



能源与环境出版工程

总主编 翁史烈

“十三五”国家重点图书出版规划项目

丝路书香工程重点翻译资助项目

上海市文教结合“高校服务国家重大战略出版工程”资助项目

痕量金属的环境行为

区域与城市污染 (英文版)

Behaviors of Trace Metals in Environment
The Pollution in Regional and Metropolis Areas

张辉 著



上海交通大学出版社
SHANGHAI JIAO TONG UNIVERSITY PRESS



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(第二期)

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内容提要

本书是“十三五”国家重点图书出版规划项目“能源与环境出版工程”之一，是作者在痕量金属污染领域多年研究成果的积累，选取主要与背景因素有关的区域性痕量金属污染案例和主要由人类活动引起的城市痕量金属污染案例为对象，从地球化学角度对其污染的成因过程、制约因素、演化趋势和污染物行为特征进行系统分析论证，以探索和归纳痕量金属污染行为的一般性规律。本书可供高校环境专业师生、相关研究人员及工程技术人员参考。

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总 序

能源是经济社会发展的基础,同时也是影响经济社会发展的主要因素。为了满足经济社会发展的需要,进入 21 世纪以来,短短 10 余年间(2002—2017 年),全世界一次能源总消费从 96 亿吨油当量增加到 135 亿吨油当量,能源资源供需矛盾和生态环境恶化问题日益突显,世界能源版图也发生了重大变化。

在此期间,改革开放政策的实施极大地解放了我国的社会生产力,我国国内生产总值从 10 万亿元人民币猛增到 82 万亿元人民币,一跃成为仅次于美国的世界第二大经济体,经济社会发展取得了举世瞩目的成绩!

为了支持经济社会的高速发展,我国能源生产和消费也有惊人的进步和变化,此期间全世界一次能源的消费增量 38.3 亿吨油当量中竟有 51.3% 发生在中国! 经济发展面临着能源供应和环境保护的双重巨大压力。

目前,为了人类社会的可持续发展,世界能源发展已进入新一轮战略调整期,发达国家和新兴国家纷纷制定能源发展战略。战略重点在于:提高化石能源开采和利用率;大力开发可再生能源;最大限度地减少有害物质和温室气体排放,从而实现能源生产和消费的高效、低碳、清洁发展。对高速发展中的我国而言,能源问题的求解直接关系到现代化建设进程,能源已成为中国可持续发展的关键! 因此,我们更有必要以加快转变能源发展方式为主线,以增强自主创新能力为着力点,深化能源体制改革、完善能源市场、加强能源科技的研究,努力建设绿色、低碳、高效、安全的能源大系统。

在国家重视和政策激励之下,我国能源领域的新概念、新技术、新成果不断涌现;上海交通大学出版社出版的江泽民学长的著作《中国能源问题研究》(2008 年)更是从战略的高度为我国指出了能源可持续发展的健康发展之路。为

了“对接国家能源可持续发展战略,构建适应世界能源科学技术发展趋势的能源科研交流平台”,我们策划、组织编写了这套“能源与环境出版工程”丛书,其目的在于:

一是系统总结几十年来机械动力中能源利用和环境保护的新技术和新成果;

二是引进、翻译一些关于“能源与环境”研究领域前沿的书籍,为我国能源与环境领域的技术攻关提供智力参考;

三是优化能源与环境专业教材,为高水平技术人员的培养提供一套系统、全面的教科书或教学参考书,满足人才培养对教材的迫切需求;

四是构建一个适应世界能源科学技术发展趋势的能源科研交流平台。

该学术丛书以能源和环境的关系为主线,重点围绕机械过程中的能源转换和利用过程以及这些过程中产生的环境污染治理问题,主要涵盖能源与动力、生物质能、燃料电池、太阳能、风能、智能电网、能源材料、能源经济、大气污染与气候变化等专业方向,汇集能源与环境领域的关键性技术和成果,注重理论与实践的结合,注重经典性与前瞻性的结合。图书分为译著、专著、教材和工具书等几个模块,其内容包括能源与环境领域的专家最先进的理论方法和技术成果,也包括能源与环境工程一线的理论 and 实践。如忻建华、钟芳源撰写的《燃气轮机设计基础》是经典性与前瞻性相统一的工程力作;黄震等撰写的《机动车可吸入颗粒物排放与城市大气污染》和王如竹等撰写的《绿色建筑能源系统》是依托国家重大科研项目的新成果和新技术。

为确保这套“能源与环境出版工程”丛书具有高品质和重大的社会价值,出版社邀请了杜祥琬院士、黄震教授、王如竹教授等专家,组建了学术指导委员会和编委会,并召开了多次编撰研讨会,商谈丛书框架,精选书目,落实作者。

该学术丛书在策划之初,就受到了国际科技出版集团 Springer 和国际学术出版集团 John Wiley & Sons 的关注,与我们签订了合作出版框架协议。经过严格的同行评审,截至 2018 年初,丛书中已有 9 本输出至 Springer, 1 本输出至 John Wiley & Sons。这些著作的成功输出体现了图书较高的学术水平和良好的品质。

“能源与环境出版工程”从2013年底开始陆续出版,并受到业界广泛关注,取得了良好的社会效益。从2014年起,丛书已连续5年入选了上海市文教结合“高校服务国家重大战略出版工程”项目。还有些图书获得国家级项目支持,如《现代燃气轮机装置》《除湿剂超声波再生技术》(英文版)、《痕量金属的环境行为》(英文版)等。另外,在图书获奖方面,也取得了一定成绩,如《机动车可吸入颗粒物排放与城市大气污染》获“第四届中国大学出版社优秀学术专著二等奖”;《除湿剂超声波再生技术》(英文版)获中国出版协会颁发的“2014年度输出版优秀图书奖”。2016年初,“能源与环境出版工程”(第二期)入选了“十三五”国家重点图书出版规划项目。

希望这套书的出版能够有益于能源与环境领域人才的培养,有益于能源与环境领域的技术创新,为我国能源与环境的科研成果提供一个展示的平台,引领国内外前沿学术交流和创新并推动平台的国际化发展!

肖史烈

2018年9月

Preface

Trace metal pollution has always been a hot topic in the field of environmental science and engineering. Based on the accumulation from exploration of years, the pollution cases of different causes with typical significances are carried out in this work for the environmental effects and the behavior rules of the trace metals in modern social and economic development. These cases include the regional trace metal pollution in the Hetao area of the Yellow River Basin and the pollution of metropolis areas from Shanghai and Nanjing, China. The study was, respectively, funded mainly by the National Natural Science Foundation of China and the international research cooperation funds (the International Collaboration Foundation of the University of Minnesota, USA and the International Collaboration Foundation of the New Energy and Industrial Technology Development Organization, Japan), etc. Through the specific research work on trace metals and the pollution in different origin background cases, the characteristics, restrictive factors, genetic process, and the evolution trends of various kinds of the pollution are discussed with a lot of work in order to explore the regular facts of trace metal pollution. The goal of this study focuses on revealing the regulation of the essential facts in the trace metal pollution in environment based on the cases in different causes of formation for their factors, processes, and features. It is emphasized that the figures from analysis, facts from observations, and experiments simulating the natural conditions are obtained from the work, in the discussion and interpreting on the conclusions for us to understand the chemical or geochemical processes, the relationships in the formation, and the control factors in the pollution. The main six sections of the work are represented in this book as follows:

- (1) Introduction on the Trends of Trace Metal and the Pollution Research.
- (2) The Study on the Regional Trace Metal Pollution in Soil and Groundwater.
- (3) The Study on the Trace Metal Pollution in Metropolis Water Systems.
- (4) The Experimental Study on the Environmental Behavior of Trace Metals.
- (5) The Study on the Research Approaches on Trace Metal Environmental Effects.
- (6) Main Conclusions from the Work.

From this work, it tries to reveal and induce the regularity of the behaviors of trace metals in environmental pollution through the study on specific cases, trace metal pollution caused by the development of society and economy in regional soil and groundwater (the Hetao area, Inner Mongolia Autonomous Region) and that caused by the development of modern metropolises (Shanghai and Nanjing, China).

Due to the close relation between metals and human daily life as well as the complex behavior and change probability, the trace metal pollution rising with human production and life may occur everywhere at any time. This pollution is more general, complex, durable, and inconspicuous than the pollutions caused by other hazardous substances. Moreover, there is a background content for every metal element in natural environmental systems so that it is always difficult to recognize the pollution from the normal status. But the crises of trace metals to the ecological systems such as hazardousness to plants, inducing lesions or deformities to animals and human, make the research on it be an important duty for environmental scientists to have to undertake for a long time, specially to understand the principle and regulations of this pollution in environment.

The impacts of the pollution of trace metals may generally be manifold because of complex behaviors of them in environment. In a recent study of trace metal pollution, the major work is the research on cases, methods, and new materials to be used for protecting the pollution. It seems to be few systematic studies on the mechanism and regularity of trace metal pollution in environment. This situation reflects that every case study as well as its problem of trace metal pollution is with the frontier nature, and at the same time the pollution cases are all with complex properties to let them be difficult to be carried out. In this book, the impact status, the cause of formation of the pollution of trace metals to be probed from common facts existing in the study cases, associated with the experimental study in years in my group, are carried out to induce and conclude some issues of the pollution of trace metals. Based on these points above, the Hetao area of the Yellow River Basin as a regional area case and Shanghai and Nanjing, respectively, as metropolis cases are selected to study for the pollution, which are the typical and heavier cases for the processes and phenomenon of the regional and modern metropolis pollution of trace metals. From the research, some rules of the behavior of trace metals controlled by chemical or geochemical habits in regional and metropolis pollution are probed with discussion.

The samples of this work were in solid and liquid phases, respectively, including rock, ore, soil, sediment from rivers and lakes, suspended particles of water, resident hair, and water, respectively, from rivers, lakes, drinking wells (phreatic water), and mining wells. The measurements were done for concentrations of metals, nitrogen, phosphorus, total organic carbon, and organochlorine pesticides, the isotope of Pb and Sr, mineral composition in soil and sediment.

As important contents of this work, the experiments that simulating conditions at the earth surface were carried out to reveal the rules and factors, respectively, for metals absorbed and desorbed by and from soil and metals released from the grains (ore or rock). In addition, a useful assessment approach on environmental impacts

or bioavailability of the trace metals is proposed based on a lot of experiments and comparison discussion.

As mentioned above, this work was funded to me, respectively, by the foundations as follows:

The National Natural Science Foundation of China (granted No. 49863001);

The Foundation of the State Key Laboratory of the Research on Deposits (granted No. SKLMD199910);

The International Collaboration Foundation of the New Energy and Industrial Technology Development Organization, Japan (granted No. F-04001);

The Foundation of the State Key Laboratory of Environmental Geochemistry (granted No. SKLEG6007);

The International Collaboration Foundation of the University of Minnesota, USA (granted No. UMN-070604);

The National Natural Science Foundation of China (granted No. 41572329), etc.

In the processes of whole of this work, the help and assistants were, respectively, obtained from the following departments: the Center of Analysis of School of Environmental Science and Engineering Shanghai Jiao Tong University, the Analysis Center of the Shanghai Jiao Tong University, the Center of Environmental Monitoring Shanghai, the State Key Laboratory of Environmental Geochemistry of the Institute of Geochemistry CAS, the State Key Laboratory of the Research on Deposits Nanjing University, the Modern Analysis Center of Nanjing University, the Laboratory of Elemental Geochemistry of the Department of Earth Sciences Nanjing University, the Center of Environmental Monitoring Nanjing, the Beijing Center of Analysis of Ministry of Nuclear Industry, the Center of Environmental Research of the University of Tsukuba Japan, the Department of Civil Engineering of the University of Minnesota USA, etc.

In the process of these research years, a lot of work was performed at the Laboratory of Environmental Pollutant Behavior Chemistry, Shanghai Jiao Tong University. The students who were mainly in the work in the laboratory of my group and who took part partially in this work are: Xiaoyi Zhou, Ying Chen, Lina Zhong, Yi Zhu, Jiying Li, Mengchan Jiang, Chenmin He, Nan Zhang, Aaron Sciore (USA), Yiqing Yao et al. Moreover, many students who took part in important work in this research can not be listed for their names here. Professor Dongsheng Ma (Department of Earth Sciences, Nanjing University), Prof. Zhongling Liu (Department of Ecological and Environmental Sciences, Inner Mongolia University), Prof. Jingsheng Chen (Department of Urban and Environmental Sciences, Peking University), Prof. Patrick L. Brezonik (Department of Civil Engineering, University of Minnesota, USA), and Prof. William Arnold (Department of Civil Engineering, University of Minnesota, USA) took part in some valuable discussion in the work of this book. In the composing process of the text, Prof. Xiaoye Liu (Shanghai University), Prof. Chiquan He (Shanghai University), Prof. Dengxin Li (Donghua University), Dr. Mingce Long, Dr. Xiaojue Yu, Dr. Yaolan Niu, and Dr. Jia Duo offered some important text-sorting helps.

This work is a huge project performed by collectivity. Except persons mentioned above, there are ones who are not listed on and who contributed common things for this research, and it should say that it would be impossible to finish the work without their participation. The names of all persons who contributed their ability and wisdom to this work will be in my heart, and the days when I worked together with these colleagues have been my most interesting and enjoyable memories, especially for the time when I worked in the Laboratory of Environmental Pollutant Behavior Chemistry, Shanghai Jiao Tong University. The helps, including fund assistances, work assistances as well as the friendship and encouragements to me from the mentioned departments and persons in this research have become my spiritual wealth to inspire and enrich myself. I would like to express my sincere thanks to everyone and each department who funded or took part in this work of the research!

The opinions in this book may only be limited to my knowledge and academic view, the extents that could not reach to will hope to be pointed out and made it perfection by readers and make it perfection.

Hui Zhang
Shanghai, China
August 2018

Contents

Chapter 1 Introduction	1
1.1 The Trace Metals and the Study History	1
1.2 The Objects of This Work	5
1.2.1 The Regional Trace Metal Behavior and Pollution Research Case	6
1.2.2 The Metropolis Trace Metal Behavior and Pollution Research Cases	8
1.3 The Methods of This Work	11
1.3.1 Sample	11
1.3.2 Analysis and Test of Composition	11
1.3.3 Simulation Experiments on Desorption and Sorption of Trace Metals from or on the Medium	12
1.3.4 The Speciation Analysis Experiment of Trace Metals	12
1.3.5 Analysis and Testing Precision and Quality Index	13
References	13
Chapter 2 The Regional Pollution of Trace Metals—The Hetao Area, China	15
2.1 The Geochemical Setting of the Study Area	15
2.2 The Distribution of Trace Metals in the Soil	16
2.2.1 The Distribution of Total Concentration of Trace Metals	18
2.2.2 The Distribution of Speciation of Trace Metals	22
2.3 The Distribution of Trace Metals in the Groundwater	40
2.3.1 The Distribution of Arsenic	40
2.3.2 The Distribution of Cu, Zn, Cd, Sb, and Pb	42
2.4 The Distribution of Trace Metals in the Resident Hair of the Area	44
2.4.1 The Progress of the Research on Trace Metals in Human Hair as an Environmental Indicator	44

2.4.2	The Distribution of Trace Metals in the Resident Hair of the Hetao Area	45
2.4.3	The Relationship Between the Trace Metals in the Resident Hair and that in the Water and Soil of the Hetao Area	47
2.5	Study on the Isotope Tracing for Trace Metals in the Soil and Groundwater	50
2.5.1	Samples	52
2.5.2	The Distribution of Pb and Sr Isotope in the Soil and Groundwater	54
2.5.3	The Discussion of the Pb and Sr Isotope in the Soil and Groundwater	58
2.6	Discussion on the Distribution, Environmental Impacts, and Evolution Trends for Trace Metals in Soil and Groundwater	61
2.6.1	The Correlation of the Concentration Distribution of Trace Metals Between Soil and Groundwater	61
2.6.2	The Difference and Correlation for the Distributions of Trace Metals Between the Soil and Groundwater	62
2.6.3	The Evolution and Factors of the Trace Metal Pollution in Study Area	62
	References	63
Chapter 3 The Metropolis Pollution of Trace Metals—Shanghai and Nanjing, China		
3.1	The Pollution of the Trace Metals in Urban Rivers	67
3.1.1	The Pollution of Trace Metals and Organic Matter (PCBs) from the Suzhou Creek, Shanghai	67
3.1.2	The Pollution of Trace Metals and Organic Matter (PAHs) from the Huangpu River, Shanghai	107
3.1.3	The Trace Metal Pollution in the Nanjing Section of the Yangtze River	120
3.2	The Pollution of the Trace Metals in Urban Lake, Shanghai	129
3.2.1	The Distribution, Pollution, Spatial, and Temporal Changes of the Trace Metals of the Dianshan Lake	129
3.2.2	The Coupling Relationship of Levels of Trace Metals, N, P, C, and Pesticides in the Dianshan Lake	156
3.2.3	The Implication from the Coupling Features of the Trace Metals, N, P, C, and Pesticides in the Sediment of the Dianshan Lake	226
	References	244

Chapter 4 The Experimental Research on the Behaviors of Trace Metals . . .	253
4.1 The Objectives, Research Idea, and the Approach Design for the Experiments	253
4.1.1 The Objectives of the Research	253
4.1.2 The Approach Design for the Experiments	253
4.2 The Simulated Experiments on the Desorption and Adsorption Behaviors of the Trace Metals in the Soil	255
4.2.1 The Simulated Experiments on the Desorption and Adsorption Behaviors of Trace Metals in the Regional Pollution Soil	255
4.2.2 Discussion on the Facts Revealed by the Experiments	279
4.3 The Simulated Experiments on the Release Mechanism of Trace Metals to Environment from Natural Substances (Rock or Mineral)	280
4.3.1 The Simulated Experiment on the Trace Metal Desorption from Particles (Rock, Mineral) at the Earth Surface Conditions	280
4.3.2 Results and Discussion	283
References	297
Chapter 5 Probing into the Speciation of Trace Metals and Research Methods	299
5.1 The Significance and Developing Trends of the Research on Trace Metal Speciation	299
5.1.1 The Concept of the Trace Metal Speciation	299
5.1.2 The Trace Metal Speciation Analysis Methods and Mechanisms	300
5.1.3 The Questions in Speciation Analysis of Trace Metals	314
5.2 The Pertinence on the Analysis Procedures of the Speciation Analysis for Trace Metals	317
5.2.1 The Speciation Analysis for the Trace Metals Dissolved in Water and Contained in Particulates	317
5.2.2 The Speciation Analysis for the Trace Metals in the Soil	320
5.2.3 The Method for Speciation Analysis of Trace Metals Used in This Work	321
5.3 Suggestions and Improving on the Trace Metal Speciation Analysis Procedures, the Method of Three-Step Speciation Analysis	321
5.3.1 The Meaning of the Method of Three-Step Speciation Analysis (Three-Step Procedure)	321
5.3.2 The Proposal of the Three-Step Procedure	322
5.3.3 The Comparison Experiments Between the Results Obtained Respectively from the Mainstream and the Three-Step Procedure Analysis Methods	323

5.3.4	The Significance and Application of the Three-Step Procedure Method on Trace Metal Speciation Analysis	337
References	339
Chapter 6	Main Conclusions and Perspectives on the Work	343
6.1	The Environmental Behaviors and Pollution of the Trace Metals in Area Pollution	343
6.1.1	The Case Studies of Trace Metals and Pollution in Soil and Groundwater	343
6.1.2	Formation Mechanism of Regional Trace Metal Pollution and Its Behavior in Related Media	344
6.2	The Environmental Behaviors and Pollution of the Trace Metals in the Modern Metropolises	345
6.2.1	The Behavior and Pollution of Trace Metals in Urban Rivers	345
6.2.2	The Behavior and Pollution of Trace Metals in Urban Lakes	350
6.3	Some Significant Behaviors and Relative Features of Trace Metals in Environment	357
6.3.1	Major Differences and Relations Between Natural Trace Metal Pollution and Artificial Trace Metal Pollution	357
6.3.2	The Simulation Experiments on the Mechanism of Trace Metal Behavior and Pollution	359
6.4	The Probing and Improving on the Research Methods for the Trace Metals in Environments	360
6.5	The Perspectives on This Study	362
References	363

Chapter 1

Introduction



1.1 The Trace Metals and the Study History

The knowledge or problem of trace metals has existed for a long time. Especially in recent decades, with the rapid development of environmental science and technology, trace metals have been paid more and more attention as one of the most important pollutants in the environment. In fact, there is also a gradual process of cognition in the concept of metals, which has negative ecological effects in the environment.

In this book, the term of “trace metals” means the metal elements with poisoning or negative impacts in environment when the amount of them reaches certain levels, and their effects on ecosystem are always associated with their chemical or geochemical properties. This term sometimes is mixed up “minor metals,” “heavy metals” with seem same implication.

“Minor metals” is quoted from “minor element,” a concept of geochemistry, and it is an important study object in the corresponding subject named as “Minor Element Geochemistry.” Minor element is named versus major element in geochemistry. Major element means the main elements composing the matter of the earth, generally containing 13 elements orderly as their abundance in the earth’s crust as follows: O, Si, Al, Fe, Ca, Na, K, Mg, H, Mn, Ti, C, and Cl. These 13 elements account for 99.67% of the total earth’s crust mass. The other 80 elements(natural elements) except the 13 elements are named minor elements, meaning all, respectively, less than 0.1% in the substances in natural world such as rock, soil, ore, aerolite, water body, air, biology, and sediments of ocean, lake, and river. These elements are generally with smaller abundance in the earth crust within 1×10^{-9} — 1×10^{-6} , and the total mass of them accounts to 0.33% of the earth crust mass. The minor element is mainly in the form of ion, dissolved compounds or complexes, hydrosol, aerosol, suspended state or gases. Most of minor elements in natural systems migrate as complexes.

It needs to be pointed out that the minor elements are regarded to be the elements that are not considered as major chemical calculating components in any phases in matter system by some scholars, and are also regarded to be those with so less concentration in studied geochemical system that should obey the law of dilute solution (Henry’s law).