically and are related to additional information such as the accident process, hazard information of related chemical substances, and the chemical production process. Searched results can be displayed as a list of accidents, including the details of the accidents, additional information, and the attributes of related substances. Additionally, the searched results can be shown as a graph on the Web browser (for instance, in relation to time or geography). In general, some databases cover accidents in specific countries such as the United States, while others cover accidents for wider geographical areas such as the EU and the world. Some of them provide information that can be used to judge the risk that a facility poses to the surrounding community and to understand the steps that can and/or need to be taken by that facility to manage risks. For several databases it is also possible to make statistical and trend analyses supporting environmental and safety management [7].

Despite considerable efforts, several deficiencies can be found regarding these data systems, among others on the number of accidents covered as well as the accuracy of the available information [11]. In addition, whenever a large amount of data is collected, there is the potential for errors. Data verification should thus be an integral part of any database, which is not always the case.

Table 1
Databases of major chemical accidents around the world.

Database name	Agency	Time coverage	Number of accidents	Area covered by data	Description
MARS	MAHB	1980 to present	450	EU and OECD countries	Distributed information network Consist of 15 local databases Standard reporting format
FACTS	TNO	From end of 1970s	21,000	Worldwide	World's most extensive database on hazardous material accidents
MHIDAS	HSE	1964 to present	11,000	Worldwide	Paid database reporting on hazardous materials accidents User friendly Submit and update the information dynamically
ERNS	EPA	1987 to present	275,000	USA	Provide the most comprehensive data compiled on notifications of oil and hazardous substance releases
APELL	UNEP	1970 to present		Worldwide	A modular, flexible methodological tool for preventing accidents
RISCAD	AIST & JST	1949–2006	4796	Japan	Link with additional information Display results in a graph
RMP*Info	EPA	1990 to present	15,430	USA	Internet-based public access system containing historical records Provide information to judge facility risks and to understand steps of risk management
IRIS	NRC	1990 to present	605,400	USA	Allow reporting of accidents online Interactive web database that allows full query of non-privacy all accidents Provide valuable overall picture of security at chemical and oil facilities

Abbreviations: Awareness and Preparedness for Emergencies at Local Level (APELL); Emergency Response Notification System (ERNS); Environmental Protection Agency (EPA); European Union (EU); Health and Safety Executive (HSE) United Kingdom; Incident Reporting Information System (IRIS); Japan Science and Technology Agency (JST); Major Accident Reporting System (MARS); Major Accidents Hazard Bureau (MAHB); Major Hazard Incident Data Service (MHIDAS); National Institute of Advanced Industrial Science and Technology (AIST); National Response Center (NRC); Netherlands Organization for Applied Scientific Research (TNO); Organization for Economic Co-operation and Development (OECD); Relational Information System for Chemical Accidents Database (RISCAD); Risk Management Plan Info (RMP*Info); United Nations Environment Program (UNEP).

Although databases vary in terms of objectives, coverage, and structure, a functional database has to reflect the following principles: comprehensive, accurate, dynamic, and standardized; feasible in development and maintenance; verifiable; and to a major extent openly accessible [12]. The ideal database on chemical accidents provides the following functional support:

- chemical accidents data storage: master data on sources and intakes, monitoring and measurement data, object relationships, addresses, personalized user data;
- chemical accidents information views: the possibility to manage user-defined objects like folders of monitoring locations, list of parameters or selectors of measurement data;
- chemical accident statistics: possibility to aggregate and interpolate measurement values, calculation of percentiles of accident times, number of deaths and injuries, economic loss, and physical damage;
- chemical accidents presentation: possibility to access or generate thematic documents like maps, diagrams or reports;
- chemical accidents decision-support: integration of additional tools for modeling, simulation or prediction, providing options, and setting priorities.

3. Existing chemical accidents databases in China

Currently, data regarding chemical accidents in China are collected and stored mainly by two departments: State Administration of Work Safety (SAWS) and MEP. SAWS is responsible for collecting and analyzing information on all industrial production accidents throughout the country and for regularly releasing data to the public. The SAWS and its affiliations, namely the China Chemical Safety Association (CCSA) and the National Registration Center for Chemicals (NRCC), own and manage three different chemical safety-related databases: the Accident Inquiry System (AIS) of SAWS, the Chemical Accident Cases (CAC) of CCSA affiliated to SAWS, and the Daily Accidents Information (DAI) of NRCC affiliated to SAWS. These three databases are publicly and freely accessible via online inquiry systems.

AIS is one of the main official databases for all types of work safety accidents in China, including coal mining safety accidents, metal and non-metal mining accidents, industrial and commercial enterprises accidents, and chemical accidents. Both CAC and DAI focus on chemical accidents taking place in different stages such as production, transportation and storage. The information included within these databases varies according to the purpose of the owner (e.g., whether the database is developed in accordance with legislative obligations, scientific research or as a means to exchange information among industries). Together these three databases cover chemical accidents throughout China with different details of description and information and different forms of reporting, containing both numerical (number of deaths/injuries, economic loss) and qualitative information (substances involved, type of process). Due to the fact that the databases get data and information from different sources, the content and form of a single accident can be different in each database. For example, when we searched with the keyword "Gan Su" in all the three databases; we found in each of the three databases information about a major explosion accident in Lanzhou Petrochemical Company; Gansu Province; but the information differed substantially from database to database. For instance; in the AIS database; information on date; deaths; and a very brief—often one line—description of the accidents is provided (Fig. 2). In the CAC database (Fig. 3); one can firstly look at the title which covers the location; type; deaths and casualties of the accidents. Then click the title and more details are provided. From the description; information is provided on the process of the accident; including the time; location; type; deaths and casualties; the

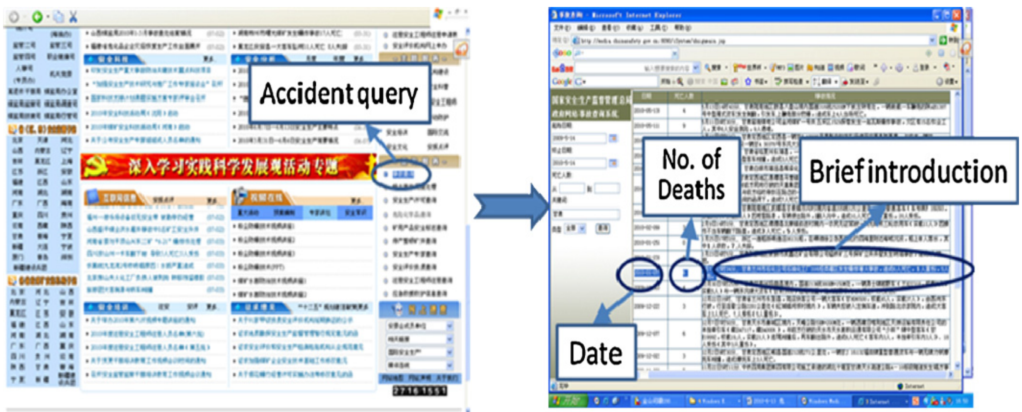

Fig. 2. The AIS database.

Fig. 3. The CAC database.

main causes; and the impacts on production processes. In the DAI database; the title and the date of the accidents are listed firstly. Subsequently; by clicking the title; more details are given. Being different from CAC; DAI presents only indirect information from news reports (Fig. 4).

MEP has one database on so-called environmental accidents. The China Environmental Yearbooks of MEP report annually only aggregate data, which are not freely accessible and originate from the local Environmental Protection Bureaus (EPBs); MEP data on environmental accidents are also not searchable online. Hence, no accident specific-data is openly available following the MEP database. Table 2 summarizes the four existing Chinese databases that include information on chemical accidents.

For work safety accident and environmental accident, the classification criteria are different. According to Regulations on the Reporting, Investigation and Disposition of Work Safety Accidents

Fig. 4. The DAI database.

Table 2
Major providers of data and information on chemical accidents in China.

Database name	Provider	Starting time	Number of accidents	Forms of presentation	Type of accident	Sources of information	Description
AIS	SAWS	July 2000	20,000	Online	All types of accidents	Local WSBs	Authority, timely, brief introduction
CAC	CCSA	January 2007	2428	Online	Chemical accidents	Other media, Association members	Indirect data, timely, more details about the accidents
DAI	NRCC, SAWS	September 2006	790	Online	Chemical accidents	Internet, newspaper, SAWS, etc.	Indirect information, not timely
Statistic	MEP	1991	32,549	Paper	Environ. accidents	Local EPBs	Only statistical data

Note: Accessed on 4 July 2010.

Table 3
Categories of the work safety accidents (1 Yuan is appr. 0.147 USD).

Level of severity of accidents	No. of deaths	No. of serious injuries	Direct economic losses (million Yuan)
I	30	100	100
II	10–29	50–99	50–99
III	3–9	10–49	10–49
IV	0–2	0–9	0–10

(2007) and Emergency Plan for Hazardous Chemicals Accidents (2006), work safety accidents are graded by four levels, based on casualties and direct economic losses (Table 3). According to Measures on the Reporting of Environmental Emergency Accidents (Trial) (MEP, 2006) [13], environmental accidents are also categorized according to four levels, based on more criteria. Before 2006, the State Environmental Protection Administration/SEPA (which became MEP in 2008) applied the Interim Measures on Reporting Environmental Pollution and Damage Accidents (SEPA, 1987) (Table 4). Thus, environmental accidents that used to be reported as major accidents may now be reported as ordinary accidents only, which partly explains the declining number of accidents reported by authorities in comparison with those before 2006. In both SAWS and MEP definitions, if an accident belongs according to one of the criteria (deaths, injuries, and direct economic losses) of level I, it is classified into level I.

SAWS and MEP use different reporting systems to collect information on chemical accidents, based on two departmental

Table 4
Classification criteria for the environmental accident in China.

Level of severity of accidents	Criteria	
	Article 5, MEP (1987)	Article 7, MEP (2006)
I	Direct economic loss: more than 100,000 Yuan A swarm of people with obviously poisoning symptom and radiating hazard; The poisoned people died; Seriously affected the social and economic activities by environmental pollution; Caused very seriously environmental damage; Hunted and felled the level I national protected wildlife.	Caused more than 30 deaths, or poisoned (serious injury) 100 people; Evacuated more than 50,000 people, or direct economic loss more than 10 million Yuan; Regional eco-function lost, or seriously polluted the endangered species' habitat; Seriously affected the social and economic activities by environmental pollution; Manmade accident caused by radioactive material, or serious radiate pollution caused by level I and level II radioactive source; Caused drinking water supply interruption because of main water source polluted by the environmental pollution in large cities; Seriously affected the production and life of public as the leakage of hazardous chemicals production and transportation; Caused cross-border environmental pollution accidents.
II	Direct economic loss: 50,000–100,000 Yuan; Personnel with poisoning symptom, radiating hazard, and possible be disabled; A swarm of people with poisoning symptom; Affected the social stability by environmental pollution; Caused seriously environmental damage; Hunted and felled the level II and III national protected wildlife.	Caused 10–30 deaths, or poisoned (serious injury) 50–100 people; Evacuated 10,000–50,000 people, affected the social and economic activities by environmental pollution; Part of regional eco-function lost, or polluted the endangered species' habitat; Level I and level II radioactive source lost, be stole and out of control; Caused large-scale pollution of main rivers, lakes, reservoirs and coastal waters, or water supply interruption in urban water sources above county level.
III	Direct economic loss: 10,000–50,000 Yuan; People with poisoning symptom; Caused the conflicts between enterprises and the public; Damaged the environment.	Caused 3–10 deaths, or poisoned (serious injury) 10–50 people; Caused cross-prefectures disputes by environmental pollution, and affected the local economic and social activities; Level III radioactive source lost, be stolen and out of control.
IV	Direct economic loss: 1000–10,000 Yuan.	Caused less than 3 deaths, or poisoned (serious injury) less than 10 people; Caused cross-counties disputes by environmental pollution, and produced social impacts; Class IV and class V radioactive source lost, be stolen and out of control.

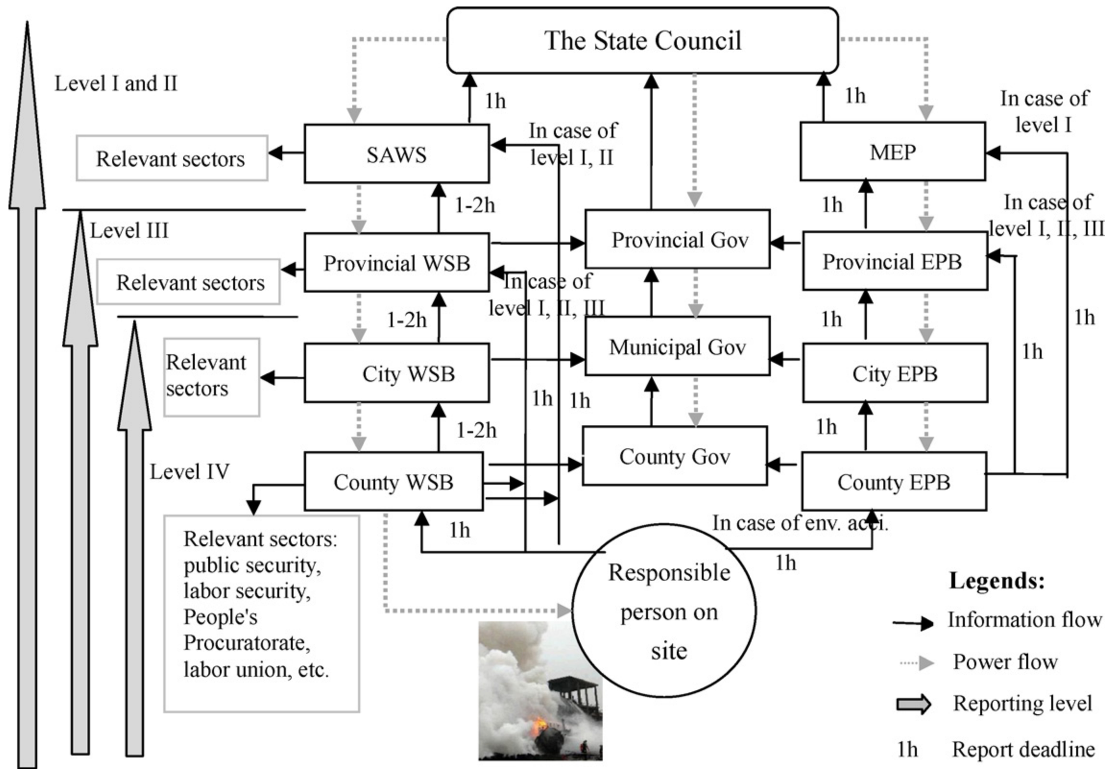

Fig. 5. The chemical accident reporting system in China.

Data from [13,14].

regulations: measures on the Reporting and Disposition of Work Safety Accidents Information 2009 by SAWS [14] and Measures on the Reporting of Environmental Emergency Accidents (Trial) 2006 by MEP. Fig. 5 illustrates the current reporting procedures involving SAWS and MEP through their own networks, depending on whether the nature of the accident is (interpreted as) a work safety accident or a pollution accident. According to Article 6, 7, 8, and 9 of SAWS Measures, when a work safety accident occurs, the responsible manager on site should report the accident to the county WSB in 1 h. At the same time, he/she should report the accident to the provincial WSB when it is at least a level III accident, and he/she should report the accident to SAWS when it is a level I or II accident. When the county WSB receives the accident information, it should report the accident to the higher level WSB and the same level government, who both continue reporting to higher levels. The WSB and SAWS are also responsible to contact other related agencies such as the Public Security Bureau and the Labor Security Office. Only when the accident is classified as a pollution accident or an environmental accident caused by a work safety accident, the reporting system of the EPB will function. According to Article 7 of MEP Measures, when the local EPB receives information on the accident, it should report the accident to a higher level EPB and to the same level government, who both continue reporting to higher levels. At the same time it should directly report the accident to the provincial EPB when it is an accident of level III or higher, and should report the accident to MEP when it is a level I accident. In the whole process, the higher level WSBs and EPBs would give direction and assist in accident management and control, and minimization of the consequences. If necessary, SAWS and MEP become the leaders of accident response and control. This leads to overlapping and missing reporting and to incompatible information on a single accident, for instance when it starts as a work safety accident but turns into an environmental accident. The absence of an integrated and shared database has resulted in a situation where no one has a complete and historical overview about chemical accidents in China.

4. Review of existing chemical accidents data of the past 40 years in China

To illustrate and assess the usefulness and limitations of the existing datasets for chemical accident analysis, we collected and analyzed data and information on major chemical accidents over the past 40 years (1970–2009). Since none of the existing databases (Table 2) fully offers data and information covering the required period of time and the required contents, we additionally consulted the book "Selected Cases of Major Chemical Accidents" [15] for complementary information. Chemical accidents of levels I–III were included in the analysis based on the classification in Table 3. We reviewed chemical accidents with respect to spatial and temporal patterns and damages.

In total, 3673 chemical accidents could be identified from the above mentioned sources. Only accidents of level I to III that occurred after 1970 and for which the number of deaths known were included in our review of accidents. After applying the above mentioned selection criteria, 976 major (level I, level II and level III as defined in Table 3) chemical accidents were singled out for review. Information on the severity of the accident is given with respect to the number of death, the number of serious injury, the number of people evacuated, and the direct economic loss to property. According to The Classification for Casualty Accidents of Enterprise Staff and Workers (GB6441-1986), serious injury was defined as those injuries that cause lose of working days over 105. As to the direct economic loss, Statistical Standard of Economic Losses from Injury–Fatal Accidents of Enterprise Staff and Workers (GB6721-1986) includes cost for medical treatment, funeral expenses, pension, allowance and relief funds, salary

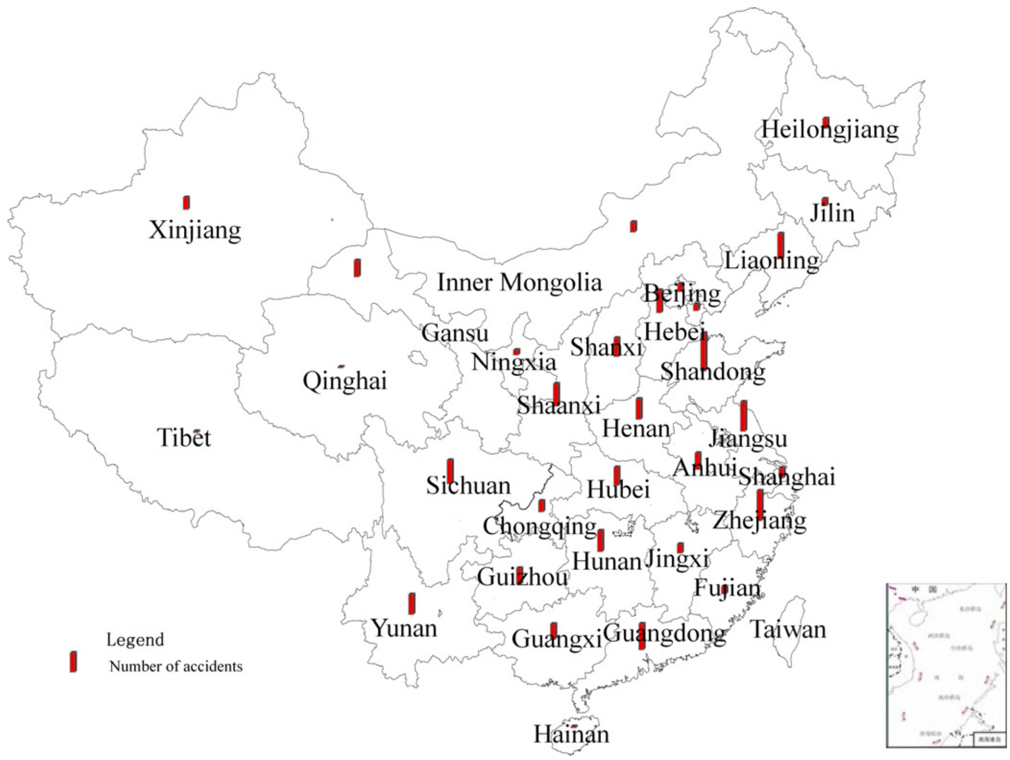

Fig. 6. Major dangerous chemical accidents in China, 1970–2009.

compensation, on-site and afterwards disposal cost, penalty and compensation and property loss.

4.1. Spatial map of the major chemical accidents

We used GIS to map the geographical distribution of the 976 major chemical accidents. The information given in the data fields 'location' of the different databases formed the input for the spatial definition of the chemical events. Since the information details on the location of the accidents varied from case to case after having consulted the various information sources, we could only position the accident at provincial level.

Fig. 6 shows the geographical distribution of the major chemical accidents in China over the last 40 years. In total, all 31 provinces/municipalities/autonomous regions reported significant chemical accidents in the last 40 years. According to these reported data, the most affected provinces, considering the total number of major chemical accidents, are Shandong Province with 77 accidents, Zhejiang Province with 60 accidents, and Jiangsu Province with 59 accidents. The least-hit province is Qinghai with 2 reported accidents, followed by Tibet and Hainan with 3 reported accidents. In terms of the average number of deaths per accident, Chongqing, Jilin and Hunan provinces are at the top and Qinghai, Guizhou, and Gansu Provinces are at the bottom (Fig. 7). Although we have no indications as such, there might be differences in reporting practices among provinces that might have interfered with these data.

In addition, we also related the chemical accidents and the deaths caused by the accident to the size of the petrochemical factory, the gross petrochemical and chemical industry product, and the number of employees, as shown in Fig. 8. Generally, Fig. 8 indicates that the more petrochemical and chemical factories, the more petrochemical and chemical employees, and the higher the gross petro-chemical and chemical industrial product the province has, the more accidents and deaths are reported in the databases. The provinces most affected by major chemical accidents are Shandong, Zhejiang, and Jiangsu which have 1618, 1332, and 2613 petrochemical and chemical plants respectively, and which produced a gross petrochemical and chemical industrial product of 163.71 billion, 82.14 billion, and 167.15 billion Yuan. At the same time, these provinces have the most employees in the petrochemical and chemical sector. Tibet, the province with the lowest number of chemical accidents, has the lowest number of chemical plants (5), the lowest gross petrochemical industrial product (10 million Yuan), and the lowest number of petrochemical employees (200 workers).

4.2. Temporal trend of the major chemical accidents and their damage

Detailed information on the damage caused by an accident is very important, among others for decision making on the severity of the accident, for accountability, for establishing compensation, and for developing insurance products (e.g., following the new Environmental Pollution Liability Insurance [16]). However, the existing data cannot support a detailed analysis of the direct economic losses, because of (adequate) data shortage. It is only possible to get a rough idea of the damage caused by chemical accidents in terms of the number of death and serious injured persons.

The temporal distribution of the major chemical accidents and their damage is presented in Figs. 9 and 10. In general, the number of the chemical accidents, deaths and serious injuries caused by the accidents have increased, especially after 2000, indicating the increasing risks of a rapidly developing chemical sector. Fig. 9 shows that the number of accidents have been increasing over the years with the stable increase of the gross petro-chemical and chemical industry product. The number of deaths caused by accidents over time indicates a fluctuating trend till 1999 and a rapid increase since 2000, with the exception for 2005–2006. This cor-

Fig. 7. The average of deaths per major dangerous chemical accident in China, 1970–2009.

responds with a parallel increase in gross industrial product of the petro-chemical and chemical industries. It seems that the number of petro-chemical and chemical factories has no direct relationship with the number of accidents, nor with the number of deaths caused by an accident. Fig. 10 provides data on the number of serious injuries, the number of the petro-chemical and chemical factories, and the gross petro-chemical and chemical industrial product from 1978 to 2008. The pattern is largely similar to Fig. 9. These historical analyses of major chemical accidents might be disturbed by recent improved flows of information, so that increased numbers of reported chemical accidents might not fully be caused by increased actual chemical accidents. Our use of a variety of data sources will limit that potential distortion, although it cannot rule it out completely.

The hypothesis adopted for this exploratory study was that the number of chemical accident and number of death/injury would be related to the local gross petro-chemical industry product. To explore whether there were detectable associations between chemical accidents/death/injury and the local gross petro-chemical industry product, Wilcoxon Signed Ranks Test was calculated in SPSS (v13.0) (Table 5). The results showed that there were positive statistically significant correlations between the number of chemical accident, the number of death/injury and the local gross petro-chemical industry product at $p < 0.01$.

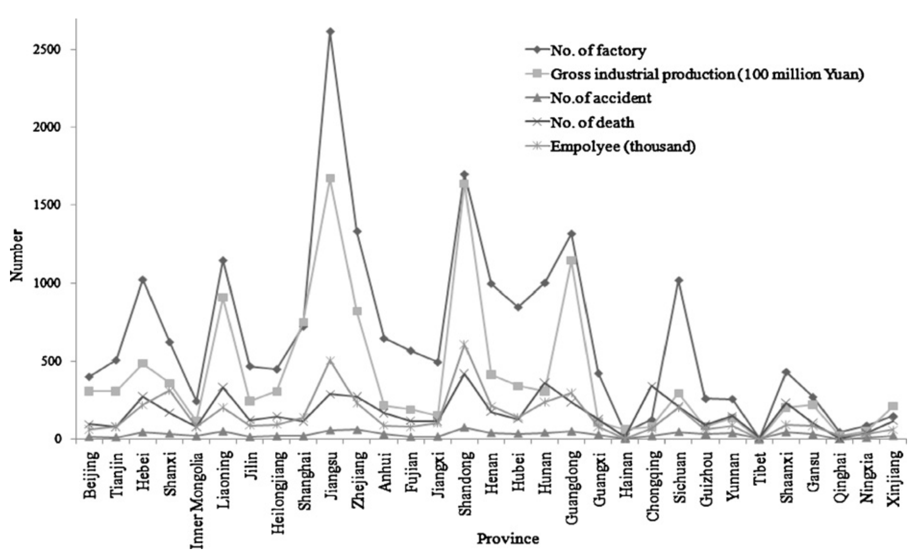

Fig. 8. The number of accidents, the number of deaths caused by accidents, the number of factories, gross industrial product, and the number of employees of the petro-chemical industry, per province in China, 1978–2008.

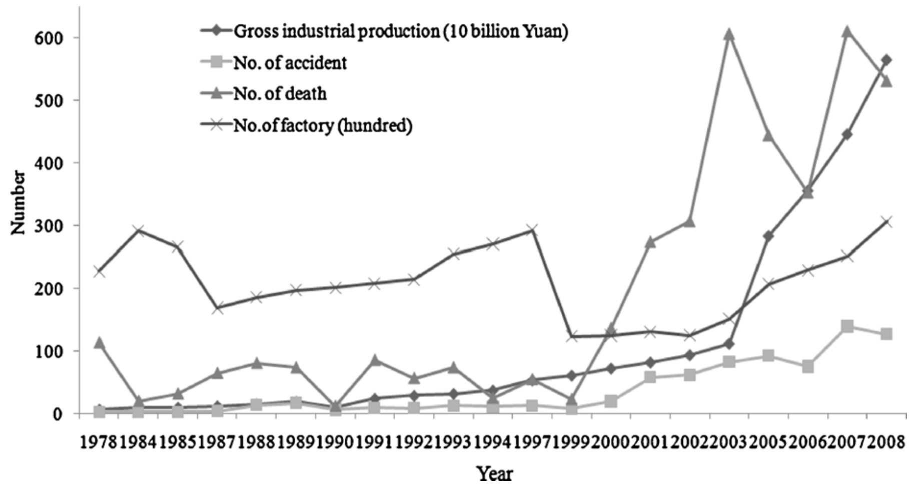

Fig. 9. Developments in the number of major chemical accidents, the number of death, the number of petro-chemical plant, and the gross petro-chemical industry product in China from 1978 to 2008 (1 Yuan is about 0.147 USD).

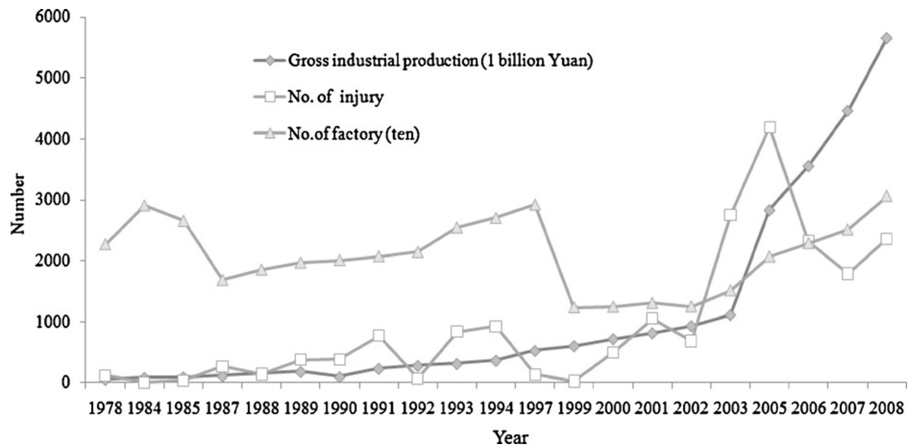

Fig. 10. Developments in the number of injury, the gross petro-chemical industry product, and the number of petro-chemical plant in China from 1978 to 2008 (1 Yuan is about 0.147 USD).

5. Assessment of the chemical accident databases

As important as a fundamental base for effective risk management, the building of a chemical accidents database faces various challenges ranging from technical, managerial and coordination difficulties. The review of the existing databases at global, regional and national levels shows that where the database functions there must be well-defined reporting standards and procedures, consistency of data and open access. An ideal chemical accidents database should have at least the following functions: (1) generate dynamic spatial and temporal distribution and development trends of chemical accidents; (2) contain data and information that support the evaluation of the economic and social damages; (3) support statistical analysis on various co-relationships of factors; (4) support supervision on the follow-ups of the accidents. To this end, important preconditions need be met: (1) necessary legislation on information disclosure by governments and openness at firm level; (2) sufficient capacity in terms of hardware and software infrastructure to generate and manage information and data; (3) willingness and determination of the responsible authorities to make the databases accessible to the public and under public supervision.

Table 5
Correlation analysis between chemical accident factors and the local gross petro-chemical industry product in different regions and different years.

		Gross petro-chemical industry product	
Different regions			
Number of accident	ZAsymp. Sig. (2-tailed)	−4.840(a)	0.000***
Number of death	ZAsymp. Sig. (2-tailed)	−3.763(a)	0.000***
Number of injury	ZAsymp. Sig. (2-tailed)	−2.821(b)	0.004***
Different years			
Number of accident	ZAsymp. Sig. (2-tailed)	−4.015(a)	0.000***
Number of death	ZAsymp. Sig. (2-tailed)	−3.146(b)	0.002***
Number of injury	ZAsymp. Sig. (2-tailed)	−3.875(b)	0.000***

Based on (a) positive ranks; (b) negative ranks. The results show that there are only positive significant correlations at $p < 0.01$.
*** Significant at $p < 0.01$.

Analyzing and comparing the databases of chemical accidents in the world and in China leads to the following conclusions:

- None of these databases covers all the information necessary for accident analysis. While information on the time, location, deaths and type of an accident is often available, it is rarely specific enough. Location information often mentions only the province and the city, making accurate positioning difficult in Chinese databases.
- The current databases do not function well as information and data analysis platform regarding all aspects of chemical accidents. They fall short on data storage, possibilities for statistical analysis, presentation of data, and functions for decision-support. The analysis of economic losses and physical damage; the detailed distribution of the accidents geographically; the analysis of number of deaths and injuries over processes, sizes and other industry characteristics; and temporal trend analysis and prediction are impossible in some databases.
- Especially information on responsible organizations, causal factors, consequences, actions taken/emergency responses, and effectiveness of follow-up actions on the accidents is often absent or incomplete. Sometimes key data are missing, sometimes only part of the information is available, but quite often hardly any information on these subjects is included in the reviewed databases.
- It is impossible to compare or combine data from these databases systematically, due to the differences in organization of the databases. Instead of being complementary, they often cause confusions as they have often contradictory information.
- Evaluation on each accident does not exist at all, leaving no base to judge the accuracy of the data and the effectiveness and effects of the actions taken.

Hence, understanding chemical accidents data in the world proves to be confusing. Current data related to chemical accidents are fragmented, because they are in the hands of different authorities in different regions and countries who adopt different data collection standards, methodologies, procedures and disclosure strategies, with different purposes [8]. Historical data on chemical accidents are neither comprehensive nor standardized, making long-term analysis difficult. In addition, the fragmentation of and limited access to information on chemical risks and accidents [17] has also caused confusion among decision makers and the public and contributed to a growing distrust in both information provision by the government, and adequate risk management by governments and companies. These problems accumulate when different administrative sectors are involved in (information provision on) chemical risks and accidents.

To conclude, the existing data about chemical accidents in the world, and especially in China, are fragmented and insufficient. And even in combination they fall short in comprehensive and adequate information collection and provision. There is no common database that integrates and uniforms information and data from different sources about a single accident, not to mention standardized working definitions and reporting procedures, or specified requirements of comprehensive reporting on a single accident.

6. Conclusions

While the number of chemical accidents in China is startling, the reasons for and responses to these accidents remain largely unveiled. Information on chemical accidents is not yet systematically and fully collected and stored, which seriously undermines chemical accident policies. Hence, lessons from these chemical accidents—their causes, consequences and management—are not easily learned and disseminated. And new policies for preventing and handling chemical accidents and risks cannot rely on rich information sources.

This study aimed to collect the data and information that should be the most basic component of any decent chemical accidents database, in order to obtain an overall picture of the temporal and spatial distribution of chemical accidents over the past 40 years in China, and to gain insight in the quality of the existing chemical accident databases. Our analysis leads to the following conclusions: (1) the existing databases in China are too fragmented and incomplete to support effective policy and decision making on chemical risk and accident management. This shortcoming is common to various extents in other databases under review; (2) China lacks a coordinated and integrated chemical risk and accidents information management system. In future, functional and integrated chemical risk management databases should include data on—but not limited to—the names of the responsible organization(s), causes, emergency response, the consequences, post-accident actions, and evaluation; (3) so far the publicly available data and information only enable us to map general temporal and spatial distributions of the major chemical accidents, the direct deaths, time and city location of each accident. Other damages, causes, exact locations and follow-ups are only reported occasionally; (4) to overcome these weaknesses a better database alone is not enough. An analysis of the existing and desired institutional arrangements for the collection, management and use of such databases is required. This should include the legal and policy frameworks, the division of responsibilities over different public and private actors, issues of information disclosure, and reporting and verification requirements at various levels (from enterprise to the national level).

For the sustainable development of a fast expanding chemical sector in China, it is strategically important to move from responding reactively to preventing proactively risks and accidents. This calls for a more coordinated management of a comprehensive information system that gives more weight to environmental pollution information of the chemical accidents. A comprehensive and publicly accessible information system would not only increase the efficiency and effectiveness of accident prevention and responses, but also help raise public awareness and gain support from the society at large. This conclusions lead to a future research agenda focused on finding solutions.

Acknowledgments

This study is supported by the National Basic Research Program of China (2007CB407307), the Netherlands Royal Academy of Arts and Sciences and the Chinese Academy of Sciences (10CDP030), National Natural Science Foundation of China (41071355). Thanks to Dr. Hongchang Ren for mapping. Also thanks to the reviewers for their comments.

References

[1] G. Malich, M. Braun, P. Loullis, C. Winder, Comparison of regulations concerning hazardous substances from an international perspective, J. Hazard. Mater. 62 (1998) 143–159.
[2] China Statistical Yearbook 2009, China Statistics Press, 2009.
[3] China Petroleum and Chemical Industry Association (CPCIA), Informatization Development of the Petrochemical Industry in China. http://miit.gov.cn/n11293472/n11293877/n11301602/n12222003/n12238755/12242260.html, 2010 (accessed 01.07.10).
[4] T.-M. Liu, M.-H. Zhong, J.-J. Xing, Industrial accidents: challenges for China's economic and social development, Saf. Sci. 43 (2005) 503–522.
[5] Xinhua News Agency, Half of China's Chemical Plants Endanger Environment. http://www.china.org.cn/english/environment/174430.htm, 12 July 2006 (accessed 29.12.09).

[6] J.-G. Liu, J.-X. Hu, X.-Y. Tang, Global governance on environmentally sound management of chemicals and improvement requirements for China's system, Res. Environ. Sci. 19 (2006) 121–126.
[7] Z. Nivolianitou, M. Konstandinidou, C. Michalis, Statistical analysis of major accidents in petrochemical industry notified to the major accident reporting system (MARS), J. Hazard. Mater. 137 (2006) 1–7.
[8] Y. Hou, T.-Z. Zhang, Evaluation of major polluting accidents in China – results and perspectives, J. Hazard. Mater. 168 (2009) 670–673.
[9] B.-K. Zhang, B.-N Lu, X. Ma, Establishment and inquiry of chemical accident database, Comput. Appl. Chem. 25 (2008) 1303–1306.
[10] M.-R. Gomez, S. Casper, E.A. Smith, The CSB accident screening database: description, summary statistics and uses, J. Hazard. Mater. 159 (2008) 119–129.
[11] P. Haastrup, H. Romer, An analysis of the database coverage of industrial accidents involving hazardous materials in Europe, J. Loss Prev. Process Ind. 8 (1995) 79–86.
[12] E. Díez, B.S. McIntosh, A review of the factors which influence the use and usefulness of information systems, Environ. Modell. Softw. 24 (2009) 588–602.
[13] Stated Administration of Work Safety, Measures on the Reporting and Disposition of Work Safety Accidents Information, SAWS Document No. 21, Promulgated on 27 May 2009, implemented on 1 July 2009.
[14] Ministry of Environmental Protection of China, Measures on the Reporting of Environmental Emergency Accidents (Trial), MEP Document No. 50, implemented on 31 March 2006.
[15] G.-H. Zhang (Ed.), Selected Cases of Major Chemical Accidents, China Labour and Social Security Publishing House, Beijing, 2007.
[16] A.P.J. Mol, G.-Z. He, L. Zhang, Information disclosure as environmental risk management: developments in China, J. Curr. Chin. Aff., accepted.
[17] L. Zhang, A.P.J. Mol, G.-Z. He, Y.-L. Lu, An implementation assessment of China's Environmental Information Disclosure Decree, J. Environ. Sci. 22 (2010) 1649–1656.