AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-201704.00215

Spatial Characteristics of Ecosystem Water Conservation in China and Its Influencing Factors: Postprint

Authors: Gong Shihan, Xiao Yang, Zheng Hua, Xiao Yi, Ouyang Zhiyun

Date: 2017-04-18T00:00:00+00:00

Abstract

Water source conservation is one of the important ecosystem service functions of terrestrial ecosystems, encompassing natural processes involving atmosphere, water, vegetation, and soil. Variations directly influence regional climate and hydrology, vegetation and soil conditions, and serve as an important indicator of regional ecosystem status. China is characterized by scarce water resources and uneven spatial-temporal distribution of precipitation. Assessing the spatial characteristics of water source conservation functions and their influencing factors for national ecosystems at the regional scale holds great significance for scientific understanding and rational protection of water source conservation in China' s ecosystems, as well as for formulating ecological environment protection decisions. With the water source conservation function of national ecosystems as the research object, this study collects and analyzes relevant data, categorizes and statistically analyzes water source conservation data for various typical ecosystems, evaluates the water source conservation function of China' s ecosystems at the regional scale, and analyzes the impacts of climate and human activities thereon. The results indicate that: (1) Water source conservation in China generally demonstrates a spatial pattern characterized by high values in the southeast and low values in the northwest, gradually decreasing from east to west. In 2010, the total water source conservation of national ecosystems was 1.222433 trillion m^3. (2) Forests constitute the main component of water source conservation in China' s ecosystems, with the highest water source conservation amount, accounting for 60.80% of the national total. Among them, evergreen coniferous forest ecosystems have the largest water source conservation amount, whereas evergreen broadleaf forests possess the highest water source conservation capacity. Based on watershed-level statistics, the Yangtze River basin ecosystem has the highest water source conservation amount compared to other first-level watersheds. (3) Water source conservation in China' s ecosystems is

affected by climate and human activities, exhibiting significant positive correlations with precipitation, temperature, evapotranspiration, slope, COD density, and Yangtze River ecological engineering, while demonstrating obvious negative correlations with GDP density and rural population density.

Full Text

Preamble

ACTA ECOLOGICA SINICA
ChinaXiv Partner Journal
Vol. 37, No. 7, Apr. 2017
DOI: 10.5846/stxb20151212406

Spatial Patterns of Ecosystem Water Conservation in China and Its Impact Factors Analysis

GONG Shihan, XIAO Yang, ZHENG Hua, XIAO Yi, OUYANG Zhiyun

State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
Graduate University of Chinese Academy of Sciences, Beijing 100039, China

Corresponding author. E-mail: zyouyang@rcees.ac.cn

Received: 2015-12-01; Online publication date: 2016-08-30

Funding: National Ecological Environment Long-term Tracking Remote Sensing Survey (KFJ-EW-ZY-004)

Abstract

Water conservation is a crucial component of ecosystem services, encompassing natural processes such as regional climate circulation, hydrological cycles, vegetation growth and survival, and soil conditions. It serves as an important indicator of regional ecosystem status. China faces severe water scarcity with uneven temporal and spatial precipitation distribution. Many researchers attribute water resource loss in China to long-term human interference and widespread changes in land use and cover, while other studies identify climate conditions—such as drought, severe storms, and temperature fluctuations—as the primary drivers of water resource changes. Regardless of the cause, recent studies demonstrate that human activities can enhance water conservation levels in selected regions across China. Investigating current water conservation capacity and its response to climatic variation and human activities is essential for better understanding their accumulated consequences.

This study analyzed literature and applied Geographic Information System techniques to examine the hydrological characteristics of different ecosystems, developing a method to assess water conservation services at a regional scale while considering how these services are formed. We quantified water conservation services across different ecosystems in China, comparing these services across ecosystem types, basins, and elevation zones separately. We then analyzed the respective effects of climate and human activities on spatial patterns in water conservation services. Our findings reveal: (1) Water conservation in China follows a decreasing trend from southeast to northwest inland areas. The total amount of water conserved in China in 2010 was 12224.33×10 m^3. The vast areas south of the Yangtze River, which experience high precipitation levels, were the primary water conservation zones, including the middle and lower reaches of the Yangtze River, the hilly areas near the southern Yangtze, the Sichuan basins, and the Yunnan, Guangxi, Guangdong, and Taiwan regions. Conversely, relatively weak water conservation services were found in ecosystems in northeastern China, northeastern Inner Mongolia, northern China, the Shaanxi-Gansu-Ningxia region, and northwestern Xinjiang. (2) Different ecosystem types performed varying water conservation services. Forests were the main carriers of water conservation, producing the highest amounts and accounting for 7432.32×10 m^3 (60.80% of the total). The contribution of different forest types to water conservation, in decreasing order, was: evergreen broadleaf forest > evergreen needleleaf forest > mixed needleleaf and broadleaf forest > deciduous broadleaf forest > deciduous needleleaf forest > sparse forest. Evergreen coniferous forests could produce the most water conservation in total, though their capacity was not the highest. (3) The spatial characteristics of water conservation services are formed by interactions among several influencing factors. There were partial correlations between water conservation and precipitation, temperature, evapotranspiration, slope, Chemical Oxygen Demand (COD) density, and ecological restoration projects in the Yangtze River basin, which were positive and statistically significant. By contrast, water conservation was negatively correlated with regional Gross Domestic Product (GDP) and rural population density. As the socio-economy developed rapidly, the influence of human activities on water conservation gradually increased; however, climate and topography remained the dominant factors influencing the spatial characteristics of water conservation.

Keywords: water conservation; spatial patterns; climatic interaction; human activities

---

1. Data Sources

This study utilized multiple datasets including ecosystem classification maps, precipitation and temperature data, evapotranspiration (ET) data, Digital Elevation Model (DEM) data, administrative boundaries, watershed delineations, conservation project data, and socioeconomic statistics. The ecosystem classification map was primarily based on Landsat TM data using object-oriented classification techniques. Precipitation and temperature data (1961–2010) were interpolated from 753 meteorological stations using thin-plate spline functions. Actual evapotranspiration data (2000–2010) were derived from MODIS (MOD16) products provided by the Land Processes Distributed Active Archive Center (LP DAAC). The DEM data had a 90 m spatial resolution. Detailed data sources and resolutions are summarized in .

2. Methods

2.1 Water Balance Equation

The water balance method treats forest ecosystems as a system where water conservation capacity is calculated from the perspective of water input and output. Water conservation is defined as the difference between precipitation and forest evapotranspiration plus other consumption losses. The calculation formula is:

$$TQ = \sum_{i=1}^{j} (P_i - R_i - ET_i) \cdot A_i$$

where TQ is the total water conservation, P_i is precipitation (mm), R_i is surface runoff (mm), ET_i is evapotranspiration (mm), A_i is the area of ecosystem type i, and j is the number of ecosystem types. This calculation includes forest, shrubland, grassland, garden, and wetland ecosystems.

Surface runoff was calculated by multiplying precipitation by the surface runoff coefficient:

$$R = P \times \alpha$$

where P is annual precipitation (mm), R is surface runoff (mm), and α is the average surface runoff coefficient. The runoff coefficient represents the ratio of surface runoff to precipitation and reflects the water conservation capacity of ecosystems. Coefficients were obtained from published literature and monographs on precipitation and surface runoff data from runoff plots for various ecosystem types.

3. Data Analysis

Based on watershed statistics, this study reveals the spatial patterns of water conservation importance across China. Using ArcGIS Spatial Analyst-Zonal Statistics, we accumulated total water conservation by watershed and classified importance levels as general, important, and extremely important. To explore relationships between water conservation and climate/human activities, we used Pearson correlation analysis at the county level. Climate factors primarily considered precipitation and temperature, while human activity factors included GDP (primary, secondary, and tertiary industry GDP), population density, rural population density, and ecological protection projects.

1. Spatial Characteristics of Water Conservation

China' s ecosystem water conservation shows a clear pattern of high values in the southeast and low values in the northwest, gradually decreasing from east to west. In 2010, the total water conservation capacity of China' s ecosystems was 12224.33 $\times$ 10 m^3. High-value areas were concentrated in the Wuyi Mountains, the middle and lower reaches of the Yangtze River, and the Yunnan-Guizhou Plateau. Moderate-value regions were mainly distributed in the Changbai Mountains and Greater and Lesser Khingan ranges, while low values occurred in the Tibetan Plateau and northwestern Xinjiang.

The spatial variation stems from differences in geographic location and vegetation structure. The Wuyi Mountains region, located in the low-latitude high mountains of the Eurasian continent with abundant rainfall and dominated by subtropical and tropical evergreen broadleaf forests, exhibited high water conservation capacity. The Greater and Lesser Khingan ranges, though less disturbed by human activities and dominated by cold-temperate coniferous forests, showed moderate capacity due to lower precipitation. The Mongolian and Tibetan Plateaus, with high elevations and grassland-dominated ecosystems, had the lowest water conservation.

Forests constitute the main body of China' s ecosystem water conservation, contributing 7432.32 $\times$ 10 m^3 (60.80% of the total). The water conservation capacities of shrubland and grassland were 1723.68 and 1912.54 $\times$ 10 m^3, accounting for 14.10% and 15.65% respectively. Forests and gardens demonstrated the strongest water conservation capacity. Among forest types, evergreen coniferous forests contributed the largest total amount, while evergreen broadleaf forests showed the highest capacity per unit area.

Among China' s ten major river basins, the Yangtze River basin had the highest water conservation (4789.79 $\times$ 10 m^3, 39.19% of the national total), followed by the Pearl River basin (2546.84 $\times$ 10 m^3, 20.84%). The Southeast Rivers basin exhibited the strongest capacity per unit area due to its subtropical coastal location with high rainfall and high forest runoff coefficients. [Figure 1: see original paper] and [Figure 2: see original paper] illustrate these spatial patterns.

To identify priority conservation areas, we classified water conservation importance at the watershed level. Extremely important areas (10.75% of total area) contributed 2977.70 $\times$ 10 m^3; important areas (15.18% of area) contributed 6486.57 $\times$ 10 m^3; and general areas (65.58% of area) contributed only 1062.85 $\times$ 10 m^3. [Figure 3: see original paper] shows the spatial pattern of water conservation importance in 2010.

2. Relationships Between Water Conservation, Climate, and Human Activities

China' s ecosystem water conservation is strongly influenced by climate and human activities, particularly precipitation. Whether through saturation-excess or infiltration-excess runoff generation, surface runoff increases with precipitation, directly affecting water conservation capacity.

Correlation analysis revealed significant positive relationships between water conservation and precipitation ($r = 0.812$, $p < 0.01$), temperature ($r = 0.465$, $p < 0.01$), evapotranspiration ($r = 0.675$, $p < 0.01$), and slope ($r = 0.415$, $p < 0.01$). Among human factors, water conservation showed significant positive correlations with population density ($r = 0.190$, $p < 0.01$) and Yangtze River ecological projects ($r = 0.110$, $p < 0.01$), but negative correlations with GDP ($r = -0.068$, $p < 0.01$) and rural population density ($r = -0.052$, $p < 0.01$). , , and present detailed correlation results.

The strong correlations with precipitation, evapotranspiration, and slope indicate that topography and climate remain the dominant factors, consistent with findings that precipitation and atmospheric water demand are primary drivers of water conservation capacity. However, human activities significantly influence water conservation through ecological engineering. China has implemented extensive ecological protection and restoration projects, including natural forest protection and afforestation in the Yangtze River basin. These projects, combined with reduced negative disturbances like deforestation, have positively impacted water conservation in implementation areas.

3. Conclusions

Based on annual precipitation, evapotranspiration, and runoff coefficients for different ecosystem types, this study calculated national ecosystem water conservation using the water balance equation and assessed its relationships with climate and human activities. The main conclusions are:

1. China' s ecosystem water conservation shows a clear southeast-high, northwest-low pattern, decreasing from east to west. In 2010, total water conservation was 12224.33×10 m^3. Forest ecosystems played the most significant role, accounting for 60.80% of the national total. Evergreen coniferous forests contributed the largest total amount, while evergreen broadleaf forests had the highest capacity per unit area.

2. Among major river basins, the Yangtze River basin had the highest water conservation, followed by the Pearl River basin. The Southeast Rivers basin showed the strongest capacity per unit area due to high rainfall and concentrated forest cover.

3. Water conservation is closely related to climate and human activities. Natural factors (precipitation, evapotranspiration, slope) are the primary direct drivers of spatial distribution, while human factors indirectly influence water conservation by altering ecosystem patterns and processes. Population density and Yangtze River ecological projects showed significant positive correlations, while GDP and rural population density showed negative correlations.

These results provide specific information to strengthen public awareness about protecting and restoring water conservation services and offer scientific support for ecosystem management and conservation in China.

References

[1] Núñez D, Nahuelhual L, Oyarzún C. Forests and water: the value of native temperate forests in supplying water for human consumption. Ecological Economics, 2006, 58(3): 606-616.
[2] 海南岛生态系统生态调节功能及其生态经济价值研究. 应用生态学报, 2004, 15(8): 1395-1402.
[3] Daily G C. Nature' s Services: Societal Dependence on Natural Ecosystems. Washington: Island Press, 1997.
[4] 中国主要森林生态系统水文功能的比较研究. 植物生态学报, 2003, 27(1): 16-22.
[5] 中国森林生态系统水源涵养功能分析. 世界林业研究, 2005, 18(1): 49-54.
[6] 水源林研究述评. 水土保持科技情报, 1990, (4): 44-46, 55-55.
[7] 水土保持林体系综合效益研究与评价. 中国科学技术出版社, 1995.
[8] 生态系统服务功能价值评估的理论、方法与应用. 中国人民大学出版社, 2008.
[9] 武夷山甜槠林水文学效应的研究. 植物生态学报, 1997, 21(5): 393-402.
[10] 热带山地雨林林冠对降雨的影响分析. 植物生态学报, 1995, 19(3): 201-207.
[11] Zhang B, Li W H, Xie G D, Xiao Y. Water conservation of forest ecosystem in Beijing and its value. Ecological Economics, 2010, 69(7): 1416-1426.
[12] 十年的中国土地覆盖变化. 第四纪研究, 2014, 34(04): 723-731.
[13] Zhou G Y, Wei X H, Luo Y, Zhang M F, Li Y L, Qiao Y N, Liu H G, Wang C L. Forest recovery and river discharge at the regional scale of Guangdong Province, China. Water Resources Research, 2010, 46(9): W09503.
[14] 基于对象变化矢量分析的土地利用变化检测方法研究. 地球信息科学学报, 2014, 16(2): 307-313.
[15] 三峡库区缓坡林地产流初探. 西南大学学报 (自然科学版), 2007, 29(5): 74-80.
[16] 贵州省喀斯特地区坡面产流产沙特征. 水土保持研究, 2012, 19(4): 1-5.
[17] 晋西黄土残塬沟壑区不同林分暴雨产流产沙作用分析. 中国水土保持科学, 2003, 1(3): 37-42.
[18] 辽西半干旱区典型人工林生态系统的水土保持功能. 应用生态学报, 2007, 18(12): 2905-2909.
[19] 滇西高原不同地类坡面产流产沙规律研究. 水土保持研究, 2005, 12(2): 71-73.
[20] 长江源区不同植被覆盖下产流产沙效应初步研究. 水土保持学报, 2005, 27(6): 869-875.
[21] 林带和牧草地径流的研究. 水土保持学报, 1994, 8(2): 56-61.
[22] 桔园地土壤水分与径流的坡位差异研究. 水土保持研究, 2004, 18(2): 74-77.
[23] 中国森林生态系统水源涵养功能. 水土保持研究, 2005, 12(4): 223-226.
[24] Hartanto H, Prabhu R, Widayat A S E, Asdak C. Factors affecting runoff and soil erosion: plot-level soil loss monitoring for assessing sustainability of forest management. Forest Ecology and Management, 2003, 180(1/3): 361-374.
[25] 年气候变化对黄河源区水源涵养量的影响. 2016, 35(1): 49-57.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.