

# Ambient air pollution in China poses a multifaceted health threat to outdoor physical activity

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## INTRODUCTION

While outdoor physical activity has been shown to promote health and well-being,<sup>1,2</sup> exercising in environments with high levels of air pollution can increase the risk of health problems ranging from asthma attacks to heart or lung pathologies.<sup>3,4</sup> The interaction of these two phenomena is of specific significance in China, where outdoor physical activity has been a traditional practice but where rapid industrialisation has led to major degradation of the environment. This situation raises the spectre of an emergent major public health crisis in the most populous country in the world.

## HEALTH-ENHANCING PHYSICAL ACTIVITY

There is clear and compelling evidence that regular physical activity produces substantial physical and mental health benefits, including improved health-related quality of life and decreased risk of premature morbidity and mortality.<sup>1,5,6</sup> However, it is important to note that in contrast to the commodification of exercise in many western industrialised nations, where exercise for health is often carried out in indoor facilities such as fitness centres, the physical and mental health benefits of physical activity can be achieved outdoors in settings such as community green spaces, parks and trails.<sup>1,2</sup> Therefore, public health policies designed to encourage participation in physical activity should focus on outdoor settings for promoting public health and improving overall quality of life,<sup>5-8</sup> because outdoors settings can accommodate a much larger scale population involvement at substantially lower costs than can physical activity in indoor facilities.

In China, cultural norms, history and public policy have presaged this logistical reality, with a significant portion of the

population, especially in the older demographic, exercising daily in outdoor settings such as parks, village squares and along streets, through leisure walking, jogging, dancing, bicycling or Tai Ji Quan.<sup>9-11</sup> Studies in China have shown a positive association between traditional outdoor-oriented activities and lowered health risks<sup>12</sup> and reduced mortality.<sup>13</sup>

## WORSENING AMBIENT AIR POLLUTION AND THE BURDEN ON HEALTH

Outdoor physical activity, however, can expose people to air pollutants (particulate matter, ozone and nitrogen oxides) that may negatively influence physical activity behaviour<sup>14,15</sup> and lead to adverse health problems such as cardiopulmonary or respiratory disease<sup>3,4,16-18</sup> and other diseases, including lung cancer.<sup>19</sup> For example, in a national cross-sectional study, increased air pollution is found to be associated with reduced leisure-time physical activity among American adults,<sup>14</sup> while other studies in the USA and Europe have found that people with asthma who walked in polluted air exhibited a significant decline in their lung function,<sup>20</sup> children who played multiple sports ( $\geq 3$ ) in high-ozone communities were at increased risk for asthma,<sup>21</sup> and the health benefits for physically active people living in high-walkable neighbourhoods were compromised by the effects of air pollution exposure.<sup>22</sup>

The health implications of increasing amounts of air pollution are a growing concern worldwide. A recent report by the WHO showed that, in 2012, poor air quality was responsible for the loss of seven million lives around the world, with more than one-third of those deaths occurring in the fast-developing nations of Asia.<sup>23</sup> The situation in China is particularly problematic as unprecedented industrial growth and the drive to urbanise has resulted in a growing population<sup>24</sup> with striking rural-urban health disparities,<sup>25</sup> as well as a substantially higher ambient air pollution across the nation.<sup>25-27</sup> Many cities are experiencing regular episodes of serious smog, with extreme PM<sub>2.5</sub> concentrations (particles with a diameter of

2.5  $\mu\text{m}$  or less). For example, on 12 January 2013, Beijing had PM<sub>2.5</sub> readings of 700–900  $\mu\text{g}/\text{m}^3$ ,<sup>28</sup> far beyond the normal value of 500  $\mu\text{g}/\text{m}^3$  indicated in the Air Quality Index (AQI) technical guidelines.<sup>29</sup> Between early 2013 and early 2014, several cities in the north were rated as ‘hazardous’ (<http://aqicn.org/map/>) for months at a time, with extremely poor visibility and school and airport closures. In November 2013, the government reported that only 3 of 74 cities met official minimum standards for air quality.<sup>30</sup> The worsening situation has made some cities ‘uninhabitable for human beings’,<sup>31</sup> with concurrent increases in emergency room visits and hospital admissions due to cardiorespiratory dysfunction.<sup>32,33</sup> Not surprisingly, results from recent research in China have mirrored those from the USA and Europe in showing a clear relationship between poor air quality and increased premature morbidity for conditions such as chronic obstructive pulmonary disease,<sup>34</sup> hypertension,<sup>35</sup> lung cancer,<sup>36</sup> increased premature mortality<sup>37,38</sup> and lowering of overall life expectancy in the general population.<sup>39</sup>

While it is evident that air pollution in China presents a direct threat to public health, especially for those with greater exposure, such as the citizens who exercise outdoors, less obvious is the fact that it also poses an indirect threat because the potential for negative health consequences may ultimately prevent people from engaging in physical activity. This dilemma is particularly evident in the case of those with existing medical conditions, such as asthma, diabetes, heart or lung conditions or lower respiratory tract disease, who could benefit from being active outdoors.

Thus, without substantial changes to the limited environmental standards and regulations currently in force, the air pollution problem in China is likely to worsen in the coming years and, consequently, expose people who routinely engage in outdoor physical activity to increasing health hazards, or, conversely, stop citizens from exercising outdoors completely.

## PUBLIC HEALTH CHALLENGES

There is little doubt that the current air pollution problem in China poses a significant challenge to policymakers responsible for enhancing public health, who have to balance the two interrelated factors of minimising environmental hazards and promoting active lifestyles. The task is exacerbated by the limited research delineating the point at which physical activity may change from being protective against negative health

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consequences associated with living with poor air quality to becoming a risk factor for poor health outcomes from increased exposure to polluted air. Additionally, the stakes are high across the demographic spectrum of China. For example, in schools, indoor activities are relatively uncommon due to the lack of large indoor facilities in most areas, even in major metropolitan cities. Therefore, most physical education curricula are outdoor-oriented. However, severe ambient air pollution may require cancellation of physical activity or sports for schoolchildren, who constitute a major part of an increasing epidemic of overweight and obesity.<sup>40–41</sup> At the other end of the age range, low-tech, group-exercise activities such as walking and dancing are particularly popular among retired residents, most of whom fall into low-income categories and are the least likely to be able to afford access to the limited number of fee-based indoor physical activities. Thus, many Chinese are trapped in a no-win scenario, which is compounded by characteristics including age, socio-economic status and/or existing health conditions that make them more vulnerable to pollution-related health risks.

The conflict for policymakers is highlighted at the individual level, where residents who engage in regular outdoor exercise, but are not aware of the potential negative health impact of doing so, may be exposing themselves to greater risk of developing acute and chronic diseases. Those residents who are aware of adverse health effects from worsening air pollution may be discouraged from continuing their outdoor exercise behaviours, resulting in an increased likelihood of becoming sedentary. These scenarios, coupled with research showing a substantial decline in overall physical activity in China because of increasing affluence,<sup>42–44</sup> point to an epidemic of cardiorespiratory and/or hypokinetic disease that will undermine individual and public health and the country's economy.<sup>45</sup>

Given the potential human and financial costs of failing to act, urgent policy and regulatory action, including improving air quality and providing appropriate guidelines to the public on the risks and benefits of outdoor physical activity under the prevailing environmental conditions, is required.

### GOVERNMENT ACTIONS AND AIR QUALITY MONITORING

Fortunately, ambient air quality can be improved. For example, technological advances and legislative action have

reduced fine particle air pollution and resulted in major improvements in air quality in the UK,<sup>46</sup> and similar changes in air quality have been shown to benefit human health in the USA<sup>18–47</sup> and Europe.<sup>48</sup> However, the regulatory action needed for these changes requires considerable political will and support from the general public, politicians and the scientific community.

In the case of China, increasing public pressure from within and outside the country has positioned the central Chinese government to address the country's air pollution problem more seriously. In 2012, it issued the first National Action Plan on Air Pollution Prevention and Control (2013–2017),<sup>49</sup> which requires that by 2017 PM10 concentrations be reduced by more than 10% compared with the 2012 level, and PM2.5 concentrations in the Beijing-Tianjin-Hebei Area, Yangtze River Delta and Pearl River Delta be decreased by 25, 20, and 15%, respectively. The plan also aims to improve air quality all over China and, in particular, reduce the number of heavily polluted days (AQI value above 200) by reducing coal consumption and investing in alternative energy, public transportation and electric cars. As part of the government's 'war on pollution', in April 2014, the Standing Committee of China's National People's Congress, the country's top legislative body, further bolstered environmental protection by voting to adopt revisions to the Environmental Protection Law,<sup>50</sup> including greater government power to coordinate regional emissions, stronger punitive actions for illegal practices and greater transparency on environmental monitoring of pollution data and impact assessments.

However, any notable improvement in air quality in China will take a substantial amount of time and sustained effort and will need to strike a balance between supporting the economic growth that has precipitated the air pollution crisis and promoting more environmentally friendly industrial and energy technologies. As China continues the industrialisation and urbanisation process that has negatively impacted the environment,<sup>25</sup> it remains to be seen whether any of the central government policies can be effectively implemented in the coming years, especially at the local government level in rural and industrial cities/areas.

Despite the obvious obstacles, some recent responses from large metropolitan cities to the central government's proposals to control air pollution are encouraging. For example, the Beijing city government has proposed a corresponding

Five-Year Clean Air Action Plan.<sup>51</sup> Under the plan, which involves 84 specific tasks across 42 government departments, anti-pollution measures have been introduced under a four-tiered warning system indicating the severity of pollution. On severely polluted days, for instance, the local government has enforced restricted driving schedules, school closures and reduced industrial production to curb emissions. Similarly, prompted by air quality monitoring and an advisory programme undertaken by the US Embassy for American citizens in Beijing,<sup>52</sup> localised pollution monitoring systems are now spreading throughout China. For example, concentrations of air pollutants in major cities, such as Shanghai<sup>53</sup> and Beijing,<sup>54</sup> and in various provinces throughout the country can be observed in real time.<sup>55</sup> These systems can provide useful information about the air quality; help track progress in reducing air pollution; and, through the AQI, an easy-to-learn on-line tool, inform the public when air pollution is likely to reach unhealthy levels. However, there have been no proposals related to protecting or expanding leisure physical activity, and simply making these data available is insufficient to bridge the health gap between the general health benefits associated with being active outdoors and diminished health-related quality of life as a result of outdoor activity in the presence of poor air quality.

### RESEARCH AND PUBLIC HEALTH POLICY NEEDS

The health benefits of regular exercise, including outdoor physical activity, are substantial and well established. Yet the increasing health risks associated with poor air quality directly threaten the tradition and health benefits of outdoor physical activity in China. It is therefore imperative to develop a research agenda that raises the awareness of the potential negative impact of outdoor physical activity in polluted environments, as well as to develop and implement public health policies that specifically combat health issues related to this emerging problem.

Although epidemiological research has shown consistent associations between outdoor air pollution exposure and poor health outcomes, there is a paucity of research on the point at which exercise in a polluted environment becomes more harmful than beneficial, thus limiting the capacity to effectively balance the risk and benefits of regular outdoor exercise in China. Therefore, much research is needed in this area.

There is also a pressing need for community-wide health impact assessments, which should focus on the influence of various components of air pollution on the number and types of patients being treated in clinics for health deficits associated with outdoor activities of varying types, intensity, length and severity of air pollution. They should also take into account seasonal effects (summer vs winter), diurnal variations, social inequities and disparities in income and access to social welfare, which are endemic in poor and marginalised communities in China. The recently revised Environmental Protection Law,<sup>50</sup> which promotes, for the first time, studies on the impact of environmental pollution on public health and the prevention and control of pollution-related disease, could be utilised as the launch pad for this work.

Outcome data from these assessments are crucial if health authorities are to develop meaningful health initiatives to promote appropriate engagement in outdoor physical activity in rural and urban settings within the context of air quality limitations.

In addition to bolstering the drive to ensure governmental measures to combat air pollution in China, the following additional public health actions can be taken to mitigate air pollution challenges to physical activity:

- A. Improve communication and collaboration among key stakeholders. Government agencies, health authorities, physical activity researchers and community volunteer groups need to work together to combat air pollution and develop shared frameworks and strategies that can be used to improve air quality (primary prevention) and mitigate the adverse health effects of air pollution exposure during outdoor exercise.
- B. Develop grass-roots, community-based campaigns to educate residents about air quality data and the health implications for outdoor physical activity. Such activities can be integrated into June 5 Environmental Day programmes.<sup>50</sup> Education should raise awareness of the negative health consequences of exercising in polluted air and help residents, especially those who are vulnerable to ambient air pollution, understand how the cardiovascular and respiratory systems are altered by outdoor exercise and exercise of different intensities. Projects should include developing educational information or toolkits on alternative methods of exercise in the presence of

air pollution (eg, away from industrial areas or main roadways),<sup>4</sup> teaching residents how to use protective devices such as filtration masks during outdoor activity to reduce exposure to pollution,<sup>3</sup> and modifying activity levels for school physical education classes.<sup>56</sup>

- C. Create environmental health policies or emergency response plans for heavy air pollution that include specific guidelines for outdoor physical activity. Only when this happens can the policies be effective. The successful mitigation of air pollution in Beijing during the 2008 Olympic Games, where a massive environmental intervention with strong governmental support and public interest resulted in a substantial improvement in air quality and an accompanying increase in the number of blue-sky days, is a clear example of the potential of this approach in having meaningful effects.
- D. Instigate community-based public health initiatives or action plans that utilise current hour-by-hour monitoring or alert systems to inform the public about appropriate levels of air quality that are conducive or harmful to outdoor physical activity. These initiatives would help inform the community's and the individual's physical activity decisions of various types (travel, household, occupational and leisure time). For example, using Beijing's four-tier alert system, health authorities can develop user-friendly warning signs that can be displayed in public spaces or residential areas regarding ways to adjust activity levels to minimise risk while attempting to maintain activity levels.
- E. Conduct observational and longitudinal studies that are directed at understanding how the health risks of ambient air pollution are exacerbated by exercise, especially in the most vulnerable populations. In addition, studies are needed to examine the relationship between the levels of ambient air pollution exposure and physiological responses to varying lengths of time spent exercising, physiological adaptation to exercise in polluted air, long-term health consequences of exercising in a polluted area, and the potential underlying mechanisms that explain the air pollution and outdoor physical activity relationship.
- F. Reduce the public health burden of air pollution on outdoor physical activity by disseminating research and/or

assessment results to better link outdoor physical activity and air quality for public policymakers who confront unique challenges in their efforts to increase the population's activity levels.

## CONCLUSIONS

Physical activity is one of the most important and readily implementable endeavours for enhancing quality of life and limiting premature mortality, and the health benefits of regular exercise outdoors are clear. However, breathing polluted air during exercise can lead to serious health problems. The current air pollution situation in China makes the tradition and logistical necessity of engaging in outdoor physical activity highly risky, especially because little is known about the threshold for the negative health impact of air pollution (either for acute or chronic exposure) and also because there is no immediate solution in sight for significantly curbing this pervasive environmental problem. Thus, health authorities in China must address the critical dilemma of how to protect, and encourage, the active population until measures to reduce the long-term threat posed by air pollution are implemented.

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REFERENCES

- 1 Centers for Disease Control and Prevention. The benefits of physical activity. <http://www.cdc.gov/physicalactivity/everyone/health> (accessed 1 Apr 2014).
- 2 Thompson Coon J, Boddy K, Stein K, et al. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environ Sci Technol* 2011;45:1761–72.
- 3 Sharman JE, Cockcroft JR, Coombes JS. Cardiovascular implications of exposure to traffic air pollution during exercise. *QJM* 2004;97:637–43.
- 4 Giles LV, Koehle MS. The health effects of exercising in air pollution. *Sports Med* 2014;44:223–49.
- 5 U.S. Dept. of Health and Human Services. 2008 Physical Activity Guidelines for Americans. <http://health.gov/paguidelines> (accessed 1 Apr 2014).
- 6 World Health Organization. Step to health: A European Framework to Promote Physical Activity for Health. [http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0020/101684/E90191.pdf](http://www.euro.who.int/__data/assets/pdf_file/0020/101684/E90191.pdf) (accessed 1 Apr 2014).
- 7 Daugbjerg SB, Kahlmeier S, Racioppi F, et al. Promotion of physical activity in the European Region: content analysis of 27 national policy documents. *J Phys Activ Health* 2009;6:805–17.
- 8 US National Physical Activity Plan Coordinating Committee. National Physical Activity Plan. <http://www.physicalactivityplan.org/NationalPhysicalActivityPlan.pdf> (accessed 1 Apr 2014).
- 9 Zhang L, Zheng X. Ageing population's sports and population health. *J Sports Sci* 2006;27:59–62.
- 10 Li G, Sun Q, Liu C. Comparative research on our mass sports condition during three investigations. *J Shenyang Sport Uni* 2013;32:27–31.
- 11 The Central People's Government of the People's Republic of China. Physical activity survey of urban and rural areas in China in 2007. [http://www.gov.cn/test/2012-04/19/content\\_2117453.htm](http://www.gov.cn/test/2012-04/19/content_2117453.htm) (accessed 29 Mar 2014).
- 12 Chen M, He M, Min X, et al. Different physical activity subtypes and risk of metabolic syndrome in middle-aged and older Chinese people. *PLoS ONE* 2013;8:e53258.
- 13 Wang N, Zhang X, Xiang Y-B, et al. Associations of Tai Chi, walking and jogging with mortality in Chinese men. *Am J Epidemiol* 2013;178:791–6.
- 14 Roberts JD, Voss JD, Knight B. The association of ambient air pollution and physical inactivity in the United States. *PLoS ONE* 2014;9:e90143.
- 15 Wen X-J, Balluz LS, Shire JD, et al. Association of self-reported leisure-time physical inactivity with particulate matter 2.5 air pollution. *J Environ Health* 2009;72:40–4.
- 16 Le Tertre A, Medina S, Samoli E, et al. Short-term effects of particulate air pollution on cardiovascular diseases in eight European cities. *J Epidemiol Community Health* 2002;56:773–9.
- 17 Shah AS, Langrish JP, Nair H, et al. Global association of air pollution and heart failure: a systematic review and meta-analysis. *Lancet* 2013;382:1039–48.
- 18 Pope CA III, Ezzati M, Dockery DW. Fine-particulate air pollution and life expectancy in the United States. *N Engl J Med* 2009;360:376–86.
- 19 Pope C, Burnett R, Thun M, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA* 2002;287:1132–41.
- 20 McCreanor J, Cullinan P, Nieuwenhuijsen MJ, et al. Respiratory effects of exposure to diesel traffic in persons with asthma. *N Eng J Med* 2007;357:2348–58.
- 21 McConnell R, Berhane K, Gilliland F, et al. Asthma in exercising children exposed to ozone: a cohort study. *Lancet* 2002;359:386–91.
- 22 Hankey S, Marshall JD, Brauer M. Health impacts of the built environment: within-urban variability in physical inactivity, air pollution, and ischemic heart disease mortality. *Environ Health Perspect* 2012;120:247–53.
- 23 World Health Organization. 7 million premature deaths annually linked to air pollution. <http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/> (accessed 30 Mar 2014).
- 24 Chen F, Liu G. Population aging in China. In: Uhlenberg P. ed *International handbook of population aging*. New York: Springer, 2009:152–72.
- 25 Gong P, Liang S, Carlton EJ, et al. Urbanisation and health in China. *Lancet* 2012;379:843–52.
- 26 Xu P, Chen Y, Ye X. Haze, air pollution, and health in China. *Lancet* 2013;382:2067.
- 27 Zhang J, Mauzerall DL, Zhu T, et al. Environmental health in China: progress towards clean air and safe water. *Lancet* 2010;375:110–19.
- 28 Beijing's air pollution episode (January 2013). <http://cleanairinitiative.org/portal/node/11599> (accessed 30 Mar 2014).
- 29 United States Environmental Protection Agency (2009) AQA guide to air quality and your health. [http://www.epa.gov/airnow/airqi\\_brochure\\_08-09.pdf](http://www.epa.gov/airnow/airqi_brochure_08-09.pdf) (accessed 30 Mar 2014).
- 30 Ministry of Environmental Protection. MEP releases air quality of key regions and 74 cities in November. [http://english.mep.gov.cn/News\\_service/news\\_release/201401/t20140106\\_266046.htm#](http://english.mep.gov.cn/News_service/news_release/201401/t20140106_266046.htm#) (accessed 29 Mar 2014).
- 31 South China Morning Post. Pollution makes Beijing almost 'uninhabitable for human beings. <http://www.scmp.com/news/china/article/1426587/pollution-makes-beijing-almost-uninhabitable-human-beings> (accessed 1 Mar 2014).
- 32 Wong CM, Vichit-Vadakan N, Kan H, et al.; PAPA Project Teams. Public health and air pollution in Asia (PAPA): A multicity study of short-term effects of air pollution on mortality. *Environ Health Perspect* 2008;116:1195–202.
- 33 Liu L, Breitner S, Schneider A, et al. Size-fractionated particulate air pollution and cardiovascular emergency room visits in Beijing, China. *Environ Res* 2013;121:52–63.
- 34 Meng X, Wang C, Cao D, et al. Short-term effect of ambient air pollution on COPD mortality in four Chinese cities. *Atmos Environ* 2013;77:149e154.
- 35 Dong G-H, Qian Z, Xaverius PK, et al. Association between long-term air pollution and increased blood pressure and hypertension in China. *Hypertension* 2013;61:578–84.
- 36 Zhang YX, Tao S, Shen HZ, et al. Inhalation exposure to ambient polycyclic aromatic hydrocarbons and lung cancer risk of Chinese population. *Proc Natl Acad Sci USA* 2009;106:21063–7.
- 37 World Bank. *Cost of pollution in China*. Washington, DC: World Bank, 2007.
- 38 Lai HK, Tsang H, Wong CM. Meta-analysis of adverse health effects due to air pollution in Chinese populations. *BMC Public Health* 2013;13:360.
- 39 Chen Y, Ebenstein A, Greenstone M, et al. Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. *Proc Natl Acad Sci USA* 2013;110:12936–41.
- 40 de Onis M, Blossner M, Borghi E. Global prevalence and trends of overweight and obesity among preschool children. *Am J Clin Nutr* 2010;92:1257–64.
- 41 Yu Z, Han S, Chu J, et al. Trends in overweight and obesity among children and adolescents in China from 1981 to 2010: a meta-analysis. *PLoS ONE* 2012;7:e51949.
- 42 Muntner P, Gu D, Wildman RP, et al. Prevalence of physical activity among Chinese adults: results from the International Collaborative Study of Cardiovascular Disease in Asia. *Am J Public Health* 2005;95:1631–6.
- 43 Ng SW, Norton EC, Popkin BM. Why have physical activity levels declined among Chinese adults? Findings from the 1991–2006 China Health and Nutrition Surveys. *Soc Sci Med* 2009;68:1305–14.
- 44 Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. *Obes Rev* 2012;13:659–80.
- 45 Zhang J, Chaddban J. The economic cost of physical inactivity in China. *Prev Med* 2013;56:75–8.
- 46 Committee on the Medical Effects of Air Pollution. *Long-term exposure to air pollution: effect on mortality*. London: Health Protection agency, 2009.
- 47 Correia AV, Pope CA III, Dockery DW, et al. Effect of air pollution control on life expectancy in the United States: an analysis of 545 U.S. counties for the period from 2000 to 2007. *Epidemiol* 2013;24:23–31.
- 48 Langrish JP, Mills NL. Air pollution and mortality in Europe. *Lancet* 2013;383:759–60.
- 49 The State Council issues action plan on prevention and control of air pollution introducing ten measures to improve air quality. [http://english.mep.gov.cn/News\\_service/infocus/201309/t20130924\\_260707.htm](http://english.mep.gov.cn/News_service/infocus/201309/t20130924_260707.htm) (accessed 30 Mar 2014).
- 50 National People's Congress of the People's Republic of China. China's legislature adopts revised Environmental Protection Law. [http://www.npc.gov.cn/englishnpc/news/Legislation/2014-04/25/content\\_1861275.htm](http://www.npc.gov.cn/englishnpc/news/Legislation/2014-04/25/content_1861275.htm) (accessed 12 May 2014).
- 51 Beijing resolved to curb air pollution. [http://news.xinhuanet.com/english/china/2013-09/25/c\\_132749648.htm](http://news.xinhuanet.com/english/china/2013-09/25/c_132749648.htm) (accessed 18 Mar 2014).
- 52 Embassy of the United States Beijing. U S Embassy Beijing Air Quality Monitor. <http://beijing.usembassy-china.org.cn/070109air.html> (accessed 30 Mar 2014).
- 53 Shanghai Environmental Monitoring Center. Real-time Air Quality Reporting System in Shanghai. <http://www.sem.gov.cn/air/home/English.aspx> (accessed 1 Apr 2014).
- 54 Beijing Municipal Environmental Monitoring Center. <http://www.bjmemc.com.cn/> (accessed 1 Apr 2014).
- 55 National City Air Quality Monitoring Center. <http://113.108.142.147:20035/emcpublish/> (accessed 1 Apr 2014).
- 56 Centers for Disease Control and Prevention. Air quality and outdoor activity guidance for schools. [http://www.cdc.gov/nceh/airpollution/airquality/pdfs/Air\\_Quality\\_and\\_Outdoor\\_Activity\\_Guidance.pdf](http://www.cdc.gov/nceh/airpollution/airquality/pdfs/Air_Quality_and_Outdoor_Activity_Guidance.pdf) (accessed 27 May 2014).