博士文丛（第三辑）

CHENGSHIQU GONG DE
HUANJING XINGWEI YU XIAOYING

城市区汞的环境行为与效应

方凤满 著

安徽人民出版社

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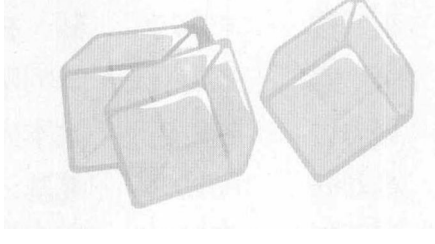

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Environmental Behaviors and Effect
of Mercury in Urban Area

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中文摘要

汞污染问题是国际上环境科学研究的热点问题之一，每年全球人为源汞释放量达2000～4000t，大气汞浓度呈增加趋势，由此带来的环境污染问题尤为突出。我国各行业每年排放到大气中的汞近1000t，尤其是北方煤烟型大气污染城市，大气汞污染问题非常严峻。大气汞的土、水界面的迁移交换作用，增加了人为源汞释放对生态系统及人类的危害作用。因此，研究城市区汞的环境行为及其效应，有助于了解汞在环境界面间的行为及最终归宿，对预测汞的污染趋势有重要作用，为评价人为源汞释放的环境效应及更好地进行健康风险管理提供理论依据，为城市政府部门控制汞污染问题提供科学指导。

本书主要以长春市区为研究区域，开展城市区各环境要素中汞含量水平及其影响因素，汞在各界面间的环境行为，汞的环境效应及城市区汞污染控制对策研究。全书共分为7章，每章的主要内容如下：

第一章阐述城市区汞污染研究背景和研究意义。首先简单介绍汞的性质、用途、地壳中汞的分布与丰度、环境介质中汞的含量、汞的危害、汞在自然界的循环、中国用汞与排汞状况，以及汞污染来源。然后提出本书研究的目的、意义。随着人类活动的增加，人为源释放到环境中的汞在逐年增加，汞污染对人类的危害风险加大，因此，控制汞污染是摆在全社会面前的紧迫问题。

第二章对城市区汞的环境行为与效应的国内外研究进展进行归纳总结。分别介绍了不同环境要素中汞分析方法研究进展，重点介绍大气中不同形态汞的分析方法；对国内外城市汞气/水界面、气/土界面、水/土界面的环境行为研究进行梳理，对城市区汞的陆生生态系统的环境效应和对人体的暴露进行分析；找出国内外汞的环境行为与环境效应研究中存在的不足，提出城市区汞污染研究展望。

目前有关大气汞形态方面的研究较缺乏，采样与测定技术应进一步完善；汞在各界面间的迁移与交换机制不清楚，今后应加强城市区汞的排放清单的研究、汞在各界面间交换机理的研究，结合计算机技术，进行模拟模型的开发。

第三章对城市区各环境要素中汞含量及其影响因素进行测定与分析。首先介绍案例城市区的概况，然后对案例城市区各环境介质中汞的含量水平及其影响因素进行分析。重点研究了长春市区大气颗粒汞浓度的时间与空间分布特征并分析其污染成因。结论为：大气中总气态汞、活性气态汞、颗粒态汞浓度均呈现出明显的季节变化和日变化特征，空间分布上也存在很大差异，主要受人为活动释放、大气中相关成分以及气象因素等影响。采暖期大气颗粒汞浓度平均超出非采暖期2倍以上。TSP与大气颗粒汞浓度呈显著正相关；燃煤与地面扬尘是大气颗粒汞的2个主要来源；采暖期地面扬尘对大气颗粒汞的贡献约占8%～38%；降水是大气颗粒汞去除的一个重要途径。对城市区土壤与灰尘的汞含量进行了国内外比较分析，发现国内城市区土壤汞污染比较严重，地表灰尘中汞呈明显富集状态。城市区湖泊与河流中汞含量往往较高。

第四章介绍大气汞沉降机制、干湿沉降研究方法、干湿沉降研究的意义，并在第三章的基础上，对长春市区汞的气/土界面行

为——干湿沉降进行研究，分析大气汞干湿沉降的规律和影响因素。主要结论为：大气汞干沉降主要采用干沉降模型估算、苔藓袋（Moss Bag）技术和 Throughfall（穿透雨法）等。湿沉降主要通过直接测定降水中汞来估算和苔藓袋技术两种方法。应用理论模型估算长春市区大气颗粒汞干沉降通量为 43.06μg m^{-2} a^{-1}；用苔藓袋技术测定的大气汞干沉降通量为 73.5μg m^{-2} a^{-1}。离释放源近的食品厂处大气汞的干沉降通量最大。冬春两季大气汞干沉降通量最大，秋季次之，夏季最低。

降水中汞浓度的影响因子有：降水量、降雨类型、季节、离点源的距离、降水持续时间等。通过分析降水对大气颗粒汞的淋洗比可知，采暖期降水中的汞主要来自于降雪对大气颗粒物的吸附与裹携作用，而非采暖期降水中的汞除主要来自颗粒物的冲刷作用外，还有其它来源。大气汞湿沉降主要集中在夏、秋季，占全年湿沉降的 83%左右，且应用两种方法获得的大气汞湿沉降通量接近。

第五章对城市区土壤、水面汞释放以及土 / 水界面汞交换进行研究。首先介绍土壤、水面汞释放对于全球大气汞库以及汞循环的重要意义，分析了土壤挥发性汞释放通量的室内模拟、微气象梯度法、野外动态通量箱法等三种不同测定方法的优缺点，并对长春市不同地点覆盖类型的表面汞释放进行测定，分析其时空分布规律及其影响因素。主要结论为：长春市不同地表覆盖类型的地表汞释放速率大小为：含汞废物堆放处（煤渣堆放地）> 沥青覆盖地面 > 裸地 > 草坪 > 市区森林土壤 > 郊区空旷地 > 郊区森林土壤。沥青覆盖地面是城市特有的人造景观，其表面汞的释放速率较大，且占市区面积的比例较大，应引起重视。土壤汞释放通量一般夏季大于冬季，白天大于晚上，晴天大于阴天；降雨期间或降雨后期由于增加了土壤含水量，土壤汞的释放通量增加。土壤汞释放通量的主要影响因子为土壤汞含量与土壤性质、太阳辐

射、土壤温度与土壤湿度、地表类型、大气汞含量、降水作用等。

用水/气界面汞交换模型估算了南湖与净月潭水库水面的汞交换，结果为南湖水面汞的释放通量为 47.4ng m^{-2} h^{-1}，净月潭水面汞的释放通量为 23.5ng m^{-2} h^{-1}。降雨径流中的汞浓度(0.39μg L^{-1})大于降水中的汞浓度，其中以公路径流中汞含量最大。

第六章建立城市区大气汞的排放清单，分析汞在各环境介质界面间的迁移特征与区域迁移量，评价长春市各环境介质中汞污染现状及趋势，然后对城市区汞的环境效应进行分析。主要结论为：长春市区由燃煤释放到大气中的汞为 425.6kg a^{-1}，进入土壤中的汞为 201.2kg a^{-1}；长春市建成区的大气汞湿沉降通量为 22.7kg a^{-1}，大气颗粒汞的干沉降通量为 6.9kg a^{-1}，大气气态汞的干沉降通量为 4.7kg a^{-1}，大气汞总沉降通量为 34.3kg a^{-1}；由土壤释放到大气中的汞为 9.1kg a^{-1}；南湖与净月潭大气汞总沉降通量分别为 170.2g a^{-1} 和 353.7g a^{-1}；由南湖与净月潭水面释放到大气中的汞分别为 108.7g a^{-1} 和 254.6g a^{-1}；地面扬尘带入大气中的汞为 3.1kg a^{-1}；由降雨引起的地表径流携带进入水体的汞约为 3.8kg a^{-1}。从区域与全球环境汞循环来看，长春市整个建成区城市生态系统是汞的源，而城市区生态系统的各组成部分在城市汞循环中又起到汇的作用。

第七章分析城市区汞的多介质环境污染特征及控制对策。汞的多介质环境污染的基本特征为：关联性、转移性、循环性。针对汞污染来源以及全球汞污染的特点，提出汞污染控制途径：一是污染源控制，主要包括建立城市区汞排放清单、法律法规控制、技术手段、政策层面、借助环保 NGO 进行宣传教育、全球合作等措施；二是建立汞标准，主要包括排放标准、环境质量标准和产品质量标准、技术标准与控制技术；三是重点开展煤中汞的去除研究，包括燃烧前脱汞、燃烧中脱汞、燃烧后脱汞三个环节。最后分析了汞污染控制存在的主要问题，并提出未来研究的展望。

Abstract

Mercury (Hg) pollution is one of the hot topics in the internationally environmental scientific research, global Hg emission come from artificial source that reaches 2000~4000t every year. Atmospheric Hg concentration becomes higher and higher,which results outstanding question of environmental pollution. Annual emissions of atmospheric Hg nearly 1000t from all industries in China, particularly in the north city that polluted by coal smoke and atmospheric Hg pollution is serious.The migration–exchange effection of atmospheric Hg between soil and water interface increased harmful function to the ecosystem and human.Therefore, research of Hg environmental behavior and effect in urban areas, which contribute to understand behavior and ultimate destination of Hg in the environmental interfaces, which has the influential role to forecast the tendency of Hg pollution, and also provides the theory basis for appraisal the artificial source Hg release's environmental effect and carrying well on the health risk management, also provide the theory basis in order that the urban governmental departments control Hg pollution.

This book took ChangChun urban district as study region, developed some researches, such as Hg content level of the various

environ mental elment in urban areas and the influencing factors, environmental behavior of Hg in various interfaces, and Hg environmental effects, as well as the research on the controlling countermeasure of urban Hg pollution.The book was divided into seven chapters, the major contents of each chapter was as follows:

Chapter 1 discussed background and significance of Hg pollution in urban areas. First,a brief introduction to the attribute and use of Hg, the distribution and abundance of Hg in the crust,Hg content in environmental compartment, the hazards of Hg, the cycle of Hg in the nature,the situation on the use and emissions of Hg in China; the sources of Hg pollution.Then, it proposed its purpose and significance. With the increase in human activities, Hg emission of anthropogenic sources into the environment increased year by year, the risk of Hg pollution to human is increasing.Therefore, control of Hg pollution is the pressing issues in all society at present.

Chapter 2 summarized progress of study on the environmental behavior and effects of Hg at home and abroad in urban areas. Respectively progress of the analytical methods of Hg in different environmental factors was introduced, then emphatically introduced the analysis methods of different forms of Hg in the atmosphere;the environmental behavior of Hg in domestic and foreign cities on Hg between air/water, air/soil and water/soil interface was hackled; Finally, analyzed environmental effects of Hg in terrestrial ecosystems and Hg exposure to human in urban areas; To find the weaknesses in the study on the environmental behavior and environmental effects of Hg at home and abroad, and to propose the prospect of study on Hg pollution in urban areas.

At present, study was lack on the forms of atmospheric Hg, sampling and measurement technology should be further improved; Migration and exchanging mechanism of Hg is unclear between the interfaces. we should be strengthened studies on establishing Hg emission lists in urban areas and exchanging mechanism of Hg in all interfaces. Combined with computer technology to exploit simulation model.

Chapter 3 measured and analyzed Hg content and its influencing factors in various environment media in urban areas. First,introduced a brief account of city, then,analyzed Hg content and its affecting factors in the environmental media respectively.Temporal and spatial distribution characteristics of atmospheric particulate Hg concentration and its causes of pollution were discussed. Conclusion: Total gaseous Hg in the atmosphere, reactive gaseous Hg, particulate Hg all shows obvious characteristics of seasonal and daily variation,it also varied considerably in spatial distribution, it mainly impacted by sources of anthropogenic emission, the relevant components in the atmosphere, meteorological factors and so on. Hg (p) concentration in heating period was over two times than non-heating period; it existed positive correlation between TSP and Hg(p) concentrations; coal-fired and dust were two main sources of atmospheric particulate Hg; In heating period, contribution of dust is about 8% ~38% to Hg(p). Precipitation is an important way to remove Hg(p) in air. A comparative analysis was done on Hg content in urban soil and dust at home and abroad, which found that domestic Hg pollution in soil was relatively serious, and Hg was significantly enriched in surface dust. In urban areas, lakes and rivers had high Hg content.

Chapter 4 introduced deposition mechanism of atmospheric Hg, study significance of Hg dry and wet-deposition, study method of atmospheric Hg dry and wet-deposition.On the basis of Chapter3,Hg behavior between gas and soil interface——dry and wet-deposition in urban areas, the law and influencing factors on atmospheric Hg dry and wet-deposition were studied. Main conclusions: Atmospheric Hg dry deposition fluxes were estimated mainly by dry-deposition model,moss bag technology and through fall method.Wet-deposition fluxes were mainly estimated by direct determination of Hg in p recipitation and moss bag technology two ways. Dry-deposition flux of Hg (p) was 43.06$\mu g\ m^{-2}a^{-1}$ by theoretical model; dry-deposition rate of atmospheric Hg measured by the moss bag technology was 73.5$\mu g\ m^{-2}\ a^{-1}$ in urban areas. Dry-deposition flux on atmospheric Hg at food plant near from the source was largest. Dry-deposition flux of atmospheric Hg in winter and spring were largest, lower in autumn, the lowest in summer.

Factors on Hg concentration in precipitation:such as precipitation, types of precipitation, season, the distance from point-sources, the duration of precipitations. Through analyzing precipitation to the leaching of atmospheric particles Hg, Hg in precipitation was mainly come from adsorption and portability of snow to atmospheric particles Hg in heating period. In non-heating period, in addition to mainly come from the role of erosion Hg in precipitation, there are other main sources. Wet-deposition of atmospheric Hg mainly concentrated in summer and autumn, accounting for about 83 percent of wet-deposition. Wet-deposition fluxes of atmospheric Hg were near through the two methods.

Chapter 5 researched Hg emission on urban soil and water,as well as Hg exchange between soil/water interface.First, important significance on Hg emission from soil and surface to global atmospheric Hg and Hg cycle was introduced, and the advantages and disadvantages on methods of estimated Hg flux in soil were analyzed, which had three different measures:such as indoor simulation, micro–meteorological gradient method, dynamic flux method in field. And Hg emission from the surface in different urban land–covered types in Changchun were measured,at the same time, analyzed the temporal and spatial distribution law and its influencing factors. Main conclusions: Hg emission flux in different land–covering types in Changchun, such as waste–dumps of Hg (dumps of cinder) > ground covered by asphalt>bare land>lawn>urban forest soil>open areas in the suburb>suburban forest soil. Ground covered by asphalt is the unique artificial landscape in city, and its emission fulx of Hg was bigger and accounted for a larger proportion in urban areas, which should pay attention to. Generally, Hg emission flux from soil were bigger in summer than in winter, bigger in day than at night, bigger in sunny than cloudy. Due to the increase of moisture in soil, Hg emission flux from soil was increased during rainfall or after rainfall. The main affecting factors on Hg emission–flux from soil: Hg concentration in soil, soil natures, solar radiation, soil temperature, soil moisture, surface types, atmospheric Hg concentration,the role of precipitation, and so on.

Exchange flux of Hg from Jingyuetan and Nanhu were estimated by the exchange model of Hg interfaces in water and gas. Hg emission flux was 47.4ng m^{-2} h^{-1} and 23.5ng m^{-2} h^{-1}respectively in

Nanhu and Jingyuetan. Hg concentration in rainfall–runoff was higher than Hg concentration in rainfall(0.39μgL^{-1}). Hg concentration was the largest in highway runoff.

Chapter 6 established atmospheric Hg emission lists in urban areas, analyzed migration characteristics of Hg in each environmental interface and the regional migration amount, and evaluated the status and trends of Hg pollution in each environmental media in Changchun, and then analyzed environmental effects of Hg in urban areas.. The main results were obtained. Hg emission caused from coal–fired into atmosphere in ChangChun was 425.6kg a^{-1}. Hg transporting into soil was 201.2kg a^{-1}. Hg wet deposition flux in built–up areas in Changchun City was 22.7kg a^{-1}. Hg(p) dry deposition rate was 6.9kg a^{-1}. Dry deposition flux of gaseous Hg was 4.7kg a^{-1}. Total deposition flux of atmospheric Hg was 34.3kg a^{-1}. Hg emission from soil into atmosphere was 9.1kg a^{-1}. Total deposition flux of atmospheric Hg from NanHu Lake and JingYuetan Reservoir was respectively 170.2g a^{-1} and 353.7g a^{-1}. Hg emission from Nanhu Lake and Jingyuetan Reservoir into atmosphere was respectively 108.7g a^{-1} and 254.6g a^{-1}. Atmospheric Hg from ground dust was 3.1kg a^{-1}. Hg transportation into water from runoff caused by rainfall was about 3.8kg a^{-1}. From the regional and global cycle of Hg, the urban ecosystem of the entire built–up areas in Changchun City is a source of Hg, while each composition of urban ecosystem plays the pool of Hg in its urban cycle.

Chapter 7 analyzed Hg multi–media pollution features and controlling measures in urban areas. The basic characteristics of Hg pollution in Multi–media were relevance, migration,circular. Aiming

at the sources of Hg pollution and the characteristics of the global Hg pollution, the control way of Hg pollution were proposed: First, controlling pollution sources, mainly including the establishment of Hg emission inventories, the control of laws and regulations, technical means, policy level, propaganda education with the help of environmental protection NGO, global cooperation, and so on. Second, establishing Hg standards, mainly including emission standards, environmental quality standards and product quality, technical standards and control technology.Third, developing the research on removal of Hg in coal, including Hg removal before combustion, between combustion and after combustion. Finally, the mainly existent problems about Hg pollution have been analyzed and the prospects on the future research have been proposed.