Chemosphere 151 (2016) 9–16

Contents lists available at ScienceDirect

Chemosphere

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

Causation mechanism analysis for haze pollution related to vehicle emission in Guangzhou, China by employing the fault tree approach

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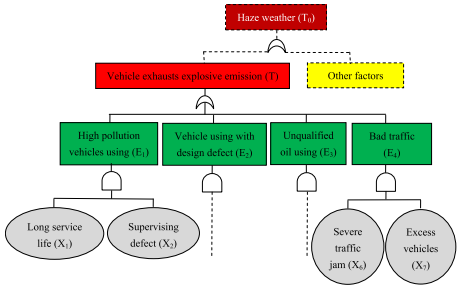
HIGHLIGHTS

- FTA was employed for the causation mechanism of haze pollution related to vehicle emission in Guangzhou, China.
- Risk factors of the causation system of urban haze related to vehicle emission were discussed and elaborated.
- FTA was proved to be an effective tool for risk analysis and management of haze pollution related to vehicle emission.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 December 2015
Received in revised form
2 February 2016
Accepted 5 February 2016
Available online 15 March 2016

Handling Editor: Dr. R Ebinghaus

Keywords:
Haze pollution
Causation mechanism
Vehicle emission
Fault tree approach

ABSTRACT

Recently, China has frequently experienced large-scale, severe and persistent haze pollution due to surging urbanization and industrialization and a rapid growth in the number of motor vehicles and energy consumption. The vehicle emission due to the consumption of a large number of fossil fuels is no doubt a critical factor of the haze pollution. This work is focused on the causation mechanism of haze pollution related to the vehicle emission for Guangzhou city by employing the Fault Tree Analysis (FTA) method for the first time. With the establishment of the fault tree system of "Haze weather—Vehicle exhausts explosive emission", all of the important risk factors are discussed and identified by using this deductive FTA method. The qualitative and quantitative assessments of the fault tree system are carried out based on the structure, probability and critical importance degree analysis of the risk factors. The study may provide a new simple and effective tool/strategy for the causation mechanism analysis and risk management of haze pollution in China.

1. Introduction

Recently, China has frequently experienced large-scale, severe and persistent haze pollution due to surging urbanization and industrialization and a rapid growth in the number of motor vehicles and energy consumption (Zhang and Cao, 2015). However, energy and chemical processes are important elements of social and industrial development, although they may cause negative ecological and environmental impacts (Yang et al., 2013). So, haze pollution treatment will be a long, difficult and complicated challenge for China (Li and Zhang, 2014). Besides China, severe haze incidents had been occurred in London in 1950s and in Los Angeles during 1940s-1970s (Li et al., 2016). It also may occur in other developing countries in the future which should receive significant attention to prevent and control potential environmental problems.

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http://dx.doi.org/10.1016/j.chemosphere.2016.02.024
0045-6535/

Atmospheric fine particulate matter such as $PM_{2.5}$ (particulate matters with aerodynamic diameter $\leq$2.5 μm) is believed to be the most important air pollutants causing haze weather in China, which can affect the air quality, clime systems and human health (Zhang et al., 2013). Wang and Fang (2016) studied the spatial-temporal characteristics and determinants of $PM_{2.5}$ in the Bohai Rim Urban Agglomeration. Zhou et al. (2016) studied the concentrations, correlations and chemical species of $PM_{2.5}/PM_{10}$ based on published data in China. Wang et al. (2016) made a study on seasonal variation of carbonaceous pollutants in $PM_{2.5}$ at an urban 'supersite' in Shanghai. The unprecedented attention on $PM_{2.5}$ from both the Chinese government and public may open a door to public participation addressing environmental challenges in China (Huang, 2015). The formation mechanism and environmental impact of haze pollution also raised concern in some other researchers. Gao et al. (2015) assessed the health impacts and economic losses of the 2013 severe haze event in Beijing area. Zhang et al. (2015) studied the effects of meteorology and secondary particle formation on visibility during heavy haze events in Beijing. Tie et al. (2015) used a chemical/dynamical regional model and a box model to study the causes of a "Beijing Haze". Yang et al. (2015) used atmospheric environmental monitoring data to investigate the formation mechanism of urban haze in Beijing. Huang et al. (2014a) investigated the chemical nature and sources of particulate matter in several typical mega-cities including Beijing and Guangzhou in China during January 2013 by using a novel statistical techniques, the analysis results indicated that the severe haze weather was driven by secondary aerosol formation to a large extent, and the fossil fuel combustion is a key factor for controlling China's $PM_{2.5}$ levels. In September 2013, The "Atmospheric Pollution Prevention and Control Action Plan" had been released by Chinese central government, which showed the haze control determination by Chinese government with primarily aiming to reduce inhalable $PM_{2.5}$ by at least 10% by 2017 against 2012 levels (Zhang and Cao, 2015). The Action Plan mainly focuses on regulation of indusial and transport-related emissions with major energy consumption from fossil fuels, which indicated that the vehicle emission is the key factor leading to the haze pollution. Based on those literature mentioned above, the vehicle emission due to the consumption of a larger number of fossil fuels is no doubt a critical factor for the haze pollution. Guangzhou, as the largest city in South China with huge vehicles possession, in which the environmental impact (Liu et al., 2014) and control strategy (Tao et al., 2015) of the vehicle emission had been discussed intensively recently. However, most of the evolution mechanism researches on haze pollution mentioned above made the achievement based on the professional perspectives such as aerosol formation mechanism, pollutants composition analysis, meteorology approaches and statistical techniques (Huang et al., 2016). It would be meaningful and popular to find a simple and effective method to explain and reveal the causation mechanism of haze pollution more understandable and acceptable for both the Chinese government and public.

For providing more simple and understandable method to recognize the causation mechanism of haze pollution related to vehicle emissions in Guangzhou, based on a new perspective of systematic methodology, the fault tree analysis (FTA) approach is employed and investigated to provide a simple and effective tool for the causation mechanism analysis of urban haze in Guangzhou in this work. Fault tree analysis (FTA) is a deductive, top-down method aimed at risk assessment for complex systems, which has been successfully applied in areas such as the assessment of reliability of nuclear reactors and spacecrafts (Bedford and Cooke, 2001). It also had been applied in other fields such as water supply systems (Lindhe et al., 2012), fuel cell degradation (Placca and Kouta, 2011) and biogas systems (Cheng et al., 2014). Compared with other methods, FTA would be more easily accepted due to a readable and understandable logic background structure.

In this work, by establishing the fault tree system of "Haze weather—Vehicle exhausts explosive emission" and identifying the risk events related to vehicle emissions, FTA was employed to the causation mechanism analysis of haze pollution related to vehicle emissions in Guangzhou for the first time. This study may provide a scientific and effective tool for causation mechanism analysis and risk management of the haze pollution in China, which also can be useful for the government to improve relevant policy to intervene and eliminate the occurrence of urban haze in China.

2. Vehicle emission scenario in Guangzhou

According to the 2014 China Vehicle Emission Control Annual Report (Ministry of Environmental Protection of the People's Republic of China (2015)), the vehicle possession was up to 232 million in China, and Guangdong province ranked the second place by 11.7 million vehicle possession. The tremendous vehicle emissions were up to 45.709 million t in 2013 including NO_X (6.046 million t), CO (34.397 million t), HC (4.312 million t) and PM (0.594 million t), which have brought huge pressure on the air pollution to China. The vehicle possession in Guangzhou was up to 2.148 million with a largest permanent population of over 8.323 million by 2013 (Guangzhou Statistical Bureau, 2015) in Guangdong province. Hence Guangzhou would be a representative city for the investigation of the causation mechanism of urban haze related to vehicle emission. To build a proper fault tree system for the causation mechanism analysis of urban haze related to vehicle emissions, some relevant survey on the vehicle emission scenario in Guangzhou should be carried out to prefer the qualitative or quantitative analysis.

(1) According to 2014 China Energy Statistical Yearbook (National Bureau of Statistics of China (2015a)), China still has large gap between supply -and- demand on energy. The total, oil, and traffic-related energy consumptions of China in 2004–2013 are demonstrated in Fig. 1, which indicated that oil is very important in the energy structure in China, accounting for 18.4% of the total energy consumed in 2013 and over 50% of the oil consumption resulted from the transportation. According to 2014 China Statistical Yearbook (National Bureau of Statistics of China (2015b)) and 2014 Guangzhou Statistical Yearbook (Guangzhou Statistical Bureau, 2015), the possession trend of vehicles in China/Guangzhou are also demonstrated in Fig. 2, which indicated that vehicle possession both in China and Guangzhou are increasing fast during 2004–2013. It would be very important and urgent to figure out the effective control strategy for

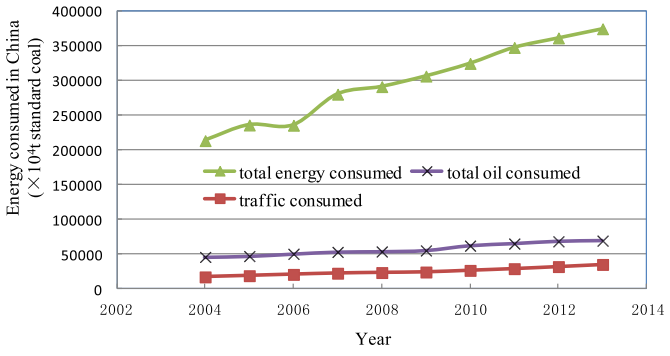

Fig. 1. Energy consumed trend in China.