Journal of Environmental Protection, 2014, 5, 731-738
Published Online June 2014 in SciRes. http://www.scirp.org/journal/jep
http://dx.doi.org/10.4236/jep.2014.58074

$PM_{2.5}$ Pollution and Risk for Lung Cancer: A Rising Issue in China

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Received 3 February 2014; revised 2 March 2014; accepted 22 March 2014

Abstract

This study is focused on the linkage between lung cancer incidence rates and $PM_{2.5}$ pollution. Researches conducted by leading research organizations in U.S. and Europe were reviewed and analyzed, and strong evidence exists that elevated fine particulate air pollution exposures are associated with significant increases in lung cancer mortality. The linkage between fine particulate air pollution and lung cancer motility is observed even after controlling for cigarette smoking, occupational exposure, and other risk factors. This finding is in alignment with observations in China which show an upward trend of lung cancer incidences coupled with a downward trend in the number of smokers. Currently, China lacks systematic research on the effect of $PM_{2.5}$ on lung cancer. As a result, this paper investigated studies on the linkage between pollution and lung cancer incidence from decades of research conducted in the U.S. and Europe. One important step in solving this issue in China is through classifying $PM_{2.5}$ pollution as a human cacinogen. Adequate government regulation, public awareness, regional collaboration and industrial compliance are also key to the successful control of $PM_{2.5}$ pollution and smog.

Keywords

$PM_{2.5}$, Smog, Lung Cancer

1. Introduction

Globally, lung cancer is estimated to account for almost 1.4 million cases of cancer each year and has been the

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How to cite this paper: Hu, D. and Jiang, J.Y. (2014) $PM_{2.5}$ Pollution and Risk for Lung Cancer: A Rising Issue in China. *Journal of Environmental Protection*, **5**, 731-738. http://dx.doi.org/10.4236/jep.2014.58074

most common cancer in the world for more than two decades [1]. It has been known that smoking and occupational exposure leads to increased cases of lung cancer. However, in some large cities in China, while the number of smokers has decreased and health and safety conditions at work places have improved, an upward trend in lung cancer cases is still observed [2]. Researchers in China have started to identify a linkage between lung cancer and particulate pollution, and suspect that the increased smog around the country may be causing increased cases of lung cancer.

Particulate matter pollutant is composed of a mixture of microscopic solids and liquid droplets suspended in air. These pollutants are made up of a number of components, including SO_x, NO_x, NH_3, organic chemicals, volatile metals, soil or dust particles, and allergens (e.g. pollen or mold spores). When suspended in the atmosphere, $PM_{2.5}$ particles are the major cause of reduced visibility in major Chinese cities, such as Beijing [3]. The icrease in smoggy days in the Beijing area [4], believed to be caused by $PM_{2.5}$ pollutants [5], has led to increased local interest in $PM_{2.5}$ pollutants.

Unlike most air pollutants that consist of only one chemical compound, $PM_{2.5}$ particles consist of a mixture of compounds and are formed from primary and secondary participles [6]. Primary particles are formed during combustion, industrial processes and in natural processes (e.g. wind erosion). Secondary particles are formed idirectly through nucleation, condensation or processes where gaseous pollutants (SO_x, NO_x, NH_3, VOCs) are involved in particle formation or growth [6]. Secondary sulfate and nitrate particles formed from SO_x or NO_x precursors are usually the dominant component in $PM_{2.5}$ particles. As a result of the chemical components in secondary participles, the environmental and health impacts from them are greater than those from primary particles.

The environmental and health impact of $PM_{2.5}$ is an emerging research topic in China. We have investigated lung cancer rate increase in Beijing area trying to find evidence of linkage between lung cancer and smog issue. We found that systematic research is needed in Beijing area. However, the linkage between lung cancer and fine particulate pollution has been investigated by many research organizations in the U.S. and Europe since the 1970s. For example, a famous study carried out by the American Cancer Society, in collaboration with U.S. universities, concluded that elevated fine particulate air pollution exposures were associated with significant increases in lung cancer mortality [7]. In contrast, $PM_{2.5}$ data collection and research into its linkage to lung cacer incidence is still lacking in China. Collecting adequate data takes not only years of dedicated efforts, but also research funding.

The objective of this study is to review the linkage between $PM_{2.5}$ and lung cancer incidence using studies conducted by reputable research organizations in western countries. The goal is to show the Chinese community that while research into the relationship between lung cancer cases and $PM_{2.5}$ pollution may be new in China, it has been investigated for decades by health organizations in western countries. These research findings can be used as the basis for further research in China and to inform the establishment of national policies for $PM_{2.5}$ pollution control.

2. Methodology

This study is a continuation of our previous research into smog issues in China [8] and is focused on the linkage between lung cancer cases and $PM_{2.5}$ pollution. In previous study shown in reference 8, we found, in Beijing, China, the high frequency of smoggy days is strongly associated with levels of $PM_{2.5}$ pollutant. Most $PM_{2.5}$ particles, especially those containing sulfates, nitrates, and many organic compounds, are created through secondary industrial and manufacturing processes. Major sources of $PM_{2.5}$ include vehicle exhaust, coal combustion from the utility industry and industrial processes, and the housing construction industry, including the cement manufacturing process. Adequate government regulation, public awareness, regional collaboration and industrial compliance are the keys to successful control of $PM_{2.5}$ pollution and smog. This paper was drafted through primary and secondary research. Primary research was conducted through interviews with environmental protection experts in China and analysis of historical data on $PM_{2.5}$ pollutant levels and regulations obtained through the U.S. EPA's air quality control office and American Cancer Society. Secondary research was conducted through literature searches of journal articles, research reports, books, conference notes and news articles. News articles containing political opinions were excluded from the literature search. All scientific literature reviewed was through December 2013 and only research and/or data published by reputable research organizations (e.g. American Cancer Society as part of the Cancer Prevention Study II (CPS-II)) were used in this analysis.

3. Results and Discussion

3.1. Long-Term Exposure to $PM_{2.5}$ Linked to Increased Lung Cancer Incidence Rates

The chemical composition of particulate matter changes with size [6] [9] and therefore, their effect on human health varies depending on the pollutant's size. The human body is unable to filter out small particulates [3] and as a result, dust and particulate matter that are smaller than 2.5 micrometers ($PM_{2.5}$) can enter into the alveoli in the lungs, where gas exchange occurs. These $PM_{2.5}$ particles negatively affect gas exchange within the lungs and can even penetrate the lung and escape into the blood stream to cause significant health problems [10].

3.1.1. Studies from U.S. Research Organizations

Over the past decade, several studies have demonstrated the linkage between exposure to fine particulate matter and adverse health effects. One study, the 1995 American Cancer Society sponsored study, concluded that annual mortality rates due to cardiopulmonary disease and lung cancer increased alongside an increase in fine particulate matter concentrations [11]. Results from the 1995 ACS study came under intense scrutiny in 1997 when the U.S. Environmental Protection Agency (EPA) used it in support of new National Ambient Air Quality Standards for $PM_{2.5}$ [12]. This study was labeled "controversial" due to uncertainty in the methodologies used in the analysis. As a result, and due to its significance in the standard setting process, an independent reanalysis was performed in 2002 which validated the quality of the data set and affirmed the findings of the 1995 ACS study [7].

The results of the 2002 follow-up study (2002 ACS study) showed significant linkage between $PM_{2.5}$ pollutant levels and elevated risks for cardiopulmonary and lung cancer mortality. The study found that each 10 $\mu g/m^3$ increase in the long-term average $PM_{2.5}$ concentrations was associated with an approximately 4% increased risk of death from all natural causes, a 6% increased risk of death from cardiopulmonary disease, and an 8% increased risk of death from lung cancer. The 2002 ACS study concluded that long-term exposure to combustion related fine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality. As shown in **Table 1**, the U.S. EPA also published a report using data collected from 100 counties in North Carolina, showing positive correlation between $PM_{2.5}$ concentration and lung cancer incidence rates [13]. A positive correlation was also found with sulfur-containing air pollutants, but not other gaseous pollutants [7].

Coal is still used as a major energy source in China, which emits SO_x during combustion. Our previous research finding revealed that secondary $PM_{2.5}$ particles contain significant amounts of SO_x [8] [14], a carcinogenic pollutant. As a result, developing clean coal technologies and/or switching to alternative fuels could lead to less $PM_{2.5}$ pollution in China.

Furthermore, in the same 2002 study (Ref 2), researchers observed that the lung cancer risk associated with exposure to fine particulate matter was comparable to that from second-hand cigarette smoke. The result is in alignment with recent findings by researchers in China who observed that while the number of smokers has decreased, the lung cancer incidence rate has increased [2].

Beeson *et al.* found that there was an increased risk of lung cancer from smoking and occupational exposure if there was also long-term exposure to particulate pollution [15]. This implies that $PM_{2.5}$ pollution can accelerate lung cancer incidence rates and mortality in groups that already face a high risk of lung cancer.

Table 2 shows American Cancer Society research (later validated by the University of Birmingham, UK) on the relative risk of lung cancer mortality associated with a 10 $\mu g/m^3$ change in $PM_{2.5}$. The risk increased by 8% using $PM_{2.5}$ concentration data from 1979 to 1983, by 13% using $PM_{2.5}$ data collected from 1999 to 2000, and 14% when an average of the two sets of $PM_{2.5}$ data was used [7] [16].

Table 1. Lung cancer incidence and mortality rates versus $PM_{2.5}$ levels for 100 counties in North Carolina.

	$PM_{2.5}$ Levels		
	7 $\mu g/m^3$	12 $\mu g/m^3$	17 $\mu g/m^3$
Lung Cancer Incidence Rate (per 100,000)	66	72	80
Lung Cancer Mortality Rate (per 100,000)	58	60	62

Note: Data cited from reference 13.

Table 2. Relative risk of lung cancer mortality associated with 10 μg/m^3 change in $PM_{2.5}$.

	Data Collection Period		
	1979-1983	1999-2000	Average of two sets
Risk of Lung Cancer Mortality	8%	13%	14%

Note: Data cited from reference 16.

The International Agency for Research on Cancer (IARC) has evaluated cancer deaths caused by particulate pollution, and the results have shown an increased risk of lung cancer with increasing levels of exposure to particulate matter and air pollution. Although the composition of air pollution and levels of exposure can vary dramatically between locations, IARC indicated that the conclusions apply to all regions of the world [17]. Today in China, the phenomena and cause of $PM_{2.5}$ are not dramatically different from those in the U.K. and U.S. in the 1970s. Therefore, the health impact of the $PM_{2.5}$ pollution should not be any different. The issue of increased lung cancer cases in association with increased $PM_{2.5}$ pollution needs to be resolved.

In the U.S, research on the health effects of particular matter has caused a revision to the National Ambient Air Quality Standards (NAAQS). During this revision, new pollutants with a diameter less than 2.5 μm, commonly called $PM_{2.5}$, are now regulated. In 2006, the U.S. EPA reissued their fine particle standard to a reduced level of 35 μg/m^3 [18].

3.1.2. Studies from European Research Organizations

An ecologic study performed by Nawrot *et al.* using data from 15 countries in Europe reported a correlation between $PM_{2.5}$ and lung cancer mortality among men, but not women [19]. **Figure 1** below illustrates the mortality rates of lung cancer in 15 European countries against their average air concentration of fine particulates [20]. For men, when the mortality rate was standardized for age and smoking prevalence at the country level a 5 μg/m^3 higher mean annual $PM_{2.5}$ was associated with a 17.7% increased risk for lung cancer. The research also indicated that at an ecological level the heterogeneity in lung cancer mortality across European countries could not be entirely explained by differences in the age distribution and/or smoking habits across the countries. The ecological analysis suggested that some of the differences in lung cancer mortality could only be explained by fine particulate air concentrations [20]. In general, this is in agreement with studies conducted by the American Cancer Society that have demonstrated a positive correlation between $PM_{2.5}$ and lung cancer mortality [21]-[23].

In a study carried out in the United Kingdom, Harrison *et al.* tested whether exposure to known chemical carcinogens in the atmosphere was capable of explaining the association between concentrations of $PM_{2.5}$ and lung cancer mortality observed in the extended ACS Cohort Study [16]. Harrison *et al.* concluded that while many uncertainties remain, it appeared plausible that known chemical carcinogens were responsible for the lung cancer cases attributed to $PM_{2.5}$ exposure. Harrison *et al.* further indicated that the possibility that particulate matter is capable of causing lung cancer independent of known carcinogens should not be ruled out.

A recent research carried out by a European consortium reported findings about air pollution and lung cancer incidence in 17 European cohorts. This study showed an association between exposure to particulate matter air pollution and the incidence of lung cancer, in particular adenocarcinoma, in Europe, adding substantially to the weight of the epidemiological evidence [24]. As shown in **Figure 2**, the $PM_{2.5}$ levels in some major Chinese cities are in heavily polluted ranges according to U.S. Department, Mission China [25]. As illustrated in **Figure 2**, $PM_{2.5}$ concentration in Beijing is 20 times more than Washington D.C. The concerns about the health impact of such a high $PM_{2.5}$ level are increasing in China.

3.1.3. Limited Research Data from China

There is always concern about pollution in the developing world, where data is not comprehensive enough to carry out statistically robust studies. In China, there is a lack of systematic research on the effect of $PM_{2.5}$ pollutants on lung cancer incidence rates. This is largely because the health impact of $PM_{2.5}$ pollutants became a concern to the general public only after 2008, when the U.S. Embassy in Beijing began posting $PM_{2.5}$ data. Most of the studies in China about the risk of exposure to $PM_{2.5}$ are from data collected in a short period of time. However, studies from western countries suggest that long-term exposure may be more important to analyze to understand the public health implications.

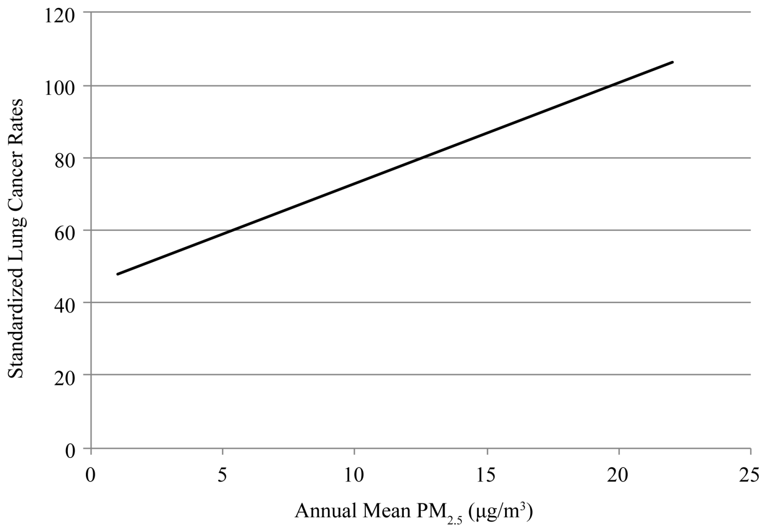

Figure 1. Impact of $PM_{2.5}$ concentration on lung cancer rate. Note: data cited from reference 20.

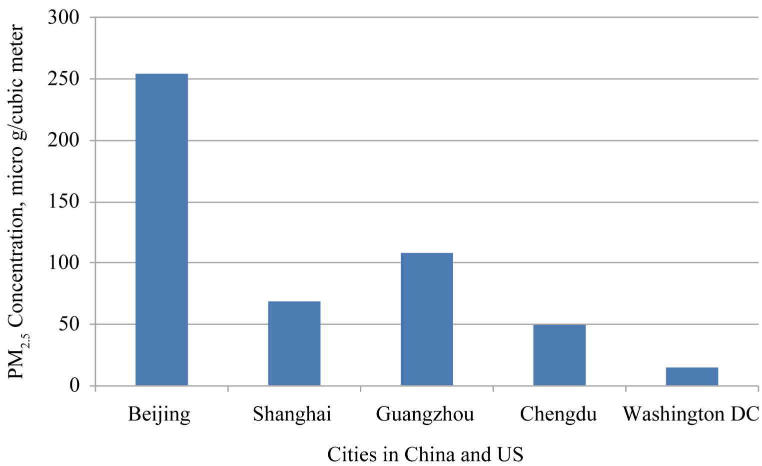

Figure 2. Average $PM_{2.5}$ concentration in different cities on April 14, 2014.

Experts in China have differing views on the linkage between smog and lung cancer. Some argue that whether the $PM_{2.5}$ pollution in Beijing is leading to increased lung cancer cases is uncertain because local scientific research is lacking and that at least 10 years of data is needed to prove a causal link to lung cancer. However, this paper believes that evidence from decades of research from western countries can be utilized.

As described in Section 3.1.1, the IARC study showed an increasing risk of lung cancer with increasing levels of exposure to particulate matter and air pollution. Although the composition of air pollution and levels of exposure can vary dramatically between locations, the conclusions of the Working Group apply to all regions of the world [17]. The most recent data indicates that in 2010, 223,000 lung cancer deaths worldwide resulted from air pollution [26].

China has just begun monitoring $PM_{2.5}$ pollutant levels and currently, there is no research data that correlates $PM_{2.5}$ pollution with various health issues. However in 2011, the China Daily newspaper reported that the lung cancer rate in Beijing had increased 60% over the past decade, even as levels of smoking had fallen, implying air pollution as a primary culprit for the increased cancer rate [27]. Recently, a Chinese girl's lung cancer was linked to particulate pollution, which has caused concern to the general public [28].

Beijing health authorities have launched a pilot project to test for the rate of cancers in the city. The project was announced after the Beijing Health Bureau released a list of the top five highest incidence cancers in Beijing. The rate of lung cancer is the highest of all cancer types, and smog and smoking have been specifically cited as causes [29].

A joint study by Greenpeace East Asia and Beijing University's School of Public Health estimates that $PM_{2.5}$ pollution caused the cities of Shanghai, Guangzhou, Xi'an and Beijing a combined total of US $1.1 billion in economic losses over the past year. Greenpeace is calling for an urgent policy adjustment, including capping regional coal consumption, retrofitting De-NO_x for existing coal-fired power plants, and shutting down inefficient coal-fired industrial boilers. The report, "$PM_{2.5}$: Measuring the Human Health and Economic Impacts on China's Largest Cities", states that if these cities can effectively lower their $PM_{2.5}$ levels to meet the World Health Organization's Air Quality Guidelines, then premature deaths could be reduced by at least 81%, and economic losses for these four cities could be reduced by US $868MM [30]. A research report from Beijing University showed that effective implementation of $PM_{2.5}$ standards in major Chinese cities could result in health benefits estimated at billions of dollars. **Table 3** shows a comparison of $PM_{2.5}$ standards adopted by different countries. Significant efforts need to be made in China to control $PM_{2.5}$ pollution.

3.2. Systematic Research is Necessary in China

$PM_{2.5}$ has not been limited to China—many other countries have experienced the same set of effects during their industrial growth periods. A research report comparing European and U.S. approaches towards controlling $PM_{2.5}$ pollution shows that in most western countries in the 1990's, the main contributors to $PM_{2.5}$ pollutants were stationary combustion, industrial processes, transportation and agriculture [31]. Research conducted during this time period clearly shows the linkage between $PM_{2.5}$ and lung cancer, and the implication from these research reports is that $PM_{2.5}$ pollution in China can lead to an increase in the lung cancer incidence rate if systematic prevention programs are not implemented.

Davison *et al.* reported that concentrations of toxic elements in fly ash from coal fired power stations increased markedly with decreasing particle size [32]. $PM_{2.5}$ formed from coal-fired power plants contains SO_2 and polyaromatics, small enough to penetrate alveoli in the lungs causing lung cancer incidence. In China, these carcinogenic pollutants lead to lung cancer.

The extended ACS cohort study provides an unequivocal message that long term exposure to $PM_{2.5}$ particulate matter leads to increased mortality due to lung cancer [7]. Identifying the agent or agents responsible for carcinogenesis due to $PM_{2.5}$ exposure has proved very difficult for a number of reasons, including the latency periods associated with lung cancer. If a latency period of at least 20 years is assumed, it is quite plausible that known chemical carcinogens in the air may account for the observed carcinogenicity of $PM_{2.5}$.

Many researchers indicate a substantial latency period between commencement of exposure and the expression of cancer. Research on how to prevent the lung infection by $PM_{2.5}$ pollutants from developing into lung cancer is important. Clinical research has just started in City of Xian in China to understand the mechanistic interaction between particulates and lung diseases [3].

4. Conclusion

The findings of this study provide strong evidence from western countries that long-term exposure to fine particulate air pollution is an important risk factor for lung cancer. Evidence from studies in the U.S. and Europe has clearly shown that elevated fine particulate air pollution exposures are associated with an increase in lung cancer

Table 3. $PM_{2.5}$ standard adopted by different countries.

Country	Annual Average μg/m^3	24 hours Average μg/m^3	Date of Implementation
U.S.	15	35	December 17, 2006
EU	25	NA	Issued January 1, 2010. Fully implementation on January 1, 2015
Japan	15	35	September 9, 2009
China	35	75	Effective 2016 (Public hearing period)
WHO	10	25	Highly recommended

mortality. While many uncertainties remain, it appears plausible that known chemical carcinogens are responsible for the lung cancer cases attributed to $PM_{2.5}$ exposure. Therefore, China should focus efforts not on verifying western countries' research findings, but on controlling $PM_{2.5}$ pollutants and conducting research on preventing and curing lung cancers caused by $PM_{2.5}$ pollution. In China, classifying $PM_{2.5}$ pollution as carcinogenic to humans is an important first step. There are effective ways to reduce particulate air pollution and, given the scale of the exposure affecting people worldwide, this study suggests that China should take action without further delay.

References

[1] Parkin, D.M., Bray, F., Ferlay, J. and Pisani, P. (2002) Global Cancer Statistics. *CA*: *A Cancer Journal of Clinicians*, **61**, 69-90.

[2] Chen, L. (2012) $PM_{2.5}$ and Lung Cancer. *Eastern Morning News*, 14 January 2002.

[3] Li, Y. (2012) Smog Weather, Be Aware of $PM_{2.5}$ Pollution. *Food & Health* (*Chinese*), **2**, 9-11.

[4] Li, H., Bai, B. and Cheng, L. (2013) Beijing Experienced 124 days in 2012, the Highest in Last 10 Years. *Legal Evening News* (*Chinese*), 14 January 2013.

[5] Ye, Y. (2012) Study of Decreasing $PM_{2.5}$ Emission from Thermal Power Plant. *Electric Power Construction*, **33**, 49-52.

[6] Ji, H., Zhao, H., Kong, S., Bai, Z. and Han, B. (2013) Seasonal Variation of Inorganic Composition in Ambient Particulate Matter In Tianjin Offshore Area and Its Source Analysis. *China Environmental Science*, **31**, 177-185.

[7] Pope, C.A., Burnett, R.T., Thun, M.J., Krewski, D., Ito, K. and Thurston, G.D. (2002) Lung Cancer, Cardiopulmonary Mortality, and Long-Tern Exposure to Fine Particulate Air Pollution. *JAMA*, **287**, 1132-1141. http://dx.doi.org/10.1001/jama.287.9.1132

[8] Hu, D. and Jiang, J. (2013) A Study of Smog Issues and $PM_{2.5}$ Pollutant Control Strategies in China. *Journal of Environmental Protection*, **4**, 746-752. http://dx.doi.org/10.4236/jep.2013.47086

[9] Wang, S. and Hao, J. (2012) Air Quality Management in China: Issues, Challenges, and Options. *Journal of Environmental Sciences*, **24**, 2-13. http://dx.doi.org/10.1016/S1001-0742(11)60724-9

[10] Fu, M., Zheng, F., Xu, X. and Niu, L. (2011) Advances of Study on Monitoring and Evaluation of $PM_{2.5}$ Pollution. *Meteorology and Disaster Reduction Research*, **34**, 1-6.

[11] California Environmental Protection Agency (2002) Long-Term Health Effects of $PM_{2.5}$: Recent Findings. http://www.arb.ca.gov/research/health/healthup/may02.pdf

[12] Pope, C.A., Thun, M.J. and Namboodiri, M.M. (1995) Particular Air Pollution as a Predictor of Mortality in a Prospective Study of US Adults. *American Journal of Respiratory and Critical Care Medicine*, **151**, 669-674. http://dx.doi.org/10.1164/ajrccm/151.3_Pt_1.669

[13] Vinikoor-Imler, L.C., Davis, J.A. and Luben, T.J. (2011) An Ecologic Analysis of County-Level $PM_{2.5}$ Concentrations and Lung Cancer Incidence and Mortality. *International Journal of Environmental Research and Public Health*, **8**, 1865-1871. http://dx.doi.org/10.3390/ijerph8061865

[14] Naess, O., Nafstad, P., Aamodt, G., Claussen, B. and Rosland, P. (2007) Relation between Concentration of Air Pollution and Cause-Specific Mortality: Four-Year Exposures to Nitrogen Dioxide and Particulate Matter Pollutants in 470 Neighborhoods in Oslo, Norway. *American Journal of Epidemiology*, **165**, 435-443. http://dx.doi.org/10.1093/aje/kwk016

[15] Beeson, W.L., Abbey, D.E. and Knutsen, S.F. (1998) Long-Term Concentrations of Ambient Air Pollutants and Incident Lung Cancer in California Adults: Results from the AHSMOG Study. *Environmental Health Perspectives*, **106**, 813-823. http://dx.doi.org/10.2307/3434125

[16] Harrison, R.M., Smith, D.J.T. and Kibble, A.J. (2004) What Is Responsible for the Carcinogenicity of $PM_{2.5}$? *Occupational and Environmental Medicine*, **61**, 799-805. http://dx.doi.org/10.1136/oem.2003.010504

[17] International Agency for Research on Cancer (2013) Outdoor Air Pollution a Leading Environmental Cause of Cancer Deaths. http://www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf

[18] Final Report (2012) Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter. EPA-452/R-12-003, EPA-452/R-12-003.

[19] Nawrot, T.S., Nackaerts, K., Hoet, P.H. and Nemery, B. (2007) Lung Cancer Mortality and Fine Particulate Air Pollution in Europe. *International Journal of Cancer*, **120**, 1825-1826. http://dx.doi.org/10.1002/ijc.22358

[20] Nawrot, T.S., Nackaerts, K., Hoet, P.H.M. and Nemery, B. (2007) Lung Cancer Mortality and Fine Particulate Air Pollution in Europe. *International Journal of Cancer*, **120**, 1825-1826. http://dx.doi.org/10.1002/ijc.22358

[21] Jerrett, M., Burnett, R.T., Ma, R., Pope, C.A., Krewski, D., Newbold, K.B., Thurston, G., Shi, Y., Finkelstein, N. and Calle, E.E. (2005) Spatial Analysis of Air Pollution and Mortality in Los Angeles. *Epidemiology*, **16**, 727-736. http://dx.doi.org/10.1097/01.ede.0000181630.15826.7d

[22] Krewski, D., Jerrett, M., Burnett, R.T., Ma, R., Hughes, E., Shi, Y., Turner, M.C., Pope, C.A., Thurston, G. and Calle, E.E. (2009) Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. *Research Report* (*Health Effects Institute*), No. 140, 115-136.

[23] McDonnell, W.F., Nishino-Ishikawa, N., Petersen, F.F., Chen, L.H. and Abbey, D.E. (2000) Relationships of Mortality with the Fine and Coarse Fractions of Long-Term Ambient PM_{10} Concentrations in Nonsmokers. *Journal of Exposure Analysis and Environmental Epidemiology*, **10**, 427-436. http://dx.doi.org/10.1038/sj.jea.7500095

[24] Raaschou-Nielsen, O., Andersen, Z.J. and Beelen, R. (2013) Air Pollution and Lung Cancer Incidence in 17 European Cohorts: Prospective Analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). http://press.thelancet.com/lungcancer.pdf

[25] US Department of State, Mission China, 14 April 2014. http://www.stateair.net/web/post/1/1.html

[26] Straif, K., Cohen, A. and Samet, J. (2013) Air Pollution and Cancer. International Agency for Research on Cancer. http://www.iarc.fr/en/publications/books/sp161/index.php

[27] "China Air Pollution Reaches Extremely Hazardous" Levels. *China Daily*. http://www.sabc.co.za/news/a/dd4b38004e285b129e36bff251b4e4e2/China-air-pollution-reaches-extremely-hazardous-levels-20131201

[28] Brink, S. (2013) A Chinese Child's Lung Cancer Is Linked to Pollution. *National Geographic*, *Daily News*, 8 November 2013.

[29] Yin, Y. (2013) City Investigates High Cancer Stats. *Global Times*, 2 April 2013.

[30] Study on Premature Deaths Reveals Health Impact of $PM_{2.5}$ in China. 2012. http://www.greenpeace.org/eastasia/press/releases/climate-energy/2012/air-pollution-health-economic/

[31] Case Study, Comparison of the EU and US Approaches towards Control of Particulate Matter. 2005. http://ec.europa.eu/environment/archives/cafe/activities/pdf/case_study4.pdf

[32] Davison, R.L., Natusch, D.F.S., Wallace, J.R. and Evans, C.A. (1974) Trace Metals in Fly Ash, Dependence of Concentrations on Particle Size. *Environmental Science & Technology*, **8**, 1107-1113. http://dx.doi.org/10.1021/es60098a003