Evolution and comparative assessment of ambient air quality standards in China

Bingtao Zhaoa, Yaxin Sub, Shushen Hea, Mei Zhonga and Guomin Cui

School of Energy and Power Engineering, University of Shanghai for Science and Technology, Shanghai, China; School of Environmental Science and Engineering, Donghua University, Shanghai, China

1. Introduction

China, the world’s largest developing country and second largest economy as of 2010, is faced with increasing pollution caused from the fast urbanization and industrialization processes. The fast development of the economy is followed by a large quantity of consumed energy especially fossil fuels such as coal (Chen 2012). This results in serious concerns to atmospheric, environmental, and public health (Chen et al. 2004; Chan & Yao 2008). Investigations on the current status of air pollution in China indicated that the species of pollutant components has changed greatly along with an increased total amount of pollutant emissions (Yi et al. 2007; Fang et al. 2009; Wang & Hao 2012; Zhang & Crooks 2012). Particularly, $\text{PM}_{2.5}$ and $\text{O}_3$ were the major pollutants contributing to the regional grey haze frequently appearing in
metropolitan areas. Also, NO\textsubscript{x} pollution has been escalated in the ambient air in the past decade (Tang 2004; Zhang et al. 2011).

An effective and strong countermeasure that the Chinese government adopted was to establish a matching national ambient air quality standard. It is also regarded as a guideline of air quality assessment and fundamental to pollution reduction (Wang & Hao 2012; Saikawa & Urpelainen 2014). To adapt to the updated situation of ambient air quality management, the Ministry of Environmental Protection (MEP) of China released the newest amended ambient air quality standard (GB 3095-2012) in 2012 (MEP 2012a) after successive releases of GB 3095-82 (EPO 1982) and GB 3095-1996 (SEPA 1996) (Figure 1). To understand the level of this standard, some studies have tried to compare the Chinese standard with other international standards (Li & Shen 2003; Chen et al. 2008; Wang et al. 2010; Chen et al. 2011). However, these investigations did not carefully analyse the deep-seated backgrounds and reasons for evolution of the standards. Moreover, they did not present insightful and comprehensive investigations on the orientation, development, challenges, differences, and applicability of China’s ambient air quality standard.

The objective of this work is to investigate China’s ambient air quality standard in terms of historical development and lateral comparison. We present the development and evolution process of the ambient air quality standard in China, and then compare China’s newest standard with the currently-used standards of representatives from developed countries and international organizations including the United States (US), the European Union (EU), Japan (JP), and the World Health Organization (WHO). These standards were analysed for similarities and differences, particularly focusing on the differences in critical pollutants and concentration thresholds. On this basis, the motives/challenges and the setting of guideline values were explored. Furthermore, the implementation of new ambient air quality standards and improvement of air quality management systems in China were prospected.

**Figure 1.** Development of the ambient air quality standard in China.
2. Development of the standard

2.1. Background

The first United Nations Conference on the Human Environment (UNCHE) held in 1972 marks the beginning of China's modern environmental protection efforts. Since then, China has strengthened the construction of environmental legislation, regulations, and standards (Siddiqi & Chong-Xian 1984; Beyer 2006; Zhang & Zhao 2007). In 1982, the ambient air quality standard (called GB 3095-82 or hereinafter referred to as GB 3095-1982) was initially issued. This standard was successively amended in 1996, 2000 and 2012 (called GB 3095-1996, GB 3095-1996 amendment and GB 3095-2012, respectively) according to the improvement of technologies and the change of environmental situations. After over 30 years development and improvement, China has now established a multi-dimensional environmental standard system which consists of two classes and five types of standards. The two classes refer to national and local standards, and the five types include quality standards, emission standards, monitoring standards, management standards, and basic standards (MOST & MEP 2012). They are considered to be adaptive to the atmospheric pollution situation, control objectives and technological level and also to be matched with the development of China's economy, energy, and environmental legislation.

In 1982 the environment Protection Office of the State Council regulated only six pollutant items including one reference item, floating dust (EPO 1982). After 14 years of rapid development, total energy consumption has been increasing and the thresholds for pollutant emissions in the standard GB 3095-1982 became too relaxed to limit the pollutant emissions. At the same time, the development of technologies for pollutant reduction makes it possible to further lower the threshold for pollutant emissions. For this reason, the State Environmental Protection Administration (SEPA) released the updated ambient air quality standard GB 3095-1996 (SePA 1996). As a further improvement, the amendment of GB 3095-1996 was released by SEPA in 2000 (SePA 2000). More recently, PM$_{2.5}$, as a high-profile pollutant, has been added into the new standard (GB 3095-2012) to address the effect of haze on air quality (MeP 2012b). An important note is that the newest ambient air quality standard includes fifteen pollutants with six primary items, four additional items, and recommended items. Overall, the trend of development of ambient air quality standards is towards more specific and concrete standards.

2.2. Evolution of key pollutants and their thresholds

2.2.1. Particulate matter

The development and evolution of China's ambient air quality standard with pollutant items and concentration thresholds at different periods is shown Table 1. In the standard GB 3095-1982 (EPO 1982), the total suspended particulates (TSP) was evaluated based on real-time, transient, or daily average concentration bases. In the standard GB 3095-1996 (SePA 1996), the real-time concentration was rejected due to increased uncertainty, instead using the daily and annual average concentrations. TSP was not used as a primary pollutant item but as one of the so-called “other pollutant” items in the standard GB 3095-2012 (MEP 2012a). Moreover, the standard for TSP was decreased from 150 to 120 μg/m$^3$ for Grade-I, but it was not changed for Grade-II. In addition, the standard GB 3095-2012 did not use the concept of Grade-III any longer.
Table 1. Thresholds of pollutants in the China’s AAQS at different periods.

| Pollutant | Average period | GB 3095-82 | GB 3095-1996 (Amendment in 2000 marked with star) | GB 3095-2012 |
|-----------|----------------|------------|-------------------------------------------------|--------------|
| **Primary pollutants** | | Grade-I<sup>a</sup> | Grade-II<sup>b</sup> | Grade-III<sup>c</sup> | Grade-I<sup>a</sup> | Grade-II<sup>b</sup> | Grade-III<sup>c</sup> | Grade-P | Grade-II<sup>b</sup> |
| TSP | realtime | 300 | 1000 | 1500 | 150 | 500 | 700 | 50 | 150 | 500 |
| | 24 h | 150 | 300 | 500 | 120 | 300 | 500 | | | |
| | yearly | 80 | 200 | 300 | 80 | 200 | 300 | | | |
| PM<sub>10</sub> | realtime | 150 | 500 | 700 | 150 | 500 | 700 | | | |
| | 24 h | 50 | 150 | 250 | 50 | 150 | 250 | 50 | 150 | 50 |
| | yearly | 40 | 100 | 150 | 40 | 100 | 150 | 40 | 70 | |
| PM<sub>2.5</sub> | yearly | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| SO<sub>2</sub> | realtime | 150 | 500 | 700 | 150 | 500 | 700 | 150 | 500 | 500 |
| | 24 h | 50 | 150 | 250 | 50 | 150 | 250 | 50 | 150 | 50 |
| | yearly | 20 | 60 | 100 | 20 | 60 | 100 | 20 | 60 | 20 |
| NO<sub>2</sub> | realtime | 100 | 150 | 300 | 150 | 150 | 300 | 150 | 150 | 150 |
| | 24 h | 50 | 100 | 150 | 100 | 150 | 150 | 100 | 150 | 150 |
| | yearly | 50 | 50 | 100 | 50 | 50 | 100 | 50 | 50 | 50 |
| NO<sub>x</sub> | 1 h | 120 | 120<sup>(240*)</sup> | 240 | 240 | 240 | 200 | 200 | 200 | 200 |
| | 24 h | 80 | 80<sup>(120*)</sup> | 120 | 80 | 80 | 80 | 80 | 80 | 80 |
| | yearly | 40 | 40<sup>(80*)</sup> | 80 | 40 | 40 | 40 | 40 | 40 | 40 |
| CO | realtime | 10 000 | 10 000 | 20 000 | 10 000 | 10 000 | 20 000 | 10 000 | 10 000 | 10 000 |
| | 1 h | 10 000 | 10 000 | 20 000 | 10 000 | 10 000 | 20 000 | 10 000 | 10 000 | 10 000 |
| | 24 h | 4 000 | 4 000 | 6 000 | 4 000 | 4 000 | 6 000 | 4 000 | 4 000 | 4 000 |
| | 8 h | 4 000 | 4 000 | 6 000 | 4 000 | 4 000 | 6 000 | 4 000 | 4 000 | 4 000 |
| O<sub>3</sub> | 1 h | 120 | 160 | 200 | 120<sup>(160*)</sup> | 160<sup>(200*)</sup> | 200 | 160 | 200 | 160 |
| | 8 h | 1 5 | 1 5 | 1 5 | 1 5 | 1 5 | 1 5 | 1 5 | 1 5 | 1 5 |
| Pb | quarterly | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| | yearly | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| B[a]P | 24 h | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| F | 1 h | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| | 24 h | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Other pollutants | TSP | realtime | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| | 24 h | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| | yearly | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| NOx | 1 h | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; | &nbsp; |
| Reference pollutants | Pb | 24 h | yearly | 24 h | 80  | 80 |
|----------------------|----|------|--------|------|-----|----|
|                      |    | yearly |        |      | 40  | 40 |
|                      |    | quarterly |      |      | 1   | 1  |
|                      | B[a]P | 24 h | yearly |      | 0.5 | 0.5|
|                      |    | yearly |        |      | 0.0025 | 0.0025 |
|                      |    | yearly |        |      | 0.001 | 0.001 |
| P | 24 h | 0.0025 |      |      | 0.00025 | 0.00025 |
| F | yearly | 20 |      |      | 20 | 20 |
| F | 1 h | 7 | 7 | |

Grade I is applicable to natural reserves, scenic areas and other specially protected areas in China.

Grade II is applicable to residential areas, commercial-traffic-residential areas, cultural areas, industrial areas and rural areas in China. Note that the Grade II in GB 3095-2012 is applicable to places previously under Grade II and Grade III in both GB 3095-1996 and GB 3095-82.

Grade III is for special industrial areas in China.
The standards in 1996 and 2012 also cancelled the real-time concentration measures for PM$_{10}$ (as called floating dust in GB 3095-82). The 24 h average concentrations of PM$_{10}$ in all three standards are the same. However, an interesting phenomenon is that the yearly average for PM$_{10}$ in the standard GB 3095-1996 is more relaxed compared with those in the standard GB 3095-1982. Specifically, the threshold concentration of PM$_{10}$ changed from 20 to 40 μg/m$^3$ for Grade-I, from 60 to 100 μg/m$^3$ for Grade-II, and from 100 to 150 μg/m$^3$ for Grade-III, respectively. This is not consistent with the general trend that the new standard usually becomes more stringent when it replaces the old one, since the PM emissions in China have trended from coarse particles to fine particles with increased PM$_{10}$ emissions seen during 1982-1996. Additionally, the loosening of the PM$_{10}$ concentration threshold in the standard GB 3095-1996 is also related to the monitoring and assay methods. PM$_{10}$ has the same annual concentration values (40 μg/m$^3$) for Grade-I in the standards GB 3095-2012 and GB 3095-1996, while it has the yearly average value of 70 μg/m$^3$ for Grade-II in the standard GB 3095-2012. This value is more severe than those in the standard GB 3095-1996 (100 μg/m$^3$) but slightly more mild than those in the standard GB 3095-1982 (60 μg/m$^3$).

### 2.2.2. Gaseous pollutants

The real-time concentration of gaseous pollutants such as sulphur dioxide (SO$_2$), nitrogen oxide (NO$_x$), and carbon monoxide (CO) were removed in the standard GB 3095-1982 while their 1-h average were included in the standards GB 3095-1996 and GB 3095-2012.
Additionally, 8-h average values for gaseous pollutant ozone (O$_3$) was added in the latest standard GB 3095-2012. NO$_x$ was first introduced in the standard GB 3095-1982 as a member of total nitrogen pollutants. However, NO$_x$ contains the nitrogen oxides with different valences and the most important species are NO and NO$_2$. These two compounds usually have different environmental toxicological and health effects. It has been demonstrated that the toxicity of NO$_2$ is five times that of NO and the concentration in the atmosphere is twice that of NO (AAQSrG 1995). In view of the strong and special toxicity, NO$_2$ was used as a separate item in the standard GB 3095-1996 but NO$_x$ was still retained. That actually means that NO$_2$ and NO$_x$ coexist in the standard GB 3095-1996. This situation lasted to year 2000 when NO$_x$ was removed from the amendment of standard GB 3095-1996 in the year 2000. Although the threshold of NO$_2$ was determined according to the proportion of NO$_2$ in NO$_x$ (AAQSDG2010), NO$_2$ still cannot accurately and completely reflect the total NO$_x$ pollution in the regions of China where NO concentrations are relatively high. Therefore, the role of NO$_x$ items cannot be neglected. In the newest standard GB 3095-2012 NO$_x$ was reused as an additional item.

The real-time concentration and Grade-III concentration of CO were not used any longer in standards GB 3095-1996 and GB 3095-2012 but the Grade-I and Grade-II CO concentration thresholds were used with the same value in all of these standards.

O$_3$ accounts for 90% of photochemical oxidants, and the advanced methods developed over the past two decades are able to be successfully used for accurate analysis of O$_3$ (AAQSrG 1995). For this reason, O$_3$ was used to replace the photochemical oxidant designation Ox. O$_3$ concentration threshold was actually loosened from the standard GB 3095-1996 amendment, but its maximum 8-h average concentration was included in the standard GB 3095-2012.

Some regional pollutants such as heavy metals were not included in the primary items. The concentration of lead (Pb) in the air increased with increasing use of motor vehicles. The standard for Pb was first introduced in the standard GB 3095-1996. In the standard GB 3095-2012 the quarterly average of Pb decreased from 1.5 to 1.0 μg/m$^3$ and the yearly average decreased from 1.0 to 0.5 μg/m$^3$. Additionally, Benzo(a)pyrene (B[a]P) was also one of the most carcinogenic compounds. In order to reduce the incidence of lung cancer, the
B. ZHAO ET AL.

24-h average concentration of B[α]P was decreased from 0.01 to 0.0025 μg/m³ while the yearly average was added in the new standard. Besides the mandatory standards for normal pollutants, there are reference standards for Cadmium (Cd), Mercury (Hg), Arsenic (As), chromium VI (Cr(VI)), and F. The reference thresholds of Pb, B[α]P, and F were formulated according to the health risk assessment results and occupational health thresholds based on the WHO guidelines.

3. Comparison with other national and organizational standards

Although there are great differences between nations in ambient air quality, levels of pollution, and levels of economic, technological, and policy development, it is necessary to compare China’s AQQS with those of other developed nations and important organizations. Specifically, we compared the US National Ambient Air Quality Standard (NAAQS) (US EPA 2010; Suh et al. 2000), EU’s Air Quality Framework Directive (AQFD) (EC, 2008; EEA 2012), Japan’s Environmental Quality Standards (EQSs) (Kawamoto et al. 2011), and the WHO’s air quality guidelines (AQGs). The purpose of the comparison is to offer a positive reference for further amendments and extensions in the future.

According to the current standards, the US’s NAAQS includes primary and secondary standards. However, only SO₂ and PM₂.₅ have separate secondary standards (US EPA 2010). The EU’s AQFD limit values and target values are formulated for their member countries. Limited values are mandatory standards while target values are performed within the deadline (EC 2008). Hence, we just select the primary pollutants in the US’s NAAQS, EU’s AQFD, Japan’s EQSs and WHO’s AQGs for comparison, as shown in Table 2. Note that the units in all standards were transformed into the unit μg/m³ to ensure uniformity. Also note the SPM in the Japan’s EQSs SPM is about PM₁₀ according to the definition of PM₁₀ or PM₂.₅ (Kawamoto et al. 2011).
4. Discussion

4.1. Motives and challenges

4.1.1. Atmospheric environment situation
Currently, the coal-dominated energy structure is unlikely to be fundamentally changed in the near future with a contribution of 65–70% to primary energy production in China. According to the National Statistics Annual Report for Environment (MEP 2000–2012), coal consumption in China increased from 1.42 billion tons in 2001 to 3.56 billion tons in 2010. As a result, air pollution caused by massive combustion, especially smoke pollutant emissions, became a serious problem, as illustrated in Figure 2 (MEP 1989–2012; MEP 1995–2012). In particular, the characteristics of ambient air pollution in China are changing and presented new developments in the last 10 years: soot emissions were effectively reduced, \( \text{SO}_2 \) emissions stabilized, and \( \text{NO}_x \) emissions increased significantly. The changes can be partly attributed to differences in requirements of the standards. Efforts has to be paid to modifying the standards to enhance adaptability to the changing environmental status. In addition, the amount of automobiles increased sharply in the last decade. Statistical data showed that there were up to 250 million motor vehicles in China by the end of October 2013 among which 53.9% (135 million vehicles) were automobiles. Private cars have increased about 13 times over the past 10 years totaling more than 85 million (MPSTMB 2013). As a result, particulate matter and \( \text{NO}_x \) pollutants emitted from motor vehicles has significantly contributed to the total pollutant emissions. According to the China Environmental Quality Bulletin (MEP 1989–2012), vehicles emitted up to 6.375 and 6.4 million tons of \( \text{NO}_2 \) in 2011 and 2012, respectively, representing about 25% of the total \( \text{NO}_2 \) emissions in China. This indicates that mobile sources have become the most important \( \text{NO}_2 \) emission source after industrial sources. Increasing pollutant emissions from mobile sources makes it necessary to change the items in the ambient air quality standards from coal-smoke-based to a model with more integrated considerations.

Figure 3 presents the distribution of the major air pollutants (PM, \( \text{SO}_2 \) and \( \text{NO}_x \)) during 1989–2012 in China reported by China Environmental Quality Bulletin and Chinese Research Academy of Environmental Science (CRAES 2010) based on continuous on-site monitoring. The annual average concentrations of these pollutants gradually decreased during 1989–2012 when the ambient air quality standards became more rigorous after two amendments. This demonstrates that the appropriate environmental quality standards are effective in improving ambient air quality. Therefore, it is necessary to establish an institutional rule which would require an update of the ambient air quality standard in order to keep abreast to new developments relating to pollutant emission control. Moreover, in the past five years, China’s combined pollution in some cities presented an increasing trend. Regional acid rain, haze and photochemical smog pollution occurred frequently. It has become very important and urgent to amend the environmental quality standards in particular for pollutant items to reduce the combined air pollution, because the legacy standards are not able to be used to completely characterize the physicochemical composition and properties of combined pollution.

Overall, the formulation and amendment of ambient air quality standards depend on changes of the environmental situation. The concentration of criteria pollutants in the ambient air quality standard is required to match the development of environmental situation, e.g. \( \text{SO}_2 \) were the same in all standards GB 3095-2012, GB 3095-1996 and GB 3095-1982 while
NO$_2$ was added and NO$_x$ and loosen flexibly in the standard GB 3095-2012. Additionally, some pollutant items became refined. For instance, the evolution of dust emissions from TSP to PM$_{10}$ and then to PM$_{2.5}$ reflects this change.

4.1.2 Public health protection

One of the important targets of the amendment to the ambient air quality standard is to protect public health. Large numbers of epidemiological investigations have presented evidence on health damage caused by ambient air pollutants to demonstrate the correlation between air pollution and mortality/morbidity (Dockery et al. 1993; Pope et al. 1995; Brunekreef & Holgate 2002). China’s AAQ is no exception to this target as it is highly related to Chinese public health.

Ambient air pollutants (particularly PM, SO$_2$, NO$_x$, and O$_3$) and their effects on public health in China has been recognized since the 1990s, focusing mainly on pathogenicity. This has included investigations of their effects on mortality, the respiratory system, the cardiovascular system, the immunologic system, and the nervous system. For instance, a report of the global burden of disease between 1991 and 2010 showed that PM$_{2.5}$ was the fourth highest health risk factor in China with around 20% of lung cancer cases considered to be related to PM$_{2.5}$ pollution (Lim et al. 2012; Kan & Wu 2013). Additionally, a Chinese 16-city combined analysis showed significant associations of PM$_{10}$ with mortality. Specifically, a 10 μg/m$^3$ increase in 2-day moving-average PM$_{10}$ was associated with a 0.35% increase in total mortality, a 0.44% increase of cardiovascular mortality, and a 0.56% increase of respiratory mortality (Chen et al. 2012). Furthermore, there was a great health-based economic burden caused by ambient air pollution. In 2004 the economic burden of disease associated with PM$_{10}$ pollution was approximately 233.4 billion CNY. In particular, the large cities in China such as Beijing, Shanghai and Guangzhou had relatively high economic losses (Kan & Chen 2004; Zhang et al. 2008). The World Bank’s assessment on the economic loss caused by air pollution in China showed that the health damage associated with ambient air pollution accounted for 3.8% of GDP, of which 75% is due to premature death (World Bank 2007). Therefore, the reduction of pollutant emissions and control of the total amount of pollutants in China

Figure 4. Percentage distribution of China’s urban air quality status from 1999 to 2012.
using more stringent air quality standards is one effective option. As expected, it would be able to decrease both direct mortality/morbidity and indirect economic burden for China.

### 4.1.3. Challenges of adopting the new standard

Inevitably, the formation and implementation of the new standard received many challenges on different aspects. From the perspective of the conflicts between economic development and Energy Conservation & Emission Reduction (ECER), it is required for the governments to strengthen and improve macro-control efforts. These efforts include development of strategic emerging industries, promotion of industrial restructure, strengthening of the supervision and management of ECER, and prevention to overcapacity. This will be a long-term, tortuous and arduous task in China. On the other hand, the increases of the concentration levels and thresholds for ambient air pollutants in the new standard forces the currently-used industrial technology to be eliminated, implying that the previously-qualified emission sources maybe unqualified. In addition, the number of cities involved in the assessment is now increasing. More and more cities met the requirement of Grade-II in the old standard (GB 3095-1996) due to continuous efforts in technological improvement and pollution control. For example, the compliance rate was only 33.1% in 1999 but increased to 91.4% in 2012 (Figure 4). However, if evaluated according to GB 3095-2012, the percentage of compliance cities in 2012 would be just 40.9%. Therefore, it requires the companies involved to balance the economic and social benefits, to increase economic costs and technological transformations, and to implement the ECER obligations.

The ambient air quality standard is bound to play an important role in prevention of air quality deterioration and in the improvement of air quality management in China (You 2014; Chen et al. 2016; Sheng & Tang 2015; You 2015). However, under the conditions of incomplete legislation and enforcement, the implementation of the new standard may be faced with conflicts. Moreover, to ensure adoption of the newest standard, it not only requires to take more aggressive measures for improvement of air quality (Liu et al. 2013; Zhong et al. 2013), but also requires the public to establish the concepts of environmental protection and green consumption. This objective is at least difficult to achieve and will take a long time.

From the perspective of environmental management, the new standard transitions the management mode from overall-volume to fine, from local to regional, and from individual pollutant to multi-pollutant integrated controls (Hu et al. 2015). It is not only required to prevent and control stationary emission sources (e.g. in industry, agriculture, and commerce) and the mobile emission sources (e.g. in transportation), but is also required to change the public’s lifestyles and consumption patterns. It will also face challenges from both industry and the public.

### 4.2. Setting of guideline values

In the last decade, a distinguishing feature of particle emissions from stationary and mobile sources in China was fine and ultrafine due to improvements of both industrial technologies (e.g. power, material, chemical and metallurgical industries) and fugitive dust management. These technologies make it possible to reduce emissions of large particles. Hence, it is necessary and feasible to decrease and even abolish the TSP concentration threshold. Meanwhile, PM$_{10}$ from industrial sources and motor vehicle exhaust has been regarded as the most important particulate pollutant. Considering the economic and technological
level, concentration thresholds for Grade I and II for PM$_{10}$ has not been revised. Most significantly, the latest standard introduced a requirement of control for the pollutant item PM$_{2.5}$ and reduction of PM$_{2.5}$ has become an urgent problem in the past five years. The Grade-II threshold of PM$_{2.5}$ in the standard GB 3095-2012 was recommended according to the WHO standard, which was comprehensively considered to match the present requirements of economic development and air quality management. However, it should be noted that a complete standard system for PM$_{2.5}$, especially relating to its physicochemical characteristics, theoretical modelling, and health effect (Xu et al. 2013), still needs to be further developed.

The standards for SO$_2$ have not changed except that the yearly average in the standard GB 3095-1982 was replaced with 1-h averages in standards GB 3095-1996 and GB 3095-2012. Also, the Grade-III is no longer used in the standard GB 3095-2012. Actually, the determination of SO$_2$ standards are associated with its effect on environmental health. SO$_2$ concentrations lower than the Grade-I standard have almost no harmful effects on human and animal health while those higher than the Grade-II standard were found to increase the risk of asthma attacks (Yang 1986). According to a pollution survey and experimental study in some regions of China, children’s respiratory disease risk significantly increased after long-term exposure to SO$_2$ concentrations between 100 and 250 μg/m$^3$ (Tang 1984). Besides the significantly increasing hospitalization rate caused by upper respiratory tract infections (Levetin & Van de Water 2001; Hajat et al. 2002; Heinrich et al. 2002; Frye et al. 2003), SO$_2$ concentration has a positive correlation to daily mortality from cardiovascular disease in China (Venners et al. 2003).

The determination of standards for NO$_x$ is a complicated and repetitious process but it improves the objectivity, pertinence, and validity of the assessment of NO$_x$ pollution. Moreover, the standard GB 3095-2012 for NO$_x$ (1-h average) appears to be looser than in standard GB 3095-1996 but the 24 h and yearly averages for NO$_2$ have not changed. Additionally, standard GB 3095-2012 has a more severe 24 h average for NO$_x$ than the standard GB 3095-1982.

Usually, the determination of CO threshold values depends on Carboxyhemoglobin (COHb), which is usually selected as the sensitivity index to evaluate the impacts of CO on human health. The normal endogenous COHb in the human body is 0.1–1%. Concentrations of CO in air under 4 000 μg/m$^3$ are considered to be physiologically safe to human blood (Tang 1984).

Ozone precursor emissions have recently been increasing in China. Investigations in exposure indicated that concentrations of ozone from 200 μg/m$^3$ to 500 μg/m$^3$ produce harmful effects (Yang 1986). Therefore, the standard for O$_3$ was tightened to comply with a long-term perspective (AAQSDG 2010). For instance, the Grade-II standard for O$_3$ was set at the same value (160 μg/m$^3$) as the WHO’s standard.

4.3. Difference analysis of the newest standard

Compared with US’s NAAQS, China’s AAQS has tight Grade-I but loose Grade-II standards for SO$_2$ (1-h average value). The standards for CO (1-h value) of both China’s AAQS Grade-I and II are more severe than the US’s NAAQS. The standard for PM$_{10}$ (24-h average) of Grade-II is the same as those of the US’s NAAQS, suggesting the corresponding Grade-I standard is tighter than the latter. There are the same standards for PM$_{2.5}$ (both 24-h and yearly average) between the US’s NAAQS and China’s AAQS Grade-I but the US’s NAAQS for PM$_{2.5}$ (yearly average) was revised in 2013 to 12 μg/m$^3$ from 15 μg/m$^3$ in 2006 (Sharma & Mehta 2011;
The 24-h average standard value for NO$_2$ in China’s AAQS was approximately equal to those of US’s NAAQS, but the yearly average standard value is significantly lower than the US’s NAAQS. The standard for O$_3$ (8-h average) of China’s AAQS Grade-II is similar to those of the US’s NAAQS. Moreover, taking into account the effects of weather and emergencies, the US’s NAAQS includes not only the concentration thresholds but also the statistical requirements, including the number of exceeded standards and concentration percentiles for each year (McClellan 2002).

Comparing the EU’s AQFD and China’s AAQS indicates that the EU’s AQFD has a moderate standard for SO$_2$ (1-h average). It has the same standard for CO (8-h average) with those of China’s AAQS for both Grade-I and II. Also, the standard for PM$_{10}$ (24-h average) of the EU’s AQFD is the same as those of China’s AAQS Grade-I, suggesting it is more severe than those of China’s AAQS Grade-II. The 24-h average standard for PM$_{2.5}$ is relatively tight while the yearly-average standard is relatively loose compared with China’s AAQS Grade-I but still slightly more severe than China’s AAQS Grade-II. The standards for NO$_2$ (yearly average) are the same but the EU standard for O$_3$ (8-h average) is between that of China’s AAQS Grade-I and II.

Also, from the comparison between Japan’s EQSs and China’s AAQS, it can be observed that the Japanese standards for SO$_2$ (both 1-h and 24-h averages) are also moderate as similar to the EU’s AQFD standard, but is much higher for the CO (24-h average). The Japanese standard for SPM (24-h average) is between the standards of China’s AAQS Grade-I and II but has the same standards for both 24-h and yearly average PM$_{2.5}$ values. Particularly, the standard for NO$_2$ (24-h average) is not a constant threshold but a concentration range which is generally loose. The standard O$_3$ (as O$_2$) has a more severe standard with 1-h average but unfortunately does not have an 8-h average standard.

The newest China’s AAQS (GB 3095-2012) actually builds on the WHO’s AQG Interim Targets. WHO estimated that some 80% of air pollution-related premature deaths were due to ischaemic heart disease and strokes, 14% of deaths were due to chronic obstructive pulmonary disease or acute lower respiratory infections, and 6% of deaths were due to lung cancer (WHO 2014). Therefore, the 2005 WHO’s AQG offered global guidance on thresholds and limits for key air pollutants that pose health risks. The WHO’s AQG gave the most severe requirement of the standard for SO$_2$ (24-h average). Moreover, it specifically provided the standard for 10 min average-based SO$_2$ since studies indicated that a proportion of people with asthma experience changes in pulmonary function and respiratory symptoms after 10 min of exposure to SO$_2$ (WHO 2006). Because of this, the WHO suggests that a SO$_2$ concentration of 500 μg/m$^3$ should not be exceeded over average periods of 10 min duration. The standard for CO (1-h average) was not given but the standards for PM$_{10}$ and PM$_{2.5}$ required by WHO’s AQG are more severe than those required by China’s AAQS as there is a close and quantitative relationship between exposure to high concentrations of small particulates (PM$_{10}$ and PM$_{2.5}$) and increased mortality or morbidity, both daily and over time. The WHO’s AQG estimated that by reducing PM$_{10}$ pollution from 70 to 20 μg/m$^3$, air pollution-related deaths could be reduced by around 15% (WHO 2014). Also, there are the same standards for NO$_2$ (1-h and yearly average) and O$_3$ (8 h average) between WHO’s AQG and China’s AAQS. This is based on the fact that the WHO has reported that daily mortality and heart disease rises by 0.3% and 0.4%, respectively, per 10 μg/m$^3$ increase in O$_3$ exposure. Also, symptoms of bronchitis in asthmatic children increases in association with long-term exposure to NO$_2$ (WHO 2014).
Overall, all quality standards for air pollutants vary between nations or organizations. In particular, the WHO’s AQG, being famous for public health assessment, is the most severe among all standards. China’s new AAQS shows comparability to the WHO’s standard to a considerable extent although there are some differences in the concentration thresholds.

It should be noted that human, animals, and materials are usually exposed in the atmosphere with mixed pollutants rather than isolated pollutants. Like Japan’s EQSs (Kawamoto et al. 2011), China’s current standard has no formulated multi-pollutant standard because of the lack of scientific research data about health effects of multi-pollutants on human health. However, many studies on this issue have been done in recent years. In 2008, The US Environmental Protection Agency (US EPA) published a technical report to facilitate a common understanding of multi-pollutant concepts (US EPA, 2008). Some specialists have carried out beneficial exploration and research on these issues such as how to set ambient air quality standards for multi-pollutants, models of evaluating cumulative health impacts of pollutants, and implementation strategies for air quality management with multi-pollutants (USEPA 2008; Dominici et al. 2010; Hidy & Pennell 2010; Cao et al., 2013; Plaia et al., 2013).

4.4. Improvement of the newest standard in assay and assessment

In addition to the amendments of pollutant item and threshold concentration, GB 3019-2012 also introduced new and automated assay methods, improved the data validity requirements and used more advanced and accurate AQI to assess the air quality. From this point of view, it can be inferred that new approaches and techniques will be incorporated in future Chinese ambient air quality standards. With the development of modern physical chemistry and technological commercialization will allow the update of assay standards to be faster and more convenient. Theoretical modelling diversification and objective, multi-dimensional approaches will be important development directions of the ambient air quality assessment methods in the long term. For instance, methods using improved indexes or new mathematical algorithms may be included in the standards as they can provide more comprehensive and reasonable predictions and impact assessments of health risk (Zhang et al. 2009; Sowlat et al. 2011; Zhen & Yin 1984; Wong et al. 2012; Chen et al. 2013). Additionally, China is going to gradually improve quality assurance and quality control as planned in the “12th Five-Year Plan” for Environmental Protection Standards (MEP 2013) to improve the data validity requirements in the future standards.

5. Conclusions and prospects

China’s ambient air quality standard GB 3095 was established in 1982 and amended three times (in 1996, 2000, and 2012) over the past 30 years. Most importantly, owing to changes in air pollution characteristics and new air quality requirements, the newest standard GB 3095-2012 added PM$_{2.5}$ items, tightened the concentration thresholds of PM$_{10}$ and NO$_2$, and cancelled the Grade-III standards for air pollutants.

Based on development and comparison, the standard GB 3095-2012 was found to be comparable with those of some developed countries or organizations in pollutant items and concentration thresholds although some important pollutants (e.g. dioxin, volatile organic compound (VOCs)) and compliance deadlines have not yet been exactly introduced and
determined. Additionally, the standard does not have a deadline for areas with serious pollution, which reflects the lack of effective management framework.

To ensure the implementation of the latest standard (GB 3095-2012) more effectively, further support of macro policy and technical measures are needed, e.g. The macro policies, “Air Pollution Prevention and Control Action Plan-China Clean Air Updates” (2013), marked that the China’s air prevention was gradually transforming from total amount control of air pollution into improvement of environmental quality. Correspondingly, specific technical measures were also taken including comprehensive improvements of air pollution sources, process control, and terminal reduction. These measures include using high-efficiency and ultra-low combustion approaches to improve the coal-fired boiler system, using pollution prevention and control systems to control motor vehicle emissions, and using advanced air pollution monitoring methods and technologies to improve the reliability for air quality assessment. However, the implementation of the new ambient air quality standards is a great, complex, and systemic project which will inevitably be faced with the contradictions of economic development, energy consumption, and public health.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

This work was jointly sponsored by National Natural Science Foundation of China grant number [50806049]; [51278095] and The Hujiang Foundation of China grant number [D14001].

**References**

[AAQSDG] The Ambient Air Quality Standard Drafting Group. 2010. The preparation instructions of ambient air quality standard (exposure draft). Beijing, Ministry of Environmental Protection of the People’s Republic of China.

[AAQRSRG] The Atmospheric Air Quality Standards Revision Group. 1995. The content and basis of revising atmospheric environment quality standard. Environ Monit China. 1:2–6.

Beyer S. 2006. Environmental law and policy in the People’s Republic of China. Chin J Int Law. 5:185–211.

Brunekreef B, Holgate ST. 2002. Air pollution and health. Lancet. 360:1233–1242.

Cao J, Chow JC, Lee FSC, Watson JG. 2013. Evolution of PM2.5 measurements and standards in the U.S. and future perspectives for China. Aerosol Air Qual Res. 13:1197–1211.

Chan CK, Yao XH. 2008. Air pollution in mega cities in China. Atmos Environ. 42:1–42.

Chen BH, Hong CJ, Kan HD. 2004. Exposures and health outcomes from outdoor air pollutants in China. Toxicology. 198:291–300.

Chen K, Dong HY, Guo SH. 2011. Comparison of China’s ambient air quality standards with foreign standards. Environ Sustainable Dev. 1:47–50.

Chen Q. 2012. The sustainable economic growth, urbanization and environmental protection in China. Forum Public Policy A J Oxford Round Table. 2012:1.

Chen R, Kan H, Chen B. 2012. Association of particulate air pollution with daily mortality: the China air pollution and health effects study. Am J Epidemiol. 175:1173–1181.

Chen W, Tang H, Zhao H. 2016. Urban air quality evaluations under two versions of the national ambient air quality standards of China. Atmos Pollut Res. 7:49–57. Available from: http://dx.doi.org/10.1016/j.apr.2015.07.004

Chen ZM, Ma HM, Xie W. 2008. The comparison of China’s ambient air quality standards with the WHO’s latest atmospheric quality benchmark. J Environ Health. 12:1103.
Chen RJ, Wang X, Meng X, Hua J, Zhou ZJ, Chen BH, Kan HD. 2013. Communicating air pollution-related health risks to the public: An application of the air Quality Health Index in Shanghai. China. Environ Int. 51:168–173.

[CRAES] Chinese Research Academy of Environmental Science. 2010. Explanation for compiling ambient air quality standard. Available from: Web site of MEP http://www.zhb.gov.cn/gkml/hbb/bgth/201011/W0201011130374443039627.pdf

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr, Speizer FE. 1993. An association between air pollution and mortality in six U.S. cities. N Engl J Med. 329:1753–1759.

Dominici F, Peng RD, Barr CD, Bell ML. 2010. Protecting human health from air pollution. Epidemiology. 21:187–194.

[EC] European Commission. 2008. Air quality standards. [cited 2013 May 1]. Available from: http://ec.europa.eu/environment/air/quality/standards.html

[EEA] European Environment Agency. 2012. Air quality in Europe – 2012. Available from: http://www.eea.europa.eu/publications/air-quality-in-europe-2012. (Report. ISSN 1725-9177)

[EPO] Environment Protection Office. 1982. Ambient air quality standard. (Document GB 3095-82) (in Chinese).

Eseworthy E. 2013. Air quality: EPA's 2013 changes to the particulate matter (PM) standard. Congressional Res Serv. 5–25.

Fang M, Chan CK, Yao XH. 2009. Managing air quality in a rapidly developing nation: China. Atmos Environ. 43:79–86.

Frye C, Hoelscher B, Cyrys J, Wjst M, Wichmann H, Heinrich J. 2003. Association of lung function with declining ambient air pollution. Environ Health Perspect. 111:383–388.

Hajat S, Anderson HR, Atkinson RW, Haines A. 2002. Effects of air pollution on general practitioner consultations for upper respiratory diseases in London * Commentary. J Occup Environ Med. 59:294–299.

Heinrich J, Hoelscher B, Frye C, Meyer I, Pitz M, Cyrys J, Wjst M, Neas L, Wichmann H. 2002. Improved air quality in reunified Germany and decreases in respiratory symptoms. Epidemiology. 13:394–401.

Hidy GM, Pennell WT. 2010. Multipollutant air quality management. J Air Waste Manage Assoc. 60:645–674.

Hu J, Ying Q, Wang Y, Zhang H. 2015. Characterizing multi-pollutant air pollution in China: comparison of three air quality indices. Environ Int. 84:17–25.

Kan H, Chen B. 2004. Particulate air pollution in urban areas of Shanghai, China: health-based economic assessment. Sci Total Environ. 322:71–79.

Kan HD, Wu TC. 2013. Ambient air pollution and human health in China: the past and future. J Second Military Med Univ. 33:697–699 (in Chinese).

Kawamoto T, Pham TTP, Matsuda T, Oyama T, Tanaka M, Yu HS, Uchiyama I. 2011. Historical review on development of environmental quality standards and guideline values for air pollutants in Japan. Int J Hyg Environ Health. 214:296–304.

Levetin E, Van de Water P. 2001. Environmental contributions to allergic disease. Curr Allergy Asthma Rep. 1:506–514.

Li JJ, Shen YQ. 2003. Comparison of ambient air quality standard between China and America. Admin Tech Environ Monit. 6:24–26.

Lim SS, Vos T, Flaxman AD. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet. 380:2224–2260.

Liu H, Wang X, Zhang J, He K, Wu Y, Xu J. 2013. Emission controls and changes in air quality in Guangzhou during the Asian Games. Atmos Environ. 76:81–93.

McClellan RO. 2002. Setting ambient air quality standards for particulate matter. Toxicology. 181-182:329–347.

[MEP] Ministry of Environmental Protection of China. 1989–2012. China Environmental Quality Bulletin. Beijing: China Environmental Science Press, Ministry of Environmental Protection of the People's Republic of China.
[MEP] Ministry of Environmental Protection of China. 1995–2012. National statistics bulletin for environment. Beijing: China Environmental Science Press, Ministry of Environmental Protection of the People's Republic of China.

[MEP] Ministry of Environmental Protection of China. 2000–2012. Annual statistic report on environment in China. Beijing: China Environmental Science Press, Ministry of Environmental Protection of the People's Republic of China.

[MEP] Ministry of Environmental Protection. 2012a. Ambient air quality standards. (Document GB 3095-2012).

[MEP] Ministry of Environmental Protection. 2012b. Technical regulation on ambient air quality standards index (on trial). (Document HJ 633-2012).

[MEP] Ministry of Environmental Protection. 2013. ‘12th Five-Year Plan’ for environmental protection standards. Beijing: Ministry of Environmental Protection of the People's Republic of China.

[MOST & MEP] Ministry of Science and Technology and Ministry of Environmental Protection. 2012. The present situation and prospect of atmospheric environmental standards system in China. Dalian.

[MPSTMB] Ministry of Public Security Traffic Management Bureau. 2013. China private cars increased by 13 times in the last decade. Retrieved from: web site of The Central People's Government of the People's Republic of China http://www.gov.cn/jrzg/2013-12/01/content_2539481.htm

Plaia A, Di Salvo FD, Ruggieri M, Agró G. 2013. A multisite-multipollutant air quality index. Atmos Environ. 70:387–391.

Pope CA, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW Jr. 1995. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Respir Crit Care Med. 151:669–674.

Saikawa E, Urpelainen J. 2014. Environmental standards as a strategy of international technology transfer. Environ Sci Policy. 38:192–206.

[SEPA] State Environmental Protection Administration. 1996. Ambient air quality standards. (Document GB 3095-1996). Beijing: State Environmental Protection Administration of the People's Republic of China.

[SEPA] State Environmental Protection Administration. 2000. Ambient air quality standards. (Document GB 3095-1996 (Amendment list)). Beijing: State Environmental Protection Administration of the People's Republic of China.

Sharma V, Mehta P. 2011. Comparing air quality standards in developed, developing, and underdeveloped nations and its relative analysis with Indian standards. J Chem Biol Phys Sci. 1:415–424.

Sheng N, Tang UW. 2015. The first official city ranking by air quality in China–A review and analysis. Cities. In press. http://dx.doi.org/10.1016/j.cities.2015.08.012.

Siddiqi TA, Chong-Xian Z. 1984. Ambient air quality standards in China. Environ Manage. 8:473–479.

Sowlat MH, Gharibi H, Yunesian M, Tayefeh Mahmoudi M, Lotfi S. 2011. A novel, fuzzy-based air quality index (FAQI) for air quality assessment. Atmos Environ. 45:2050–2059.

Suh HH, Bahadori T, Vallarino J, Spengler JD. 2000. Criteria air pollutants and toxic air pollutants. Environ Health Perspect. 108:625–633.

Tang RR. 1984. Discussion of classification principles for atmospheric environmental quality standards in China. Environ Prot Sci. 3:39–47.

Tang XY. 2004. The characteristics of urban air pollution in China. In: Urbanization energy, and air pollution in China: the challenges ahead – Proceedings of a Symposium. Washington (DC): The National Academies Press; p. 47–54.

[USEPA] United States Environment Protection Agency. 2008. The multi-pollutant report: technical concepts & examples. Available from: http://www.epa.gov/airtrends/specialstudies/20080702_multipoll.pdf

[USEPA] United States Environment Protection Agency. 2010. National Ambient Air Quality Standards (NAAQS). Available from: http://www3.epa.gov/tnn/naaqs/criteria.html

Venners SA, Wang B, Peng Z, Xu Y, Wang L, Xu X. 2003. Particulate matter, sulfur dioxide and daily mortality in Chongqing, China. Environ Health Perspect. 111:562–567.

Wang S, Hao J. 2012. Air quality management in China: issues, challenges, and options. J Environ Sci. 24:2–13.
Wang ZS, Wu T, Che F, Wang S, Zhou YH, Qian XP, Wu XF. 2010. Comparison between domestic and international ambient air quality standards. Res Environ Sci. 3:253–260.

[WHO] World Health Organization. 2014. Ambient (outdoor) air quality and health. [revised 2014 Mar]. http://www.who.int/mediacentre/factsheets/fs313/en/ (Fact sheet No. 313).

Wong TW, Tam WWS, Yu ITS, Lau AKH, Pang SW, Wong AHS. 2012. Developing a risk-based air quality health index. Atmos Environ. 76:52–58.

World Bank. 2007. Cost of pollution in China: economic estimates of physical damages. Washington (DC): World Bank.

World Health Organization. 2006. Air quality guidelines-global update 2005. Bonn: WHO Regional Office for Europe.

Xu YR, Wang DX, Zhang JW, Zhang YQ, Han RB, Shen JY, Yu XC. 2013. General situation for the hazards, control and evaluation standard system of PM_{10} and PM_{2.5}. Occup Health. 1:117–119.

Yang YF. 1986. Try to talk about the basis and principles of formulating air quality standards in our country. Chongqing Environ Prot. 2:26–32.

Yi HH, Hao JM, Tang XL. 2007. Atmospheric environmental protection in China: current status, developmental trend and research emphasis. Energy Policy. 35:907–915.

You M. 2014. Addition of PM_{2.5} into the national ambient air quality standards of China and the contribution to air pollution control: the case study of Wuhan, China. Sci World J. 2014:1–10. doi:10.1155/2014/768405

You M. 2015. Changes and challenges of the 2014 revised environmental protection law in the context of China's five fundamental transitions. Hong Kong Law J. 2:621–650.

Zhang F, Zhang PL, Lv ZY, Wang P. 2009. Assessment of urban air quality based on cloud models. Environ Sci Technol. 6:160–164.

Zhang JZ, Ouyang ZY, Miao H, Wang XK. 2011. Ambient air quality trends and driving factor analysis in Beijing, 1983–2007. J Environ Sci. 23:2019–2028.

Zhang LH, Zhao LY. 2007. The historical evolution of China’s environmental protection policy from 1953 to 2003. Res Chin Econ Hist. 4:63–72.

Zhang M, Song Y, Cai X, Zhou J. 2008. Economic assessment of the health effects related to particulate matter pollution in 111 Chinese cities by using economic burden of disease analysis. J Environ Manage. 88:947–954.

Zhang QF, Crooks R. 2012. Toward an environmentally sustainable future: country environmental analysis of the People's Republic of China. Philippines: Asian Development Bank.

Zhen JX, Yin LG. 1984. Application of fuzzy cluster analysis in evaluation of regional environmental quality. J East China Normal Univ. 3:106–112.

Zhong LJ, Louie PKK, Zheng JY, Yuan ZB, Yue DL, Lau AKH, Ho JWK. 2013. Science-policy interplay: air quality management in the Pearl River Delta region and Hong Kong. Atmos Environ. 76:1–8.