Sustainability **2014**, *6*, 5820-5838; doi:10.3390/su6095820

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

A Study of Heavy Metal Pollution in China: Current Status, Pollution-Control Policies and Countermeasures

Hui Hu [1], Qian Jin [2,*] and Philip Kavan [3]

[1] Economics and Management School, Wuhan University, Wuhan 430072, China; E-Mail: huizai1368@126.com

[2] School of Tourism and Human Geography, Xi'an International Studies University, Xi'an 710128, China

[3] Faculty of Education, Science, Technology & Maths, University of Canberra, Bruce ACT 2601, Australia; E-Mail: Philip.Kavan@canberra.edu.au

* Author to whom correspondence should be addressed; E-Mail: jinqian@xisu.edu.cn; Tel.: +86-153-1996-5526.

Received: 22 June 2014; in revised form: 19 August 2014 / Accepted: 20 August 2014 / Published: 1 September 2014

Abstract: In the past 30 years, China's economy has experienced rapid development, which led to a vast increase in energy consumption and serious environmental pollution. Among the different types of pollution, heavy metal pollution has become one of the major environmental issues in China. A number of studies show that high level of heavy metal exposure is a frequent cause of permanent intellectual and developmental disabilities. In recent years, some traditional pollutants, such as sulfur dioxide and carbon dioxide, have been put under control in China. However, heavy metal pollution, which poses even greater risks to public health and sustainable development, has yet to gain policymakers' attention. The purpose of this paper is to explore effective countermeasures for heavy metal pollution in China. The present study reviews the current status of China's heavy metal pollution and analyzes related public policies and countermeasures against that pollution. It also presents a few recommendations and measures for prevention of heavy metal pollution.

Keywords: heavy metal pollution; waste gas; waste water; solid wastes; pollution control; public policy; China

1. Introduction

Heavy metal pollution is an inorganic chemical hazard, which is mainly caused by lead (Pb), chromium (Cr), arsenic (As), cadmium (Cd), mercury (Hg), zinc (Zn), copper (Cu), cobalt (Co), and nickel (Ni) [1]. Five metals among them, Pb, Cr, As, Cd, and Hg, are the key heavy metal pollutants in China. These heavy metals are classified as strong carcinogens by the International Agency for Research on Cancer [2]. High level of heavy metal exposure can also cause permanent intellectual and developmental disabilities, including reading and learning disabilities, behavioral problems, hearing loss, attention problems, and disruption in the development of visual and motor function [2].

In the past 30 years, China's economy has experienced rapid development. Therefore, it led to a huge increase in energy consumption and environmental pollution. Among various types of pollution, heavy metal pollution is a crucial environmental problem. Some traditional pollutants, such as sulfur dioxide and carbon dioxide, have been put under control, but heavy metal pollution, which poses even greater risks to public health, have yet to gain policymakers' attention.

In China, the environmental pollution caused by heavy metals has become increasingly prominent. There is an urgent need to properly resolve these complex environmental problems. In order to support ecologically and socially sustainable development, it is necessary to coordinate the activities of the governments and markets to control the discharges of heavy metals. The purpose of this paper is to explore effective measures to reduce levels of heavy metal pollution through analyzing the status of heavy metal pollution and policies related to pollution control.

The remainder of this article is organized as follows. Section 2 provides an overview of China's heavy metal pollution. Section 3 discusses China's policies and plans for heavy metal pollution control. The challenges and difficulties are also analyzed in this section. Section 4 proposes corresponding countermeasures to address heavy metal pollution, followed by concluding remarks in Section 5.

2. The Status Quo of Heavy Metal Pollution in China

2.1. The Sources of Heavy Metal Pollutants in China

Heavy metal pollutants mainly come from mining, sewage irrigation, the manufacturing of metal-containing products, and other related production activities. Major heavy metals, such as Pb, Hg, Cr, Cd, and As, are discharged into the atmosphere, water and soil [3]. Heavy metals are not biodegradable and they can be involved in the food chain with biomagnification of these toxic substances. Consequently, the enriched heavy metals finally can be absorbed into the human body. Although some heavy metals, such as Co, Cu, Zn, and some other essential trace elements, are necessary for life activities, beyond a certain threshold, all the metal elements can be deadly.

In 2011, the Ministry of Environmental Protection of China (MEPC) indicated that the key exposure sources of Pb, Hg, Cr, Cd, As, and other heavy metal pollutants in China, are mainly involved in several industries, including the manufacture of chemical materials and chemical products, ferrous metal smelting and rolling processing industry, non-ferrous metal smelting and rolling processing industry, manufacture of fabricated metal products, the electroplating industry, and the mining industry. For example, as can be seen in Table 1, these industries are the main sources of heavy metal pollutants in waste water in Hubei province, which is a severely heavy-metal-polluted area. Similarly, in Shandong province, these industries also discharged over 90% of total heavy metal pollutants [4].

Additionally, according to the data of a national census of pollution, China has more than 1.5 million sites of heavy metals exposure. The total volume of discharged heavy metals in the waste water, waste gas and solid wastes are around 900,000 tons each year from 2005–2011 [5].

Table 1. Heavy metal pollutants in waste water in Hubei province (2007) [4,5].

Source	Waste water with heavy metals discharged (10,000 tons)	Hg in waste water (kg)	Cd in waste water (kg)	Total Cr in waste water (kg)	Cr (VI) in waste water (kg)	Pb in waste water (kg)	As in waste water (kg)
Manufacture of chemical materials and chemical products	18,741	9.6	0.7	221.1	61	5.4	9988.3
Ferrous metal smelting and rolling processing industry	23,942	0	0.1	1724.2	1724.2	0.1	0
Non-ferrous metal smelting and rolling processing industry	559	8.4	510.2	1.3	1.3	1870.3	2567.7
Manufacture of fabricated metal products	904	0	0	6133.4	6131.6	945.4	0
Electroplating industry	2458	0	3.2	8629.7	8628.5	46.2	0
Mining industry	12,916	4.5	131.6	4	3.9	557	2630

2.2. Heavy Metal Pollutants in Waste Gas

Waste gas is a key source of heavy metal pollutants. Heavy metals in the waste gas can be transferred in the form of dust particles. The particles in the atmosphere usually fall onto the land and water, and the metal elements in the gaseous state may also dissolve on the surface of water or soil. They increase the level of heavy metal pollution in the environment.

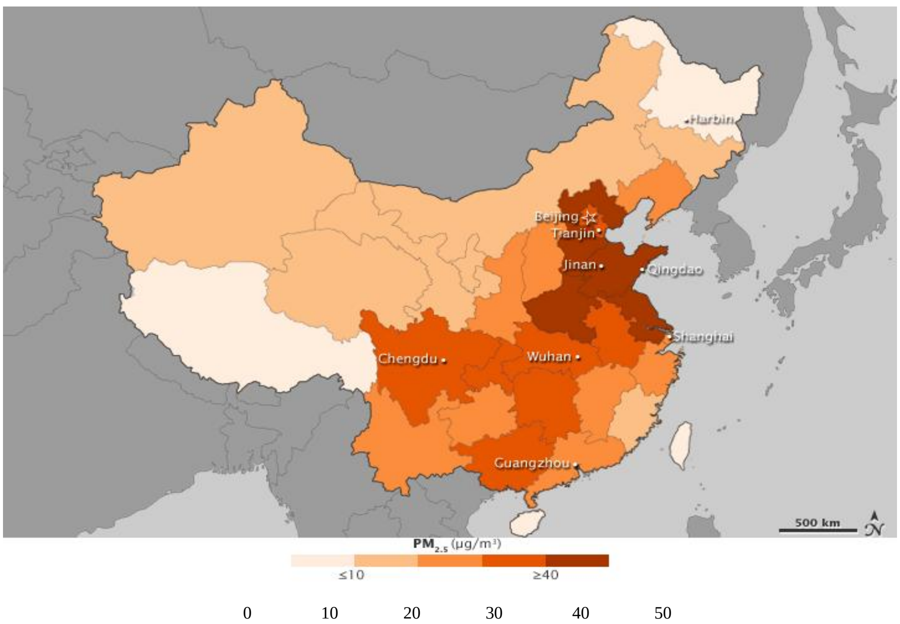
In China, the rapid industrialization has resulted in massive emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs) and dust. The amount of air pollutants is tremendous in China, and the emissions of SO_2 and NO_x are the highest in the world. Based on the data revealed by the MEPC, China emitted 22.7 million tons of SO_2, 22.7 million tons of NO_x and 14.7 million tons of dust in 2010 [6]. Eventually, the heavy metal pollutants in atmosphere are precipitated into water and soil. Zhang [7] investigated the effects of atmosphere precipitation on heavy metals accumulation in soil and found that the importation of Hg, Cd, and Pb into soil was 4.5, 5.8 and 347 grams per hectare of land, respectively.

Table 2 presents the amount of waste gas in China from 2005 to 2010 [8]. The emissions of SO_2, soot and dust declined gradually, but the total volume of waste gas was rising year by year. The average annual volume of waste gas emitted was 359.4 billion m^3. In 2008, a multi-stage sequential extraction procedure was applied to study the particulate matter up to 2.5 micrometers in size (PM2.5) at different elevations [9]. The data show that the average concentration of PM2.5-bound heavy metals are 201.6 nanograms per cubic meter of air (ng/m^3) for Pb, 24.3 ng/m^3 for As, 7.7 ng/m^3 for Cr and 4.4 ng/m^3 for Cd, respectively [9]. Figure 1 shows the average exposure to PM2.5 in China between 2008 and 2010. It also indicates that most areas in China had PM2.5 levels that exceeded World Health Organization's guidelines (10 micrograms per cubic meter of air) [9]. Obviously, the waste gas emission exacerbates heavy metal pollution in the atmosphere.

Table 2. Emission of waste gas and dust in China (2003–2010) [8].

Year	Total volume of waste gas emission (100 million m^3)	Total volume of SO_2 emission (10,000 tons)	Total volume of soot emission (10,000 tons)	Total volume of dust emission (10,000 tons)
2003	198,906	2158.5	1048.5	1021.3
2004	237,696	2254.9	1095	904.8
2005	268,988	2549.4	1182.5	911.2
2006	330,990	2588.8	1088.8	808.4
2007	388,169	2468.1	986.6	698.7
2008	403,866	2321.2	901.6	584.9
2009	436,054	2214.4	847.7	523.6
2010	519,168	2185.1	829.1	448.7

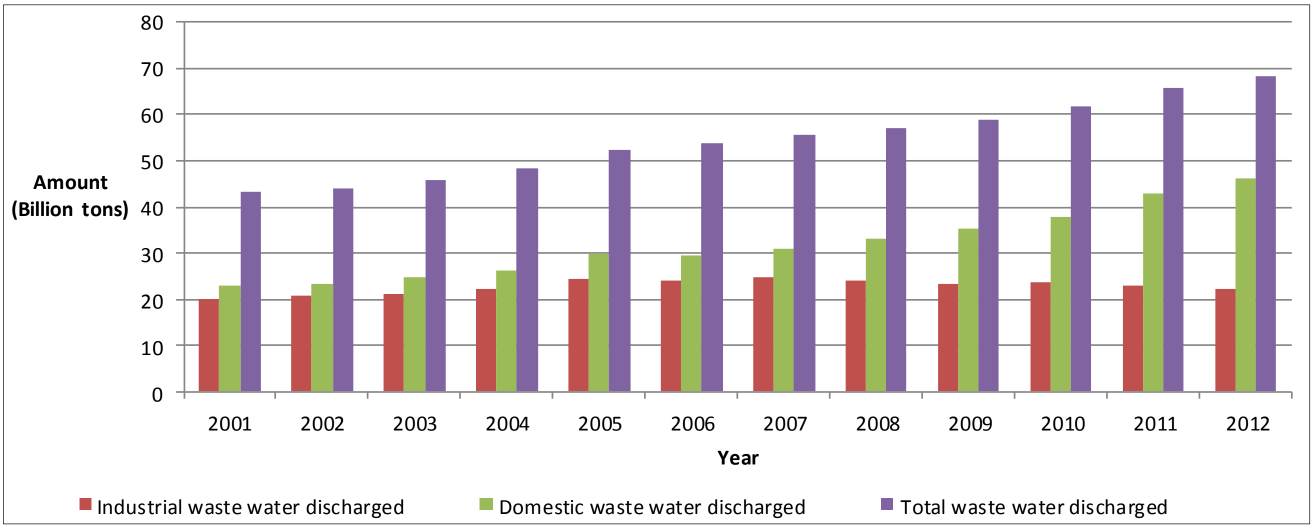
Figure 1. Average exposure to PM2.5 in China (2008–2010).



2.3. Heavy Metal Pollutants in Waste Water

In China, the discharge of waste water is another major source of heavy metal pollution. Based on the data of pollution sources, an average of 45.7 billion tons of waste water containing heavy metals were discharged each year from 2001 to 2012 [8]. In 2012, the total discharged amount of waste water across the country reached 68.46 billion tons [8,10]. As shown in Figure 2, the total amount of waste water had experienced a sharp rise from 2001 to 2012, in which the amount of the industrial waste water had declined gradually whereas the amount of the domestic waste water had increased remarkably [8,10].

Figure 2. Waste water discharged in China (2001–2012).



According to the 12th Five Year (2011–2015) Plan on prevention and control of heavy metal pollution, controlling five major heavy metal pollutants (Pb, Hg, Cr, Cd, and As) is an urgent task. Table 3 lists the discharged key heavy metals in waste water by China's regions in 2011 [10]. As can be seen from Table 3, the discharged amount of key heavy metals totaled 740.15 tons. In several provinces, which are located in southern and central China, such as Hunan, Guangdong, Jiangxi, Hubei, and Henan provinces, the levels of heavy metals in waste water are comparatively high. These provinces are the vital areas for industrial activities. The pollution levels in these provinces are 2.9 to 3.6 times higher than the nation's average [11]. Particularly in Hunan province, the discharged amount of major heavy metals in waste water was 150.91 tons in 2011 and the discharged amount to the national total was over 20%. Otherwise, northeastern China, namely Liaoning, Jilin, and Heilongjiang provinces, have low heavy metal proportion in waste water. Thus, the heavy metal pollution problem is not so prominent in this region.

Based on the waste water data of China's provincial capitals and municipalities in 2011, the amount of waste water discharged in these cities were 16.92 billion tons (see Table 4), accounting for 2.56% of national discharged loads [10]. The amount of key heavy metals in waste water was 96.06 tons in these cities for 2011 (see Table 4), accounting for over 10% of national discharged loads [10]. The share of waste water discharged for these cities is relatively low, but the share of key heavy metals discharged is high. It means that the concentrations of heavy metals in waste water for the urban areas are higher compared with other areas.

Table 3. Key heavy metals in waste water by region (2011) [10].

Region	Total volume of waste water discharged (10,000 tons)	Pb in waste water (kg)	Hg in waste water (kg)	Cd in waste water (kg)	Cr(VI) in waste water (kg)	Total Cr in waste water (kg)	As in waste water (kg)
Total	6,591,922	155,242	2829	35,899	106,395	293,166	146,616
Beijing	145,469	186.2	1.7	12.4	339.6	508.7	28.1
Tianjin	67,147	1450.4	1.1	9.8	105.9	285.2	22.8
Hebei	278,551	566.5	4.6	33.7	3141.3	8480.5	78.1
Shanxi	116,132	662.7	5.1	830.9	490.9	519.8	755.4
Inner Mongolia	100,389	3086.7	43.5	549.1	31.4	114.2	4529.6
Liaoning	232,247	982.0	10.5	96.4	463.8	692.5	478.8
Jilin	116,162	267.8	7.7	35.3	131.5	199.8	1028.7
Heilongjiang	150,661	37.9	1.7	5.6	195.3	875.4	78.5
Shanghai	214,155	175.5	3.4	18.2	1024.6	2548.9	38.0
Jiangsu	592,774	3608.5	98.0	147.8	5400.4	12,318.3	804.5
Zhejiang	420,134	568.4	98.3	281.2	10,008.9	21,660.5	218.1
Anhui	243,265	3026.1	9.6	777.7	5744.0	6965.2	7166.1
Fujian	316,178	5104.5	55.0	422.1	2906.8	15,327.6	1504.5
Jiangxi	184,432	9401.6	1537.1	2791.8	17,352.9	22,669.2	10,851.6
Shandong	443,331	1096.6	48.4	1097.6	754.1	13,959.0	2177.7
Henan	378,765	7140.8	27.3	2781.3	1606.9	37,379.5	1810.7
Hubei	293,064	4166.8	223.3	846.6	16,645.4	17,456.8	11,961.7
Hunan	278,811	42,466.5	279.6	14,518.2	3336.0	34,606.4	55,704.9
Guangdong	785,587	11,512.2	66.1	1147.7	27,986.6	75254.3	2287.7
Guangxi	222,439	15,639.6	81.1	2498.1	4300.4	4666.5	9070.5
Hainan	35,725	32.5	0.4	6.2	0.1	137.6	28.8
Chongqing	131,450	188.0	3.6	12.2	304.2	740.6	1418.3
Sichuan	279,852	1760.6	71.2	183.3	542.2	1809.1	3596.2
Guizhou	77,927	536.7	40.1	123.6	202.1	268.8	619.8
Yunnan	147,523	37,946.6	56.7	3343.6	46.8	134.7	15,580.8
Tibet	4635	0.2	0	0.1	0	1.0	2721.1
Shaanxi	121,815	4241.9	32.7	965.1	262.8	1655.1	965.6
Gansu	59,232	6884.8	72.5	1424.9	240.2	4672.3	5735.6
Qinghai	21,292	1120.0	11.0	148.0	1018.3	1033.3	2067.8
Ningxia	39,432	110.8	4.5	29.4	113.4	452.1	212.9
Xinjiang	83,329	1263.8	23.6	760.9	1699.5	5773.5	2673.0

Table 4. Key heavy metals in waste water in mains cities (2011) [10].

City	Total wastewater discharged (10,000 tons)	Pb (kg)	Hg (kg)	Cd (kg)	Cr(VI) (kg)	Total Cr (kg)	As (kg)
Beijing	145,469	186.2	1.7	12.4	339.6	508.7	28.1
Tianjin	67,147	1459.3	1.1	9.8	105.9	285.2	22.8
Shijiazhuang	54,230	16.7	0.5	1.4	5	2141.3	1.7
Taiyuan	19,205	173.9	2.1	13.3	126.9	128	64.4
Hohhot	13,754	3.8	2.2	0.4	0.9	0.9	0.5
Shenyang	41,055	38.4	0.04	1.9	94.5	95.7	0.5
Changchun	26,767	16.5	0.01	0.1	98.4	102.6	0.3
Harbin	41,901	22.2	0.3	1.1	151.6	153.9	2.3
Shanghai	214,155	175.5	3.4	18.2	1024.6	2548.9	38.1
Nanjing	82,769	40	0.8	10.6	355.2	428.7	52.1
Hangzhou	96,219	45	0.3	2.9	2214.3	2659.2	12.8
Hefei	40,213	71.9	0.6	7	9.6	26.3	92
Fuzhou	36,069	39.4	13.7	2.8	489.1	517.4	8.4
Nanchang	40,492	70.4	0.4	9.6	16940.4	16,955.7	23.8
Jinan	29,794	6.6	0.3	1.5	202	244.4	43.3
Zhengzhou	47,307	21.2	0.2	6.3	44.4	52.5	30.6
Wuhan	76,666	189.5	2.2	4.7	1182.2	1193.6	219.4
Changsha	42,271	149.1	0.3	22.4	412.1	554.4	30.1
Guangzhou	141,610	682.1	1.1	11.7	2004.9	5352.5	51.7
Nanning	36,355	84.6	12.3	3.4	532.7	534.5	82
Haikou	11,911	0.3	0	0.1	0	131.3	0.5
Chongqing	31,450	188	3.6	12.2	304.2	740.6	1418.3
Chengdu	84,467	38	0.2	1.7	58.3	400	98.4
Guiyang	14,508	8.1	0.1	1.2	44.3	60.3	0.5
Kunming	45,335	11,678.4	3.4	2042.7	2.5	34.3	6751.1
Lhasa	2088	0.2	0	0.1	0	0.2	2721.1
Xian	40,770	60.7	0.2	4.5	73.9	182.2	0.02
Lanzhou	16,102	99.7	0.4	18.5	149.3	154.7	3.8
Xining	10,174	129.5	2.4	75.6	1018.3	1030.1	67.4
Yinchuan	17,703	11.8	0.1	0.5	2.2	175.5	38.3
Urumqi	24,195	22.5	12.4	40.2	160	400	77.5

2.4. Heavy Metals in Solid Wastes

Heavy metal-bearing solid wastes at contaminated sites usually originate from a wide variety of anthropogenic sources in the forms of metal mine tailings, heavy metal wastes in improperly protected landfills and fossil fuels combustion residues. Application of fertilizer, pesticides and leaded gasoline are also important sources [12,13]. The concentration of heavy metals in industrial solid wastes depends on site-specific conditions, as well as the type and size of solid waste sources [14].

The state of the solid wastes in China between 2000 and 2011 is given in Table 5. As can be seen from the table, the amount of solid wastes increased annually. The discharged amounts decreased, but the discharging levels were comparatively high. It was 15.9 million tons on average annually. In 2011, the generated solid wastes amounted to 3.2 billion tons, which is 34% more than in 2010 [10]. However, in 2011, 4.33 million tons of these wastes were discharged to the environment without any treatment, which is 1.3% less than in 2010. 603.8 million tons of solid wastes were stored and nearly two billion tons wastes (including some wastes stored in previous years) were utilized with the utilization rate of 60.5% [10].

Table 5. The state of solid waste in China (2000–2011) [10].

Year	Solid waste generated (10,000 tons)	Solid waste discharged (10,000 tons)	Solid waste utilized (10,000 tons)	Stock of solid waste (10,000 tons)
2000	81,608	3186.2	37,451	28,921
2001	88,840	2893.8	47,290	30,183
2002	94,509	2635.2	50,061	30,040
2003	100,428	1940.9	56,040	27,667
2004	120,030	1762.0	67,796	26,012
2005	134,449	1654.7	76,993	27,876
2006	151,541	1302.1	92,601	22,399
2007	175,767	1302.1	92,601	22,399
2008	190,127	781.8	123,482	21,883
2009	203,043	710.5	138,186	20,929
2010	240,944	498.2	161,772	23,918
2011	322,772	433.3	195,214	60,376

2.5. The Characteristics of Heavy Metal Pollution and the Effects on Public Health

With rapid economic growth since China's reform and opening up, environmental degradation has, as a result, become such a highly charged issue. The issues of damaging public health caused by heavy metal pollution have become increasingly serious in recent years. There exist four characteristics of heavy metal pollution:

(1) The scope of pollution is extensive and the exposure of Chinese population to the pollution has been promoted;
(2) The effected people are exposed to heavy metal pollution for a long time since the impact of the accumulated heavy metal pollution on people's health cannot be eliminated in a short time;
(3) Air pollution, including heavy metals particulates in contaminated air, is the main environmental health issue in urban areas, while heavy metals in water and soil are the main issues in rural areas;
(4) Given that the traditional environmental and health problems caused by the inadequate sanitation infrastructure have not been properly solved in China, heavy metal pollution and its threats to public health may cause an aggravation of the condition.

The problems for the above four aspects are the biggest challenges for social progress and public health. For instance, in China, the skeletal fluorosis—a bone disease caused by fluoride pollution—has afflicted 196,000 people in 35,672 villages in recent years. The disease was caused primarily by heavy metal pollutants from coal-burning [15].

2.6. A Sharp Increase in the Number of Heavy Metal Pollution Incidents

Heavy metals can be absorbed into the human body via three ways mainly: from the food, the water and the atmosphere. The number of heavy metal pollution incidents has experienced an extraordinary raise since 2009 in China. According to the statistics, over 40 serious heavy metal pollution incidents happened in the past four years. Two of such typical cases are as follows:

In August 2011, it was reported that a chemical corporate in southwest China—Luliang Chemicals—had dumped 5000 tons of toxic chromium tailings near a big river in Yuezhou, Yunan Province. It contaminated the drinking water source of over ten million people and attracted widespread media attention across China [16].

In May 2013, the Food and Drug Administration of Guangzhou announced over 40% of sample rice and rice products from the market in the city were found containing excessive cadmium. The national standards for food indicate that the highest cadmium content in rice cannot exceed 0.2 milligrams per kilogram of rice. However, the cadmium content is more than two times in some sample rice compared to the standard [9].

3. The Policies and Challenges of Heavy Metal Pollution Control

3.1. China's Policies and Plans for Heavy Metal Pollution Control

Since the Chinese government enacted The Law of Environmental Protection in 1986, China has established a comprehensive legal system for environmental protection. However, the related policies and plans for prevention and control of heavy metal pollution lagged behind, which has made the quality of water, soil and waste continuously degenerate [17]. By 2011, two national plans for prevention of heavy metal pollution, namely the "12th Five-Year Plan on Prevention and Control of Heavy Metal Pollution" and "Xiangjiang River Basin Control Plan for Heavy Metal Pollution", have been approved by the State Council of China [18].

3.1.1. The 12th Five-Year Plan for Preventing Heavy Metal Pollution

In February 2011, the first special 12th Five-Year Plan on prevention and control of heavy metal pollution has been promulgated by the MEPC. This national plan states that from 2011 to 2015, tens of billions of Renminbi (RMB) will be allocated by the central government as the investment for prevention and control of heavy metal pollution [19]. The main goals of pollution management in the period are set in this plan:

- Establishing the complete heavy metal pollution control system and environmental and health risk assessment system to address the problems concerning the public health;
- Effectively controlling heavy metal pollution through reducing the discharges of major heavy metals (Hg, Cr, As, Cd, and Pb) in key regions (13 provinces in East and Central China) by 15% within the period 2011 to 2015, taking 2007 as the base year;
- Keeping the discharges of major heavy metals in non-key regions not exceeding the level of 2007;
- Properly monitoring heavy metal contamination and significantly reducing heavy metal pollution incidents.

3.1.2. The Xiangjiang River Basin Control Plan for Heavy Metal Pollution

The Xiangjiang River is the second largest tributary of the Yangtze River and its main stream length is 856 km. Population in the Xiangjiang River basin was over 40 million in 2012. Several researches have found that the Xiangjiang River basin has become China's most heavily polluted area by heavy metals [20–23].

In 2011, the State Council approved the Xiangjiang river basin control plan for heavy metal pollution. This is a regional plan for prevention of heavy metal pollution, which is China’s first officially approved heavy metal pollution control plan for a particular area. The primary tasks and targets of this plan are as follows [24]:

- Planning to invest 59.5 billion RMB (9.8 billion US Dollars) and complete 927 projects to control the industrial pollution in this area between 2012 and 2015;
- By 2015, the number of enterprises involving heavy metal pollution in this area should be 50% less than in 2008;
- By 2015, the amount of heavy metal emission should decrease by 50% and heavy metal pollution incidents have to be curbed.

3.2. The Main Challenges to Heavy Metal Pollution Control in Urban Areas

3.2.1. Serious Pollution from Particular Industries

In recent years, China has realized remarkable achievements in waste treatment and reutilization in urban areas. In 2009, the major measures to reduce levels of pollution through economic transition and environmental management have brought benefits. By implementing various pollution control projects, the country saw sewage treatment capacity increased by 13.3 million tons per day, exceeding the target of 10 million tons per day set in early 2009. From 2008 to 2011, the urban sewage treated and household waste treatment capacity has also increased annually, effectively reducing the contamination of heavy metals [25,26]. However, there still exists severe pollution from particular industries in some areas, such as Shandong province. In 2010, the leather industry only accounted for 0.24% of Shandong’s total industrial output value, but the Cr discharged in this industry accounted for 41.70% of the province’s total Cr discharges. Similarly, total industrial output value of metal products industry only accounted for 0.08% of the province’s industrial output value, but the Cr discharged in this industry accounted for 45.1% of the total discharges [27].

3.2.2. Airborne Heavy Metal Pollution

In December 2012, the MEPC issued the Airborne Pollution Prevention and Control Action Plan (2013–2017). This plan covers three most developed regions in China (Beijing-Tianjin-Hebei region, Yangtze River Delta and Pearl River Delta) and 10 city clusters, including 117 cities. These areas covers only 14% of the country’s land, where nearly half of the country’s population lives, 71% of the nation’s GDP comes, 52% of the country’s coal is consumed. The level of air pollution in these areas is around three times higher than the nation’s average [6]. In 2010, the annual average concentration of SO_2 and PM10 in these regions were 40 micrograms per cubic meter of air (μg/m^3) and 86 μg/m^3

respectively, which are two to four times greater than the average level in developed countries. Annual average concentration of NO_2 was 33 μg/m^3. Based on the latest revised National Ambient Air Quality Standards, 82% of the major cities' air quality is worse than the standards [6]. In other words, severe ambient air pollution threatens the public health and increases the mortality rate and morbidity risk caused by respiratory, cardiovascular, and cerebrovascular diseases [28].

Airborne sources of heavy metals include duct emissions in waste gas and vapor streams and other fugitive emissions from industrial areas. Heavy metals from airborne sources are generally released as particulates contained in the gas stream. Given that most forms of fossil fuels contain heavy metals, some heavy metals such as As, Cd, and Pb can volatilize during fossil fuels burning. These metals will be converted to oxides and then condensed as fine particulates in smoke emitted from factory chimneys [29]. This is, therefore, a form of contamination, which can be widely spread. Very high concentration of Cd, Pb, and Zn can usually be found in plants and soils adjacent to smelting works [30]. Another major source of airborne heavy metal contamination is the aerial emission of Pb from the combustion of petrol that contains tetraethyl Pb. Although petrol with tetraethyl Pb has been officially forbidden in China since 2000, some small petrol producers still supply leaded petrol. This contributes substantially to the pollution of Pb in urban areas and the area adjacent to major roads [31].

Given the two major challenges of heavy metal pollution control in urban areas, the MEPC adopted amendments to the Law of Air Pollution Control in 2009. The draft amendments made adjustments to the control of the total amount of pollutants, the management of pollution permits, the environmental management systems, and the environmental penalties [31]. Nevertheless, under the existing conditions stated above, accomplishing these goals set in these plans is still a long journey.

3.3. The Main Challenges to Heavy Metal Pollution Control in Rural Areas

The principle sources of heavy metal pollution in rural areas are industrial pollution from 1.6 million township enterprises and many other enterprises, which were moved to the countryside to take advantage of cheaper land and labor. According to the results of a country-wide survey, the waste water discharged from these enterprises in rural areas amounted to 5.9 billion tons, accounting for 21% of all industrial waste water in China. The amount of particulate emissions was 13.2 million tons or 67% of total industrial emissions and there were 380 million tons of solid wastes, which accounts for 37% of the industrial total solid wastes [32]. Because all these enterprises are located in the countryside and 80% of enterprises are lack of funds for pollution control, they have economic incentives to directly pollute farmland and it results in an annual grain loss of a few million tons [33]. This has also led to the severe pollution of surface water and groundwater, eventually threatening food safety [15].

3.4. Major Difficulties in Heavy Metal Pollution Control

3.4.1. Major Difficulties in Air Pollution Control

Recently, China's air pollution has reached an extremely critical state. With coal-smoke pollution yet to be capped, regional air pollutants like PM2.5 are becoming more serious and frequently form regional air pollution. Simultaneously large-scale severe air pollution episodes in many regions have been rising. According to forecasts, as the GDP of the key polluted regions increases by 50%, the total consumption of coal would increase over 30%, and the total number of vehicles ownership would increase over 50% by 2015 [34]. Based on the current pollution control efforts, the SO_2, NO_x, industrial PM2.5, and VOCs emission loads were 1.6, 2.5, 1.0 and 2.2 million tons, respectively, accounting for 15%, 22%, 17%, and 20% of the total emission, respectively [4]. Existing control efforts for heavy metal pollution from airborne are difficult to meet the urgent demand of the public to improve the quality of ambient air. The report of China's environment suggested that 43.4% of the country's air quality does not meet the national standards. In other words, air in many areas is not safe for residents [35]. Hence, achieving the national goals of controlling airborne heavy metal pollution is extremely arduous.

3.4.2. Major Difficulties in Water Pollution Control

3.4.2.1. Aggravation of Surface Water Pollution

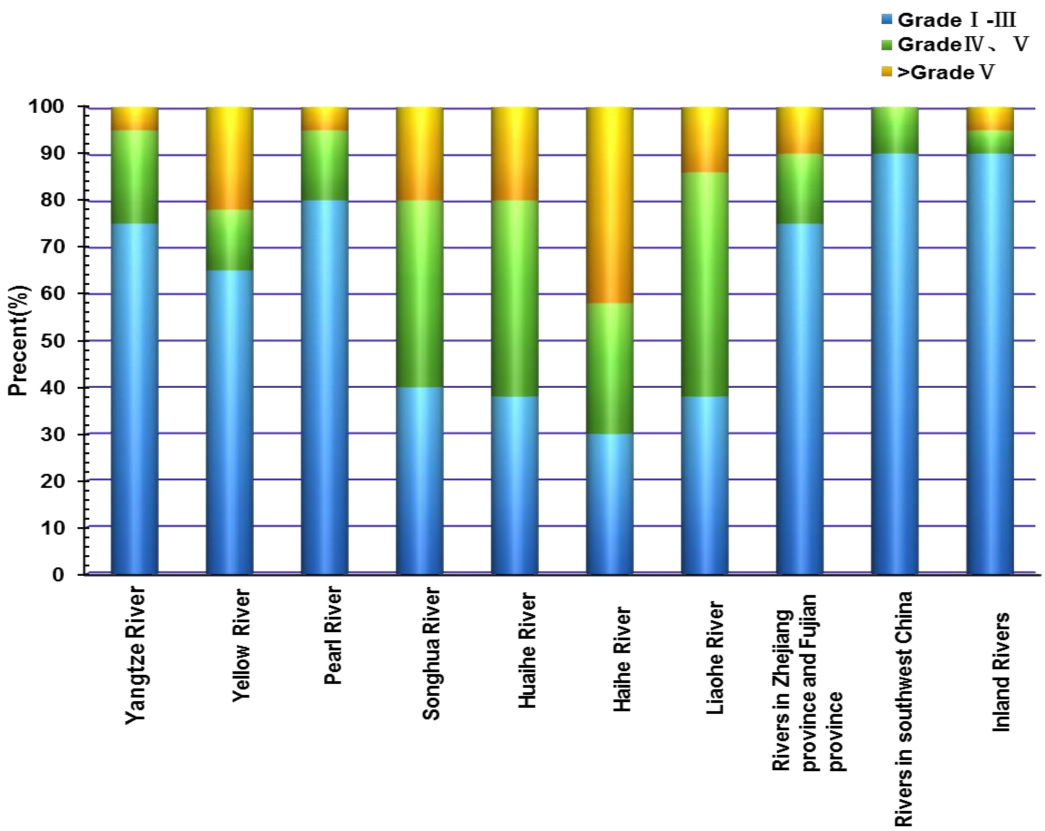
Control of heavy metal pollution in water is one of major challenges to sustainable development. Surface water pollution is prominent. The contamination rate of rivers and lakes sediment is 80.1% in China. Yangtze River basin is a principle region for heavy metal pollution control and waste water discharged in this area accounted for 17.8% of the national total discharges. The discharged Cd and As accounted for 56.6% and 63.5% of the national total discharges, respectively [36]. The 12th Five-Year plan on prevention and control of water pollution in this basin is an important stimulation to build a stable security system for detecting environmental condition. However, in some provinces like Anhui, for the past two years, the planned projects have been carried out slowly and their completion rate is lower than 20%. Moreover, most projects in Yangtze River basin have been suspended [37].

China has also spent huge sums of money in the past ten years in an effort to relieve and prevent severe pollution in the Huaihe River, but little progress has been made. Although the amount of heavy metals in waste water has not changed much from 2007 to 2011, for five major heavy metals, only the discharge of lead decreased by 1.7%. The other four kinds of heavy metals discharges increased with varying rates, in which the discharged Hg has the highest growth rate of 26.1% [38]. In the same period, over 500 tons of heavy metals were discharged into Huaihe River, Liaohe River, Taihu, Chaohu, and Dianchi Lake [34], which exacerbated heavy metal pollution in their drainage areas and exercised a malign influence on millions of people.

3.4.2.2. Deterioration of Groundwater Quality

According to the Report on the State of the Environment in China, the groundwater is largely polluted. Only 40% of the groundwater remains suitable for drinking or fishing and 28% of it cannot be used even for industrial purposes [35]. As can be seen from Figure 3, in 2012, most of the big rivers in China were serious polluted which had water rated worse than Grade III (undrinkable but suitable for human contact) [8,10]. According to the Chinese Environmental Quality Standards for Water (GB3838-2002), Grade I is the level for water of the best quality whereas Grade V is the level for water of the worst quality [39]. Thus, a higher grade of water means that water has been more polluted.

Figure 3. Qualities of 10 big waters in China.



Due to the lack of fund, the construction of waste water pipe network is lagging behind. The maintenance of the pipes is usually not timely and the pipes leakage and waste water overflow resulted in the contamination of the ground water. Additionally, the seepage of Cr, Pb, and Co in solid wastes and slag dumps cannot be easily controlled. It would make cross contamination between aquifers and pollute the groundwater. Some industries, such as the petrochemical industry, and their related production activities affect groundwater's quality. For instance, in 2009, 200 million tons of industrial solid wastes were not properly treated. Some enterprises, without considering corporate social responsibility, discharged untreated industrial waste water through the seepage wells [4].

Since the groundwater contamination is in a broad area, the pollution control is becoming increasingly difficult. In recent years, the effects of surface water contamination are also significant, especially for the Yellow River, Liaohe, Haihe River basin, and Taihu Lake. Given that the surface water and groundwater communicate with each other, the level of groundwater pollution is associated with the quality of surface water [40]. The Communique on Land and Resources of China 2012 suggests that nearly 60% of groundwater quality was identified as poor, in which 16.8% of it was regarded very poor. In some groundwater sources in the Pearl River Delta, the presence of heavy metals can be detected [41].

3.4.3. Severe Soil Contamination

In China, soils in some areas have been contaminated by the accumulation of heavy metals, which come from discharges and emissions in the rapidly expanding industrial zones. Thus far, researchers have found that some soil collected from the area along middle and lower reaches of the Yangtze

River, where lots of industrial zones locate, contained high levels of Cd, Hg, Pb, and As. Meanwhile, heavy metal pollution in soil is more sever in densely populated eastern and southern China, compared with the early 1990s [33].

Based on the MEPC's reports and experts' estimation, there are over twenty million hectares of land contaminated by heavy metals in China. This accounts for one sixth of China's arable land. About 12 million tons of grains were contaminated by heavy metals annually, causing an economic loss of 20 billion RMB (3.3 billion US Dollars) [42]. For instance, Hunan province is one of the country's top five producers of nonferrous metals like Cd and Pb because it has a large number of mines that accounted for 7.5% of the country's total [43]. Further, Hunan is also China's largest rice producer and it grew nearly 26 million tons of unhusked rice, which accounts for nearly 13% of China's total in 2011. In recent years, some cadmium-tainted rice was found in the market with a high proportion of the polluted rice from Hunan province [43].

4. The Primary Measures to Control Heavy Metal Pollution

The hazards of heavy metal pollution reflect both market and government's failures in environmental management. In order to solve this problem, it is necessary to coordinate the activities of the governments and markets to control the discharges of heavy metal.

4.1. Increasing the Green GDP

In China, higher GDP is usually regarded as the "achievement of the government". In order to rising GDP, heavily consuming natural resources in some provinces has become an applicable method for governments [44].

As a matter of fact, GDP is not a perfect measure of social welfare because it does not measure some dimensions of life, such as people's health, environmental quality, social equity, *etc.* Moreover, as GDP fails to be a perfect measure of social welfare, it also fails to be a measure of economic efficiency. The importance of this failure can be easily explained by a case: the increase of cancer occurrence which is due to heavy metal pollution in the environment could enhance GDP because more money would be spent on health care.

China has made efforts to reduce levels of environmental pollution and spends over 500 billion RMB (82 billion US Dollars) annually, or about 1.3% of its GDP, on environmental protection and pollution control, which is regarded as a part of the Green GDP. According to estimation, a further investment, which is around 2% to 4% of GDP or up to 2000 billion RMB (248 billion US Dollars), is needed to clean up heavy metal pollutants [45].

To increase green GDP, the authorities should enact some priority research programs that cover the following areas:

- Cleaner production and environmental protection industry;
- Clean energy, green transportation and buildings;
- Conservation and sustainable utilization of natural resources;
- Pollution control technology for waste gas, waste water and solid wastes;
- Public health and human settlements in polluted areas.

4.2. Reducing Heavy Metals in Fuel

In China, there are a few sectors, which need great reduction on the use of heavy metals, such as manufacturing, metallurgy, power generation, transportation, *etc.* For example, China has the second largest fleet of automobiles in the world, with over 137 million in 2013 [46]. The heavy metals in gasoline would become airborne pollutants when the fuel is burned in the engine. Moreover, a 10 years old engine usually emits over 40 times of pollutants than a new vehicle does. In China, each liter of unleaded gasoline still contains over 0.01 gram of lead. Gasoline with less lead should be required for new cars because the lead also damages the catalytic converter that is used to control other pollutants derived from auto exhaust. Hence, it is necessary that China issued a timetable for upgrading the fuel quality in the following decade [47].

4.3. Utilizing Renewable Energies

China contains 12% of the world's coal reserves, and nearly 70% of the country's energy was derived from coal in 2012. China burned over 2 billion tons of coal per year, which is more than the United States, India, and Russia's consumption combined [26]. Meanwhile, in terms of the economic costs of air pollution like health care cost, the total cost of coal-burning was estimated at 1400 billion RMB (230 billion US Dollars) [48]. Thus, it was a matter of utmost urgency to vigorously develop renewable energies and lower the portion of coal in energy consumption.

China's Renewable Energy Law went into effect in 2006. It aims to provide over 10% of the country's energy from renewable sources by 2020. To achieve this strategic goal, three principle steps should be taken:

- Introducing regulations that favor generation and marketization of renewable energy;
- Making renewable energies become more cost-competitive by providing new technologies to power producers;
- Establishing financial support frameworks to increase renewable and clean energies utilization, especially for solar power, wind power and shale gas.

4.4. Adopting Market-based Approaches to Reduce Pollution

In order to look for more efficient methods of cleaning up the heavy metal pollutants, some market-based incentives are necessary for reducing pollution. Markets incentives generally include two forms: pollution fees and pollution taxes [49]. In China, pollution fees are relatively common. In fact, the sewage charges paid by enterprises are usually not enough to make up for the costs of environmental management and ecosystem restoration. For example, Kunming city, the largest city in Southwest China, collected only 81.2 million RMB (13.3 million US Dollars) sewage charges for the waste water discharged into Dianchi Lake from 2011 to 2012. Nevertheless it needed 13.7 billion RMB (2.2 billion US Dollars) for this period to treat the waste water [50]. Pollution taxes are environmental taxes on polluters that penalize them for the pollutants they discharged into airshed, waterway, or local landfill. Such taxes have not been broadly used in China. Lots of researches have suggested that the pollution tax should be implemented as soon as possible. It is not only conducive to heavy metal pollution control but also conducive to promote the enterprise's scientific and technological progress [51].

From an economic point of view, the free markets for tradable permits to pollute, like free markets for some natural resources, can ensure that heavy metal pollution is controlled at a low cost.

5. Conclusions

With the rapid industrialization since the reform and opening up, heavy metal pollution, which is mainly caused by lead, chromium, arsenic, cadmium, mercury, zinc, copper, cobalt and nickel, has become increasingly serious in China. There is an urgent need to properly resolve this complex environmental problem and protect the environment and public health. China's heavy metal pollutants, which usually come from waste gas, waste water, and solid wastes, are widely distributed. Meanwhile, the number of heavy metal pollution incidents has experienced an extraordinary raise since 2009. Heavy metal pollution endangers public health via three ways primarily: the food, the water, and the atmosphere. By 2011, Chinese government had approved two crucial plans for prevention of heavy metal pollution, which are the "12th Five-Year Plan on Prevention and Control of Heavy Metal Pollution" and "Xiangjiang River Basin Control Plan for Heavy Metal Pollution". Since then, remarkable achievements in waste treatment and reutilization have been realized in some urban areas.

However, there are still a few problems related to heavy metal pollution. Air pollution, including heavy metals in contaminated air, is omnipresent and the main environmental problem in urban areas, while heavy metals in water and soil are the major problems in rural areas. The difficulties of air pollution control, water pollution control, and soil pollution control impede the settlement of heavy metal pollution cases. For air pollution control, the severe coal-smoke pollution and people's desire to improve the quality of ambient air require a prompt solution. For water pollution control, cross contamination between aquifers and the failure of the pipe network construction are the main concerns. In terms of soil pollution, there are over twenty million hectares contaminated land, which might grow over 12 million tons of grains with heavy metals annually. In order to support ecologically and socially sustainable development, it is necessary to coordinate the activities of the governments and markets to control the discharges of heavy metals. In addition, we should take actions in the following aspects: increasing the Green GDP, reducing the heavy metals in fuel, implementing more renewable energies and adopting market-based approaches.

Acknowledgments

This work was financially supported by the Fundamental Research Funds for the Central Universities in China and Social Science Research Fund (No.14YJCZH055) from the Chinese Ministry of Education.

Author Contributions

Hui Hu collected the data and wrote the manuscript with significant contribution from other authors. Qian Jin designed this research and reviewed related studies. Philip Kavan contributed to the manuscript draft and its revisions.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Järup, L. Hazards of heavy metal contamination. *Br. Med. Bull.* **2003**, *68*, 167–182.
2. Sarkar, B. *Heavy Metals in the Environment*; CRC Press: New York, NY, USA, 2002.
3. Nadal, M.; Bocio, A.; Schuhmacher, M.; Domingo, J. Trends in the levels of metals in soils and vegetation samples collected near a hazardous waste incinerator. *Arch. Environ. Contam. Toxicol.* **2005**, *49*, 290–298.
4. Ministry of Environmental Protection of China (MEPC). *Annual Report on the State of the Environment of China 2010*; Department of Environmental Monitoring: Beijing, China, 2011.
5. Department of Industrial Statistics, National Bureau of Statistics of China (DISNBS). *China Industrial Economy Statistical Yearbook 2011*; China Statistics Press: Beijing, China, 2012.
6. Ministry of Environmental Protection of China (MEPC). *The Airborne Pollution Prevention and Control Action Plan (2013–2017)*; Department of Environmental Monitoring: Beijing, China, 2012.
7. Zhang, N. Effects of air settlement on heavy metal accumulation in soil. *Soil Environ. Sci.* **2001**, *10*, 91–93. (In Chinese)
8. Ministry of Environmental Protection of China (MEPC). *Annual Report on the State of the Environment in China 2012*; Department of Environmental Monitoring: Beijing, China, 2013.
9. Van Donkelaar, A.; Martin, R.V.; Brauer, M.; Kahn, R.; Levy, R.; Verduzco, C.; Villeneuve, P.J. Global estimates of ambient fine particulate matter concentrations from satellite-based aerosol optical depth: Development and application. *Environ. Health Perspect.* **2010**, *118*, 847–855.
10. Ministry of Environmental Protection of China (MEPC). *Annual Report on the State of the Environment in China 2011*; Department of Environmental Monitoring: Beijing, China, 2012.
11. Wang, J.; Song, Z. Ultrasensitive Determination of Cadmium in Rice by Flow Injection Chemiluminescence Analysis. *Food Anal. Methods* **2014**, *1*, 1–6.
12. Huang, L.M.; Deng, C.B.; Huang, N.; Huang, X.J. Multivariate statistical approach to identify heavy metal sources in agricultural soil around an abandoned Pb-Zn mine in Guangxi Zhuang Autonomous Region, China. *Environ. Earth Sci.* **2013**, *68*, 1331–1348.
13. Yu, J.; Sun, L.; Xiang, J.; Jin, L.; Hu, S.; Su, S.; Qiu, J. Physical and chemical characterization of ashes from a municipal solid waste incinerator in China. *Waste Manag. Res.* **2013**, *31*, 663–673.
14. Marques, A.P.; Rangel, A.O.; Castro, P.M. Remediation of heavy metal contaminated soils: an overview of site remediation techniques. *Critical Rev. Environ. Sci. Technol.* **2011**, *41*, 879–914.
15. Zhou, Y.C.; Li, M.S. Heavy metal contamination and transportation in soil-tea leaf-tea liquor system in two tea gardens of Guangxi. *J. Agro-Environ. Sci.* **2008**, *6*, 2151–2157.
16. Wu, M.; Yang, L.; Wang, G. The Chromium Pollution and Environmental Management in Yunan, Annual Conference of Chinese Society for Environmental Science, Kunming, China, 1–2 August 2013. (In Chinese)
17. Evanko, C.R.; Dzombak, D.A. *Remediation of Metals-contaminated Soils and Groundwater*; Ground-water remediation Technologies Snalysis Center: Pittsburgh, PA, USA, 1997.
18. Tang, W.; Zhao, Y.; Wang, C.; Shan, B.; Cui, J. Heavy metal contamination of overlying waters and bed sediments of Haihe Basin in China. *Ecotox. Environ. Safe* **2013**, *98*, 317–323.
19. Ministry of Environmental Protection of China (MEPC) *12th Five-Year Plan for the Prevention and Control of Heavy Metal Pollution*; Department of Environmental Monitoring: Beijing, China, 2011.

20. Wang, L.; Wang, Y.; Zhang, W.; Xu, C.; An, Z. Multivariate statistical techniques for evaluating and identifying the environmental significance of heavy metal contamination in sediments of the Yangtze River, China. *Environ. Earth Sci.* **2014**, *71*, 1183–1193.
21. Wu, F.T.; Zhu, H.Y.; Guo, J.; Lei, Y.N. Assessment of heavy metal levels in sediment of the Xiangjiang river section flowing through Changsha. *Appl. Mech. Mater.* **2013**, *368*, 482–485.
22. Zhong, L.; Liu, L.; Yang, J. Characterization of heavy metal pollution in the paddy soils of Xiangyin County, Dongting lake drainage basin, central south China. *Environ. Earth Sci.* **2012**, *67*, 2261–2268.
23. Zhu, J.; Zhang, J.; Li, Q.; Han, T.; Xie, J.; Hu, Y.; Chai, L. Phylogenetic analysis of bacterial community composition in sediment contaminated with multiple heavy metals from the Xiangjiang River in China. *Mar. Pollut. Bull.* **2013**, *70*, 134–139.
24. Ministry of Environmental Protection of China (MEPC). *Xiangjiang River Basin Control Plan for Heavy Metal Pollution*; Department of Environmental Monitoring: Beijing, China, 2011.
25. National Development and Reform Commission (NDRC). Report on China's Economic and Social Development Plan. Available online: http://www.sdpc.gov.cn/ (accessed on 22 June 2014).
26. Report on the implementation of the 2011 Plan for National Economic and Social Development and the 2012 Draft Plan for National Economic and Social Development. Available online: http://www.sdpc.gov.cn/ (accessed on 22 June 2014).
27. Environmental Protection Office of Shandong Province (EPOSP). The 12th Five-Year Plan for the Prevention and Control of Heavy Metal Pollution in Shandong Province, 2011. Available online: http://www.sdein.gov.cn/ (accessed on 22 June 2014).
28. Zhang, Y.; Mo, J.; Weschler, C.J. Reducing Health Risks from Indoor Exposures in Rapidly Developing Urban China. *Environ. Health Perspect.* **2013**, *121*, 751–755.
29. Pietrzak, U.; Uren, N.C. Remedial options for copper-contaminated vineyard soils. *Soil Res.* **2011**, *49*, 44–55.
30. Luo, C.; Liu, C.; Wang, Y.; Liu, X.; Li, F.; Zhang, G.; Li, X. Heavy metal contamination in soils and vegetables near an e-waste processing site, South China. *J. Hazard. Mater.* **2011**, *186*, 481–490.
31. Duong, T.T.; Lee, B.K. Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. *J. Environ. Manag.* **2011**, *92*, 554–562.
32. Ministry of Environmental Protection of China (MEPC). *Annual Report on the State of the Environment of China 2009*; Department of Environmental Monitoring: Beijing, China, 2010.
33. Li, J. Land Ministry to map the extent of soil contamination by heavy metals. Available online: http://news.flanders-china.be/land-ministry-to-map-the-extent-of-soil-contamination (accessed on 22 June 2014).
34. The First National Pollution Census Bulletin, 2010. Available online: http://www.zhb.gov.cn/gkml/hbb/bgg/201002/W020100210571553247154.pdf (accessed on 22 June 2014).
35. Ministry of Environmental Protection of China (MEPC). *Annual Report on the State of the Environment of China 2006*; Department of Environmental Monitoring: Beijing, China, 2007.
36. Ministry of Environmental Protection of China (MEPC). *Yangtze River Basin Water Pollution Control Plan (2011–2015)*; Department of Environmental Monitoring: Beijing, China, 2010.

37. Environmental Protection Office of Anhui Province. The 12th Five-year Plan for the Prevention and Control of Water Pollution in Anhui Province, 2012. Available online: http://www.aepb.gov.cn/pages/Home.html (accessed on 22 June 2014).
38. Pan, K.; Wang, W.X. Trace metal contamination in estuarine and coastal environments in China. *Sci. Total Environ.* **2012**, *421*, 3–16.
39. State Environmental Protection Administration. Environmental Quality Standards for Surface Water of China, 2002. Available online: http://www.nxep.gov.cn/readnews.asp?newsid=543 (accessed on 22 June 2014).
40. Ministry of Environmental Protection of China (MEPC). *The National Groundwater Pollution Prevention and Control Plan (2011–2020)*; Department of Environmental Monitoring: Beijing, China, 2011.
41. Ministry of Land and Resources of China. *Communique on Land and Resources of China 2012*; Geological Publishing House: Beijing, China, 2013.
42. Huang, R. Heavy Metal Pollution of Grain Costs China 20 Billion Yuan Annually. *Guangzhou Daily*, 2011. Available online: http://eng.greensos.cn/ShowArticle.aspx?articleId=1099 (accessed on 22 June 2014).
43. Chin, J.; Spegele, B. China's Bad Earth. *Wall Street J.* Available online: http://online.wsj.com/news/articles/SB10001424127887323829104578624010648228142 (accessed on 22 June 2014)
44. Wang, R.; Liu, W.; Xiao, L.; Liu, J.; Kao, W. Path towards achieving of China's 2020 carbon emission reduction target—A discussion of low-carbon energy policies at province level. *Energy Policy* **2011**, *39*, 2740–2747.
45. Pan, J.; Ma, H.; Zhang, Y. *Green Economy and Green Jobs in China: Current Status and Potentials for 2020*; Worldwatch Institute: Washington, DC, USA, 2011.
46. Department of Energy Statistics, National Bureau of Statistics of China. *China Energy Statistical Year Book 2013*; China Statistics Press: Beijing, China, 2013.
47. Zhang, Q.; Crooks, R. *Toward an Environmentally Sustainable Future: Country Environmental Analysis of the Peoples Republic of China*; Asian Development Bank: Mandaluyong City, Philippines, 2012.
48. Wong, E. Air pollution linked to 1.2 million premature deaths in China. Available online: http://www.nytimes.com/2013/04/02/world/asia/air-pollution-linked-to-1-2-million-deaths-in-china.html?_r=0 (accessed on 22 June 2014).
49. Kemp, R.; Pontoglio, S. The innovation effects of environmental policy instruments—A typical case of the blind men and the elephant? *Ecol. Econ.* **2011**, *72*, 28–36.
50. Li, Z. China's Environmental Governance: Global challenges and comparative solution. *Vermont J. Environ. Law* **2012**, *13*, 797–865.
51. Peretto, P. Energy taxes and endogenous technological change. *J. Environ. Econ. Manag.* **2009**, *57*, 269–283.