太湖流域生态风险评估研究

Ecological Risk Assessment of Taihu Basin

高俊峰　许　妍　著

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内 容 简 介

本书从流域复合生态系统的机理分析入手，综合考虑流域内各生态系统之间的相互影响机制与作用关系，分析了流域生态风险评估的内涵与特征，构建了由“风险源危险度—生态环境脆弱度—风险受体损失度”构成的流域生态风险评估技术体系。并以太湖流域为例，利用GIS和RS等空间分析技术进行流域尺度生态风险评估，划分出生态风险等级，编制了生态风险空间分布图，揭示了太湖流域生态风险空间分异状况及其动态演变趋势。最后，提出控制生态风险源、促进生态环境改善、维持区域生态系统稳定的差别化风险管理对策，为流域生态风险和环境管理提供定量化的决策依据和理论支持。

本书可供地理学、生态学、环境学、湖泊学等学科的科研人员、高等院校师生及政府部门的管理人员阅读参考。

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Ecological Risk Assessment of Taihu Basin

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前　言

流域是人类主要的生居场所，流域内的水、土、环境、生物资源等在维系人类社会的生存与发展中发挥着不可替代的作用。同时，湖泊、河流及其流域作为生物栖息地也为生物的繁衍及其多样性提供了保障。流域作为一类复杂的自然地理区域，以地表水和地下水为主要纽带，密切连接水循环、土地覆被、生态系统等自然支撑系统。纵观历史文明古国和当代经济最发达的地区莫不都位于大型流域附近。随着城镇的急剧扩张和经济的快速增长，流域内生态环境遭到极大冲击和破坏，致使生态系统出现资源退化、环境恶化与灾害加剧的趋势，湖泊及其流域上中下游之间、部门之间的利益冲突不断出现，流域成为区域人-地关系最为紧张和复杂的地理单元，是生态压力和风险最大的区域之一。

为了抑制区域生态环境的恶化，改善人类的生存环境，世界各国已开展了大量有关生态环境的研究，在环境评价方面也不断深化。近年来，随着环境管理目标和环境观念的转变，生态风险评价作为一种重要的生态环境管理手段，正逐渐兴起并成为国内外学术界研究的热点问题之一。作为生态学、灾害学、地理学以及资源与环境科学的前沿任务和主要的研究领域，近年来国内外许多学者及研究机构从理论与方法上对生态风险进行了广泛的研究。历经 20 余年的发展，生态风险评价已由生物毒理以及单一化学污染物对环境和人类健康影响的研究逐渐转向景观、区域等大尺度空间内自然灾害、人类活动（包括土地利用、城市化等）生态风险评估。风险源从单一风险源扩展到多风险源，风险受体从单一受体发展到多受体，评价范围也从种群、生态系统扩展到流域区域水平。与局地生态风险相比，目前大尺度的生态风险评价研究还处在探讨阶段，在理论方法与评价体系上还存在很多不足。基于资料、技术和工具的局限以及流域生态系统复杂多样的特点，流域生态风险评估研究较为薄弱，至今尚未形成统一的评估指标体系及评估框架。

太湖流域位于长江中下游，是我国经济最发达地区之一，也是自然灾害频繁的区域。区域的发展和社会的进步使得流域内土地利用的格局、深度和强度不断发生变化，人地矛盾突显，生态环境面临巨大压力，生态系统的结构和功能受到强烈影响。其生态风险研究对于区域经济增长战略的实施有着关键性的作用，对于维护流域生态系统功

能、加强流域生态系统管理、保障流域的生态安全具有重要的现实意义。目前，关于太湖流域生态风险的研究还相对薄弱，仅有重金属污染、洪涝灾害等单一风险源的评价，综合和定量研究相对较少。因此，选取太湖流域作为典型湖泊流域进行生态风险案例分析具有重要意义。

本研究从湖泊-流域生态地域系统出发，通过对流域内已发生或是潜在的风险进行评估，分析判断流域的生态风险状态与发展趋势，并依此建立湖泊流域生态风险管理体系，针对不同等级风险区建立预警与防范机制，依据风险表征结果，提出合理的差别化风险管理策略，力争在损失造成前对生态环境实施保护与防范措施，从而控制风险源，降低风险负效应。

本书共八章，第一章至第三章为理论研究部分。结合灾害学、地理学、生态学等相关学科的理论和观点，从流域复合生态系统的机理分析入手，深入探讨流域生态风险评估的内涵与特征，综合考虑多风险源、风险因子以及多评价受体和生态终点共存情况下的风险大小，构建了流域生态风险评估技术体系。第四章至第七章为实证分析部分。从大气圈、水圈、生物圈、岩石圈及人类活动圈角度辨识主要生态风险源，依据流域生态风险评估技术体系，采用 GIS 叠加分析、统计分析、空间插值分析等方法对太湖流域生态风险进行评估，辨识不同区域的主导生态风险源及其分布规律，并在此基础上，模拟流域生态风险水平的时空演变趋势，并运用“驱动力-压力-状态-影响-响应”（DP-SIR）模型对太湖生态安全现状进行评估。第八章为建议与对策部分。依据生态风险评估结果，提出各风险区降低生态风险的管理对策。

本书由高俊峰、许妍撰写，高俊峰统稿和定稿。赵家虎、黄佳聪、董川永等参与了部分文字与图片的修改工作。在本研究开展与本书写作过程中，得到中国环境科学研究院金相灿研究员，上海交通大学孔海南教授，中国科学院南京地理与湖泊研究所孔繁翔研究员，江苏省环境保护厅柏仇勇副厅长、于红霞副厅长，江苏省环境监测中心张宁红主任、张咏研究员等给予的指导和宝贵支持，特此致谢。本书的出版得到国家水体污染控制与治理科技重大专项（2008ZX07101-014）的资助，一并表示感谢。

本书虽几经修改，但由于是首次比较全面地对流域生态风险评估理论、技术体系、实证分析进行系统的研究，加之资料的限制及流域生态系统的复杂性以及编著者水平所限，书中不妥之处在所难免，恳请广大读者批评指正，以便在今后的工作中加以改进。

作　者

2012 年 2 月

摘　要

随着城镇的急剧扩张和经济的快速增长，流域生态环境遭到极大冲击和破坏，致使生态系统出现资源退化、环境恶化与灾害加剧的趋势，生态环境面临前所未有的挑战。

本书从湖泊-流域复合生态系统的机理分析入手，综合考虑流域内各生态系统要素之间相互影响机制与相互作用，探讨湖泊流域生态风险评估的内涵与特征，综合考虑多风险源、风险因子以及多风险受体和评估终点共存情况下的风险大小，从风险源危险度、生态环境脆弱度及生态风险受体损失度三方面构建了流域生态风险评估技术体系，并对太湖流域2000年、2008年两个时期生态风险的时空演化特征进行评估与分析，结果有5个方面。

（1）太湖流域内的洪涝、干旱、极端气象、水土流失及污染排放等综合生态风险源危险度的空间分布具有明显的空间差异性，整体围绕太湖呈现环带状分布格局。其中，高生态风险源危险区集中分布在环太湖北部一带，面积约占流域面积的11.47%；较高生态风险源危险区主要呈“西北—北—东北—东”半环状分布格局，所占面积约24.59%，生态风险源危险度较低的区域集中在流域西南部的苕溪流域一带，面积占15.7%。此外，区域不同，生态风险源不同，其主导生态风险源类型也不尽相同。全流域有约59.9%以污染排放为主导生态风险源，主要分布在镇江—宜兴—长兴—安吉一线以东的地区；25.45%区域主导生态风险源为干旱，主要集中在镇江—宜兴—长兴—安吉一线以西；12.44%的区域是以洪涝灾害为主导风险源；以水土流失、极端气象灾害为主导风险源的地区相对较为分散，所占比例较小。

（2）通过对2000年、2008年太湖流域生态脆弱度的时空演化分析得到，太湖流域生态脆弱的空间范围和脆弱程度均呈明显增长，已成为制约太湖地区可持续发展的重要因素。流域生态脆弱度整体呈现四周高中间低、南部高于北部、东部高于西部的空间分布特征。大体以太湖为中心，由内及外逐步升高，具有显著的地域分异规律。近十年间，太湖流域极强脆弱区面积增长趋势明显，由2000年的5868.62km^{2}扩展至2008年

的9235.27km^2，增加了约10.56%；微度脆弱区的面积则缩减了740.58km^2，所占比例也由2000年的9.4%下降至2008年的7.01%。此外，通过计算不同单元内自然地理、生态环境及人类社会三大因素对生态脆弱的贡献率表明，流域内人类活动在加速太湖流域生态脆弱进程中起着越来越重要的支配作用。

(3) 采用相对评估法，从自然生态系统生态价值及社会经济系统的相对损失程度来定量表征生态风险受体潜在损失度。潜在损失较大的区域集中在太湖湖体及北部区域、杭州市区西部区域、海宁市及平湖市。随着社会经济的发展，绝大部分区域的综合损失度水平呈升高趋势，仅有小部分区域由于区内生态价值高的景观逐渐减少进而导致区内潜在损失度呈减小趋势，这些区域主要集中在嘉兴市区、嘉善县及安吉县北部一带。

(4) 运用流域生态风险评估模型对太湖流域生态风险现状及其演变趋势进行了分析，并对生态风险等级进行了划分。结果表明，太湖流域生态风险指数为0.015～0.253，以中等和较低生态风险为主。2000年太湖流域内以较低生态风险为主，分布在流域南部的苕溪流域、浙西山区一带；至2008年，较低生态风险比例降至28.99%，流域内以中等生态风险为主，集中于湖西平原的丹阳市、金坛市等农业灌溉区及东南部的杭嘉湖平原。高、较高生态风险所占面积逐渐扩大，所占比例分别增加至2008年的5.98%和27.01%，增加面积共计1696.13km^2，主要分布在流域北部的常州市区、江阴市大部分地区以及无锡市区、苏州市区、吴江市、宜兴市的北部区域，该区由于受污染、洪涝、干旱、极端气象等多种风险源的综合影响，区域内生态系统受到较大的负面作用。

(5) 最后，依据评估结果分析判断流域的生态风险发展状态与趋势并结合不同级别的生态风险区的特点，提出了控制生态风险源，促进生态环境改善及维持区域生态系统稳定的差别化风险管理对策，进而为流域生态风险和环境管理提供定量化的决策依据和理论支持。

关键词：风险源；生态脆弱；损失度；生态风险；评估；太湖流域

Abstract

With the rapid urban expansion and economic growth, watershed ecological environment has been sufferring great shock and damage. The ecological system appears a trend of resources degradation, environmental degradation and disasters exacerbation. Thus, the ecological environment of the lake basin is facing unprecedented challenges. In order to restrain the deterioration of the regional ecological environment and improve the human environment, a lot of countries in the world have done much research on the ecological environment, so the environmental assessment has also been deepened gradually. In recent years, with the change of environmental management objectives and environmental concept, ecological risk assessment (ERA) as an important ecological management tool is gradually springing up and becomes a hot topic in academic research. As the frontier and the main research field of ecology, disaster science, earth science as well as resources and environmental science, many scholars and research institutions at home and abroad do a wide range research on the theories and methods of ecological risk in recent years. Through 20 years' development, the ecological risk assessment has been switched from the research on biological toxicology and the effect of single chemical pollutant on environment and human health to the effect of nature disaster, the human activities, such as the land use, urbanization process on the ecosystem in the landscape, regional scales, et al. Risk source and receptor have been extended from a single source to multiple ones, so the evaluation range has been enlarged from the population and ecosystem field to the watershed level. Compared with the local ecological risk, the large-scale ecological risk assessment is still in the exploratory stage at present, the methods and evaluation system still have many deficiencies. Caused by the limitations of information, technology, evaluation

tools and the complex and diverse characteristics of watershed ecosystems, ecological risk assessment studies are relatively weak, which have not formed a unified evaluation system and evaluation framework until now.

Locating in Yangtze River, Taihu watershed is one of the most economically developed regions in China, but is also a natural disaster frequently occurrence region. Regional development and social progress made the patterns, depth and intensity of landuse constantly change in watershed, as a result, human-land conflict is highlighted and the ecological environment is facing tremendous pressure, what' s more, the ecosystem structure and function are strongly affected. The researches on ecological risks not only play a crucial role for the strategy implementation of regional economic growth, but also have important practical significance for maintenance of watershed ecosystem function; strengthen the river basin ecosystem management and protection of the ecological security. At present, study on the ecological risk of Taihu watershed is not plentitude, which only evaluates single risk sources such as heavy metal pollution, floods, et al, and is lack of quantitative research. Therefore, choosing Taihu watershed as a typical case region for ecological risk assessment has great practical meaning.

Reference to the research results of ecological risk assessment in recent years, the book firstly considers the interaction mechanism and relationship among each ecosystems in watershed from the watershed ecosystem perspective, and also study the content and features of ecological risk assessment about typical lake watershed. Secondly, base on the analysis of the risk size under the situation of many risk sources, risk factors, multi-endpoint and ecological receptors coexistence, we construct an index system which includes the hazard indicators of risk sources, the vulnerability indicators of habitats as well as the potential loss of risk receptors according to the three basic elements of ecological risk assessment consist of risk sources, habitat and effect. Finally, we use several analysis technologies to evaluate the time-spacial evolution character of Taihu Lake watershed ecological risk in 2000 and 2008, and determine the status and

trends of ecological risk development based on the assessment results. The results show five areas.

(1) Based on the hazard degree assessment of ecological risk source model, we use the probability analysis to assess the occurrence indensity of floods, droughts, extreme weather, soil erosion, pollution and other natural disasters and human activities in Taihu watershed, and finally receive the spatial distribution of comprehensive risk sources. High-risk areas of risk source account for 11.47% of total area, mainly concentrating in the northern regions of the Taihu watershed. Higher ecological risk areas appear the "Northwest-North-Northeast-East" semi-circular distribution pattern, accounting for 24.59% , and lower risk source areas are concentrated in the Tiaoxi basin located in northwestern of Taihu watershed, accounting for 15.7%. In addition, different regions have different leading risk source types.

(2) Using integrated assessment model to analyze the temporal-spatial evolution trends of ecological vulnerability in 2000 and 2008, the results show that the distribution of ecological vulnerability has significant territorial differentiation, appearing that the vulnerability is lower in the middle but higher in surrounding areas. In the past decades, ecological vulnerability of most areas increased, only a small part of the region showed a decreasing trend: the highly vulnerable area grows evidently, increasing about 10.56% from 5868.62 km^2 in 2000 extended to 9235.27 km^2 in 2008years; micro-vulnerability areas have reduced 740.58 km^2, the proportion falling from 9.4% to 7.01%. Ecological vulnerability decreased areas concentrate in the west and southwest of the watershed, and increased areas are in the eastern and northern regions of watershed. In addition, by calculating the contribution rate of natural factors, ecological factors and human factors to the ecologically vulnerability of different units, the main source of ecological fragility and its influencing factors has been drawn.

(3) Based on the ecological value of natural ecosystems and socio-economic system, the paper quantifies the potential loss of ecological risk using relative evaluation method. The largest potential loss areas concentrate in the northern part, the Hang-

zhou West region, and Pinghu, Haining City, which are developed regions of Taihu watershed. The level of comprehensive loss in most regions is tended to increase, only a small part appear reduced tends because of the gradually reducing landscape, which mainly distribute in Jiaxing city, Jiashan County and the north of Anji County.

(4) The ecological risk value of Taihu watershed ranges between 0.015 and 0.253, mainly belongs to medium and low level according to the division standard of ecological risk level. In 2000, the lower level areas were dominant, distributing in Tiaoxi River Basin in the southern watershed and the mountainous area of western Zhejiang; But in 2008, the proportion of lower level areas fell to 28.99%, the medium level area became dominant, distributing in Danyang City, Jintan and other agricultural irrigation areas in western lake plain as well as southeastern Hangjiahu Plain. In 2008, areas of higher and high level of ecological risk grew, with the proportion increasing from 5.98% in 2000 to 27.01% and number of total increasing area about 1696.13km^2, which mainly concentrated in the northern of watershed, such as Changzhou, Wuxi, Jiangyin City, Suzhou City, Wujiang City, Yixing City, et al. Because of the comprehensive influence of pollution, floods, droughts, extreme weather and other risk sources, the regional ecosystems have got a negative effect.

(5) Finally, according to the characteristic of different ecological risk level areas, we not only put forward differentiation risk management policy to improve ecological environment and maintain the stable situation of ecological system. What' s more, we also give a brief judgment of the trend of ecological risk areas, and give the corresponding suggestion to control the risk. The paper will provide decision-making references and theoretical support for watershed ecological risk and environment management.

Keywords: risk source; ecological vulnerability; loss degree; ecological risk; assessment; Taihu watershed

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