Journal of Environmental Management 199 (2017) 21–30

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Characterization of post-disaster environmental management for Hazardous Materials Incidents: Lessons learnt from the Tianjin warehouse explosion, China

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ARTICLE INFO

Article history:
Received 23 August 2016
Received in revised form
6 April 2017
Accepted 7 May 2017

Keywords:
Hazardous Materials Incidents
Tianjin warehouse explosion
Post-disaster environmental management systems

ABSTRACT

Hazardous Materials Incidents (HMIs) have attracted a growing public concern worldwide. The health risks and environmental implications associated with HMIs are almost invariably severe, and underscore the urgency for sound management. Hazardous Materials Explosion incidents (HMEIs) belong to a category of extremely serious HMIs. Existing studies placed focuses predominately on the promptness and efficiency of emergency responses to HMIs and HMEIs. By contrast, post-disaster environmental management has been largely overlooked. Very few studies attempted to examine the post-disaster environmental management plan particularly its effectiveness and sufficiency. In the event of the Tianjin warehouse explosion (TWE), apart from the immediate emergency response, the post-disaster environmental management systems (P-EMSs) have been reported to be effective and sufficient in dealing with the environmental concerns. Therefore, this study aims to critically investigate the P-EMSs for the TWE, and consequently to propose a framework and procedures for P-EMSs in general for HMIs, particularly for HMEIs. These findings provide a useful reference to develop P-EMSs for HMIs in the future, not only in China but also other countries.

1. Introduction

A new chemical is introduced every 8 h, and over 100,000 different substances are in use today (Tolba, 1990; UNEP, 2015). It is predicted that the production and use of chemicals will increase globally, especially in developing countries (Shie and Chan, 2013). Chemicals play a role in every economic sector and nearly every industry. “Hazardous materials (hazmat)” refers to “highly toxic substances and other chemicals that are toxic, corrosive, explosive, or flammable, or are combustion-supporting and can do harm to people, facilities or the environment” (Lee et al., 2016; UNEP, 2015). When entering the environment, hazmat can have significant impacts on the health of human beings and ecosystem (Millner et al., 2014). An increasing frequency and variety of Hazardous Materials Incidents (HMIs) has presented a significant challenge to human beings (Fabiano and Curro, 2012; He et al., 2011). Previous studies suggested that the impacts of accidents in developing countries are more severe than those occurred in developed countries (Carol et al., 2002; Chen et al., 2012). In particular, present developing countries have entered a period of high environmental pollution derived from HMIs (Yang et al., 2010). The impacts of an HMI depend on the chemical and physical properties of the hazmat (Wei, 2011), however could be mitigated largely by means of appropriate post-disaster environmental management systems (P-EMSs) (Pena-Fernandez et al., 2014). Without proper post-disaster management of HMIs, and particularly of Hazardous Materials Explosion incidents (HMEIs), these events could cause serious damage to the environment (CCTV Half Hour Economy, 2014). A

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http://dx.doi.org/10.1016/j.jenvman.2017.05.021
0301-4797/

serious explosion of 91 tons of AN in a storage warehouse in Shenzhen City occurred on August 5, 1993 where fifteen people were killed and 141 were injured (Zhang, 2000). In total, the explosion produced approximately 20,000 tons of hazardous wastes (seriously contaminated soil and building structures) which contained a number of 48 harmful chemicals, including flammable substances, explosive substances and toxic substances. A large quantity of harmful substances seriously exceeded the national standard reference values: the maximal concentrations of As, Ba, Mn, P, and F were as much as 16 times, 65 times, 200 times, 128 times and 150 times higher than the standard values, respectively (Yang et al., 1996; Yuan et al., 1997a, b) (Tables S1 and S2 in supporting information). However, until 1993, there was no hazardous waste treatment facility in Shenzhen City. These hazardous wastes inevitably imposed serious impacts on human health and environmental media.

The recent Tianjin Warehouse Explosion (TWE) occurred on 12 August 2015 (to be described in detail in Section 3). Due to nitrate (ammonium nitrate and potassium nitrate) and cyanide (sodium cyanide), TWE could result in more serious consequences. Although the explosion was extremely severe, the environmental pollution was effectively controlled in a relatively short period of time. There is no poisoning or death accident as a result of possible environmental contamination, which indicated the effectiveness of the P-EMS. Therefore, the analysis of TWE could probably offer good reference to deal with similar HMEIs.

HMIs have, unfortunately, occurred frequently in past few decades across the world. Much attention has been paid to the large number of casualties and amount of property loss, the impacts on environmental quality, the root causes of the incidents, the prevention of HMIs (Cunha et al., 2015; Duan et al., 2011; Yang et al., 2010), and improvements in the safety management of hazmat (Laboureur et al., 2016; Pittman et al., 2014; Tinney et al., 2016). However, there is lack of studies on post-disaster Environmental Management (P-EM) for HMIs. These include remediation strategies and recovery options, and how environmental quality is affected by the release of multiple substances. Furthermore, relatively little work has attempted to examine how post-disaster environmental governance can be effectively implemented or how effective these measures are determined. These measures include: the prevention and control of hazmat leakage to surrounding environmental media, the clean-up of post-disaster chemicals and other waste, and the remediation of the contaminated site (Pena-Fernandez et al., 2014; Wei, 2011). This is arguably the first study attempting to systematically analyze the P-EMS of TWE with main focus on the significant HMEIs (SHMEIs) via a case study approach.

The objective of this study, therefore, was to clearly identify the key points from the TWE case study, and then draw experiences and lessons for the sound management of HMIs, and particularly for SHMEIs, with the combination of extensive literature review and detailed comparisons. In order to achieve this goal, we first reviewed and clarified the characteristics of recent HMIs and their environmental management procedures, both in China and other countries. Secondly, we conducted a detailed analysis of the P-EMSs for the TWE. Consequently, P-EMS strategies and specific procedures targeting HMIs (HMEIs) were proposed.

2. Methods and data sources

This study combines qualitative and quantitative information on HMIs and HMEIs and to highlight their post-disaster environmental management (P-EM). These include: characterization of the HMIs and HMEIs from the statistical data; an analysis of P-EM for typical SHMIs and SHMEIs in worldwide by reviewing official investigation and media reports; and a case study of TWE in China. Information on the TWE Incident was collected mainly from major media sources (e.g. Xinhua News, Huanqiu News, China Daily), official investigation report (State Council, 2016), and website of related authorities (e.g. the State Administration on Work Safety in China, the Chinese Chemical Safety Association, Tianjin environmental protection bureau. Please see in Fig. S1 in supporting information. Content analysis was conducted in order to highlight the emerging themes from various sources in relation to causes of TWE and corresponding measures as well as the performance of treatments. As an effective approach to analyze qualitative data, content analysis has been widely employed in environmental management related studies (e.g. Le Gentil and Mongruel, 2015; Tan et al., 2017).

3. Characterization of the HMIs and HMEIs

3.1. HMIs and HMEIs in China

3.1.1. Quantity and major impacts of HMIs and HMEIs

China sustained rapid economic growth since 1980s (National Bureau of Statistics of China (NBSC), 2015). China accounts for 22% (903 billion USD) of the global chemical market (4 trillion USD), ranking the first (Lee et al., 2016). The volatility and toxicity of some chemicals, however, have led to many chemical-related incidents in recent years, causing catastrophic losses of life and damage to the environment in China (Duan et al., 2011; Yang et al., 2010). A total of 3559 HMIs in China occurred from 2007 to 2015. HMEIs caused approximately 30% of the total number of HMIs and 40% of the death toll from such incidents (see Fig. 1). The occurrences of HMIs, specifically HMEIs, have shown a similar trend of change over time, and 69% of them occurred during the period between 2007 and 2011. However, year 2011 was a turning point. The average annual decreases in the number of incidents of, and the death toll from, HMIs are 56.9% and 86.1%, respectively. These decreases can be attributed to lessons learned from past incidents. Especifically, by strengthening supervision and management on hazardous materials by passing a series of laws and regulations (see Tables S3 and S4 in Supporting Information). Moreover, the serious economic crisis from 2008 to 2010 led to a sharp decline in the chemical industry market, which may have played a role in reducing the frequency of HMIs. The past few years, though, have seen a steady increase in HMIs and HMEIs because of the recovery from the world economic recession and the continued development of the industry.

3.1.2. Geographical distribution of HMEIs

Guangdong, Zhejiang, Jiangsu and Shandong account for over 50% of chemical enterprises nationwide, leading to a corresponding high frequency of HMEIs in these economically developed provinces in eastern coastal China (see Fig. 2). More than 56% of the incidents occurred along the eastern coast, 23% in the central inland, and 21% in the remote western regions.

3.1.3. Retrospective on the Tianjin warehouse explosion

On August 12, 2015, chemicals in a container terminal in the Tianjin Binhai New Area exploded. The cause of the accident was the spontaneous ignition of overly dry nitrocellulose stored in a container that was overheated (State Council, 2016). The subsequent major fire then resulted in a domino effect of warehouse stored chemicals fires and explosions, and toxic release. Detailed information can be seen in section 9.1 of supporting information. Consequently, domino effect of TWE has very high destruction consequences, as shown in section 9.2 of supporting information. The explosion also posed serious environmental damage to air, water and soil, see section 9.3 in supporting information, Tables S5-