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厦门大学

硕士学位论文

九龙江流域水足迹研究

Study on the Water Footprint of Jiulong River Watershed

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摘 要

水资源是支撑一个地区可持续发展的基本条件和战略资源，目前中国普遍关注干旱的北方内陆地区，却对湿润的南方地区的水资源隐患有所忽视。建立在虚拟水基础上的水足迹虽然仅有十年的历史，但却弥补了传统水资源评估中对土壤水（绿水）和贸易虚拟水的忽略，极大地拓展了水资源评价体系的外延和内涵。

水足迹理论已经得到了广泛的应用，但多数研究集中于对具体农作物的虚拟水计算和某行政区域的水足迹计算，缺乏在流域范围的具体应用，同时也缺乏系统的评价体系和有效的预测方法。

本文以典型的亚热带流域——九龙江流域为研究对象，完成了 2002-2011 十年间的水足迹账户，全面研究了流域内水足迹的主要特征和变化规律，系统建立了水足迹的评价体系并在九龙江流域进行了应用。在此基础上，构建四种未来发展情景，利用水足迹与主要影响因子的回归预测模型对流域未来水足迹进行了情景预测分析，最后为流域未来的发展模式提供了建议和水资源适应性对策。主要研究结论如下：

（1）研究的十年间，九龙江流域水足迹呈现规模化增长趋势，年均增长率约为 2%，水资源利用依然处于粗放阶段。农业水足迹占据主导地位且增长明显，工业水足迹缓慢增长。流域内农业灌溉和施肥效率有所提升，动物类食物虚拟水消费比例方面农村升高而城镇下降。水资源自给率保持极高水平，农业用水比例保持平稳。

（2）流域内经济效益不高但保持持续增长，流域为虚拟水出口导向型，具有逐渐增强的外向性。水资源匮乏度总体较低，但呈现一定不可持续性。流域内的综合评价指标维持在中等偏好的水平（评分 0.6 左右），但在极端情况下存在不可持续性风险。

（3）与人均水足迹有显著相关性的主要影响因素有人口、经济和技术。未来 15 年在四种预测情景下九龙江流域水足迹都会呈现增长的趋势，其年均增长速度从大到小排列依次是全球协同、组合适应、实力秩序和技术家园。当前水足迹发展趋势最接近全球协同情景，建议调整策略按照技术家园发展模式来缓解水资源压力。

（4）流域内的水足迹同人均 GDP 的关系基本符合“N”型环境库兹涅茨曲线，

在不同情景下 2020 年前都将出现拐点，未来经济发展对水足迹增长依然起着主导性的影响。

（5）建议采取以下适应性对策：发展和利用节水技术；提高水资源循环利用率；合理规划和调整产业结构；倡导科学合理的消费模式；科学调配水资源；合理利用虚拟水战略。

关键词：九龙江流域；水足迹；评价指标；情景预测；适应性措施

Abstract

Water resource is the basic requirement and strategic resource for supporting the sustainable development of a region. In China, the public generally focus on the northern arid region and ignore the water resource risks in humid South China. Water footprint, which is established on the base of virtual water, only has about 10 years' history. Water footprint makes up the ignorance to soil water (green water) and virtual water in trade. The concept also expands the denotation and connotation of water resource assessment system immensely.

The water footprint theory has been applied widely. Most studies focus on the calculation of specific crops and the water footprint of some administrative region but applications in a basin perimeter are quite rare. Systematic assessment method and effective prediction methods are also needed for water footprint studies.

In this study, Jiulong River Watershed, a typical subtropical watershed, is chosen as the subject. The water footprint account during 2002-2011 is established to research the characteristics and variation rules. Then a systematic assessment system on water footprint is improved and applied to the watershed. Based on the water footprint account, a regression prediction model is established with the main influence factors to predict the water footprint variation in future under four development scenarios. Finally, a proper development model is advised and adaptive measurements are put forward in the watershed. The main conlusions are shown as following:

(1) The water footprint of Jiulong River Watershed represented the trend of pristine scale growth and the average annual growth rate was about 2%. The agricultural footprint dominated the total footprint and was growing obviously as well as the industrial water footprint. The efficiency of agricultural irrigation and fertilization has been improved. The virtual water consuming proportion of animal food in rural regions has increased while in urban regions the proportion of that has decreased.

(2) In the watershed, the self-sufficiency rate of water resource stayed at extremely high stage and the agricultural water proportion were almost stable. In the watershed the growing economic benefit of water was not high at present and the watershed was

an export-oriented region with growing output ability of virtual water. The water scarcity was quite low but the trend of water footprint indicated unsustainability. As a whole, the comprehensive assessment index fluctuated at better stage (about 0.6 point), but risks existed under extreme situation.

(3) Significant correlations exist between water footprint per capita with important influence factors like population, economy and technology. The water footprint in the watershed will all increase under four prediction scenarios until 2025. Four prediction scenarios could be arranged in descending order of average annual increase rate as the order of “Global orchestration”, “Adapting mosaic”, “Order from strength” and “Techno garden”. The development trend of water footprint at president is most close to “Global orchestration” scenario. The “Techno garden” development pattern is advised to adjust the strategy in order to deal with water resource pressure in future.

(4) The relationship between water footprint and GDP per capita fits the “N” style environmental Kuznets curve. There will be an inflection point under all prediction scenarios before 2020. The growth of economic will still dominate the increase of water footprint in future.

(5) Following adaptive measurements are advised: improve and apply water saving technology; improve the recycling efficiency of water resource; adjust the industrial structure; propose scientific consuming pattern; allocate water resource scientifically; take full advantage of virtual water strategy.

Key Words: Jiulong River Watershed; water footprint; assessment indexes; scenario prediction; adaptive measures

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